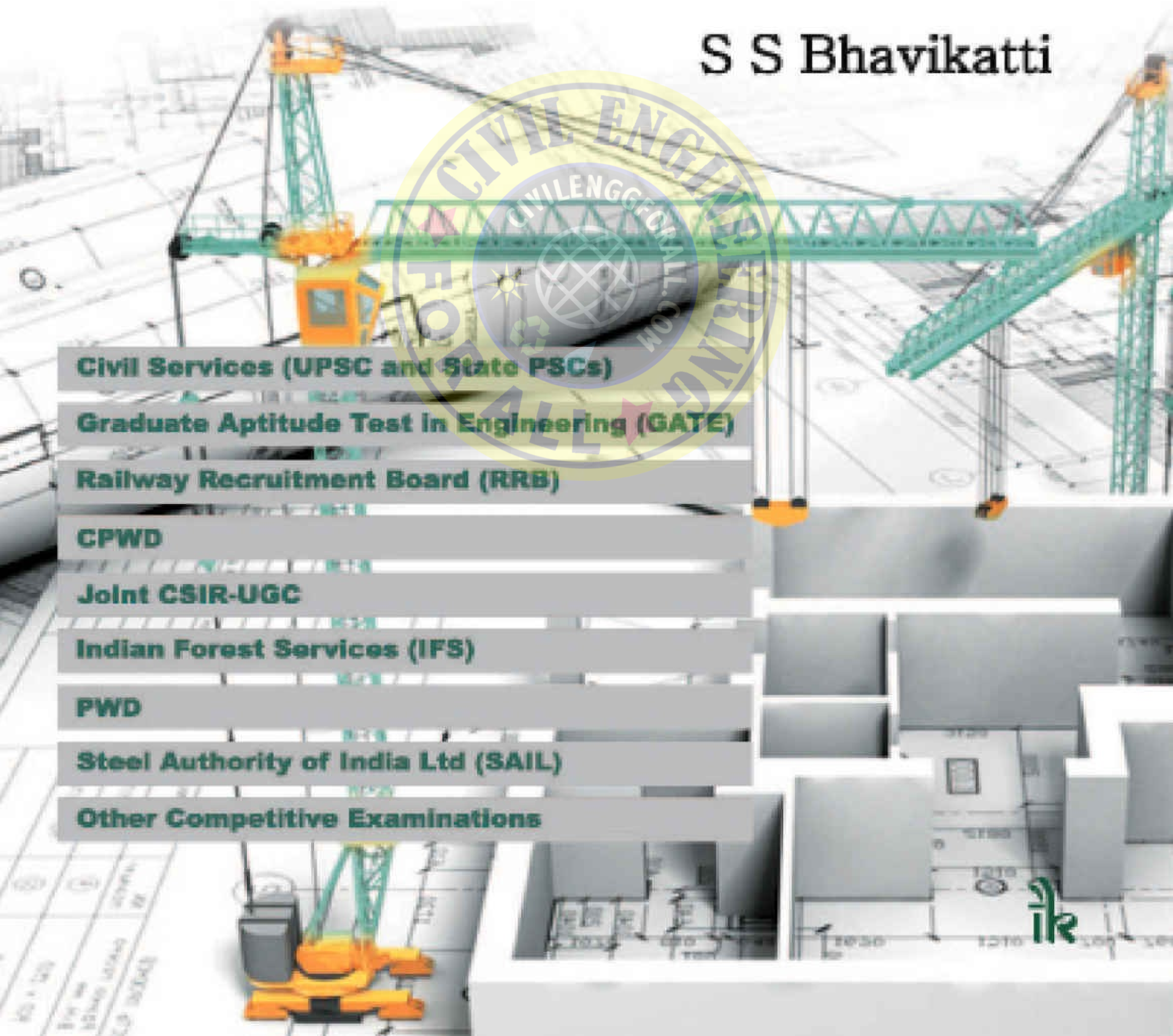
Civil Engineering

Objective Type Questions

S S Bhavikatti



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Civil Engineering

Objective Type Questions

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I.K. International Publishing House Pvt. Ltd.

NEW DELHI

Published by

I.K. International Publishing House Pvt. Ltd.
S-25, Green Park Extension
Uphaar Cinema Market
New Delhi–110 016 (India)
E-mail: info@ikinternational.com
Website: www.ikbooks.com

ISBN: 978-93-84588-31-1

Published by Krishan Makhijani for I.K. International Publishing House Pvt. Ltd., S-25, Green Park Extension, Uphaar Cinema Market, New Delhi–110 016 and Printed by Rekha Printers Pvt. Ltd., Okhla Industrial Area, Phase II, New Delhi–110 020

Preface

Civil Engineering is a vast subject. After graduation a civil engineer must remember important points on every aspect of civil engineering. With this objective, competitive examinations are conducted to select candidates for admission to postgraduate courses, UPSE, BHEL, ONGC, NTPC and many more organizations. As it is difficult to go through all books on various subjects, this book has been prepared to enable the candidates to glance through all the subjects and prepare themselves for the competitive examinations.

Each aspect with important formulae, equations, definitions, principles, etc., is first presented briefly and then an exhaustive set of objective type questions with keys at the end are presented.

The author hopes all UG students, students preparing for competitive examinations and practising engineers will find this book useful.

Although every care has been taken to ensure accuracy, yet some errors might have crept in, the author will be thankful, if they are pointed out along with suggestions to further improve the book.

S.S. Bhavikatti

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5. Strength of Materials

6. Structural Analysis

7. R.C.C. Design (As Per IS : 456-2000)

8. Steel Structures (As Per IS 800-2007)

1

Materials of Construction

1.1 STONES

Rocks from which stones are obtained may be classified in the following three ways:

1. Geological classification
2. Physical classification
3. Chemical classification.

1. Geological classification On the process of formation, rocks are classified as igneous rocks, sedimentary rocks and metamorphic rocks.

(a) **Igneous Rocks:** These are the rocks formed by cooling of magma. These rocks are strong and durable. They are further classified as:

Volcanic rocks: Cooling of magma at earth's surface – extremely fine grained and glossy. Examples: Basalt and trap.

Hypahyssal rocks: Cooling of magma at shallow depth – fine grained crystallized structure. Examples: Quartz, dolerite and gneiss.

Plutonic rocks: Cooling of magma at considerable depth – very strong and crystalline structure. Examples: Granite and dolerite.

(b) **Sedimentary Rocks:** Disintegrated rock material is carried by flowing water and deposited elsewhere. Year after year new layers of materials are deposited and consolidated under pressure, heat and chemical action. Hence, the rocks so formed are uniform, fine grained and bedded. Examples: sandstones, mudstones, limestones.

(c) **Metamorphic Rocks:** These are the rocks formed after igneous rocks and sedimentary rocks undergo changes due to pressure, heat and chemical actions. These rocks have foliated structure. For example:

- Granite becomes gneiss.
- Basalt changes to schist and laterite
- Limestone changes to marble
- Mudstone becomes slate.

2. Physical classification Based on the structure, rocks may be classified as stratified, unstratified and foliated rocks.

(a) **Stratified Rocks:** They have layered structure. Examples: Sandstones, limestones, mud-stones.

(b) **Unstratified Rocks:** They possess crystalline and compact grains. Examples: Granite, trap, marble.

(c) **Foliated Rocks:** They have foliated structure. Along the planes of foliation they split easily. These planes are not parallel to each other.

3. Chemical classification

(a) **Siliceous Rocks:** Main constituent is silica. These rocks are hard and durable. Examples: Granite, trap, sandstone.

(b) **Argillaceous Rocks:** Clay is the main constituent. These rocks are brittle. They cannot withstand shock. Examples: Slate, laterite.

(c) **Calcareous Rocks:** Calcium carbonate is the main constituent. Examples: Limestone, marble.

1.2 CHARACTERISTICS OF GOOD BUILDING STONES

1. It should possess fine grained structure, uniform and pleasing colour. It should be free from soft patches, flaws and cracks.
2. The minimum strength of 3.5 N/mm^2 is required for stone to be used for load bearing walls.
3. It should not absorb more than 5% water.
4. The specific gravity should not be less than 2.5.
5. In attrition test, it should not show wear of more than 2%.
6. Toughness index should be more than 10.
7. It should have good resistance to shocks and it should be durable.

Quarrying It is the process of extracting stones from rockbed, located near the earth's surface and exposed to sun.

Quarrying may be done using hand tools, channeling machine or by blasting.

(a) **Quarrying using hand tools:** In soft rocks hand tools like chisels, hammers, pick axes and shovels may be used. Heating technique is suitable for getting aggregates. Wedging technique is suitable for quarrying in thin bedded rocks.

(b) **Quarrying using channelling machine:** This is suitable for large size quarrying in soft rocks like marble and limestone. Channels are 50 to 75 mm wide and 2.4 to 3.6 m deep. After channelling with machine wedges and drills are used to get stones.

(c) **Quarrying by blasting:** It consists of boring, charging, tamping and firing. The gas produced in the blast tries to come out by breaking the rock in all directions and succeeds in escaping along the Line of Least Resistance (LLR).

Dressing of stones The aim of preliminary dressing is to bring the size of stone approximately to the required size and reduce the transportation cost to great extent. Final dressing is as per the requirement of the user. The different methods of final dressing are:

(1) Hammer face; (2) Chisel drafted face; (3) Polished face and (4) Tooled finish.

Seasoning of stones The process of removing sap from the pores is known as seasoning. The best method of seasoning is to allow the stones to dry for a period of 6 to 12 months in a shed.

Preservation of stones The following preservatives are used:

(1) Linseed oil; (2) Solution of alum and soap; (3) Solution of barium hydroxide; (4) Coal tar; (5) Paint and (6) Paraffin.

Tests on stones

Field Tests

1. **Smith's test:** It is to check whether the stone contains muddy substance. A sample of stone is kept in a glass of distilled water for 24 hours and stirred well to remove muddy substance.
2. **Toughness test:** Stone is hit with a hammer and metallic sound is indication of strong stone.
3. **Hardness test:** Mohr's hardness may be found by scratching the stone with knife.

Laboratory Tests

1. **Crushing strength test:** 40 × 40 × 40 mm cubes are used for testing. Load is applied in a compression testing machine at the rate 14 N/mm^2 per minute. A stone with crushing strength more than 100 N/mm^2 is treated as good stone.
2. **Water absorption test:** For good stone water absorption after 24 hours immersion in water, should not exceed 0.60.
3. **Attrition test:** Los Angeles abrasion test is conducted to find the resistance of the stone to surface wear. Los Angeles value recommended are (a) for bitumen mix: 30%, (b) for base course 50%.
4. **Impact test:** Impact testing machine consists of a frame with guides. A metal hammer weighing 13.5–15 kg falls from a height of 380 mm. Recommended values for various works are
   - For wearing coat $\ngtr$ 30%
   - For bituminous mechadam $\ngtr$ 35%
   - For water bound mechadam $\ngtr$ 40%
5. **Acid test:** Sandstones are checked for the presence of calcium carbonate. Sample of 50–100 gm of stone is kept in 1% hydrochloric acid for seven days. If calcium chloride is present, edges are broken and powder is formed.

Common building stones Basalt, granite, sandstones, limestones, marble, quartzite, laterite and slate. Solid and hollow concrete blocks are known as artificial stones.

1.3 TIMBER

Living tree, yielding good timber is called standing timber. After felling and separating branches it is known as rough timber. When bark is removed and stem is roughly converted into pieces of suitable length it is known as log. After the log is seasoned and converted into commercial sizes like planks, battens, posts and beams, it is known as converted timber.

Classification

1. On the basis of mode of growth timber is classified as exogenous and endogenous. Exogenous trees grow outward adding a distinct ring every year while endogenous trees grow inwards. Example of exogenous trees are mahogony, sal, teak , babul while examples of endogenous trees are bamboo and cane. Exogenous trees are further classified as coniferous and deciduous. Coniferous trees have cone shape and their leaves do not fall till new ones grow. Deciduous trees have broad leaves and they fall in autumn and new ones appear in the spring.

   In the cross section of deciduous trees the following components are clearly visible from inside to outside. Pith, heartwood, sapwood, cambium layer, inner bark, outer bark and medullary rays. Sapwood contains annual rings, count of which gives the age of the tree.

2. Classification based on durability: Durability test is conducted by Forest Research Institute of

India, Dehradun by burrying 600 × 50 × 50 size specimen upto half their length and observing them over several years. Then timber is classified as

(a) High durability: Average life of more than 10 years

(b) Moderate durability: Average life 5 to 10 years

(c) Low durability: Average life is less than 5 years.

3. Classification based on grading: On the basis of strength, defects, etc. IS: 12326–1976 classifies timber as special grade, Grade – I and Grade – II.
4. Classification based on Availability:

   X : Most common, 1415 m^3 or more every year

   Y : Common, 335 m^3 to 1415 m^3 per year

   Z : Less common, less than 335 m^3 every year.

Seasoning of timber Seasoning is the process of reducing moisture content in a freshly cut tree to the desired level. Seasoning makes timber more durable and stable. The various methods of seasoning used are:

– Natural seasoning: Air seasoning or water seasoning.
– Artificial seasoning: Boiling, kiln seasoning.
– Chemical seasoning or electrical seasoning.

Conversion of timber Market names of converted timber are battens, plank, pole, scanting, beams, etc. They are available in different sizes and length. They are obtained by sawing logs. The various methods adopted for sawing are: ordinary, quarter, tangential and radial.

Defects in timber Defects may be due to natural forces, attack by fungi or insects or due to erroneous seasoning. The defects due to natural causes are knots, shakes, rind galls, upsets, twisted fibres, wind cracks, burls, dead wood, foxiness and stain.

Preservation of timber The widely used preservatives are coal tar, solignum paints, chemical salt, creosote and ASCU. ASCU is a special preservative developed by FRI, Dehradun.

Industrial timber Veneers, plywood, fibreboards, particle boards, block boards, hard boards and Glulam.

Indian timber trees Babul, Bamboo, Casurina, Deodar, Jack, Mango Mahogany, Rosewood, Teak, Sandalwood, Sisso.

1.4 BRICKS

• Standard sizes are 190 × 90 × 40 mm, with mortar the size comes out to be 200 × 100 × 50 mm.

However, the old size of $8\frac{3}{4}'' \times 4\frac{1}{4}'' \times 2\frac{5}{8}''$ giving masonry of $9'' \times 4\frac{1}{2}'' \times 3''$ are still used in many parts of India.

• Clay suitable for making bricks contain

Alumina – 20 to 30% is desirable

Silica – 50 to 60% is desirable

Lime – 5% is desirable

• Iron oxide – 5 to 6%

Magnesia – A small quantity only

• Pebbles, vegetable and organic matter, excess lime, iron pyrites, sulphates of calcium and potassium are harmful.

• Manufacture of bricks involves preparation of clay, moulding, drying and burning processes.

1. Preparation of clay: It involves unsoling, digging, cleaning, weathering, blending and tempering; pug mills are used for tempering.

2. Moulding: It may be by hand moulding or by machine moulding.

3. Drying: It may be by natural drying or by artificial drying.

4. Burning: It may be in clamps or in kilns. Intermittent and continuous kilns are used depending upon the demand in the locality. Bull's trench kiln, Hoffman's kiln and Tunnel kilns are the continuous kilns.

• Classification of Bricks

1. Based on strength, bricks are classified as class 3.5, 5.0, etc. to mean compressive strength is 3.5 N/mm^2, 5.0 N/mm^2, etc. Each class is subdivided into *A* and *B* on the basis of tolerances in sizes.

2. However, in practice the bricks are classified as first, second, third and fourth class.

The following types of special bricks are also available in markets:

(1) High duty bricks; (2) Perforated bricks; (3) Hollow bricks; (4) Specially shaped bricks; (5) Fire clay bricks; (6) Paving bricks; (7) Facing bricks; (8) Soling bricks; (9) Sewer bricks.

• Tests on Bricks

1. **Field tests:** Observing size, colour, structure, hardness by scratching, sound test by striking two bricks with each other and strength test by dropping from a height of 1 m.

2. Laboratory tests conducted on bricks are:

(a) Crushing strength test; (b) Absorption test; (c) Shape and size test; (d) Efflorescence test.

Requirement of good bricks are:

Compressive strength > 3.5 N/mm^2

Water absorption $\ngtr$ 20%

Variation in sizes should be within the tolerances prescribed by code. They should not show white patches when soaked in water for 24 hours.

To meet local requirement, the following materials substitute for bricks:

1. Stabilized soil bricks; 2. Sand + lime blocks; 3. Fly ash bricks; 4. Concrete blocks.

1.5 CLAY PRODUCTS

Apart from bricks, the following clay products are used by burning, glazing and vitrifying clay.

(1) Tiles; (2) Terracotta; (3) Earthenware and (4) Stoneware.

1. Tiles Different types of tiles used are roofing tiles, ceiling tiles, ridge tiles, flooring and wall tiles, drain tiles.

The following roofing tiles are used in India:

(a) Half round tiles; (b) Corrugated tiles: (c) Pan tiles; (d) Allahabad tiles and (e) Mangalore tiles.

Ceiling tiles are flat tiles provided under roofing tiles to give good appearance when viewed from below. Ridge tiles are specially shaped tiles to cover ridges in sloping roofs. Clay tiles, glazed tiles and vitrified tiles are used for flooring and to give finishing to walls. Drain tiles are laid in waterlogged areas to drain the water.

2. ***Terracotta*** Terracotta means baked earth. It may be manufactured in different colours also. There are two types of terracotta, viz. porous terracotta and polished terracotta. They are used for making art pieces and lavatory fittings.

3. ***Earthenware*** It is a type of terracotta in which the moulded product is burnt at low temperature to get semi-vitrified surface. These products are used for making cheap lavatory fittings and drain pipes.

4. ***Stoneware*** These are the pipes manufactured from refractory clays to which ground flint and crushed pottery are added and ground. During grinding pigments are also added. They are produced under pressure and then burnt at high temperature. They are used for making wash-basins, gully traps, jars and sewer pipes.

1.6 FERROUS METALS

Metals which contain iron predominantly are termed ferrous metals. By varying carbon content slightly, ferrous materials of different varieties are manufactured. By hot rolling, cold drawing and heat treatment properties of ferrous materials can be modified. Cast iron, wrought iron and steel are the three popular varieties.

1. ***Cast iron*** Carbon content is 2 to 4%. The varieties of cast iron are: Grey cast iron, white cast iron, molten cast iron, chilled cast iron, toughened cast iron, ductile cast iron and malleable cast iron. Cast irons are coarse, crystalline and fibrous. They cannot be welded. They are used for water pipes, sanitary pipes and manhole covers. They are also used for making ornamental castings like gates, lamp posts, spiral railings, rail chairs etc.

2. ***Wrought iron*** It contains less than 0.15% carbon. It is fibrous and has silky lustre. It can absorb shocks. It is used for making nails, nuts, bolts, chains, roofing sheets, grills and straps.

3. ***Steel*** It contains 0.25 to 1.5% carbon. It is equally strong in tension and compression. It is suitable for all construction purposes. The types of steel are mild steel, medium carbon steel, high carbon steel. In the market they are available as rolled steel sections, tubes, flats, plates, sheets, corrugated sheets, expanded metal, bars and weld meshes. Thermo-mechanically treated (TMT) bars are manufactured by sudden quenching of red hot steels by spraying water, which results into high strength at the surface while the core portion is mild steel. These are ideally suited for R.C.C. works.

1.7 NON-FERROUS METALS

Copper, aluminium, zinc, lead and tin are commonly used non-ferrous materials.

1. ***Copper*** By roasting, smelting, converting and electrolytic refining copper ores like cuprite, glance, malachite or copper pyrites, copper is produced. Market forms of copper are ingots sheets, wires and tubes. Copper is brown in colour but becomes greenish when exposed to atmosphere. It is malleable, ductile, a good conductor of heat and electricity, copper wires are used as electric cables. Copper straps are used as electric conductors and for closing construction joints. It is used as an alloy for making brass and bronze.
2. ***Aluminium*** Aluminium is extracted mainly from bauxite (Al_2O_3 $2H_2O$). It is silvery white with bluish tinge. Its strength-weight ratio is favourable for construction. It is marketed in the following forms:

(1) Casting based, (2) Extrusion based, (3) Foil and powder form, (4) Sheet form, and (5) Wires. Aluminium is used for doors, windows, partitions, decorative laminates, false ceiling, cable trays, sealing construction joints, transmitting electricity and for making paints.

3. ***Zinc*** Zinc ores are zinc calamine ($ZnCO_3$) which contains 65% zinc and zinc blende (ZnS) which contains 50% zinc. When heated at 1100°C, zinc is liberated in the form of vapour which is collected and condensed. Zinc is a bluish white metal which is a good conductor of heat and electricity. It is used for making electrical cells and batteries, for galvanizing iron plates and in making paints and brass.
4. ***Lead*** Lead is extracted from the ore galena (PbS), which contains 86% lead. The ore is roasted, mixed with coke, smelted in blast furnace and reverberatory furnace. It is bluish grey in colour. It is poisonous. It is used as pigments in paints, for making storage battery solders and for making sanitary fittings.
5. ***Tin*** Tin ore is found as cassiterite (SnO_2). The ore is crushed, roasted, smelted and refined by electrolysis. It is a silvery white lustrous metal. It withstands corrosion. It is used to provide protective coating to iron, copper, brass and lead. It is used for silvering mirrors and its foils are used for protecting food products.

1.8 ALLOYS

Alloy is an intimate mixture of two or more metals. Aluminium alloys, copper alloys and steel alloys are commonly used alloys.

1. ***Aluminum alloys***

(a) Duralumin; (b) Aldural; (c) Aluminum bronze; (d) *Y*-alloy.

2. ***Copper alloys*** Brass and bronze are copper alloys. Brass is the alloy of copper and zinc. White brass, yellow brass, red brass, delta metal, cartridge brass and low brass are different types of brasses. Bronze is an alloy of copper, tin and minor percentage of other materials. Beryllium bronze, prospher bronze, green metal, bell metal, speculum metal are different types of bronzes.
3. ***Alloys of steel*** Alloying of steel with other metals is made to increase strength, hardness, toughness, resistance to wear. Varieties of steel alloys found in market are:

(1) Stainless steel (2) Nickel steel (3) Tungsten steel (4) Invar steel (5) Manganese steel (6) Molybdenum steel and (7) Chromium steel.

1.9 CEMENT

Cement is a reliable bonding material. It is obtained by burning calcareous material (lime) and argillaceous material (clay) and then grinding. Cement was first produced by Joseph Aspidin, a mason from England. As its colour resembled a variety of sandstone found in Portland, he named it Portland cement (1842).

Limestones containing 20 to 40 per cent clay may be burnt and crushed to powder to get natural cement. Best variety of natural cement is known as Roman cement. Artificial cement is manufactured by mixing argillaceous and calcareous materials in suitable proportions and burning at a temperature 1400°C to 1450°C to get clinkers, which are then ground to get cement.

Ordinary Portland cement (OPC) contains lime (60 – 67%), silica (17 – 25%), alumina (3 – 8%) iron oxide (0.5 – 5.0%), calcium sulphate (3 – 4%), magnesia (0.1 – 3.0%), sulphur oxide (1 – 3%) and alkalies (0.4 – 1.3%). Lime imparts strength. Silica contributes to strength by forming dicalcium and tricalcium silicates. Excess silica prolongs setting lime. Alumina imparts quick setting property. Iron oxide provides colour, hardness and strength. Calcium sulphate increases the initial setting time. Magnesia provides hardness and colour. Sulphur makes cement unsound. Alkalies, if in excess, cause efflorescence.

OPC contains the following chemical compounds

1. Tricalcium silicate $3CaO\lozenge\ SiO_2$ (C_3S) 40%
2. Dicalcium silicate $2CaO\lozenge\ SiO_2$ (C_2S) 30%
3. Tricalcium aluminate $3CaO\lozenge\ Al_2O_3$ (C_3A) 11%
4. Tetracalcium alumino ferrite. $4CaO\lozenge\ Al_2O_3\ Fe_2O_3$ (C_4 AF) 11%

It also contains small quantities of impurities like calcium oxide (CaO) and magnesium oxide (M_2O). When water is added

- C_3A is first to react and sets generating heat
- C_3S hardens early and develops strength in first 28 days.
- C_2S hydrates slowly and increases strength over a year and contributes to ultimate strength.
- C_4 AF is a comparatively inactive compound.

Physical requirements of OPC are:

1. Fineness: The material retained on 90 micron sieve should not be more than 10%. In terms of specific surface, it should not be less than 2250 cm^2/gm [225 m^2/kg].

2. Setting time: Minimum initial setting time should be 30 minutes and maximum final setting time should be 600 minutes.

3. Soundness: After the test is conducted in Le Chatelier mould, the indicator should not show more than 10 mm widening.

4. Compressive strength: Mortar cubes of size 70.6 mm $(\sqrt{5000}\ mm^2)$ with 1 part cement, 3 parts of standard sand with specified water should give the strength as shown in Table 1.1.

Table 1.1 Compressive strength of cement in N/mm^2

Age	Grade 33	Grade 43	Grade 53

3 days	16	23	27
7 days	22	33	37
28 days	33	43	53

Manufacture of cement consists of mixing, burning and grinding processes.

1. Mixing: It may be wet process or by dry process. In wet process wash mill is used which is a heavy cylinder of 2.5 to 3.0 m in diameter and 9 to 12 m in length. It is kept slightly inclined to the horizontal and can rotate at 15–20 revolutions per minute. The cylinder is provided with steel balls.

2. Burning: Burning is carried out in a rotary kiln, which is a steel tube of diameter 2.5 to 3.0 m and length 90 to 120 m, placed at an inclination 1 in 25 to 1 in 30. It rotates at a rate of 1 to 3 rotation per minute. Coal dust is injected from lower end and mix is fed from top end. The temperature at feed end is 1400°C to 1500°C.

3. Grinding: The clinkers from rotary kiln are fed into a ball mill or tube mill. During the process of grinding about 3 to 4 per cent of gypsum is added. The ball mill or tube mill contains steel balls.

Storage of cement: Cement absorbs moisture from air and hydrates, which results into loss of strength. Hence, cement should be stored on a raised platform in a covered room. First- in-first-out rule should be used while taking out cement. The drainage system on the roof and around the storage should be well maintained. Storage period should be as little as possible.

Types of cement are

1. OPC: 33 grade, 43 grade and 53 grade (OPC)
2. Portland Pozzolana cement (PPC)
3. Fly ash cement
4. Blast furnace slag cement
5. Acid resistant cement
6. Sulphate resistant cement
7. High alumina cement
8. Quick setting cement – obtained by reducing the quantity of gypsum.
9. Rapid hardening
10. Expanding cement
11. Low heat cement
12. Hydrophobic cement
13. White cement
14. Coloured cement

Fine and Coarse Aggregates

- Sand, gravel, crushed stones which are the products of weathering or crushing of rocks are known as aggregates. Sources of fine aggregates on the basis of which sand is classified are: sea sand, river sand, stream sand, pit sand and manufactured sand. On the basis of grains size sand is classified as fine sand, coarse sand and gravelly sand. IS code classifies sand as grading zone - 1, Grading zone - 2, Grading zone - 3 and Grading zone - 4 on the basis of percentage of sand passing through different sized sieves.

- **Function of sand:** It subdivides the cement paste into thin films and allows it to spread and adhere. It allows carbon dioxide from air to penetrate and improve setting. It prevents shrinkage and adds to density of mortar. It fills the gap between building blocks and gives level surface to mortar.
- **Bulking of sand:** The increase in volume due to moisture content is known as bulking of sand. It is due to formation of thin films around sand particles. Increase in volume is as high as 30 – 37 per cent. At around 8% of moisture content, there is maximum bulking. Finer the sand more is the bulking. After about 20% moisture content, thin films start breaking and volume reduction takes place.
- A good sand has the following properties:

  (1) Chemically inert; (2) Hard; (3) Contains sharp and angular grains; (4) Free from salt, clay and organic matter; (5) Well graded.
- The field tests are possible to find presence of clay, salt and organic impurities. The size and shape of gains may be felt by touching it with fingers. Laboratory tests may be conducted to ascertain grading, bulking and to find fineness modulus. To determine fineness modulus sieves to be used are 10 mm, 4.75 mm, 2.36 mm, 1.18 mm, 600 micron, 300 micron and 150 micron. The cumulative percentage of weight retained on the above sieves divided by 100 gives fineness modulus (FM). If FM is between 2.20 and 2.60 it is fine sand, 2.6 to 2.9 FM indicates it is medium sand and more than 2.9 FM indicates it is coarse sand.
- Coarse aggregate gives mass to concrete.
- For structures like abutment, retaining walls and bed concrete 40 mm down size aggregates are used. For normal R.C.C. works like flooring roofing and columns 20 mm down size aggregates are preferred. For thin members 12.5 mm sized aggregates are used.
- The various tests conducted on coarse aggregates are to determine:

  1. Flakiness and elongation indices
  2. Fineness and grain size distribution
  3. Specific gravity and water absorption
  4. Clay, silt and dust content
  5. Resistance to crushing
  6. Resistance to impact
  7. Resistance to abrasion.

1.10 MORTAR

Mortar is an intimate mixture obtained by adding water to dry mixture of sand and binding material like clay, lime or cement.

Classification of Mortar:

1. On the basis of bulk density: Heavy weight, if weight is more than 15 kN/m^3, light weight, if its weight is less than 15 kN/m^3.

2. On the basis of application: Brick laying mortar, finishing mortar.

3. On the basis of binding material: Mud mortar, lime mortar, surkhi mortar, cement mortar and gauged mortar.

The proportions of cement to sand for various works used are show in Table 1.2.

Table 1.2 Cement-sand proportions

S. No.	*Name of work*	*Cement: sand*
1.	Brickwork below ground level	1 : 3 to 1 : 4
2.	General brickwork and stone masonry	1 : 6
3.	For arch work	1 : 3
4.	Damp-proof course	1 : 2
5.	External plastering and ceiling plastering	1 : 4
6.	Internal plastering	1 : 5 to 1 : 6
7.	Pointing	1 : 2 to 1 : 3

The strength obtained with different proportion is as shown below:

(1) 1 : 3 Mix – 10 N/mm^2; (2) 1 : 4 Mix – 7.5 N/mm^2; (3) 1 : 5 Mix – 5.0 N/mm^2; (4) 1 : 6 Mix – 3.0 N/mm^2; (5) 1 : 8 Mix – 0.7 N/mm^2.

Cement mortar may be prepared by hand mixing or by machine mixing.

Mortars with special properties are also used: Fire resistant, sand absorbing, X-ray shielding, packing mortar and decorative mortars are the special mortars.

1.11 CEMENT CONCRETE

Cement concrete is an intimate mixture of cement, sand, coarse aggregates and water. Occasionally some admixtures are added to introduce special properties. Water lubricates aggregates, activates chemical reactions and give workability to mix. However, the quantity of water to be used should be determined carefully since workability of concrete increases with quantity of water but the strength decreases.

Various admixtures used with concrete are:

(1) Accelerators; (2) Retarders; (3) Air entraining agents and (4) Colouring agents.

Important properties of concrete in plastic stage (green concrete) are workability, segregation and bleeding.

The important properties of hardened concrete are:

(1) Strength; (2) Resistance to wear; (3) Impermeability and (4) Durability.

IS code classifies concrete mix as M 20, M 25, etc. which means mix of strength 20 N/mm^2, mix of strength 25 N/mm^2, etc. at the age of 28 days.

IS: 10262–1982 and SP 23–1982 give detailed procedure to design concrete mix of required strength.

For small works nominal mixes as shown is Table 1.3 may be used.

Table 1.3 Normal mixes for minor works

Mix	Proportion	Nature of works
M : 7.5	1 : 4 : 8	For bed concrete
M : 10	1 : 3 : 6	For sill concrete and mass concrete works
M : 15	1 : 2 : 4	For R.C.C. structural elements
M : 20	$1:1\frac{1}{2}:3$	For water retaining structures
M : 25	1 : 1 : 2	For heavily loaded columns, beams, etc.

1.12 CONCRETING

It involves mixing, transporting, placing, compacting and curing.

1. **Mixing:** One can adopt hand mixing or machine mixing. Coarse aggregate and fine aggregates are dry mixed, then cement is mixed till uniform colour is seen to the dry mix. The required quantity of water is mixed gradually while mixing process is kept continuous.
2. **Transportation:** Care should be taken to avoid segregation during transport.
3. **Placing:** Concrete should be placed to its final position by dropping it as close to final position as possible, in any case not more than 0.8 m.
4. **Compacting:** To remove entrapped air compacting of concrete is necessary. It may be hand compacting or by using vibrators. Over-compacting should be avoided to avoid segregation.
5. **Curing:** It is the process of maintaining satisfactory moisture and temperature in a freshly laid concrete. Curing should be done well in first 2 weeks and continued for another 1–2 weeks. If curing is not satisfactory shrinkage cracks may develop and durability is reduced. The various methods of curing are:

(1) Spraying water; (2) Covering with gunny bags; (3) Ponding; (4) Steam curing and (5) Applying curing compounds.

Different Concrete Works

1. Plain concrete 2. R.C.C.
3. P.S.C. 4. Precast concrete
5. Special concrete.

To meet the requirements of special situations, the following types of concrete are manufactured:

1. Fibre reinforced concrete (FRC).
2. Polymer impregnated concrete (PIC)
3. High performance concrete
4. Light weight concrete
5. Self-compacting concrete.

Tests on Concrete

To measure workability slump test, compaction factor test or Vee-Bee consistometer tests are conducted.

To find the strength, compression tests are conducted on 150 × 150 × 150 mm cubes after 28 days.

1.13 LIME

- Lime has been used as cementing material from ancient times. It contains clay (8 to 10%), magnesium carbonate (not more than 30%) and very small quantities of soluble silica, alkalies, sulphate and iron apart from the main constituent calcium carbonate.
- Lime is classified as fat lime, hydraulic lime and poor lime. Fat lime contains 95% of calcium oxide. When water is added, it slakes vigorously and its volume increases 2 to 2.5 times. Hydraulic lime sets by chemically combining with water. It is classified as feeble hydraulic lime (5 to 10% clay), moderately hydraulic lime (10 to 20% clay), eminently hydraulic lime (20 to 30% clay). It is used for making mortar to be used for plastering and in damp-proof constructions. Lime containing more than 30% clay is poor lime.
- Manufacture of lime involves preparation, burning and hydration (slaking). For burning clamps or kilns are used. The kiln may be intermittent or continuous.
- IS: 1624–1974 specifies various tests to assess the quality of lime. The tests prescribed are:

(1) Physical properties tests; (2) Acid tests; (3) Heat test; (4) Ball test; (5) Impurity test; (6) Plasticity test; (7) Workability test.

1.14 POZZOLANAS

Pozzolana is defined as a siliceous material that does not possess cementation property, but reacts with lime in the presence of water at normal temperature to form compounds.

- Pozzolana is added to fat lime to produce hydraulic lime. Addition of pozzolana to cement makes product cheap, which is known as PPC. It gets strength slowly but final strength is same as that of OPC. It possesses better impermeability compared to OPC. Addition to concrete helps in getting dense concrete and it reacts with free lime. Hence, chances of blisters appearing latter is eliminated. Heat of hydration is reduced, which is essential in mass concrete works.
- Surkhi, blast furnace slag, fly ash, silica fame and rice husk ash are the pozzolanic materials.

1.15 PAINTS, VARNISHES AND DISTEMPERS

- The surfaces of walls, ceiling, wood and metal works are coated with paints, varnishes or distempers to protect them and give them good appearance.
- Paint is a mixture of solid pigments in liquid vehicles. The essential constituents of oil-borne paints are base, vehicle, solvent, pigment, filler and drier.

1. Base: It is a solid substance in a fine state forming bulk of the paint. White lead, red lead, zinc oxide, iron oxide, aluminium powder are commonly used base materials.

2. Vehicle: The liquid substance that holds the ingredients of paint is known as vehicle. Linseed oil, tung oil, poppy oil, nut oil, etc., are the commonly used vehicles.

3. Solvents: Solvents are the paint thinners. The common solvents are turpentine, petroleum spirit and naptha.

4. Pigment: Pigments provide colour to the paint

Black – Lampblack, charcoal black

Brown – Burnt umber, burnt sienna

Blue – Persian blue, ultramarine
Green – Chrome green, copper sulphate
Red – Red lead, venetian red
Yellow – Zinc chrome, raw sienna chrome yellow.

5. Fillers: Fillers are inert materials added to reduce cost of paint. They make paint durable. Magnesia, alumina, gypsum, silicate, barite are the commonly used fillers.

6. Driers: Its function is to absorb oxygen from air and supply it to the vehicle. It is added just before painting. They are compounds like lead, manganese and cobalt.

Types of paints are

1. Oil paint: These paints contain white lead as base.

2. Enamel paint: This paint is prepared by adding white lead or zinc to varnish. It is desirable to provide titanium under coat. It may be used for exterior walls also.

3. Emulsion paint: It contains binding material like polyvinyl acetate and polystyrene. Cobalt and manganese are the pigments and driers. The paint becomes surface dry within 15 minutes and hardens in 2 hours. The surface is washable.

4. Cement paint: It consists of white or coloured cement as base. It is available in the form of powder, which is mixed with water and used.

5. Aluminium paint: It consists of finely ground aluminium particles in suspension, in spirit or oil varnish. It is visible in darkness.

6. Bituminous paint: It is manufactured by dissolving asphalt of vegetable bitumen in oil or petroleum. It is black in colour. It is used for painting portions of wooden posts buried underground.

7. Synthetic rubber paint: It is prepared by dissolving chlorinated rubber in a solvent. It may be applied to concrete surfaces also.

8. Celluloid paint: It is prepared by dissolving celluloid sheets or nitro cotton in petroleum. Castor oil is added to improve adhesive property. It is used for painting vehicles.

9. Asbestos paint: It consists of fibrous asbestos. It is used for stopping leakages in metal roof, basements. It is used for painting gutters.

10. Plastic paint: It consists of plastic as a base and water as a thinner. It gives attractive colours. This is widely used for painting walls in auditoriums and show rooms.

11. Anticorrosive paint: It consists of linseed oil as vehicle and lead or zinc chrome as base. Finely ground sand is added as filler. It is black in colour and gives protection from corrosion.

Painting

1. ***Plastered surfaces*** Emulsion paints may be applied after a curing period of 4 – 6 weeks. Final coat is to be applied after 6 – 12 months only. Before painting the surface should be made dust free. For new surfaces primer coat is required.
2. ***Concrete surface*** Usually, two coats of cement paint are required. Painted surface should be cured for 10 – 15 days.
3. ***Wood surface*** Before painting a new surface all nail heads should be punched to a depth of 3 mm.

The surface should be made free from loose particles, dust and grease. Knots if any should be levelled and two coats of varnish applied. Fill all cracks, dents, loose joints with putty. Apply primer, two undercoats before the finishing coat. In case of old wood works clean the surface with sand paper and pumice stone wash with caustic soda solution of 200 gm in a litre of water. Apply primary coat, undercoat and finishing coats.

4. ***Iron and steel surface*** Remove dust with wire brushes. Remove grease by washing with caustic soda. Then apply the coats.

Varnishes: Varnish is a transparent solution containing resinous solutions like amber, coal, shellac, gum, etc. Solvent is turpentine or alcohol or water. The process of applying varnish is known as varnishing. It makes surface glossy.

Distemper: It is also called water paint. It is a paint with chalk as base and water as carrier. It is readily available in the market in the form of powder. There are two types of distempers: dry distempers and oil bound distempers.

1.16 MISCELLANEOUS MATERIALS

1. ***Glass and glass wool*** It is manufactured by fusion of silica with varying proportions of oxides of sodium, calcium, potassium and magnesia. They are fabricated by blowing, drawing, pressing, rolling or casting. After annealing they are given treatment by tempering, opaque making, silvering, bonding or cutting. It can be made stronger than steel and lighter than cork.

Types of glass are many:

(1) Common glass; (2) Soda lime glass; (3) Potash lime glass; (4) Potash lead glass; (5) Coloured glass; (6) Special glasses.

Special glasses are fibre glass, wired glass, safety glass, bullet proof glass, shielding glass, ultraviolet ray glass, structured glass, glass blocks, ribbed glass, perforated glass and glass wool, etc.

2. ***Plastics*** Plastic is a natural synthetic material, which has a property of being plastic at some stage of its manufacture. Synthetic material nay be phenol, formaldehyde, cellulose vinyl, etc. At present there are more than 1000 varieties of plastic.

- Synthetic of plastics are polymers. Polymerization is the process in which relatively small molecules, called monomers combine chemically to produce a very large network molecules, called polymers.
- Classification of the plastics may be on various basis.

  1. On the basis of structure: Homogeneous plastics and heterogeneous plastics.
  2. On the basis of physical and mechanical properties. Rigid plastics, semi-rigid plastics, soft plastics and elastomers.
  3. On the basis of thermal properties: Thermoplastics and thermosetting plastic. Thermoplastics soften on heating and harden on cooling. The process of softening and hardening can be repeated several times. Thermosetting plastic undergo chemical changes at 127 – 177° C and set into permanent shape under pressure. Reheating will not soften them.

- Advantages of plastic are — they can be moulded easily, do not rust, resist chemical action, light in weight and possess high strength to weight ratio. Disadvantage is that they have low modulus of elasticity.

3. *Glass fibre reinforced plastics (GFRP)* In these glass fibres provide stiffness and strength while resin provides a matrix to transfer load to fibres. GFRP is used for door and window frames, partition walls, roofing sheets, skylights, water tanks, for making chairs and tables.

4. *Asbestos* Asbestos is a naturally available mineral substance. It is fire-proof, acid-proof. It is a good insulator of heat and electricity. It is used with cement to produce asbestos cement sheets for roofing, wall panelling, to cover fuse and electric boxes, for making downtake pipes, etc.

5. *Bitumen, asphalt and tar* These are called bituminous materials and their main constituent is hydrocarbon.

(**a**) **Bitumen:** It is obtained by fractional distillation of crude petroleum. It is specified by term penetration, say 80/100 means penetration of standard needle is 80 to 100 mm at a temperature of 25°C. It is used for damp proof course, roofing felt.

(**b**) **Asphalt:** It is bitumen mixed with inert material like sand, gravel and crushed stone. It is found in natural form. It is artificially manufactured also. It is used for waterproofing floors and roofs, lining reservoirs and swimming pools, for grouting expansion joints.

(**c**) **Tar:** It is obtained by destructive distillation of coal, wood or mineral tar. It is used for road work, anti-termite treatment and waterproofing.

6. *Fly Ash* It is a by-product in coal based thermal plants. Its particles can fly in ordinary air. At one time it was considered a nuisance but now it is used as a useful material in manufacturing bricks, for stabilizing soil and to improve workability of concrete.

7. *Steel Putty* It is a plaster filler which can be applied with knife to fill dents in steel plates. It has good adhesive property and dries hard.

8. *Adhesive, sealants and joint fillers*

- An adhesive is a material used to join two or more surfaces. Asphalt, shellac and cresin are natural adhesives which are used to glue papers. Rubber is another natural adhesive used to join plastic, glass and rubber. There are many synthetic varieties of adhesives like melamine resin, phenoil resin, urea resin and polyvinyl resin. They are used for joining plywood and laminated products. Starch glue, animal glue, casein glue (glue from skimmed milk), sodium silicate glue are also available for joining various materials.
- **Sealants:** Sealants are the substances used to seal cracks or joints between wall and window frames, glazing and window frame or between roofing sheets. Elastomeric sealants are most efficient. They are based on silicon, acrylic or polysulphide.
- **Joints fillers:** To prevent seepage of water through construction joints, these materials are used. They should be compressible and resilient. The common joint fillers used are built in strips of metals, bitumen treated felt and cork bound rubber.

9. *Heat, electrical and sound insulating materials*

- Thermal comfort may be achieved by providing air spaces by using aerated concrete, hollow blocks, using blast furnace slag in mortar and concrete and providing insulators and reflecting paints.

- Electric insulators are used to separate the conductors carrying electric current. Mica, asbestos, porcelain, rubber, leakalite are electrical insulators. Paraffin and chlorinated diphenyl are liquid insulators which are used in transformers. In refrigerators thermocol is used.
- In auditoriums and cinema halls, sound insulators are required. The commonly used sound insulators are cellular concrete, asbestos, gypsum plaster, pulp boards, perforated plywood, glass mineral wool, etc.

10. Waterproofing and damp-proofing materials

- Preventing passage of water from one side of a surface to other side under normal hydrostatic pressure is known as waterproofing while damp-proofing is to prevent transfer of water by capillary action.
- Bituminous materials, integral compounds, epoxy based materials, slurry coat and elastomeric materials are various waterproofing materials.

11. Thermocol It is a general-purpose crystal polysterene. It can be cut easily with knife or saw. It contains 3–6 million discrete cells/litre. It has insulating efficiency against heat, sound, humidity and shock. It is used as packing material and display board.

12. Epoxy It is a thermosetting polymer. It possesses excellent mechanical and adhesive properties. It is used with paints also.

13. Polyurethene It is a product produced by mixing polymeric diol or triol with a silicon surfactant and a catalyst. This has elasticity of rubber, combined with the toughness of metal. It is used for making gaskets, tiers, bushings, shoe soles, pipes, waterproofing chemicals, etc.

14. Geosynthetics These are synthetic materials made of nylon, PVC, polypropylene etc. They last long even when buried under soil. Geotextiles, geogrids, geomembranes and geocomposites are commonly used geosynthetics. These materials are used for soil stabilization.

15. Ferrocement Wire meshes embedded with cement and baby jelly is known as ferrocement. They are used for making door/window frames and shutters, partition walls, signboards, furnitures and even boats.

16. Cladding materials Cladding materials are used to enhance aesthetic appeal of walls, kitchen slab, stairs, roofs, ceiling, etc. Slate, granite, marble, clay tiles, mosaic, glass, wall papers etc. are the commonly used cladding materials in buildings.

17. PVC building products Polyvinyl chloride (PVC) is versatile plastic. Its properties can be easily modified by addition of other compounds. PVC pipes, door and window frames, partition walls, kitchen cabinets, tiles and false ceiling are very popular products.

MULTIPLE-CHOICE QUESTIONS

I.

Stones

1. The rocks formed due to solidification of molten mass are called

(a) aqueous rocks
(b) sedimentary rocks
(c) metamorphic rocks
(d) igneous rocks

2. Granite is an example of

(a) aqueous rocks
(b) sedimentary rocks
(c) metamorphic rocks
(d) igneous rocks

3. Solidification of molten magma at the surface of the earth results in the formation of

(a) sedimentary rock
(b) basalt and traps
(c) granite
(d) metamorphic rock

4. Solidification of molten magma within the earth's crust results in the formation of

(a) sedimentary rock
(b) basalt and trap
(c) granite
(d) metamorphic rack

5. Sedimentary rocks are formed due to

(a) solidification of molten mass
(b) gradual deposition of materials like sand, clay, generally by setting water
(c) alteration of original stones under heat and pressure
(d) none of the above

6. In the options given in question No. 5, identify the process responsible for the formation of metamorphic rocks.

7. Under metamorphism, which of the following changes is correct?

(a) granite changes to gnesis.
(b) trap and basalt change into laterite.
(c) limestones change into marble.
(d) all the above

8. Granite has

(a) crystalline, glossy and fused texture
(b) foliated structure
(c) layers of different compositions
(d) none of the above

9. The principal constituent of argillaceous rock is

(a) sand

(b) lime
(c) clay
(d) all the above

10. Laterite is chemically classified as
(a) calcareous rock
(b) siliceous rock
(c) metamorphic rock
(d) argillaceous rock

11. Which of the following is an example of siliceous rock?
(a) granite
(b) gnesis
(c) quartzite
(d) all the above

12. Marble is an example of
(a) aqueous rock
(b) metamorphic rock
(c) sedimentary rock
(d) igneous rock

13. Slate is used for
(a) building walls
(b) road metal
(c) manufacture of cement
(d) roofing

14. Which one of the following takes polish very well?
(a) basalt and trap
(b) granite
(c) sandstone
(d) quartzite

15. The colour of granite is
(a) grey
(b) green
(c) brown
(d) all of these

16. A fine grained granite
(a) can be polished well
(b) can be used for exterior facing of buildings
(c) offers higher resistance to weathering
(d) all of the above

17. Siliceous sand subjected to metamorphic action is known as

(a) laterite
(b) murram
(c) quartzite
(d) dolomite

18. When quarrying is to be done in hard and compact rocks, the usual method employed is
(a) wedging
(b) using channeling machine
(c) blasting
(d) all of the above

19. Quarrying by using channeling machine is employed for quarrying in
(a) soft rock
(b) hard rock
(c) sandstones
(d) all the above

20. Heating technique of breaking rocks is suitable if the aim is to get
(a) aggregates
(b) slabs
(c) building blocks
(d) none of the above

21. The process of taking out stones of various sizes from natural rock is known as
(a) dressing
(b) seasoning
(c) polishing
(d) quarrying

22. The process of giving required shape and size to stones is known as
(a) dressing
(b) seasoning
(c) polishing
(d) quarrying

23. Boasted finish of dressing stone is
(a) making non-continuous parallel marks
(b) giving finish to a 20 mm margin only at edges
(c) providing continuous lines on the face
(d) working out 30–50 mm wide margin around the face with chisel

24. Dressing of the stone is made
(a) immediately after quarrying
(b) after three months of quarrying
(c) just before using for building works
(d) after seasoning

25. The most powerful explosive used in blasting is

(a) gunpowder
(b) guncotton
(c) dynamite
(d) cordite

26. Moisture absorption of a good stone should be less than

(a) 1%
(b) 5%
(c) 8%
(d) 12%

27. Most of the stones possess the specific gravity in the range of

(a) 1.2 – 1.6
(b) 1.6 – 2.0
(c) 2.4 – 2.8
(d) 3.0 – 4.0

28. Which of the following has the lowest strength?

(a) granite
(b) sandstone
(c) marble
(d) laterite

29. Limestone used for manufacture of cement is

(a) *kankar*
(b) magnesium limestone
(c) compact limestone
(d) granular limestone

30. Which of the following has the highest crushing strength?

(a) granite
(b) gneiss
(c) basalt
(d) trap

31. Which of the following stone has the highest resistance to fire?

(a) granite
(b) limestone
(c) sandstone
(d) argillaceous material

32. Smith's test on stone is to check

(a) toughness
(b) hardness
(c) compressive strength
(d) presence of muddy substance

33. Los Angeles testing machine is used to find the following in stone

(a) surface wear
(b) hardness
(c) compressive strength
(d) presence of mud

34. Impact value of stone for road work specified are

(a) wearing coat $\ngtr$ 30%
(b) bituminous macadam $\ngtr$ 35%
(c) water bound macadam $\ngtr$ 40%
(d) all the above

35. Deterioration of stones takes place due to

(a) temperature variation
(b) freezing and thawing
(c) rainwater

(d) all of the above

36. Which one of the following is not a preservative of stone

(a) coal tar
(b) paraffin
(c) linseed oil
(d) ASCU

Timber

37. After felling and separating branches the tree is known as

(a) log
(b) converted timber
(c) rough timber
(d) none of the above

38. Which one of the following does not belong to exogenous tree

(a) deodar
(b) pine
(c) mahogany
(d) bamboo

39. Which one of the following dose not belong to endogenous trees

(a) teak
(b) coconut
(c) bamboo
(d) cane

40. On the basis of durability test, Forest Research Institute of India, Dehradun, a tree is highly durable if its average life is more than

(a) 5 years
(b) 10 years
(c) 15 years
(d) 20 years

41. The trees, of which leaves fall in autumn and new ones appear in spring are classified as
(a) coniferous trees
(b) deciduous trees
(c) endogenous trees
(d) none of the above

42. The oldest part of exogenous tree is
(a) pith
(b) heartwood
(c) sapwood
(d) cambium layer

43. Age of exogenous tree can be judged from
(a) medullary rays
(b) annual rings
(c) cambium layer
(d) inner bark

44. The layer between the dark and sapwood which is yet to be converted into wood is known as
(a) pith
(b) heartwood
(c) softwood
(d) cambium layer

45. Which one of the following is softwood
(a) deodar
(b) teak
(c) sal
(d) mahogany

46. Which one of the following is not a softwood:
(a) oak
(b) pine
(c) deodar
(d) bamboo

47. On the basis of availability, timber is classified as
(a) I. II, III Class
(b) grade I, II, and III
(c) A, B, C Class
(d) X, Y, Z Class

48. The main purpose of seasoning of timber is to

(a) reduce moisture content
(b) make it fire resistant
(c) make it waterproof
(d) none of the above

49. Seasoning makes timber
(a) durable
(b) light, strong and stable
(c) resistant to fungi and termites
(d) all of the above

50. Which of the following statements is not correct?
(a) by kiln seasoning moisture content can be reduced to the desired extent.
(b) kiln seasoning is quicker than natural seasoning.
(c) kiln seasoning is superior to natural seasoning.
(d) kiln seasoning needs less stacking place than natural seasoning.

51. In water seasoning
(a) timber is placed with thicker end pointing upstream
(b) timber is placed with thicker end pointing downstream
(c) timber log is placed at right angle to the stream
(d) timber may be placed in any direction

52. Most economical method of sawing wood is
(a) ordinary sawing
(b) quarter sawing
(c) tangential sawing
(d) radial sawing

53. Sections of more uniform moisture content are obtained by
(a) ordinary sawing
(b) quarter sawing
(c) tangential sawing
(d) radial sawing

54. The defect in timber due to broken branch of the tree during the tree growth is
(a) knot
(b) shake
(c) rind gall
(d) burl

55. Due to improper cutting of the branches during the growth of the tree, the defect caused in timber is
(a) shake
(b) rind gall
(c) twisted fibre

(d) burl

56. Stain appears in wood due to
   (a) poor ventilation during storage
   (b) contact with water and chemicals for long time
   (c) shock when it was young
   (d) crushing during growth
57. Honeycomb and cracks may occur in timber due to
   (a) erroneous conversion
   (b) erroneous seasoning
   (c) attack by fungi
   (d) contact with water for a long time
58. Which one of the following is not a preservative of timber
   (a) solignum salt
   (b) chemical salt
   (c) creosote
   (d) solution of barium hydroxide
59. A thin sheet of wood sliced from a log is called
   (a) plywood
   (b) lamin board
   (c) veneer
   (d) particle board
60. In a plywood the veneers are placed such that the grains of a layer are
   (a) at 45° to the grains of a layer below it
   (b) at 60° to the grains of a layer below it
   (c) at right angles to the layer below it
   (d) at 180° to the grains of a layer below it
61. Plywood is identified by
   (a) volume
   (b) weight
   (c) area
   (d) thickness
62. An assembled product made up of veneers and adhesives is called
   (a) batten
   (b) plank
   (c) board
   (d) plywood
63. To get plywood of thickness 25 mm, minimum number of plies is
   (a) 5
   (b) 7

(c) 9

(d) 11

64. Particle boards are manufactured by using
(a) chips of wood, rice husk and bagasse
(b) strips of wood of width 25–80 mm
(c) wood pulp
(d) none of the above

65. The wood that cannot be attacked by white ants is
(a) mahogany
(b) rosewood
(c) sissoo
(d) teak

66. The standard size of bricks as per Indian Standards is
(a) 230 × 120 × 80 mm
(b) 200 × 100 × 100 mm
(c) 190 × 90 × 90 mm
(d) 190 × 100 × 100 mm

67. Red colour of brick is due to the presence of
(a) lime
(b) silica
(c) manganese
(d) iron oxide

68. Excess of lime in the brick earth makes the bricks
(a) brittle and weak
(b) crack and warp
(c) melt and lose shape
(d) improve durability

69. Excess of iron oxide in brick earth makes the bricks
(a) stronger
(b) darker
(c) brittle
(d) crack

70. Alumina in brick earth gives the bricks
(a) strength
(b) colour
(c) plasticity
(d) resistance to shrinkage

71. Excess of alkalies in the brick earth results into
(a) brittleness

(b) white patches
(c) yellowish colour
(d) porous structure

72. Pug mill is used to
(a) blend clay
(b) tempering
(c) weathering clay
(d) burning bricks

73. The size of mould used for making bricks compared to size of brick is
(a) 10% more
(b) 5% more
(c) exactly equal
(d) 5% less

74. Pallet board is used to
(a) make frog in the brick
(b) to mount the mould
(c) for table moulding of bricks
(d) none of the above

75. In stiff mud process of machine moulding, water used for mixing is
(a) 8–12%
(b) 12–18%
(c) 20–24%
(d) 30%

76. Gradual drying of moulded bricks is necessary to
(a) prevent shrinkage
(b) permit shrinkage without cracking
(c) permit blending of alumina and silica
(d) none of the above

77. The brick is considered dry when the moisture content is
(a) 8%
(b) 5%
(c) 2%
(d) zero

78. Hand moulded bricks take ______ days for drying while stiff-mud machine made bricks ______ days.
(a) 30, 5
(b) 15, 2
(c) 10, 1
(d) 8, 1/4

79. The indentation mark left on bricks during the process of moulding are

(a) pallets
(b) fillets
(c) marks
(d) frog

80. Which one of the following statements is wrong about clamp burning

(a) it is cheap
(b) does not need skilled labour
(c) control on burning process is good
(d) burning process is slow

81. Continuous kiln is

(a) bull's trench kiln
(b) Hoffman's kiln
(c) tunnel kiln
(d) all of the above

82. The minimum strength of brick required for building wall is

(a) 7.5 N/mm^2
(b) 5.0 N/mm^2
(c) 3.5 N/mm^2
(d) 2.5 N/mm^2

83. To check the size of brick number of bricks to be kept side by side is

(a) 30
(b) 20
(c) 10
(d) 5

84. The bricks which may be used to build wall but to be provided with plaster are

(a) Ist Class
(b) IInd Class
(c) IIIrd Class
(d) IVth Class

85. The compressive strength of high duty bricks should be more than

(a) 40 N/mm^2
(b) 20 N/mm^2
(c) 5 N/mm^2
(d) 3.5 N/mm^2

86. Thickness of web of hollow bricks should not be less than

(a) 20 mm
(b) 16 mm
(c) 12 mm

(d) 8 mm

87. Compressive strength of paving bricks should not be less than

(a) 40 N/mm^2

(b) 30 N/mm^2

(c) 20 N/mm^2

(d) 40 N/mm^2

88. Field test for strength of good bricks is to drop it from a height of ______ and they should not break

(a) 1.2 m

(b) 1.0 m

(c) 0.7 m

(d) 0.75 m

89. For making stabilized soil brick the soil is stabilized with

(a) sand

(b) coal

(c) cement

(d) salt

90. Refractory bricks resist

(a) high temperature

(b) chemical action

(c) action of frost

(d) all of the above

Clay Products

91. In case of round tiles, under-tiles are used with their narrow ends

(a) towards eve

(b) towards ridge

(c) towards valley

(d) in any one fashion

92. Maximum water absorption permitted on class AA type Mangalore tiles is

(a) 13%

(b) 15%

(c) 17%

(d) 19%

93. Which of the following statement is wrong?

(a) Pan tiles are similar to half round tiles but less curved

(b) Pan tiles are weaker than half round tiles

(c) Allahabad tiles are interlocking tiles

(d) Mangalore tiles are also interlocking tiles

94. The word vitrified means

(a) glazed
(b) like glass
(c) given attractive colour
(d) all of the above

95. Terracotta means
(a) insulated
(b) fit for sanitary services
(c) good for ornamental work
(d) baked earth

96. Water absorption of vitrified tiles is not more than
(a) 0.5%
(b) 1.0%
(c) 2.0%
(d) 5.0%

97. To make terracotta porous, the following is mixed with clay before burning.
(a) lime
(b) silica
(c) sawdust
(d) none of the above

Ferrous Materials

98. By calcining and smelting iron ores, a crude and impure form of iron obtained is known as
(a) cast iron
(b) wrought iron
(c) steel
(d) pig iron

99. The colour of cast iron is
(a) grey
(b) white
(c) both grey and white
(d) none of the above

100. The compressive and tensile strength of cast iron are
(a) 700 N/m^2 and 150 N/mm^2
(b) 600 N/mm^2 and 400 N/mm^2
(c) 415 N/mm^2 and 415 N/mm^2
(d) 400 N/mm^2 and 600 N/mm^2.

101. For making spiral staircases, ideal material is
(a) pig iron
(b) cast iron

(c) wrought iron

(d) steel

102. Purest form of iron is
(a) pig iron
(b) cast iron
(c) wrought iron
(d) steel

103. Carbon content in wrought iron is
(a) 0.15%
(b) 0.25 to 1.5%
(c) 2 to 4%
(d) more than 4%

104. The ratio of tensile strength to compressive strength of steel is
(a) less than 1
(b) equal to 1
(c) more than 1
(d) nothing can be said definitely

105. Ribs are made on steel wires to increase
(a) strength is compression
(b) strength is tension
(c) bond strength
(d) fatigue quality

106. The property of metal enabling it to be drawn into thin wire is known as
(a) malleability
(b) ductility
(c) toughness
(d) plasticity

107. The property of the metal enabling it to be transformed it into different shapes by heating is
a, b, c, d as per Question No. 106

108. The property of metals due to which it can withstand shock is
a, b, c, d as per Question No. 107

Non-ferrous Materials

109. Market form of copper is/are
(a) ingots
(b) sheets
(c) tubes
(d) all of the above

110. The ore from which aluminium is extracted economically is
(a) kaolin

(b) kryolite

(c) corundum
(d) bauxite

111. Specific gravity of aluminium is
(a) 1.5
(b) 2.7
(c) 3.5
(d) 4.2

112. Zinc is
(a) an alloy of aluminium and copper
(b) an alloy of aluminium and chrome
(c) an alloy of copper and chrome
(d) a metal

113. The heaviest metal is
(a) steel
(b) lead
(c) tin
(d) cast iron

114. Which of the following metal is poisonous?
(a) aluminium
(b) tin
(c) lead
(d) copper

Alloys

115. Duralumin is an alloy of
(a) aluminium and copper
(b) aluminium, copper, nickel and magnesium
(c) aluminium and zinc
(d) aluminium and tin

116. Which of the following is a variety of aluminium alloy
(a) duralumin
(b) aldural
(c) Y-alloy
(d) all the above

117. Aluminium alloys used in building bodies of aeroplane are
(a) duralumin and aldural
(b) aldural and aluminium bronze
(c) aluminium bronze and Y-alloy
(d) Y-alloy and duralumin

118. Which one of the following is not a variety of brass

(a) white brass
(b) yellow brass
(c) red brass
(d) brown brass

119. Bronze is an alloy of

(a) aluminium and copper
(b) copper and zinc
(c) copper and tin
(d) none of the above

120. The constituents of stainless steel are

(a) steel, chromium and nickel
(b) steel and nickel
(c) steel and manganese
(d) steel and molybdenum

121. Quick lime is

(a) calcium carbonate
(b) calcium oxide
(c) calcium hydroxide
(d) none of the above

122. When fat lime is slaked, its volume

(a) decreases to 50%
(b) remains same
(c) increases by 2 to 2.5 times
(d) increases by 4 times.

123. Which one of the following statement is correct?

(a) Fat lime contains hardly 5% clay
(b) Hydraulic lime contains 5.30% clay
(c) Poor lime contains more than 30% clay
(d) All the above

124. For plastering work lime used is

(a) quicklime
(b) fat lime
(c) hydraulic lime
(d) poor lime

125. Hydraulic lime is obtained by

(a) burning *kankar*
(b) calcination of limestone
(c) slaking quicklime

(d) calcination of pure clay

126. The process of adding water to quicklime in order to convert it into hydrated lime is known as

(a) quenching
(b) hydration
(c) calcination
(d) slaking

127. The commonly used lime for whitewashing is

(a) hydraulic lime
(b) lean lime
(c) fat lime
(d) quicklime

128. Quicklime on reaction with water gives

(a) calcium oxide
(b) calcium carbonate
(c) calcium hydroxide
(d) none of the above

129. The lime which has property of setting in water is known as

(a) fat lime
(b) hydraulic lime
(c) quicklime
(d) magnesium lime

130. The fuel generally used for burning lime stone is

(a) firewood
(b) charcoal
(c) coal
(d) any one of these

131. Fat lime

(a) slakes rapidly with considerable evolution of heat
(b) has high plasticity
(c) takes longer to develop adequate strength
(d) all of the above

132. The main constituent which imparts hydraulicity to hydraulic lime is

(a) calcium oxide
(b) silica
(c) clay
(d) water

133. The constituent responsible for setting of hydraulic lime under water is

(a) calcium oxide
(b) clay

(c) silica

(d) carbon dioxide

134. The process of heating limestone to redness is termed as

(a) hydration
(b) carbonation
(c) oxidation
(d) calcination

135. The major constituent of cement is

(a) lime
(b) silica
(c) alumina
(d) iron oxide

136. The constituent which imparts strength to cement is

(a) lime
(b) silica
(c) alumina
(d) magnesia

137. The constituent which imparts colour to cement is

(a) lime
(b) silica
(c) alumina
(d) iron oxide

138. Rotary kiln used in manufacturing cement rotates at a speed of

(a) 1–3 rpm
(b) 10–12 rpm
(c) 18–22 rpm
(d) more than 25 rpm

139. The clinker is formed at a temperature of

(a) 500–600° C
(b) 900–1000° C
(c) 1100–1300° C
(d) 1400–1500° C

140. The amount of gypsum added in the manufacture of cement is

(a) 0.1–0.5%
(b) 0.5–1%
(c) 1–3.0%
(d) 3–4%

141. Gypsum is added in the manufacture of Portland cement to

(a) reduce setting time of cement

(b) increase setting time of cement

(c) to enhance the strength of cement
(d) to decrease grinding time

142. Gypsum is added during the manufacture of cement
(a) while mixing the raw materials
(b) during burning in the kiln
(c) at the beginning of grinding the clinker
(d) after grinding the clinker

143. Specific surface of cement is
(a) measure of fineness
(b) measure of volume of cement
(c) measure of smoothness of cement
(d) none of the above

144. Specific surface of cement should not be less than
(a) 100 cm^2/gm
(b) 1500 cm^2/gm
(c) 2000 cm^2/gm
(d) 2250 cm^2/gm

145. Specification for setting time of ordinary Portland cement are:

	Initial setting lime	*Final setting lime*
(a)	> 30 min	> 600 min
(b)	> 30 min	< 600 min
(c)	< 30 min	< 600 min
(d)	< 30 min	> 600 min

146. The compound responsible for initial setting of cement is
(a) Tricalcium aluminate
(b) Tricalcium silicate
(c) Dicalcium silicate
(d) Tetra alumino ferrite

147. The compound that hydrates early and is responsible for gain in strength in 28 days is
a, b, c, d as in Question No. 146.

148. The compound that hydrates slowly and responsible for gain of strength over a period of 1 year is
a, b, c, d as per Question No. 146.

149. Unsoundness in cement is due to
(a) free lime
(b) free magnesia

(c) insufficient grinding

(d) all the above

150. Le Chatelier apparatus is used for testing cement for its

(a) strength

(b) setting time

(c) fineness

(d) soundness

151. At the end of the test on cement, increase in the distance between the two indicators of Le Chatelier apparatus should not be more than

(a) 5 mm

(b) 10 mm

(c) 15 mm

(d) 20 mm

152. 43-grade cement has a strength of 43 N/mm^2 at the age of

(a) 3 days

(b) 7 days

(c) 28 days

(d) 1 year

153. Vicat apparatus is used for determining

(a) initial setting time of cement

(b) final setting time of cement

(c) normal consistency of cement

(d) all of these

154. Normal consistency of cement is about

(a) 7%

(b) 14%

(c) 21%

(d) 28%

155. Addition of Pozzolana to Portland cement causes

(a) increase in heat of hydration

(b) increase in strength

(c) increase in water tightness

(d) all the above

156. Blast furnace slag cement is

(a) durable

(b) gains strength slowly

(c) cheap

(d) all the above

157. High alumina cement is

(a) more resistant to sulphate attack

(b) more resistant to acid attack
(c) gains almost full strength within 24 hours after adding water
(d) all the above

158. Which one of the following is not correct statement about fly ash blended cement?
(a) They have superior resistance to weathering action.
(b) They gain strength fast.
(c) Ultimate strength is same as OPC.
(d) All the above.

159. To prevent setting of cement during storage the material added to cement during grinding is
(a) acidol
(b) oleic acid
(c) oxidized petroleum
(d) any of the above

160. Rapid hardening cement is produced by
(a) increasing the lime content
(b) burning it at high temperature
(c) grinding to a finer size
(d) all the above

161. Which one of the following is the correct statement about quick setting cement?

	Initial setting lime	*Final setting lime*
(a)	< 5 min	< 30 min
(b)	< 5 min	> 30 min
(c)	> 5 min	< 30 min
(d)	> 5 min	< 30 min

162. Which statement given below is wrong? The pigment used to produce coloured cement
(a) cobalt oxide to get blue colour.
(b) chloride oxide to get green colour.
(c) manganese oxide to get brown colour.
(d) aluminium oxide to get white colour.

163. Identify the correct statement given below: The natural Pozzolanic material is/are
(a) clay
(b) shale
(c) volcanic sand
(d) all the above

164. Which one of the following is not a Pozzolanic material?
(a) fly ash

(b) rice husk ash

(c) gypsum

(d) blast furnace slag

165. Silica fumes have found their use in

(a) pumped concrete

(b) high strength concrete

(c) shutcrete application

(d) all the above

166. For testing compressive strength of cement, the size of cubes used is

(a) 50 mm

(b) 70.6 mm

(c) 100 mm

(d) 150 mm

167. The sand in mortar

(a) prevents shrinkage

(b) spreads mortar

(c) allows carbon dioxide from the atmosphere to penetrate deeply

(d) all the above

168. An aggregate is called fine aggregate if it is completely passes through

(a) 150 micron sieve

(b) 300 micron sieve

(c) 600 micron sieve

(d) 4.75 mm sieve

169. The aggregate is called coarse aggregate if it is completely retained on

(a) 20 mm sieve

(b) 12 mm sieve

(c) 8 mm sieve

(d) 4.75 mm sieve

170. Due to bulking of sand, increase in volume is as high as

(a) 5%

(b) 15%

(c) 25%

(d) 30–40%

171. Maximum increase in the bulk of sand is at the moisture content

(a) 2 – 4%

(b) 4 – 6%

(c) 8 – 10%

(d) 12 – 15%

172. Bulking of sand is due to

(a) water films

(b) swelling of sand

(c) added mass of water

(d) none of the above

173. Which one of the following is not a desirable property of sand?

(a) It should be chemically active.

(b) It should contain sharp, angular grains.

(c) It should be hard.

(d) It should be well graded.

174. The increase in volume of sand when water is added is known as

(a) segregation

(b) bleeding

(c) bulking

(d) honeycombing

175. The cement to dry sand proportion recommended for masonry work is

(a) 1 : 3

(b) 1 : 6

(c) 1 : 10

(d) 1 : 12

176. The cement to dry sand proportion recommended for plastering external wall is

(a) 1 : 3 – 1 : 4

(b) 1 : 6

(c) 1 : 8

(d) 1 : 10

177. The cement to dry sand proportion recommended for plastering concrete surface is

(a) 1 : 3

(b) 1 : 6

(c) 1 : 8

(d) 1 : 10

178. The cement to dry sand proportion for pointing work is

(a) 1 : 2

(b) 1 : 4

(c) 1 : 6

(d) 1 : 8

179. The inert material to be used for making lime mortar is

(a) sand

(b) surkhi

(c) cinder

(d) any of the above

180. Gauged cement mortar consists of

(a) cement and sand
(b) cement, surkhi, sand
(c) cement, lime, sand
(d) cement, cinder, sand

181. Briquettes are the specimen of mortar used for finding

(a) compressive strength
(b) tensile strength
(c) flexural strength
(d) shear strength

182. Fineness modulus is

(a) the ratio of fine aggregates to coarse aggregate.
(b) the ratio of fine aggregates to total aggregate.
(c) an index which gives the mean size of the aggregates used in a mix.
(d) none of the above.

183. Which one of the following statement is wrong?

(a) Lime concrete is used as base course for foundations.
(b) Lime concrete is used as base course to ground floor.
(c) Lime concrete is used to make roof waterproof.
(d) It is used for R.C.C structural elements.

184. Which one of the following statement is wrong? In the absence of mix design, the ingredients of concrete are proportioned as

(a) 1 : 1 : 2 – mass concrete work
(b) 1 : 1 $\frac{1}{2}$: 3 – water tanks
(c) 1 : 2 : 4 – slabs, beams
(d) 1 : 3 : 6 – sills of windows

185. M : 20 concrete means

(a) 1 : 2 : 4 concrete
(b) concrete with a strength of 20 kg/cm^2 after 28 days
(c) concrete with a strength of 20 N/mm^2 after 7 days
(d) concrete with a strength of 20 N/mm^2 after 28 days

186. In order to achieve required workability and good strength at the same time, water cement ratio, in case of machine mixing is

(a) 0.3 – 0.4
(b) 0.4 – 0.5
(c) 0.5 – 0.6
(d) none of the above

187. In case of hand mixing in order to achieve good workability and good strength at the same time

is

(a) 0.3 – 0.4
(b) 0.4 – 0.5
(c) 0.5 – 0.6
(d) none of the above

188. The weight and volume of one bag of cement respectively are
(a) 50 kg and 35 litres
(b) 60 kg and 30 litres
(c) 50 kg and 30 litres
(d) 60 kg and 35 litres

189. If the water cement ratio to be used is 0.5, then water to be added to one bag of cement is
(a) 30 kg
(b) 25 kg
(c) 20 kg
(d) 18 kg

190. In machine mixing of concrete, the drum is rotated to make about
(a) 35 rotations
(b) 50 rotations
(c) 65 rotations
(d) 80 rotations

191. For transporting concrete which one of the following is not used?
(a) pans
(b) chutes
(c) belt conveyor
(d) tractor

192. Concrete should not be placed by dropping at a height more than
(a) 400 mm
(b) 600 mm
(c) 800 mm
(d) 1000 mm

193. Compaction of concrete is to
(a) remove entrapped air
(b) spread cement paste uniformly
(c) get level surface at top
(d) all of the above

194. Curing of concrete is the process of
(a) keeping the surrounding cool
(b) ponding the water on the surface
(c) covering the surface with wet gunny bags

(d) maintaining satisfactory moisture and temperature for a specific time

195. In precast industries, best method of curing is

(a) ponding
(b) covering with wet gunny bags
(c) spraying water
(d) steam curing

196. Curing compound mainly consists of

(a) calcium hydroxide
(b) calcium oxide
(c) chlorinated rubber
(d) calcium nitrate

197. Workability of concrete depends on

(a) water content
(b) aggregate shape and size
(c) mix proportion
(d) all the above

198. Which one of the following yields more workable concrete?

(a) Bigger size aggregates with rounded shape.
(b) Bigger size aggregates with angular shape.
(c) Smaller size aggregates with rounded shape.
(d) Smaller size aggregates with angular shape.

199. Which one of the following mix has higher workability?

(a) Well graded aggregate with richer mix.
(b) Well graded aggregate with poorer mix.
(c) Uniform grade aggregate with rich mix.
(d) Uniform grade aggregate with poor mix.

200. Workability of concrete is determined by

(a) slump test
(b) compaction factor test
(c) Vee-Bee test
(d) all the above

201. Slump required for concreting lightly reinforced sections without vibration is

(a) up to 25 mm
(b) 25 – 75 mm
(c) 25 – 100 mm
(d) more than 100 mm

202. Slump required for concreting heavily reinforced sections without vibration is

(a) up to 25 mm
(b) 25 – 50 mm

(c) 50 – 75 mm

(d) 75 – 125 mm

203. For concreting heavily reinforced sections without vibrations, compaction factor should be

(a) 0.75 – 0.80
(b) 0.80 – 0.85
(c) 0.85 – 0.92
(d) more than 0.92

204. Vee-Bee consistometer test is suitable for finding workability of

(a) rich concrete
(b) lean concrete
(c) stiff concrete
(d) all the above

205. Segregation is due to

(a) lack of sufficient quantity of fine aggregates
(b) dropping concrete from a greater height
(c) over vibration
(d) all the above

206. Bleeding of freshly laid concrete means

(a) segregation of concrete
(b) voids appearing on the surface
(c) appearance of water along with cement paste on the surface
(d) all the above

207. The ratio of strength of concrete after 1 year to that at 28 days is

(a) 0.9
(b) 1.0
(c) 1.1
(d) 1.2

208. On cylindrical specimen, split test is conducted to determine

(a) compressive strength of concrete
(b) tensile strength
(c) flexural strength
(d) all the above

209. Indian Standards specifications for estimating tensile strength and modulus of elasticity of concrete, if characteristic strength f_{ck} is known, are respectively

(a) 0.75 $\sqrt{f_{ck}}$ and 7000 $\sqrt{f_{ck}}$

(b) 0.7 $\sqrt{f_{ck}}$ and 5000 $\sqrt{f_{ck}}$

(c) 0.75 f_{ck} and 7000 f_{ck}

(d) 0.7 f_{ck} and 5000 f_{ck}

210. Creep is permanent change in dimensions due to

(a) temperature variation
(b) whethering action caused by moisture in the air
(c) sustained load
(d) all the above

211. Creep coefficient of concrete depends upon

(a) stress in concrete
(b) the age of concrete at the time of loading
(c) duration of loading
(d) all the above

212. Coefficient of thermal expansion is highest in

(a) quartzite
(b) sandstone
(c) granite
(d) basalt

213. Which one of the following is not workability enhancing agent?

(a) air entraining agents
(b) plasticizer
(c) super plasticizer
(d) silica fume

214. Which one of the following is not a construction chemical?

(a) silica fume
(b) bonding agents
(c) curing compound
(d) none of the above

215. Which one of the following is not a light-weight concrete?

(a) aerated concrete
(b) no fine concrete
(c) polymer concrete
(d) foamed slag concrete

216. Concrete mix design is intended to

(a) achieve specified characteristic strength
(b) achieve required workability
(c) achieve impermeability
(d) both (a) and (b)

217. Minimum cement content for moderate exposure with normal weight aggregates of size 20 mm in concrete is

(a) 280 kg/m^3
(b) 300 kg/m^3

(c) 320 kg/m^3

(d) 340 kg/m^3

218. Fibre reinforced concrete is used in

(a) wearing coat of roads

(b) pipes, manhole covers

(c) door and window frames

(d) all the above

219. Which one of the following is not correct about the use of ferrocement?

(a) for doors and window shutters

(b) domestic water tanks

(c) furnitures

(d) beam and columns

220. The ingredient of paint which gives it the binding property and form opaque coating is

(a) base

(b) vehicle

(c) solvent

(d) filler

221. The ingredient of paint that holds the ingredients in liquid suspension and allows them to be applied on the surface is:

(a) base

(b) vehicle

(c) solvent

(d) filler

222. The ingredient of paint that increases coverage area and makes application easy is

(a) base

(b) vehicle

(c) solvent

(d) filler

223. The ingredient of paint that reduces the cost and increases durability is

(a) base

(b) vehicle

(c) solvent

(d) filler

224. The cheap ingredient of a paint is

(a) base

(b) vehicle

(c) filler

(d) solvent

225. The presence of dampness while applying the primer affects the life of

(a) oil paint

(b) enamel paint
(c) aluminium paint
(d) plastic paint

226. Commonly used base for paint is
(a) iron oxide
(b) red lead
(c) titanium white
(d) any one of the above

227. Commonly used vehicle in paint is
(a) linseed oil
(b) poppy oil
(c) nut oil
(d) any one of the above

228. Commonly used solvent in paint is
(a) white lead
(b) turpentine
(c) linseed oil
(d) any of the above

229. Commonly used inert extenders used in paint is
(a) magnesia
(b) alumina
(c) charcoal
(d) any one of the above

230. Enamel paint is prepared by adding white lead or zinc to
(a) varnish
(b) polysterene
(c) spirit
(d) to any one of the above

231. The surface of which paint can be cleaned by washing with water?
(a) oil paint
(b) enamel paint
(c) emulsion paint
(d) bituminous paint

232. The paint which shines and is visible even in darkness is
(a) synthetic rubber paint
(b) cellulose paint
(c) aluminium paint
(d) emulsion paint

233. Which paint is ideally suited to get damp-proof surface?

(a) plastic paint
(b) asbestos paint
(c) synthetic rubber paint
(d) aluminium rubber paint

234. The base material for distemper is

(a) iron oxide
(b) lithopone
(c) chalk
(d) lime

235. The solvent used in cement paint is

(a) spirit
(b) water
(c) turpentine
(d) naptha

236. Paint with white lead base is suitable for painting

(a) concrete surfaces
(b) walls
(c) woodwork
(d) iron work

237. Painting work is generally specified by

(a) weight of the paint used
(b) volume of the paint used
(c) labour used for painting
(d) area of the painted surface.

238. The small areas on painted surface enclosed by hair line cracks are known as

(a) blistering
(b) crazing
(c) wrinkling
(d) chalking

239. Varnish is generally made of

(a) spirit
(b) solvent
(c) resin
(d) both (b) and (c)

240. In the fractional distillation of crude oil the components of crude which do not evaporate is

(a) kerosene
(b) spirit
(c) bitumen

(d) fuel oil

241. Select correct option about bitumen
(a) Its components are carbon, hydrogen and oxygen.
(b) It becomes soft at 30° to 100° C.
(c) It is susceptible to oxidation, forming blisters and cracks.
(d) All the above.

242. Cut back bitumen is produced by adding
(a) gasolin
(b) kerosene
(c) high boiling point light oil
(d) any of the above

243. Asphalt is obtained by adding
(a) kerosene
(b) gasolin
(c) sand
(d) any of the above

244. Tar is obtained by destructive distillation of
(a) coal
(b) wood
(c) mineral tar
(d) any one of the above

245. At 30°C asphalt is available in the state of
(a) solid or semisolid
(b) solid
(c) viscous
(d) any of the above

246. Adhesive power is highest in case of
(a) asphalt
(b) bitumen
(c) cold tar
(d) none of the above

247. Main constituent of glass is
(a) alumina
(b) silica
(c) acrylic
(d) none of the above

248. Molten glass can be fabricated by
(a) blowing
(b) drawing

(c) casting

(d) any of the above

249. Annealing the glass is the process of

(a) blowing and drawing
(b) drawing and casting
(c) heating and slow cooling
(d) any of the above

250. Tempering the glass is the process of

(a) giving requisite degree of hardness
(b) making it impervious to light
(c) a method of fabrication
(d) none of the above

251. The glass used as windowpanes and laboratory tables is

(a) soda lime glass
(b) potash lime glass
(c) potash lead glass
(d) common glass

252. The glass used for making artificial gem is

(a) soda lime glass
(b) potash lime glass
(c) potash lime glass
(d) coloured glass

253. Wired glass is used for

(a) telephone communication
(b) medicine bottles
(c) fire resistant doors
(d) artificial gems

254. Bulletproof glass has

(a) a number of layers all of same thickness
(b) outer layers thinner than inner layers
(c) outer layers thicker than inner layers
(d) inner layers with steel wires

255. Shielding glass contains

(a) steel wires
(b) fibre glass
(c) lead oxide
(d) chrome

256. Structured glass is

(a) usually coloured

(b) mirrored

(c) heat resistant

(d) all the above

257. Polymerization is the process of

(a) combine monomers to form a large chain-like molecule

(b) combine monomers to form a small chain-like molecule

(c) Break a polymer into a number of small monomers

(d) Break a polymer to form into a number of long monomers

258. Phenol formaldehyde is produced by

(a) addition polymerization

(b) condensation polymerization

(c) copolymerization

(d) any of the above

259. Which is wrong statement about thermosetting plastics?

(a) Undergo chemical changes at 127–177°C.

(b) Reheating will soften them.

(c) If heated to 340° C charring takes place.

(d) Soluble in alcohol.

260. Which one of the following is correct statement about thermo plastics?

(a) Soften on heating and hardens on cooling.

(b) The process of hardening and softening may be repeated any number of times.

(c) Scrap obtained from old article can be reused by softening and reshaping.

(d) All the above.

261. Fibre reinforced plastics are manufactured by reinforcing plastic with

(a) paper

(b) asbestos

(c) glass

(d) any of the above

262. Cork is obtained from

(a) bark of oak tree

(b) destructive distillation of wood

(c) mines

(d) any of the above sources

263. Vulcanization of rubber is to

(a) purify rubber

(b) toughen rubber

(c) make it soft

(d) all the above

264. Gypsum boards are manufactured by mixing gypsum with

(a) tar

(b) bitumin
(c) asphalt
(d) rubber

265. Turpentine is a natural material obtained from
(a) oak trees
(b) pine trees
(c) mines
(d) any of the above

266. Which one is the correct statement about geosynthetics?
(a) They are fabrics of nylon.
(b) They last long even if they are buried under soil.
(c) They are not affected by water.
(d) All the above.

II. Match List I with List II and select the correct answer code given below the *List*

267.

	List I Class		List II Example
A.	Volcanic rocks	1	Gneiss
B.	Hyperbyssal rocks	2	Granite
C.	Plutonic rocks	3	Quartz
D.	Metamorphic rocks	4	Basalt

Codes:	A	B	C	D
(a)	3	2	4	1
(b)	1	3	2	4
(c)	4	3	2	1
(d)	2	4	3	1

268.

	List I Type of stone		List II Strength
A.	Trap	1	104 – 140 N/mm^2
B.	Marble	2	300 – 350 N/mm^2
C.	Granite	3	70 – 210 N/mm^2
D.	Sandstone	4	65 – 70 N/mm^2

Code

(a)	A – 3	B – 2	C – 1	D – 4
(b)	A – 2	B – 1	C – 4	D – 3
(c)	A – 1	B – 2	C – 4	D – 3
(d)	A – 2	B – 3	C – 1	D – 4

269.

	List I Stone		List II Mohs hardness number
A.	Gypsum	1	2
B.	Calcite	2	3
C.	Quartz	3	7
D.	Corundum	4	9

Codes

(a)	A – 1	B – 2	C – 4	D – 3
(b)	A – 2	B – 1	C – 4	D – 3
(c)	A – 1	B – 2	C – 3	D – 4
(d)	A – 2	B – 1	C – 4	D – 3

270.

	List I Type of wood		List II Used for
A.	Jack	1.	Agricultural implements
B.	Deodar	2.	Boat construction
C.	Babul	3.	Railway sleepers
D.	Benteak	4.	Musical instruments

Codes:

(a)	A – 1	B – 3	C – 4	D – 2
(b)	A – 4	B – 2	C – 3	D – 1
(c)	A – 3	B – 4	C – 1	D – 2
(d)	A – 4	B – 3	C – 1	D – 2

271.

List I	List II
Defects in timber	Defect due to

A.	Knot	1.	Crushing during growth
B.	Shake	2.	Fungi attack
C.	Rot	3.	Excessive heat, wind or frost during the growth
D.	Upset	4.	Fallen branches during growth

Codes:

(a)	A – 4	B – 3	C – 2	D – 1
(b)	A – 1	B – 2	C – 3	D – 4
(c)	A – 2	B – 3	C – 4	D – 1
(d)	A – 4	B – 1	C – 2	D – 3

272.

	List I		**List II**
A.	Exogenous tree	1.	grow inward
B.	Endogenous tree	2.	cone shaped leaves
C.	Deciduous	3.	broad leaves
D.	Coniferous	4.	grow outward

Codes

(a)	A – 1	B – 4	C – 3	D – 4
(b)	A – 2	B – 3	C – 4	D – 1
(c)	A – 3	B – 2	C – 1	D – 4
(d)	A – 4	B – 1	C – 3	D – 2

273.

	List I		**List II**
	Parts of exogenous tree		**Character**
A.	Cambium layer	1.	Youngest layer
B.	Pith	2.	Innermost part
C.	Heartwood	3.	Thin layer of fresh sap.
D.	Sapwood	4.	Portion surrounding pith

Codes:

(a)	A – 1	B – 2	C – 3	D – 4
(b)	A – 3	B – 2	C – 4	D – 1
(c)	A – 4	B – 1	C – 3	D – 2
(d)	A – 1	B – 3	C – 2	D – 4

274.

	List I		List II
	Method of sawing		**Character of sawing**
A.	Ordinary sawing	1.	All cuts are parallel to each other
B.	Quarter sawing	2.	Adopted when modular rays are not distinct
C.	Tangential sawing	3.	Suitable for hardwood
D.	Radial sawing	4.	Least warpage

Codes:

(a)	A – 2	B – 1	C – 3	D – 4
(b)	A – 1	B – 3	C – 4	D – 2
(c)	A – 2	B – 3	C – 4	D – 1
(d)	A – 1	B – 4	C – 2	D – 3

275.

	List I		List II
	Constituent of brick earth		**Effect on brick**
A.	Silica	1.	Gives red colour
B.	Alumina	2.	Makes sand to fuse and act as cementing material
C.	Lime	3.	Prevents cracking and warping
D.	Oxide	4.	Gives plasticity

Codes:

(a)	A – 1	B – 4	C – 3	D – 2
(b)	A – 2	B – 3	C – 4	D – 1
(c)	A – 3	B – 4	C – 2	D – 1
(d)	A – 4	B – 3	C – 1	D – 2

276.

	List I		List II
A.	pug mill	1.	for burning bricks
B.	fillet	2.	for table moulding
C.	stock board	3.	for making frog
D.	clamp	4.	for tempering

Codes:

(a)	A – 1	B – 3	C – 2	D – 4
(b)	A – 4	B – 3	C – 2	D – 1
(c)	A – 4	B – 2	C – 1	D – 3
(d)	A – 2	B – 3	C – 4	D – 1

277.

	List I		List II
A.	Quicklime	1.	limestone
B.	Slaked lime	2.	calcium oxide
C.	Moderately hydraulic lime	3.	calcium hydroxide
D.	Kankar	4.	contains 20 – 30% clay

Codes:

(a)	A – 2	B – 3	C – 4	D – 1
(b)	A – 3	B – 2	C – 1	D – 4
(c)	A – 1	B – 2	C – 3	D – 4
(d)	A – 4	B – 1	C – 3	D – 2

278.

	List I *In acid test on lime*		**List II**
A.	Vigorous efflorescence	1.	Class A lime
B.	Higher volume of residue	2.	Class B lime
C.	Thick gel	3.	High percentage of lime
D.	Flowing gel	4.	Unwanted inert material

Codes:

(a)	A – 4	B – 3	C – 1	D – 2
(b)	A – 3	B – 4	C – 2	D – 1
(c)	A – 2	B – 3	C – 4	D – 1
(d)	A – 3	B – 4	C – 1	D – 2

279.

	List I **Constituent of raw materials in OPC**	**List II** **Percentage**
A.	Iron oxide	62
B.	Alumina	22

C.	Silica	5.5
D.	Lime	3.0

Codes:

(a)	A – 3	B – 4	C – 1	D – 2
(b)	A – 3	B – 1	C – 2	D – 4
(c)	A – 4	B – 3	C – 2	D – 1
(d)	A – 4	B – 1	C – 3	D – 2

280.

	List I		**List II**
	Constituent of cement		**Contribution to property of cement**
A.	Lime	1.	Influences setting property
B.	Alkalies	2.	Cause efflorescence and staining
C.	Alumina	3.	Imparts strength
D.	Iron oxide	4.	Imparts colour

Codes:

(a)	A – 3	B – 2	C – 1	D – 4
(b)	A – 2	B – 3	C – 4	D – 1
(c)	A – 3	B – 1	C – 2	D – 4
(d)	A – 2	B – 4	C – 1	D – 3

281.

	List I		**List II**
	Compounds of cement		**Percentage in cement**
A.	Tricalcium silicate	1.	11
B.	Dicalcium silicate	2.	11
C.	Tricalcium alumina	3.	40
D.	Tetra calcium alumino ferrite	4.	30

Codes:

(a)	A – 4	B – 3	C – 2	D – 1
(b)	A – 3	B – 4	C – 1	D – 2
(c)	A – 1	B – 2	C – 3	D – 4
(d)	A – 3	B – 1	C – 2	D – 4

282.

List I		List II
Compound in OPC		**Its influence on the property of cement**
A. C_2S	1.	First to react and set
B. C_3S	2.	Responsible for 28 days strength
C. C_4 AF	3.	Responsible for increase in strength even after 28 days
D. C_3A	4.	Inactive compound

Codes:

(a)	A – 3	B – 2	C – 4	D – 1
(b)	A – 1	B – 2	C – 3	D – 4
(c)	A – 3	B – 4	C – 2	D – 1
(d)	A – 2	B – 3	C – 4	D – 1

283.

	List I		List II
A.	bins	1	for storing slurry
B.	silos	2	for storing dry powders
C.	wash mill	3	to burn
D.	rotary kiln	4	to reduce mix to required fineness

Codes:

(a)	A – 1	B – 2	C – 3	D – 4
(b)	A – 2	B – 1	C – 4	D – 3
(c)	A – 2	B – 1	C – 3	D – 4
(d)	A – 1	B – 2	C – 4	D – 3

284.

	List 1		List 2
A.	Specimen for finding compressive strength of cement	1.	150 mm diameter cylinders
B.	Specimen for finding tensile strength of cement	2.	7.08 mm cube
C.	Specimen to find compressive strength of concrete	3.	150 mm cube
D.	Specimen of find tensile strength of concrete	4.	briquettes

Codes:

(a)	A – 1	B – 2	C – 3	D – 4
(b)	A – 2	B – 1	C – 3	D – 4
(c)	A – 1	B – 3	C – 4	D – 2
(d)	A – 2	B – 4	C – 3	D – 1

285.

	List I		**List II**
	Type of cement		**Use**
A.	Blast furnace slag cement	1.	For laying concrete under water
B.	High alumina cement	2.	Construction of dams
C.	Sulphate resisting cement	3.	Properties same as OPC but cheap
D.	Low heat cement	4.	Construction of canals and culverts

Codes:

(a)	A – 1	B – 2	C – 3	D – 4
(b)	A – 3	B – 1	C – 4	D – 2
(c)	A – 2	B – 1	C – 3	D – 4
(d)	A – 4	B – 3	C – 2	D – 1

286.

	List I		**List II**
	Pigments used with cement		**Colour obtained**
A.	Chloride	1.	Brown or black
B.	Cobalt oxide	2.	Red
C.	Iron oxide	3.	Green
D.	Manganese oxide	4.	Blue

Codes:

(a)	A – 1	B – 2	C – 4	D – 3
(b)	A – 2	B – 3	C – 4	D – 1
(c)	A – 3	B – 4	C – 1	D – 2
(d)	A – 3	B – 4	C – 2	D – 1

287.

	List I		**List II**
	Cement : Sand		**Mortar used for**
A.	1 : 2 to 1 : 3	1.	Masonry work
B.	1 : 3	2.	Pointing

C.	1 : 3 to 1 : 4	3.	Plastering concrete
D.	1 : 6 to 1 : 8	4.	Plastering masonry

Codes:

(a)	A – 2	B – 3	C – 4	D – 1
(b)	A – 2	B – 3	C – 1	D – 4
(c)	A – 4	B – 3	C – 2	D – 1
(d)	A – 3	B – 2	C – 4	D – 1

288.

	List I Nominal	List II Used for
A.	$1 : 1\frac{1}{2} : 3$	1. Foundation coarse
B.	1 : 2 : 4	2. Water tanks
C.	1: 3 : 6	3. Slab and beams
D.	1 : 4 : 8	4. Sills of windows

Codes:

(a)	A – 1	B – 2	C – 3	D – 4
(b)	A – 3	B – 2	C – 4	D – 1
(c)	A – 2	B – 3	C – 4	D – 1
(d)	A – 4	B – 3	C – 2	D – 1

289.

	List I Method of compaction		List II For the works
A.	Hand compaction	1.	For columns
B.	Needle vibrations	2.	Precast elements
C.	Surface vibrations	3.	Floor resting on ground
D.	Table vibrations	4.	For slabs

Codes:

(a)	A – 2	B – 3	C – 4	D – 1
(b)	A – 1	B – 3	C – 4	D – 2

(c)	A – 3	B – 1	C – 4	D – 2
(d)	A – 2	B – 1	C – 3	D – 4

290.

	List I	**List II**
	Concrete work	**Desirable compaction factor**
A.	Concreting heavily reinforced sections without vibrators	0.75–0.80
B.	Concreting shallow sections with vibrators	0.80–0.85
C.	Concreting lightly reinforced sections with vibrators	0.85–0.92
D.	Concreting lightly reinforced sections without vibrators	> 0.92

Codes:

(a)	A – 3	B – 1	C – 2	D – 4
(b)	A – 1	B – 2	C – 4	D – 3
(c)	A – 4	B – 3	C – 2	D – 1
(d)	A – 4	B – 1	C – 2	D – 3

291.

	List I		**List II**
	Nature of concrete		**Effect**
A.	Seggregation	1	Causes pores
B.	Bleeding	2	High strength
C.	Harsh	3	Rough surface finish
D.	Dense	4	Results in weaker pockets

Codes:

(a)	A – 1	B – 3	C – 4	D – 2
(b)	A – 3	B – 1	C – 2	D – 4
(c)	A – 4	B – 1	C – 3	D – 2
(d)	A – 4	B – 2	C – 1	D – 3

292.

	List I		**List II**
	Exposure conditions		**Minimum cement content in kg/m^3**
A.	Mild	1.	280

B.	Severe	2.	300
C.	Very severe	3.	320
D.	Extreme	4.	340
		5.	360

Codes:

(a)	A – 1	B – 2	C – 3	D – 4
(b)	A – 2	B – 3	C – 4	D – 5
(c)	A – 3	B – 4	C – 5	D – 1
(d)	A – 2	B – 4	C – 5	D – 3

293.

	List I		**List II**
	Varieties of iron ores		**Iron content**
A.	Magnetite	1.	40–45%
B.	Haemetite	2.	60%
C.	Limonite	3.	70%
D.	Pyrite	4.	> 70%

Codes:

(a)	A – 2	B – 1	C – 3	D – 4
(b)	A – 3	B – 2	C – 1	D – 4
(c)	A – 1	B – 2	C – 3	D – 4
(d)	A – 4	B – 3	C – 2	D – 1

294.

	List I		**List II**
	Type of cast iron		**Use**
A.	White cast iron	1.	Small casting
B.	Mottled cast iron	2.	Agricultural implements
C.	Chilled cast iron	3.	Manufacture of wrought iron
D.	Malleable cast iron	4.	Railway wheels

Codes:

(a)	A – 1	B – 3	C – 2	D – 4
(b)	A – 3	B – 1	C – 4	D – 2
(c)	A – 4	B – 2	C – 3	D – 1
(d)	A – 3	B – 2	C – 1	D – 4

295.

	List I		List II
	Metal		**% of carbon**
A.	Steel	1.	< 0.15%
B.	Cast iron	2.	0.25–1.5%
C.	Pig iron	3.	2–4%
D.	Wrought iron	4.	3–4%
		5.	5%

Codes:

(a)	A – 3	B – 4	C – 5	D – 1
(b)	A – 2	B – 3	C – 5	D – 1
(c)	A – 1	B – 2	C – 3	D – 4
(d)	A – 2	B – 3	C – 4	D – 1

296.

	List I		List II
	Material		**Composition**
A.	Brass	1.	Basic material
B.	Bronze	2.	Alloy of copper and zinc
C.	German silver	3.	Alloy of copper and tin
D.	Lead	4.	Alloy of copper, zinc and nickel

Codes:

(a)	A – 2	B – 3	C – 4	D – 1
(b)	A – 1	B – 2	C – 3	D – 4
(c)	A – 2	B – 1	C – 3	D – 4
(d)	A – 1	B – 2	C – 4	D – 3

297.

	List I		List II
	Ingredients of oil paints		**Role in paint**
A.	Base	1.	Absorbs oxygen from air for hardening
B.	Vehicle	2.	Hold the ingredients in suspension
C.	Solvent	3.	Principal constituent

D. Drier	4. Increases coverage

Codes:

(a)	A – 1	B – 2	C – 3	D – 4
(b)	A – 2	B – 3	C – 1	D – 4
(c)	A – 3	B – 2	C – 4	D – 1
(d)	A – 4	B – 3	C – 2	D – 1

298.

List I	List II
Defects in painted surface	**Due to**
A. Blistering	1. Poor workmanship
B. Flaking	2. Excessively thick paint
C. Flashing	3. Poor adhesion
D. Wrinkling	4. Entrapped water vapour

Codes:

(a)	A – 4	B – 3	C – 1	D – 2
(b)	A – 3	B – 2	C – 4	D – 1
(c)	A – 4	B – 2	C – 3	D – 1
(d)	A – 1	B – 2	C – 3	D – 4

III. *Select your answer according to the coding system given for the assertion A and reason R given in the following item.*

Code:

(a) Both A and R are true and R is the correct explanation of A.
(b) Both A and R are true but R is not the correct explanation of A.
(c) A is true but R is false.
(d) A is false but R is true.

299. A: Metamorphic rocks have bedded or stratified structure.
R: Metamorphic rocks are formed due to the action of pressure, internal heat and chemical action of water.

300. A: Freshly quarried stones are soft.
R: They contain quarry sap.

301. A: Age of exogenous trees can be easily found by counting medullary rays.
R: Exogenous trees grow outward, in the form of concentric circle around the pith, adding

distinct ring every year.

302. A: In artificial seasoning defects such as shrinkage, cracking and warping are minimum.

R: In artificial seasoning drying is uniform.

303. A: A log with twisted fibre may be used as a pole.

B: Twisted fibres add to the strength of a pole.

304. A: Very thick and heavy timber sections resist fire well.

R: Combustion helps form charcoal in the outer layer and prevents fire from spreading to internal layers.

305. A: Block boards are known as batten boards.

R: The core of these boards consists of strips of wood glued together.

306. A: During the process of grinding clinkers, gypsum is added.

R: Gypsum limits final setting time to 600 min.

307. A: Soundness is the ability of hardened cement paste to retain its volume after it has set.

R: The slow reactions of free lime or magnesia or insufficient grinding cause change in volume after setting.

308. A: Rapid hardening cement is used for construction of roads.

R: Strength of this cement is high.

309. A: Quick setting cement starts setting within 5 minutes after adding water.

R: This property is achieved by reducing the percentage of alumina.

310. A: Blast furnace slag cement is cheap.

R: Blast furnace slag is cheap.

311. A: Rice husk ash is mixed with cement.

R: It becomes good acid resistant cement.

312. A: Sea sand should not be used for making mortar.

R: It reduces the strength of mortar.

313. A: Sand is mixed with cement to make mortar.

R: It prevents shrinkage.

314. A: At about 12 per cent moisture content bulking of sand is maximum.

R: With addition of moisture to dry sand water films are formed and hence bulking of sand is seen.

315. A: Concrete should be placed in its final position by dropping it as closely as possible.

R: It is to avoid segregation.

316. A: After concrete is placed in its final position, it should be compacted.

R: Compaction helps in improving chemical reaction.

317. A: In the first 14 days curing of concrete should be done carefully.

R: During this period tricalcium sulphate in cement reacts and sets.

318. A: Improving workability by increasing with water content should be avoided as far as possible.
 R: Higher water content results in shrinkage of concrete.
319. A: Dense concrete is generally durable.
 R: Pores on dense concrete are small.
320. A: Plasticizers are waterproofing elements.
 R: Plasticizers introduce soapy action into the mix.
321. A: Silica fume concrete is high strength concrete.
 R: Silica fume fills up minute pores in concrete.
322. A: Limestone is added to the smelted iron.
 R: Lime acts as a flux and removes sulphur.
323. A: Rusting is the formation of reddish or yellowish-brown coating on steel.
 R: It is due to chlorination.
324. A: In a distemper chalk is the base and water is the carrier.
 R: Pigments are added to whitewash to get distemper.
325. A: Viscocity of cut back bitumen is less.
 R: It is diluted with gasoline or kerosene.
326. A: Asphalt is in solid state at a lower temperature and is in liquid form at 50–100° C.
 R: It is bitumen mixed with inert materials like sand and gravel.
327. A: Wood tar contains creosote oil.
 R: It is obtained by destructive distillation of pine.
328. A: Sand is the main constituent of glass.
 R: Addition of lime to sand makes the glass fluid and hence it becomes suitable for blowing.
329. A: Thermoplastics soften on heating and harden on cooling.
 R: These plastics undergo chemical changes when heated.

IV. *State whether the following statements are True or False (Item No: 330 to 350)*

330. Stone used for buildings should be very strong.
331. Smith's test on stones is to find its abrasion property.
332. Los Angeles machine is used for attrition test of stone.
333. Medular rays are thin radial fibres extending from the pith to the cambium layer.
334. Except teak all other timbers need treatment with preservatives.
335. Field tests are conducted on bricks to correctly assess the quality of bricks.
336. Permanent structures used to burn bricks are known as clamps.
337. Red colour to tiles is due to iron content in clay.
338. Maximum permitted water content in class AA tiles is 10%.

339. To make teracotta porous sawdust or cork is added.

340. The crude and impure form of iron is known as cast iron.
341. Tin is used for providing protective cover to other metals.
342. When aluminium sheets are coated with pure aluminum, it is known as aldural.
343. Lime provides strength to cement.
344. For finding specific area of cement Blaine's apparatus is used.
345. If sea sand is used with cement, after sometimes blisters appear.
346. Highest fineness modulus indicates that sand is coarser.
347. A mortar is considered light weight, if its bulk density is less than 15 kN/m^3.
348. Separation of cement slurry from freshly laid concrete and appearing on the surface is termed segregation.
349. Varnish is visible in darkness also.
350. Soda lime glass can be easily welded by moderate heat.

Answers to Multiple-Choice Questions

I.

1.	(d)	2.	(d)	3.	(b)	4.	(c)	5.	(b)
6.	(c)	7.	(d)	8.	(a)	9.	(c)	10.	(d)
11.	(c)	12.	(b)	13.	(d)	14.	(b)	15.	(d)
16.	(d)	17.	(c)	18.	(c)	19.	(a)	20.	(a)
21.	(d)	22.	(a)	23.	(a)	24.	(a)	25.	(b)
26.	(b)	27.	(c)	28.	(d)	29.	(a)	30.	(d)
31.	(d)	32.	(d)	33.	(a)	34.	(d)	35.	(d)
36.	(d)	37.	(c)	38.	(c)	39.	(c)	40.	(b)
41.	(b)	42.	(a)	43.	(b)	44.	(d)	45.	(a)
46.	(a)	47.	(d)	48.	(a)	49.	(d)	50.	(c)
51.	(a)	52.	(a)	53.	(b)	54.	(a)	55.	(b)
56.	(b)	57.	(b)	58.	(d)	59.	(c)	60.	(c)
61.	(d)	62.	(d)	63.	(d)	64.	(a)	65.	(d)
66.	(c)	67.	(d)	68.	(c)	69.	(b)	70.	(c)
71.	(b)	72.	(b)	73.	(a)	74.	(b)	75.	(b)
76.	(b)	77.	(c)	78.	(b)	79.	(d)	80.	(c)
81.	(d)	82.	(c)	83.	(b)	84.	(b)	85.	(a)
86.	(d)	87.	(a)	88.	(b)	89.	(c)	90.	(a)
91.	(a)	92.	(d)	93.	(b)	94.	(b)	95.	(d)
96.	(a)	97.	(c)	98.	(d)	99.	(c)	100.	(a)
101.	(b)	102.	(c)	103.	(a)	104.	(b)	105.	(c)
106.	(b)	107.	(a)	108.	(c)	109.	(d)	110.	(d)
111.	(b)	112.	(d)	113.	(b)	114.	(c)	115.	(b)

116.	(d)	117.	(a)	118.	(d)	119.	(c)	120.	(a)
121.	(b)	122.	(c)	123.	(a)	124.	(c)	125.	(c)
126.	(d)	127.	(c)	128.	(c)	129.	(b)	130.	(a)
131.	(d)	132.	(c)	133.	(c)	134.	(d)	135.	(a)
136.	(a)	137.	(d)	138.	(a)	139.	(d)	140.	(d)
141.	(b)	142.	(c)	143.	(a)	144.	(d)	145.	(b)
146.	(a)	147.	(b)	148.	(c)	149.	(a)	150.	(d)
151.	(b)	152.	(c)	153.	(d)	154.	(d)	155.	(c)
156.	(d)	157.	(a)	158.	(b)	159.	(a)	160.	(d)
161.	(a)	162.	(d)	163.	(d)	164.	(c)	165.	(d)
166.	(b)	167.	(d)	168.	(d)	169.	(d)	170.	(d)
171.	(c)	172.	(a)	173.	(a)	174.	(c)	175.	(b)
176.	(a)	177.	(a)	178.	(a)	179.	(d)	180.	(c)
181.	(b)	182.	(c)	183.	(d)	184.	(a)	185.	(d)
186.	(b)	187.	(c)	188.	(a)	189.	(b)	190.	(b)
191.	(d)	192.	(c)	193.	(a)	194.	(d)	195.	(d)
196.	(c)	197.	(d)	198.	(a)	199.	(a)	200.	(d)
201.	(b)	202.	(d)	203.	(d)	204.	(c)	205.	(d)
206.	(c)	207.	(d)	208.	(b)	209.	(b)	210.	(c)
211.	(d)	212.	(a)	213.	(d)	214.	(a)	215.	(d)
216.	(d)	217.	(b)	218.	(d)	219.	(d)	220.	(a)
221.	(b)	222.	(c)	223.	(d)	224.	(c)	225.	(a)
226.	(d)	227.	(a)	228.	(b)	229.	(d)	230.	(a)
231.	(c)	232.	(c)	233.	(b)	234.	(c)	235.	(b)
236.	(d)	237.	(d)	238.	(c)	239.	(d)	240.	(c)
241.	(d)	242.	(d)	243.	(c)	244.	(b)	245.	(b)
246.	(c)	247.	(b)	248.	(d)	249.	(c)	250.	(a)
251.	(a)	252.	(c)	253.	(c)	254.	(b)	255.	(c)
256.	(d)	257.	(a)	258.	(c)	259.	(b)	260.	(d)
261.	(d)	262.	(a)	263.	(b)	264.	(c)	265.	(b)
266.	(d)	267.	(c)	268.	(d)	269.	(c)	270.	(d)
271.	(d)	272.	(d)	273.	(b)	274.	(d)	275.	(c)
276.	(b)	277.	(a)	278.	(d)	279.	(c)	280.	(a)
281.	(b)	282.	(a)	283.	(b)	284.	(d)	285.	(b)
286.	(d)	287.	(a)	288.	(c)	289.	(c)	290.	(d)
291.	(c)	292.	(b)	293.	(d)	294.	(b)	295.	(d)
296.	(a)	297.	(c)	298.	(a)	299.	(d)	300.	(a)
301.	(d)	302.	(a)	303.	(a)	304.	(a)	305.	(a)
306.	(c)	307.	(a)	308.	(c)	309.	(c)	310.	(a)
311.	(c)	312.	(c)	313.	(a)	314.	(d)	315.	(a)
316.	(c)	317.	(a)	318.	(c)	319.	(a)	320.	(d)
321.	(a)	322.	(a)	323.	(c)	324.	(c)	325.	(a)

326.	(a)	327.	(a)	328.	(a)	329.	(c)	330.	False
331.	False	332.	True	333.	True	334.	True	335.	False
336.	False	337.	True	338.	False	339.	True	340.	False
341.	True	342.	True	343.	False	344.	True	345.	True
346.	True	347.	True	348.	False	349.	False	350.	True

2

Building Construction

2.1 INTRODUCTION

The National Building Code (NBC) of India defines a building as any structure for whatsoever purpose and of whatsoever material constructed and every part thereof whether used as human habitat or not. Tents, shamianas, tarpaulin shelters, etc., erected for temporary and ceremonial occasions are not to be considered as buildings.

1. Classifications as per NBC of India

1. Group A : Residential
2. Group B : Educational
3. Group C : Institutional
4. Group D : Assembly
5. Group E : Business
6. Group F : Mercantine
7. Group G : Industrial
8. Group H : Storage
9. Group I : Hazardous

1. Residential buildings are subdivided as

A–1 : Lodging or rooming houses.
A–2 : One or two family private dwellings.
A–3 : Dormitories.
A–4 : Apartment houses
A–5 : Hotels

2. Educational Buildings

B–1 : Schools upto senior secondary level with not less than 20 students.
B–2 : All other training institutions upto 100 students.

3. Institutional Buildings

C–1 : Hospitals and sanatoria
C–2 : Custodian institutions
C–3 : Penal and mental institutions

4. Assembly Buildings

D–1 : Buildings with theatrical stage and fixed chairs for over 1000 persons.
D–2 : Buildings having a theatrical stage and fixed seats for less than 1000 persons.
D–3 : Buildings without a stage and having accommodation for 300 or more persons but without permanent seating arrangements.
D–4 : Buildings without a stage, having accommodation for less than 300 persons.
D–5 : All other buildings designed for assembly of people not covered by D–1 to D–4, e.g., grand

stands, stadia, circus tents, amusement park structures.

5. Business Buildings

The building that is used as shop, store, market for display and sale.

6. Mercantile Buildings

F–1 : Shops, stores, markets with area upto 500 m^2.

F–2 : Underground shopping centres, departmental stores with area more than 500 m^2.

7. Industrial Buildings

G–1 : Buildings used for low hazard industries.

G–2 : Buildings used for moderate hazard industries.

G–3 : Buildings used for high-hazard industries.

8. Storage Buildings

Buildings used for storing materials and animals such as warehouses, cold storages, freight depots, garages, hangars and stables.

9. Hazardous Buildings

These are the buildings used for storage, handling, manufacturing or processing of highly combustible or explosive materials. Buildings used for storage of LPG, rocket propellers, ammunition, explosives and fireworks fall under this category.

*2. **Classification based on the method of load transfer*** According to this buildings may be classified as load bearing structures and framed structures. Load bearing structures are suitable for one- or two-storey residential buildings only.

*3. **Classification According to materials*** Structures may be classified as wooden structures, R.C.C. structures, steel structures, etc.

*4. **Classification according to fire resistance*** NBC of India classifies buildings as Type 1 to Type 4 on the basis of fire resistance.

- Basic components of a building are: Foundation, plinth, walls and columns, sills, lintels and sunshades, floors, roofs, steps, stairs and ramps, finishing works and building services.
- A structure should be designed to withstand various loads during its life span. IS 875–1987 gives the various loads to be considered.

Building Planning

- It refers to the process of imagining the details of a building to be built and showing them in the form of drawings.
- The building by-laws are prescribed in IS : 1256–1967 and municipalities and other competent authorities have the power to make changes to suit local requirements. The laws are necessary to ensure orderly growth, afford safety against fire, noise and health hazards and give guidelines about minimum standards.

Terminology

*1. **Building height*** It is vertical distance between the centre line street in front and the highest point of building including parapet at terrace. If building is sloping towards the street, the building height is considered upto the point where the external wall touches the sloping roof. In case of gable facing the street, it is considered upto the midpoint of gable end.

2. ***Building line*** It is the least horizontal distance of the permanent portion of the building from the centre line of the street.

3. ***Setbacks*** Setbacks are lines parallel to the boundaries of the site.

4. ***Covered or built-up area*** The area covered by the building immediately above the plinth level is called covered area or built-up area. It does not include well, storage tank, open verandah, portico, ramp, steps, compound wall, watchman's booth, uncovered staircase.

5. ***Floor area*** It is equal to plinth area minus the area occupied by walls and columns.

6. ***Floor-area-ratio (FAR)***

$$\text{FAR} = \frac{\sum \text{Covered area of floors}}{\text{Area of plot}}$$

Important By-laws

1. Distances from power supply main

Distances from power supply main is shown in Table 2.1.

Table 2.1

Voltage of electric line	*Minimum Distance*	
	Vertical	*Horizontal*
Low–medium	2.5 m	1.2 m
High voltage: (a) Upto 11 kV	3.7 m	1.2 m
(b) More than 11 kV	3.7 m	2.0 m

2. Exterior open spaces

(a) *Minimum front open space* As shown in Table 2.2.

Table 2.2 Minimum front open space

Sr. No.	*Width of street fronting*	*Front open space*
1	Up to 7.5 m	1.5 m
2	7.5 to 18.0 m	3.0 m
3	18.0 to 30.0 m	4.5 m
4	Above 30 m	6.0 m

* For building up to a maximum of 7 m.

(b) *Rear open space:* The minimum rear open space should be an average of 3.0 m and in no case less than 1.8 m. In case of back-to-back site the rear open space should be 3.0 m throughout. For plots of depth less than 9 m and buildings of height less than 7 m, the minimum is reduced to 1.5 m.

(c) *Side open space:* For detached buildings, the minimum open space recommended is 3.0 m on each side. However, for smaller plots it may be reduced to 1.5 m by the competent authority. For buildings of height above 10 m, minimum rear and side open spaces required increases with the height of a rule of 1 m for 5 m height. For buildings above 50 m high, it is 16.0 m.

3. ***Floor area ratio (FAR)*** It is different for different occupancy buildings.

4. ***Height of buildings*** The height and number of stories are related to the requirements of FAR and open space. It is also limited by the width of the street in front of the building. The height is limited to 1.5 times the width of front road plus the front open space. The height of buildings in the vicinity of an airport is fixed in consultation with the civil aviation authority.

Other Requirements of Buildings

1. ***Plinth height*** It should be 0.45 m above the surrounding ground level. It should be at least 0.15 m above the nearest street.

2. ***Habitable rooms*** The requirements are shown in Table 2.3.

Table 2.3 Minimum requirements of habitable room

Buildings with single habitable room	*Building with two habitable rooms*	
	1st room	*2nd room*
Min. area 9.5 m^2	9.5 m^2	7.5 m^2
Min. width 2.4 m	2.1 m	2.1 m
Min. height 2.75 m	2.75 m	2.75 m
Min. head room 2.4 m	2.4 m	2.4 m

3. ***Kitchen*** Minimum size requirements of a kitchen are as shown in Table 2.4.

Table 2.4 Minimum size requirements of a kitchen

Type	*Min. floor area*	*Min. width*	*Min height*
Kitchen-cum-store	5.0 m^2	1.8 m	2.75 m
Kitchen-cum-dining	7.5 m^2	2.10 m	2.75 m
Kitchen only	4.5 m^2	1.8 m	2.75 m

4. ***Bathroom and water closet*** At least one wall should abut the exterior open space. Should have impervious floor and wall. Other requirements are shown in Table 2.5.

Table 2.5 Minimum requirement of bathroom and water closet

	Bath	*W.C.*	*Bath-cum-W.C.*
Min. floor area	1.8 m^2	1.2 m^2	2.8 m^2
Recommended size	1.5 × 1.2 m	1.10 × 1.0 m	2.3 × 1.2 m
Min. height	2.0 m	2.0 m	2.0 m

5. ***Storeroom*** In a residential building storeroom size shall not be less than 3.2 m^2. Minimum height 2.2 m.

6. ***Parapet*** Not less than 1.05 m high and not more than 1.2 m above the finished floor level.

7. ***Compound wall*** Maximum height 1.5 m above the centre line of the front street. Upto 2.4 m also permitted if the top 0.9 m is open type. In case of corner plots, the lower 0.75 m may be of solid type but the top 0.75 m should be open type at least for a distance of 10 m.

Elementary Principles of Planning

1. ***Aspects*** Kitchen-eastern aspect, Dining-southern aspect, Drawing and living rooms-Southern or South-eastern. Bed rooms–Western aspect.

2. ***Prospects*** It is about locating and selecting the type of doors and windows in the outer walls so as to reveal the pleasant features and hide undesirable features.

3. ***Roominess*** Length to width ratio should be 1.2 to 1.5. If it is nearly square, there will be wastage due to circulation area and if it is more than 1.5 it gives tunnel effect.

4. ***Furniture requirement*** Position of chairs, sofas, tables, beds, wardrobes, etc., should be drawn and checked for circulation area.

5. ***Groupings*** A dining room should be close to kitchen, sanitary blocks should be close to bed-rooms. In offices administrative block is located centrally.

6. ***Circulation*** Circulation refers to the space provided for movement. Passages, lobbies and wells serve as horizontal circulation area, while stairs and lifts serve as vertical circulation area. Circulation area should be least but sufficient also.

7. ***Elegance*** It refers to the effect felt by a viewer from outside. The width, length, height, balconies and projection contributes to elegance of a building.

8. ***Sanitation*** It includes good lighting, ventilation and sanitary conveniences.

9. ***Flexibility*** A study room may be planned for using as guestroom; by providing partition, living room and dining room may be utilized for family functions, whenever necessary. By providing independent access to backyard from the kitchen, backyard can be used for hosting dinners.

10. ***Privacy*** By the proper grouping of rooms privacy of rooms from one to other and from outside can be achieved.

11. ***Practical considerations*** Economy is major practical consideration. Future provisions should be made to improve flooring, extending building and improving elevation without dismantling any part of the building.

- Basic requirements of a building are strength and stability, dimensional stability, resistance to dampness, resistance to fire, heat insulation, sound insulation, protection from termite, durability, protection against burglary, lighting and ventilation, comforts and conveniences and economy.
- A residential building essentially consists of living, sleeping and service area. These areas should be clubbed properly to get comfortable living condition.

• Essential components of an industrial building are office, factory, godown and other facilities. The other facilities include proper entrance, parking, cloakroom, drinking water, canteen, sanitary block, medical aid, loading and unloading platform.

• To get building permission from competent authority notice for intended construction should be given along with key plan in 1 : 10000 scale, site plan in 1:500 to 1 in 1000 scale, building plan in 1:100 scale along with elevation and sectional views. Fee receipt copy should accompany the notice.

2.2 FOUNDATIONS

The lowest load bearing part of the building, usually located below the ground level, which transfers the load to the soil is known as foundation.

Functions of foundations are to distribute load on soil, minimize unequal settlement, providing stability, level surface and safety against undermining and prevention of soil movement.

Foundations are classified as shallow and deep. The minimum depth of shallow foundation should be

$$H = \frac{p}{w}\frac{(1-\sin\theta)^2}{(1+\sin\theta)^2}$$

where p = SBC of soil w = unit weight of soil and q = angle of repose of soil. In any case it shall not be less than the width of wall plus 300 mm. For walls inverted arch footing may be used wherever SBC of soil is less.

For providing footing for walls and masonry columns, trenches of required sizes are made, the soil is rammed and a led concrete of 1 : 4 : 8 is laid to a thickness of 150 to 200 mm. Then foundation is built with stone masonry in courses 150–200 mm depth and projecting at 50 to 75 mm is each course.

For R.C.C. columns isolated column footing, combined footing, cantilever footing, continuous footings or raft footings are provided. For steel columns, grillage footing are ideal.

Pile foundations are the examples of deep foundations used for buildings. They may be classified as frictional piles and bearing piles. According to the materials used piles may be classified as timber piles, concrete piles (cast in site or precast), steel piles, composite piles and sand piles. To facilitate pile penetration during driving it they are provided with cast iron or steel shoes. Pile driving is usually by dropping a hammer freely over the pile cap. A pile is supposed to have reached a hard stratum when it does not settle more than 10 mm with 10 blows of a 30 kN hammer falling freely from a height of 800 mm.

From geological and agricultural maps and also from local enquiries preliminary investigation may be carried out to find out type of soil, nature of soil strata, groundwater condition, etc. The detailed investigations are carried out by collecting and testing soil samples from open trial pit, probing, boring, sanding, seismic method and by electric resistivity method. SBC is determined by laboratory tests. For small works presumptive values may be picked up from tables.

The methods of improving SBC of soil are by

1. Increase depth of foundation
2. Compaction
3. Draining the soil

4. Confining
5. Grouting
6. Chemical treatment
7. Using geo-synthesis.

The steps followed for the layout of foundations are:

1. Establish an important line
2. Drive two other pegs to mask width of foundation
3. Trace foundation plane on ground and check from other points
4. Build masonry pillars at a distance of at least 1 m from the foundation trench. Top of the pillars are plastered and kept at plinth level. The centre line is marked and a nail is fixed.

The width of excavation should be a little more than the width of the footing. However, it should be wide enough to ensure safe and efficient working. The depth of the foundation is checked by holding a string along the grooves on the opposite pillars and holding a boning rod. Sheetings, struts, bracing and waling are used to timber the trenching. Such timbering is known as shoring. Depending upon the nature of soil and depth of trench different methods of shoring are adopted. Stay bracing, box sheeting, vertical sheeting, runners and sheet piling are different methods of shoring.

Foundations in B.C. soil: If depth of B.C. soil is 1 to 1.5 m, it is economical to replace B.C. soil. The sides of foundation trench should be filled with sand and gravel. Below the bed level of foundation about 600 mm sand filling should be provided. If black cotton soil is more than 1.5 m deep short columns may be built at regular intervals and connected by concrete beams or masonry arches. If depth of B.C. soil is more than 3 m, pile foundations should be provided.

If a foundation is to be laid for a new building close to the existing building the minimum horizontal distance between the two foundations should be equal to the width of the wider one. The line joining the nearest points of the two foundations should not be more than 30° in soft soil and 45° in average soil. However, using geosynthesis it is possible to manage closer spacings.

If reclamation is by filling with good soil on layers of 300–400 mm with good consolidation, the foundation should be started on reclaimed soil only after two years.

For laying foundations in waterlogged areas drains and sumps are made to pump out water. Water may be drained by well point system, multi-stage well point system, deep well system or by vacuum method.

To prevent leakage of water in foundation trenches cement grouting, chemical grouting, freezing process or electro osmosis process are used.

A cofferdam is a temporary structure built around a construction site to make the site reasonably dry. Sand bag dikes, earthern cofferdams, rock fill cofferdams, rock fill crib cofferdam, single wall cofferdam, double walled coffer dam or cellular cofferdams are used.

A caisson is a water tight chamber in which underwater constructions can be carried out. Types of caissons used are box caisson, open caisson, pneumatic caisson.

A foundation may fail due to unequal settlement, sub-soil moisture movement or by movement of sub-soil.

Stone Masonry

- Masonry refers to anything constructed by a mason using materials such as stones, bricks, tiles, etc. In stone masonry mortar is used to bind stones.
- Types of stone masonry are rubble masonry and ashlar masonry. In rubble stone masonry stones of irregular shape and size are used. Dry rubble masonry, random rubble masonry, square rubble masonry, polygon walling and flint walling are some of the types of rubble stone masonry. In ashlar stone masonry stones are dressed neatly to regular shapes and used is regular courses. Ashlar fine tooled, rough tooled, rock or quarry face, chamfered, block in course and ashlar facing are some of the types of ashlar masonry.
- Structural members built with stones are steps, walls, plinth, sill, string course, frieze, parapet and coping.
- The types of joint made are butt joint, lap joint, joggle joint, bed joint, slate joint, cramp joint and plugged joint.
- To lift stones during construction chain, chain dogs, grab hooks, Lewis or tongs are used.
- Stones should be laid on their natural bed. Through stones within 1.5 m distances should be used. Under beams, trusses, etc., large flat stones should be used. Proper curing is necessary for 2–3 weeks.

Brick Masonry

- Bricks with mortar are the materials used in brick masonry. Stretcher is a brick with longer face in the direction of wall. Header is the brick at right angles to a stretcher. Bed joint is the horizontal layer of mortar over which bricks are laid. Perpend is an imaginary line passing through the vertical joints in the alternate courses. Quoin is the angle at corner on the face side of wall which is normally 90°. Bat is the portion of the brick cut across the width. Closer is the portion of the brick cut along its length. Queen closer, king closer, bevelled closer and mitred closer are some of the types of closers. Toothing is a method of terminating a wall with alternate courses projecting. At the end of days work a wall is terminated in a stepped manner. This is known as racking back.
- Construction of a brick wall always starts from a corner. About 15 mm thick bed is prepared with mortar over an area to be covered by the corner of the wall. The first brick is pressed on it and then closer is placed with mortar on its sides. The joint thickness of 10 mm throughout should be ensured. The brick is gently hammered. The headers are laid on the same manner. The edge line is checked after laying each brick other courses are laid and vertically is checked frequently.
- Trowel, bolster, brick hammer, spirit level, plumb rule, masons square, line and pins and end frames are the tools used in brickworks.
- Various types of bonds used are stretcher bond, header bond, English bond, Flemish bond, English cross bond, Dutch bond, Raking bond, zig-zig bond, garden wall bond, facing bond. The English bond is stronger for walls thicker than $1\frac{1}{2}$ brick, since it uses large number of headers compared to flemish bond.
- The following types of junctions are built in brick walls: T-junction, intersection, squint junction.
- Apart from wall, brick masonry is used for columns, footings, buttress, threshold, window sills,

corbels, coping, ornamental works, brick nogging, fire places and flues, chimneys. Brick nogging is brickwork in wooden frame. This type of walls are provided in earth- quack-prone areas.

• Defects in brick masonry are: small depressions with nodules due to use of interior bricks, development of cracks due to expansion of bricks due to sulphate action disfiguration of surface when soluble salts present come in contact with water, corrosion of embedded fixture, shrinkage on drying and cracking due to frost action.

• Walls should be raised uniformly and in no case difference between adjoining walls should be more than 1 m. No wall should be raised by more than 1.5 m in a day. The face joint should be raked to a depth of 12–20 mm when the mortar is green in order to ensure proper key to plaster. Masonry should be cured regularly for two weeks.

• Thickness of a wall is always in terms of multiples of 1/2 brick length. To get better thermal comfort in 1–3 storey residential building, $1\frac{1}{2}$ thick bricks exterior walls may be used.

Concrete Block Masonry and Composite Masonry

* In cities concrete block masonry is becoming more popular. The following types of composite masonry are also used: stones-composite, brick-stone composite, reinforced brick masonry.

* To build a wall of 1 m^2 and thickness 200 mm it needs only 13 litres of cement as against 45 litres required for brick masonry.

* Concrete blocks may be given the following surface finishes: coarse texture, glazed finish, slumped finish, specially faced finish and coloured finish.

Partitions and Cavity Walls

* A thin wall constructed to divide an enclosed area is known as partition wall. It carries self weight only. A cavity wall consists of two separate walls with a cavity between them.

* In upper floors, partition walls are built over beams or over concealed beams. In ground floors $\frac{1}{2}$ brick thick partition wall is built with 1 brick thick plinth which is having a 300 mm wide and 150 mm thick concrete bed.

* The following types of partitions may be built. Brick partition, clay block partitions, concrete partitions, glass partitions, timber partitions, asbestos sheet partitions, straw board partitions and metal partitions.

* In cavity walls, as far as possible, cavity should be continuous. The ties are usually placed at 900 mm apart vertically and 450 mm apart horizontally. The advantages of providing cavity are (i) external moisture does not enter the building, (ii) they provide good thermal and sound insulation.

* Cavity walls are provided at foundation level, at cave or parapet level and at sill and lintel levels.

Doors, Windows and Ventilators

* The function of a door is to give access to a building or a part of it or deny access whenever necessary. Windows ensure light and ventilation. The main idea behind providing ventilation is to allow hot air to escape.

* Doors should be provided in the corner of the room to ensure least circulation area.

* The window area should be 15 to 20 per cent of the floor area. Another guideline is for every 30 m^3 internal volume, there should be at least 1 m^2 of window opening. The windows are located at 0.75 to 0.90 m from floor level. However, for bathrooms they may be at a height 2.0 m. They should be positioned so as to ensure good cross ventilation. To get diffused light location of windows is preferred on the northern side of rooms.

• Ventilators are preferably located on the underside of top floor/roof.

• Wood is a common material used for doors, windows and ventilations. Plywood is preferred for internal doors. R.C.C frames are also preferred. For shutters glazing is with glasses. For bathrooms PVC doors and windows may be preferred.

* Threshold is a cross wooden member of the door at floor level. Sill is the lowermost horizontal member of a window frame. The topmost horizontal member of window/door is known as head.

  Transome is the horizontal member of a frame provided to subdivided the opening. Horn is the projection of the frame beyond the opening. Rebate is the recess made in the frame to receive the shutter. Style is the outside vertical member of the shutter. Top rail is the topmost vertical member of the shutter. The lowermost horizontal member of the shutter is known as bottom rails. The middle horizontal member of shutter is lock rail. The additional horizontal rails fixed are known as cross rails.

  The area of shutter enclosed between the adjacent rails is known as panel. The light weight unit of a frame which holds the glass within the door or window is sash bar. The vertical member employed to subdivide a window or a door opening vertically is mullian. Louvre is a piece of timber fixed in an inclined position within a frame. Jamb is the vertical face of the opening that supports the frame. External portion of jamb is known as reveal. Architrave is the strip of wood fixed round a door frame when the frame is flushed with the external surface of wall. Holdfasts are the steel flats used to fix door/window frames with wall. They are made with steel flats of size 30 × 6 mm wide and 200 mm long.

* Size of doors: Guideline is width = 0.4 to 0.5 times height or height = (width + 1.2) metres. In residential buildings common sizes of doors are external doors: 1.0 × 2.0 m, internal doors: 0.9 × 2.0 m. Bathrooms: 0.7 × 2.0 m. BIS recommends the sizes and size of frames by designation of the form in which D is for, S for single shutter and T for double shutters. Thus, 10DS20 means size of opening 1000 × 2000 mm door with single shutter and 12DT20 means the door with double shutter of size 1200 × 2000 mm.

* The size of timber usually adapted are:

Frame	100 × 65 mm
Shutters—vertical style and top rail	100 × 40 mm
Bottom rail	250 × 40 mm
Lock rail	160 × 40 mm
Single panel leaf	15 mm thick
Double panel leaf	12 mm thick

* Types of doors used are: Battened and ledged, battened ledged and braced; battened ledged and

framed ledged framed and braced, framed and panelled, glazed, flushed, louvered, swing, revolving, wire-gauged, sliding, collapsible and rolling shutter doors.

* BIS designates windows 6WS 12, 10WT12, 12WT12, 6WS13, 10WT13 and 12WT13. In the above W is for window, S for single shutter and T for double shutter. 10WT13 means double shutter window of size 1000 mm wide × 1300 mm high. For all those windows the size of frames and shutters are also given. Thickness of shutters to be used are 20, 25 or 30 mm, depending upon the size.

* Windows may be classified on the various basis:
  1. Material used: Timber, steel, aluminium, etc.
  2. Types of shutters: Panelled, glazed, louvered, etc.
  3. Types of opening of shutters: Hinged on sides, centrally pivoted, double hung, sliding, rolling, etc.
  4. Position of windows: Bay windows, corner windows, clear storey, gable windows, skylight windows, dormer windows.

* Ventilators: The standard dimensions of ventilators are 6V6, 10V6, 12V6. They may be with simple brick jali work, mortar jali work or horizontally pivoted or with two glasses one fixed to bottom of the frame and another hung from top frame with a certain gap.

* Hinges, bolts, handles and locks are the fixtures and fasteners for doors and windows.

Lintel and Arches

* Lintel and arches are provided wherever it is necessary to support a wall over an opening. The width of lintel is same as that of wall. The end bearing for lintels should be greater than 100 mm, depth of lintels should be $\frac{1}{12}^{\text{th}}$ span.

* Types of lintels according to materials used are timber lintel, stone lintels, brick lintels, steel lintels and R.C.C. lintels. R.C.C. lintels may be cut lintels, continuous lintels, and lintels with sunshades (chajjas).

* Arch is a curved intel in vertical plane. The various terms used with arches are:

Voussoirs	:	Wedge-shaped units forming the course of an arch
Arcades	:	It is the row of arches supported on piers and carrying a wall over it.
Springing points	:	The points from which the curve of an arch springs.
Springing line	:	The imaginary line joining the two springing points of on arch.
Intrados	:	This is the inner curve of an arch.
Extrados	:	This is the outer curve of an arch.
Key	:	This is the wedge-shaped unit at the crown of the arch.
Spandril	:	It is the space between the extrados and the horizontal line through the crown.
Skewback	:	This is the arch inclined surface on the abutment from the arch springs.
Import	:	This is the projecting course on the upper part of a pier or abutment stressing the springing line.

* Types of arches:

1. On the basis of shape. Flat arch, segment arch, semicircular arch, semi-elliptic arch, horseshoe arch, pointed arch, stilled arch, venition arch, florentine arch, relieving arch, inverted arch.
2. On the basis of number of centres: Bullseye arch, three-centred arch, four-centred arch, five-centred arch.

* On the basis of materials used: stone arches, brick arch and concrete arch. Stone arches are further, classified as rubble arches and ashlar arches. Brick arches are further classified as rough brick arch, axed brick arch, hinged gauged brick arch and purpose made brick arch. Concrete arches are classified as concrete block arches, monolithic concrete arch and R.C.C. arches.
* Construction of arch involves three steps namely, installation of centring, laying of arch and removal of centring. Decentring may be by using wedges or by sand box method.

Floor and Flooring

* Floors divide the building into different levels. The floor at plinth level is called the ground floor, floors above it are upper floor and below it are basement floors.
* For constructing ground, the ground is rammed well, a layer of red earth or sand is placed over it and compacted. A layer of brickbats and stones is provided upto the level 150 mm below the floor finish. The layer is kept moist and compacted. A plain concrete course of 100 to 150 mm is provided with 1 : 4 : 8 concrete using 40 mm down size aggregates. The materials used for floor finish are : mud and muram, bricks, flag stones, cement mortar, terrazzo, mosaic, marble, tiles, timber rubber or PVC.
* The following types of upper floors are used: Timber floor, steel joints and flagstones, Jack arch floor, R.C.C. floor, reinforced brick slab, ribbed or hollow tiled floor and precast concrete floors. R.C.C. floors may be a slab floor, beam and slab floor or flat slab.

2.3 ROOFS

Roof is the topmost portion of the building. The roofs may be classified as flat or terraced roofs, pitched or sloping roofs, folded plate and shell roofs.

Flat roofs They may have slight slope (not more than 10°) in order to drain rainwater. The following types of flat roofs are popular in India: Punjab terrace roofs, Maharashtra and M.P. terrace roofs, Madras terrace roofs, Bengal terrace roofs and R.C.C. roofs.

* Pitched/Sloping Roofs : In areas where rainfall is more or snowfall takes place, pitched roofs are preferred. The slope of the roof may vary as much as 40° to 60°.
* Technical terms used with pitched roofs are : Ridge is apex line of sloping roof. Hip is the line formed by intersection of two sloping surfaces, where exterior angle is more than 180°. In valleys interior angle is less than 180°. The lower edge of the sloping surface of a roof is known as eave. Gable is the vertical triangle of the wall supporting a sloping roof. Ridge piece is a wooden piece providing at the ridge, which runs horizontally. Eave board is a wooden board along the eves which hides the view of rafters from outside. Rafters are the pieces of wood which extend from the ridge to eave. Battens are the thin sheets of wood which are fixed on the rafter to support tiles. Wall plates are the long wooden members, provided on walls for fixing the feet of common rafters.

Post plates run over the posts and support the feet of the common rafters. Purlins are the wooden or steel pieces that are placed horizontally on principal rafters and carry common rafters. Cleats are small blocks of wood which are fixed on the trusses to prevent the sliding of purlins.

* Pitched roofs are broadly classified into single, double and trussed roofs.

1. Single Roofs: Lean to roof, couple roof, couple close roof, collar beam roof.
2. Double Roofs: If the span of the roof is more than 5.5 m common rafters become uneconomically. In such cases purlins are provided.
3. Trussed Roofs: Truss is a framework of slender members. Longer halls are covered by pitch roof using trusses at regular interval depending upon the span various shapes of trusses are used. The trusses may be timber trusses or steel trusses.

* Various types of covering materials used for pitched roof are : Thatch, shingle, tiles, slates, A.C. sheets and GI sheets. If A.C. sheets are used and lap should be at least 150 mm, side lap 50–120 mm. The holes for fixing should be drilled, i.e., should not be punched. Bituminous washers should be used under GI flat washers.

* Folded plate or shells may be used to cover large column-free areas.

Vertical Transportation

* The transportation of people and goods from floor to floor is by means of stairs, lifts, ramps and escalators.

Stairs A stairs is a series of steps arranged to connect different floors of a building. The space housing the stairs is called staircase.

* The various parts of stairs are as explained below: Tread is the upper horizontal portion of a step. Rise is the vertical distance covered in a step. Riser is the vertical portion of step providing support to the trend. Going is the horizontal distance between two successive riser faces. Flight is a series of steps without any landing and break in the direction. Flier is an ordinary step of rectangular shape in plan. Winder is a tapering step used for changing the direction of stairs. The sloping member supporting the steps is known as stringer. The thickness of sloping slab in R.C.C stairs is known as waist. The projecting part of the tread beyond the face of the rises is nosing. Baluster is the vertical member which supports the handrail. Newel post is the vertical member placed at the end of flights to connect the ends of stringer and handrails.

* Types of stairs:

1. *On the basis of shapes :* Straight stairs, dog logged stairs, open-newel stairs, turning stairs, geometric stairs, spiral stairs.
2. On the basis of materials used:

   (a) Stone stairs – Rectangular steps, spandril steps, tread and riser steps, cantilevered tread steps, built-up steps.

   (b) Brick stairs – Exterior steps are typical brick stairs. Many times brick stairs of single flight are built with arches.

   (c) Wooden stairs : Timber stairs are used for low rise buildings. Disadvantage of timber steps is they are very poor in fire resistance.

(d) R.C.C. stairs : Nowadays very widely used stairs.

(e) Metal stairs : In factories mild steel or cast-iron stairs are used.

* Requirement of good stairs :

1. Width : 0.9 m in residential buildings and 1.5 to 2.5 m in public buildings.
2. Number of steps in a flight : Maximum 12 to 14 numbers. Minimum three.
3. Rise : 150–175 mm in residential buildings. In public building 120–150 mm.
4. Going : 250 mm in residential buildings and 270–300 mm in public buildings

Empirical formula to be used is

$$2R + G > 550 \text{ but} < 600 \text{ to } 700.$$

where R is rise and G is going in mm.

5. Headrooms : $\nless$ 2.1 m
6. Handrails : At a height of 850–900 mm.

Ramps A ramp is a sloping surface connecting two floors. The slope of a ramp should not be more than 1 in 15. Whenever the direction of ramp changes, a level landing equal to the width of the ramp should be provided. At door opening, at least 1.1 m landing is required. For hospitals such landing should be at least 2.25 m. Ramps are usually provided at railway stations, stadiums, shopping malls, hospitals and multistorey car parkings.

Escalators Escalators are electronically operated moving steps. The speed of escalators is usually 25 to 30 m/minute. Their inclination is kept 30° to the horizontal. They handle heavy traffic of persons and require no operators. They are used in commercial complexes, airports and underground railways stations.

Lifts Lifts may be classified as passenger lifts, goods lifts, hospital lifts, service lifts. It is mandatory to provide lifts in buildings with more than four storeys. Lifts of different capacities are available in the market, ranging from 4 to 20 persons. For designing lifts, the weight of a person is considered to be 68 kg. IS : 14665 gives guidelines to find capacity of lift and number of lifts required for multistorey building. The lift well usually extends from 1.6 to 2.6 m below the bottom landing. The opening of 2 m height is required for entry of people at every floor.

Plastering and Pointing

* Plastering is to give a smooth and decorative surface to walls and ceiling. It gives protection to walls from rodents, insects and atmospheric action.

* Types of mortars used are mud plaster and lime plaster.

1. Mud plaster It is for low cost houses in which brickwork is also in mud. Ten per cent of clay content should pass through 2.36 mm sieve and not less than 75 per cent should pass through 850 micron sieve. For making mortar, soil is mixed with water and left for 1–2 weeks. Then dried and reduced to powder and mixed with 33 kg of chopped straw is mixed and plenty of water.

2. Lime plaster Hydraulic lime should be ground dry with sand in the ratio 1 : 2 and left for 2–3 weeks before regrounding and using. In case of fat lime the mix proportion used is 1 : 3 or 1 : 4 which are wet mixed. To improve binding property a kind of gum known as gugal is added to lime.

The gugal added is about 16 N/m^3. About 10 N of fibres of jute also added to per cubic metre of mortar. The mortar so prepared is kept for weathering for two days.

3. Cement mortar 1 : 4 or 1 : 6 mortar is used for plastering external and internal walls respectively. To make mortar waterproof, pulverized alum is added. Soap water containing 0.75 N of soft soap/litre water is added.

4. Lime-cement plaster To improve plasticity and at the same time to maintain strength cement : lime : sand mortar is used. Mix proportions of cement : lime : sand is usually 1 : 1 : 8 or 1 : 2 : 8. Fat lime is preferred over hydraulic lime.

* For plastering new surface, all masonry joints should be raked to a depth of 10–15 mm and loose particles removed with wire brush. The surface is washed and kept damp till plaster is applied.

* Plaster is usually applied in one, two or three coats depending upon the background. The first coat, known as undercoat is 10–15 mm thick. The second coat, known as floating coat is usually 6–9 m thick and finishing coat is 2–3 mm thick. External walls should have a minimum of 20 mm thick while internal wall may be provided with 12 mm thick plaster.

* Plastered surfaces may be with the following finishes:

1. Smooth-cast finish
2. Sand-faces finish
3. Rough cast finish
4. Pebble or flint-dash finish
5. Strucco plastering.

* For plastering wooden surfaces wooden laths or metal lathes are used.

* The following defects may appear in plasters:

1. Unevenness
2. Rust stains
3. Efflorescence
4. Blistering
5. Cracking
6. Crazing
7. Flaking and peeling
8. Popping

* Pointing is the process of finishing mortar joints only to make the surface watertight. The joints are raked to a depth of 10–20 mm after which they are filled with richer mortar. The mix proportion used is 1 : 2 for lime mortar and 1 : 3 for cement mortar.

* The types of pointing are: Flush pointing, recessed pointing, *V*-pointing, weathered pointing, rubble pointing, beaded pointing, struck pointing and tuck pointing.

Temporary Works

* The various temporary works in building construction are formworks, scaffolding, shoring and underpinning.

1. Form work The temporary works used to mould concrete elements like slab, beams, lintels and columns are known as formworks. Temporary work for arches is centring. The cost of form-work is as high as 30–40 per cent of the cost of concrete. The form work should be strong enough to take care of weight concrete, labourers, equipment used for placing concrete and vibrations. It should be easy to remove formwork after concrete hardens. Wood or steel formworks are generally used. Formwork should be rigid. Slip forms are preferred for the construction of shafts, chimneys, towers, piers, etc.

2. ***Scaffolding*** When the work is at a height more than 1.5 m, temporary platforms are required for masons and materials. These are known as scaffolding. If the scaffolding is at a height more than 2 m, guard rails should be provided. The vertical posts are known as standards. The horizontal members parallel to the wall are ledgers. Diagonal members fixed on standards are braces. Horizontal members normal to wall are putlogs. Putlogs, if supported on both ends are known as transforms. The plates provided below standards to distribution load over ground are known as base plate or sole plate. Types of scaffolding used are (a) single scaffolding or bricklayers scaffolding (b) double scaffolding or masons scaffolding, (c) cantilever scaffolding, (d) suspended scaffolding and (e) trestle scaffolding.

3. ***Shoring*** Temporary support provided to prop up a building for repair is known as shore and such works are known as shoring. Types of shores are (a) raking or inclined shores, (b) flying or horizontal shores, (c) dead or vertical shores.

4. ***Underpinning*** It means giving support from below. In civil engineering it refers to repair, strengthening or renewal of the foundation of an existing building. Pit method or pile method of underpinnings are normally carried out.

Plumbing Services

* Services that allow water supply and drainage of wastewater are known as plumbing services.
* Water requirement in a residential building is about 135 litres/day/person whereas in hospitals it is upto 340 litres/day/bed. In schools water requirement is 45 litres/day/child.
* Pipes of 20 mm diameter are normally adequate for residential buildings. If the number of occupants is about 24, go for 25 mm dia. pipes. If the number of occupants is 60, use 30 mm dia pipes. The distributary pipes in the building may be 12 mm dia pipes.
* GI pipes and unplasticized PVC pipes are generally used for water supply. Water meters are to be provided for every tapping from municipal line. Values are provided as an additional precaution to avoid wastage of water. Usually, sump is provided at grand level and storage tank over roof.
* House drainage system: It includes the arrangements for disposing of the used water from kitchen, washbasins, baths, urinals and water closets. The used water from kitchen, washbasin and bath is wastewater while that from urinals and toilets is sewage. In order to prevent the entry of foul gases, traps should be provided. The slope of drainage pipes should be sufficient to maintain self-cleansing velocity. A chamber should be provided wherever a change of direction of pipe alignment is required.
* The types of pipes used in house drainage system are: (a) waste pipe, (b) soil pipes, (c) vent pipes, and (d) anti-siphonage pipe.
* Traps may be of P-type, Q-type, S-type, floor or Nohni type, gully trap, intercepting type, grease type or combined silt and grease type. The depth of water seal should be 25–75 mm.
* Main sanitary fittings used are washbasins, sinks, bathtubs, urinals and water closets.

* Systems of plumbings adopted are: single stack system, partial vented single slack system, one-pipe system and two-pipe system.

Electric Supply

* The supply voltage is 230 V between phase and neutral and 400 V between phases. In order to install the electric supply system in a building strong coordination among the architect, civil engineer and electrical engineer is required. Main switches and meters should be installed close to entrance. Electrical installation in a new building should begin immediately after the completion of the structured work completion and before commencement of finishing works. Cables, fuse, miniature circuit breaker (MCB), earth leakage circuit breaker (ELCB), residual current circuit breaker (RCCB), plug fuses are the materials and devices used in electric supply to a building. Pipe earthing or plate earthing is an essential part of wiring.

Damp-proofing and Waterproofing

* Causes of dampness are: (1) moisture rising from the ground, (2) splashing of rain, (3) moisture entering from top of parapet walls, (4) condensation, (5) construction defects such as improper planning of drainage, lack of proper slope in roof, defective pipe fittings, improperly sealed construction joints.
* Materials used for damp proofing are hot bitumen, mastic asphalt, bituminous belt, metal sheets, plastic sheets, bricks, mortars and cement concrete.
* For waterproofing flat slabs the methods adopted are lime concrete terracing, membrane waterproofing, using waterproofing compounds.

Antitermite Treatment

* Woodwork in the building are often attacked and damaged by termites, popularly known as white ants.
* There are two types of termites, namely, ground-nesting termites and dry wood termites.

Ground nesting termites always maintain connection with the soil and form soil tubes to move into buildings. Then form secondary nests into wood and continue to eat. Dry wood termites live on wood without maintaining any connection with the soil.

* Chemicals used to provide antitermite treatment are
  1. Chloropyrofos concentrate : 1% by weight
  2. Heptachlor concentrate : 0.5% by weight
  3. Chlordane concentrate : 1.0% by weight
* It is better to provide antitermite treatment before constructing foundation itself. In case existence of termite is found in the exciting building, post-construction treatment may be provided.

Ventilation, Air Conditioning and Thermal Insulation

1. Ventilation

* Ventilation is the entry of fresh air and removal of vitiated air from the building by natural or

mechanical means.

* Ventilation system in a building is designed with three main considerations—respiration, vitiation by body odour and heat balance of body.
* Enough air normally enters the building through crevices and other openings. Hence, concentration of carbon dioxide does not form the basis for fixing the rate of ventilation in a residential building.
* Body odours and other odours such as from smoking and cooking need consideration in ventilation.
* In case of factories, assembly halls, auditorium, etc., at least 14–16 m^3 of space should be provided for every person and for this purpose, no space more than 4.25 m above the floor level should be taken into consideration. For various buildings, the standards recommended air changes should be met.
* In order to prevent discomfort and injury to health, ventilation should provide conditions that will assist in the maintenance of heat balance of the body. Thermal comfort depends upon temperature as well as air movement. In India, the upper limit of comfort for every day work is 27.5°C. Depending upon the temperature and relative humidity desirable wind speed for thermal comforts are available. One should aim at achieving that by natural means or by mechanical means.
* Mechanical ventilation may be: (1) Exhaust system (extract system), (2) Supply or plenum system, (3) Combination of the above two systems, and (4) air conditioning.
* Requirement of comfort A.C. are
  1. Temperature: 20–25° C
  2. Humidity: 40–50% in summer and 50–60% in winter
  3. Air quality: It should be clear air free from dust, ash, chemicals, etc.
  4. Air velocity: 6–9 m/sec is desirable
* Air conditioning may be of the following type:
  1. Central system
  2. Self-contained system
  3. Semi-conditioned system
  4. Combined system
* Essential parts of air conditioning system consist of filters, heating system, cooling system, humidification, dehumidification system and air circulation system (air pumps, delivery system and distribution system).
* Thermal insulation is the conservation of constant heat or temperature inside the buildings irrespective of the external temperature.
* Various insulating materials used are:
  1. Slab or block insulation
  2. Blanket insulation
  3. Batt insulating materials
  4. Loose fill insulation
  5. Reflector type materials
  6. Light-weight aggregates

* Various methods of thermal insulation are:
  1. Use of materials with low conductivity
  2. Using thicker walls and roofs
  3. Providing air space in walls and roofs
  4. Heat insulation by orientation
  5. Thermal insulation by shading
  6. Increasing ceiling heights
  7. Using thermal insulating materials

Accoustics of Buildings

* Accoustics deals with the control of sound in buildings. Velocity of sound in various mediums are:
  1. Air – 350 m/sec
  2. Water – 1310 m/sec
  3. Brick – 3600 m/sec
  4. Steel – 4900 m/sec
  5. Vacuum – zero.
* A shrill voice has a frequency of 20,000 cps while a whisper has a frequency of 20 cps. One cycle per second is equal to 1 hertz and is denoted as Hz. The range of audible frequency is 20–20,000 Hz. In music frequencies of 63, 125, 250, 500, 1000, 2000, 4000 and 8000 Hz are used.
* Noise is defined as unpleasant sound. Acceptable indoor noise levels are:
  1. Auditoriums, Radio and T.V. stations 20–25 dB
  2. Music rooms 25–30 decibels (dB)
  3. Hospitals and film theatres 35–40 dB
  4. Offices and banks 45–50 dB
  5. Restaurants 50–55 dB

  Noise level of aircraft at a height of 450 m is 101 to 114 dB while that of trains at a distance of 30 m is 77–85 dB.
* When a sound wave is generated in a room, it is partly reflected by hard and plane surfaces, partly absorbed by soft surfaces and the rest is transmitted outside the room.
* The wavefront is spherical and its centre of curvature is the source of sound. Sound waves reflected from a concave surface are magnified while those from concave surfaces are condensed.
* Echo and reverberations are ill effects of reflected sound. Reverberation time of 5 seconds is bad while 0.5 to 1.5 seconds is excellent.
* These are special materials used to absorb sound. They are known as absorbents. Hairfelt, acoustic plaster, acoustic tiles, pulp board, straw board, particle board, wood wool board, quilts and mats are the absorbents.
* Acoustics design of auditorium is important. To achieve it:
  1. Provide corridors and closets to act as buffers against external noise.
  2. In auditorium volume per person should be 3.5 to 5.5 m^3.
  3. A fan-shaped floor area is ideal but walls should not be splayed by more than 100° with the

curtain line.

4. Seats should be staggered and they should be absorptive. Width of seat should be 450–550 mm and distance between two rows should be at least 450 mm.

5. The ceiling should be at such a height that the difference between direct sound path and reflected sound path is not less than 8 m.

Fire-Resistive Construction

* The construction designed to prevent or slow down the spread of fire using fire-resistive material is called fire-resistive construction.
* Stone resists fire well but it bursts into pieces due to sudden heating and cooling. Brick masonry provides superior fire resistance. Timber may also be made fire resistant by coating its surface with chemicals such as ammonium phosphate and sulphate, borax and zinc chloride. Concrete offers higher resistance to fire. By using aggregates like foamed slag, cinder and bricks it may be made more fire resistant. Steel, aluminium and glass are poor in resisting fire. Asbestos has high resistance to fire.
* National Building Code of India classifies buildings into 4 types on the basis of fire resistance. Type 1–4 hours, Type 2–3 hours, Types 3–2 hours and Type 4–1 hour fire resistance.
* In all big buildings fire alarms and fire extinguishing arrangements should be made.

Earthquake-Resistant Buildings

* The horizontal movement of earth surface during earthquake is most dangerous to building.
* The point on the fault where the slipping of earth material starts is known as focus or hypocentre. The point vertically above the focus on the surface of the earth is epicentre. The depth of focus from the epicentre is focal depth. Distance of the point of interest from the epicentre is called epicentral distance.
* Magnitude of an earthquake is a quantitative measure of the earthquake, which indicates the amount of energy released at the source. It is represented by letter M followed by a number. An increase of one number means it is 10 times higher wave amplitude and 31 times higher energy release. Thus M6 earthquake has amplitude 10 times more than that is M5 earthquake and energy release is 31 times more.
* Intensity of earthquake is a qualitative measure of shaking at a location. Hence, intensity of a earthquake varies from place to place. The Modified Mercalli Intensity (MMI) scale is commonly used to express the intensity of earthquake. It is from I to XII. Very slight, felt only by instruments is MMI-I whereas MMI-XII is utter catastrophe.
* The first Indian Seismic Code identified seven seismic zones based on the intensity experienced till 1967. In 1970 revised it to five zones. Zone I is the zone of least intensity and zone V is the zone of highest intensity.
* Earthquake resistance of small buildings can be improved by taking care in proper selection of site, shape and also in constructing foundations and masonry. Position of doors and widows also contribute to earthquake resistance. Roof shape, sunshade dimension, height of parapets and

concrete and mortar selection also decide earthquake resistance of a building. It is suggested to provide plinth band, lintel band roof band and gable bands. Retrofitting of all elements of building so as to integrate them is desirable. For tall structures apart from providing shear walls, base isolation and use of seismic dampers are necessary.

Equipment for Building Constructions

1. ***Excavating equipment*** Bulldozers fitted with S, U, S–U type blades and rippers, power shovel excavator, drag line excavators, trenchers loaders and scrapers.
2. ***Earth compaction equipment*** They consist of heavy rollers. Sheep foot rollers compact the soil by kneeding.
3. ***Concrete construction equipment*** Concrete mixers of rotating non-fitting, rotating tilling, pan type, paddle type, pumps vibrators.
4. ***Bar bending machines***
5. ***Hauling equipment*** Tractors, trucks, damp trucks, dampers, trailors, elevators and conveyors.
6. ***Hoisting equipment*** Forklift trucks, cranes, gin wheels.
7. ***Drilling equipment*** Abrasion drill, percussion drill with drill bits.

Mass Housing Schemes

* The cost of construction is directly proportional to the built up area. Hence, in low cost housing the built up area is restricted but the minimum standards are to be ensured. Minimum standards prescribed are: living room – 11.1 m^2, varandah and kitchen 6.5 m^2, bath zoom 1.3 m^2, lavatory 1.1 m^2 and total area 20 m^2.
* Cost effective construction techniques should be adopted in each and every component of building without violating minimum requirements.

Green Buildings

* Buildings account for 40 per cent of the world's total primary energy consumption and for 24 per cent of global carbon dioxide emersion. A green building is broadly defined as a structure that aims to reduce negative environmental impact and has positive impact on the environment over its life cycle. It generally refers to using energy, water and other resources efficiently and reducing waste, pollution and environmental degradation.
* Leadership in Energy and Environmental Design (LEED) rates the buildings as certified, if points scored is 26–32, silver level if 33–38 points, gold level if 39–51 points and platinum level if the points are more than 52.
* Bureau of Energy Efficiency (BEE) in India assigns rating of green buildings on scale 1 to 5. It fixes different parameters to be considered for the three climatic zones, namely, composite zone (Delhi), hot and dry zone (Jaipur, Ahmedabad) and hot and humid zone (Mumbai and Chennai).
* Energy consumption in a building may be grouped into the four phases : (1) Embodied energy of materials, (2) embodied energy required during construction, (3) energy required for maintenance

of building and (4) energy spent in demolition.

* In making a building green, apart from reducing the energy requirements, its positive impact on economy and productivity also should be considered.

Construction Management

* Successful execution of a project depends upon—management, money, manpower, machinery and material.
* Average of cost of civil works for a building at various levels are foundation: 10–15%, walls, stairs and roofs: 30–40%, doors and windows: 12 to 18%, flooring 10–20%, Finishing 8–20%, water proofing 8–12%. A provision of about 30% of civil works is required for water supply and sanitation (12.5 %), electrification (12.5 %) and external work (5%).
* Commonly employed methods of planning in construction are bar charts and network method. In network method one can adopt Program Evaluation and Review Technique (PERT) or Critical Path Method (CPM). PERT is suitable in the management of works where previous data and experience are not available. For building construction CPM is the best method.
* **Elements of a network:** Activity is defined as number of small jobs to be performed in a sequence to complete a job. Event is an activity that takes place at a particular time. A dummy activity neither requires any time nor any resource. It is used only to identify a dependency between various events.
* Development of a network involves identifying various activities, finding out proceeding and succeeding activity about each activity and drawing network. For each activity duration required in terms of days or weeks is then worked by consultation with junior and senior engineers and contractors. Then the following details are worked out:

1. ***Earliest event time*** It is the time at which an event can be completed earliest. Naturally, it depends upon the completion of its proceeding activities.
2. ***Latest finish time*** The latest time by which an event should be completed to avoid any delay in the project, is worked out by tracking the events in the reverse order.
3. ***Slack or float*** The difference between latest finish time and earliest finish time is slack.
4. ***Critical path*** It is the line connecting the activities with zero slack.

* The total cost of a project is grouped into two heads, i.e., direct and indirect costs.

MULTIPLE-CHOICE QUESTIONS

I. Select the correct choice to answer the following questions.

1. In case of gable facing the street, height of building is considered upto
   (a) the top of gable end.
   (b) up to the midpoint of gable end.
   (c) up to the lower end of gable.
   (d) up to $\frac{1}{3}$rd the height of gable end.
2. Building line is

(a) least horizontal distance of the permanent portion of the building from centre line of street in front of the building.
(b) least horizontal distance of the permanent portion of the building from the edge of the street in front of the building.
(c) least horizontal distance of temporary or permanent building from centre line of street.
(d) least horizontal distance of temporary or permanent part of the building from the edge of street.

3. In case of corner plots, according to National Building Code,
(a) only lower 0.75 m should be solid for a distance of at least 10 m
(b) only lower 1.0 m should be solid for a distance of at least 5 m
(c) only lower 0.75 inch should be solid for a distance of at least 5 m.
(d) only 1.0 m should be solid for a distance of at least 5 m.

4. Rankine's formula to fix minimum depth of foundation for wall with usual rotation is
(a) $H = \frac{p}{w}\left(\frac{1+\sin\phi}{1-\sin\phi}\right)^2$
(b) $H = \frac{p}{w}\left(\frac{1-\sin\phi}{1+\sin\phi}\right)^2$
(c) $H = \frac{p}{w}\left(\frac{1+\sin\phi}{1-\sin\phi}\right)$
(d) $H = \frac{p}{w}\left(\frac{1-\sin\phi}{1+\sin\phi}\right)$

5. Suitable foundation for steel columns is
(a) mat foundation
(b) combined foundation
(c) strap footing
(d) grillage footing

6. Pile is a slender column made of
(a) wood
(b) concrete
(c) sound
(d) any of the above

7. For pile driving near the existing buildings piles preferred are
(a) steel
(b) precast concrete piles
(c) cast in situ concrete piles
(d) timber piles

8. The maximum intensity of loading that the soil will safely carry without the risk of shear failure irrespective of settlement is known as
(a) ultimate bearing capacity
(b) safe bearing capacity
(c) safe bearing pressure

(d) gross allowable bearing pressure

9. Factor of safety of soil is

(a) $\frac{\text{Ultimate shear strength}}{\text{Safe bearing capacity}}$

(b) $\frac{\text{Ultimate compressive strength}}{\text{Safe bearing capacity}}$

(c) $\frac{\text{Ultimate tensile strength}}{\text{Safe bearing capacity}}$

(d) $\frac{\text{Load for maximum permitted settlement}}{\text{Safe bearing capacity}}$

10. Maximum bearing capacity of soil is that of
(a) soft rock
(b) coarse sand
(c) fine sand
(d) sand-clay mixture

11. Bearing capacity of soil can be improved by
(a) draining the soil
(b) confining the soil
(c) compacting
(d) any of the above

12. In trenching for foundations boning rod is used to
(a) maintain the required spacing between the sheetings
(b) to strengthen the frame supporting sheeting
(c) to check the level of foundation depth
(d) to strengthen sheeting

13. To ensure that the older structure is not damaged due to the depth of foundation of new structure being more, the line joining the nearest points of two foundations in case of soft soil should not be more than
(a) 10°
(b) 20°
(c) 30°
(d) 45°

14. A temporary structure built around a construction site to remove water and make the area reasonably dry is known as
(a) caisson
(b) cofferdam
(b) well foundation
(d) raft foundation

15. If depth and flow of water is high, the type of cofferdam to be used is
(a) sandbag dike

(b) earthen cofferdam

(c) rockfill cofferdam

(d) rockfill crib cofferdam

16. A watertight chamber, which becomes a permanent part of the construction work is known as

(a) cofferdam

(b) well foundation

(c) raft foundation

(d) caisson

17. In summer cracks developed in black cotton soil are

(a) 5–10 mm wide and 1–2 m deep

(b) 30–40 mm wide and 3–5 deep

(c) 100–150 mm wide and 0.5–2.0 m deep

(d) 300–400 mm wide and 3–m deep

18. In rainy season black cotton soil swells by

(a) 5–10 %

(b) 10–15 %

(c) 20–30 %

(d) 35–45 %

19. Sand blasting is the process of

(a) quarrying of igneous rock

(b) quarrying of sedimentary rock

(c) dressing stones

(d) making carvings on the surface of stone

20. The cheapest stone masonry is

(a) dry rubble masonry

(b) uncoursed random rubble masonry

(c) random square rubble masonry

(d) flint walling

21. Among the following the costliest masonry work is

(a) ashlar champered

(b) ashlar rock faced

(c) ashlar fine tooled

(d) ashlar block in course

22. The types of joints made in stone masonry are

(a) butt joint

(b) lap joint

(c) dowel joint

(d) all the above

23. For lifting stones in building works device used is

(a) chain or rope

(b) Lewis
(c) tongs
(d) any of above

24. The common thickness used for stone walls in a building is
(a) 200 mm
(b) 230 mm
(c) 300 mm
(d) 400 mm

25. In stone masonry works, through stones should be provided at
(a) 1.0 m distances
(b) 1.5 m distances
(c) 2.0 m distances
(d) 2.5 m distances

26. A brick with its longer face in the direction of wall is known as
(a) stretchers
(b) header
(c) quoin
(d) perpend

27. A brick with its shorter face in the direction of the wall is
(a) stretcher
(b) header
(c) quoin
(d) perpend

28. Perpend is an imaging line of mortar joints in brick masonry which is
(a) horizontal
(b) vertical passing through all courses
(c) vertical passing through alternate courses.
(d) none of the above

29. Portion of the brick cut across full width is known as
(a) queen closer
(b) king closer
(c) mitred closer
(d) bat

30. Construction of a wall starts from
(a) one corner and proceeds to other corner
(b) both corners and proceeds to middle portion
(c) middle portion and proceeds towards corners
(d) any of the above

31. Header bonds are used in the construction of

(a) half brick thick walls

(b) one brick thick walls
(c) $1\frac{1}{2}$ brick thick walls
(d) 2 brick thick wall

32. A type of bond in brick masonry consisting of alternate courses of header and stretchers, is
(a) stretchers band
(b) header band
(c) English band
(d) Flemish band

33. A type of bond in the brick masonry in which each course consists of alternate headers and stretchers is
(a) English bond
(b) Raking bond
(c) Dutch bond
(d) Flemish bond

34. Diagonal bond is a pattern of bond in
(a) English bond
(b) Flemish bond
(c) Dutch bond
(d) Raking bond

35. Quoins in brick masonry are
(a) bricks cut at corners in a triangular fashion
(b) half brick with length same but width halved
(c) squint junction of walls
(d) corner junction of walls

36. The wall provided to increase the capacity of a wall to resist latest thrust is known as
(a) wing wall
(b) retaining wall
(c) buttress wall
(d) all the above

37. Vertical faces of walls meant for fixing door, window or ventilator are known as
(a) jambs
(b) sills
(c) corbels
(d) coping

38. Curing is required for
(a) R.C.C. works
(b) lime concrete work
(c) brickwork

(d) all the above

39. Fire resistance is highest in case of

(a) R.C.C. works

(b) stone masonry

(c) brick masonry

(d) timber structure

40. Number of standard bricks required for 1 m^3 of masonry is

(a) 400

(b) 500

(c) 600

(d) 800

41. A groove provided on the underside of coping to keep rainwater clear of wall is known as

(a) cornice

(b) corbel

(c) jamb

(d) throating

42. Steps provided from ground to main entrance in external wall is called

(a) threshold

(b) stairs

(c) pedestal

(d) any of the above

43. To make concrete blocks light

(a) fine aggregate may be avoided

(b) light weight aggregates may be used

(c) sections may be made hollow

(d) any of the above may be used

44. Usual sizes of concrete blocks are

(a) 190 × 90 × 90 mm

(b) 200 × 200 × 100 mm

(c) 400 × 200 × 200 mm

(d) 400 × 200 × 190 mm

45. The minimum strength of concrete blocks should be

(a) 30 N/mm^2

(b) 40 N/mm^2

(c) 50 N/mm^2

(d) 60 N/mm^2

46. Concrete blocks may be given the following finishes:

(a) coarse textured

(b) glazed finish

(c) coloured finish

(d) any of the above

47. Reinforced brick construction is commonly used for

(a) walls

(b) partition walls

(c) compound walls

(d) lintels

48. Brick masonry constructed within a framework of wooden members to act as partition walls is called

(a) lath partition

(b) block partition

(c) brick nogging

(d) trussed partition

49. Glass block partitions are made using blocks of size

(a) 100 × 100 × 200 mm

(b) 120 × 120 × 100 mm

(c) 140 × 140 × 100 mm

(d) 150 × 150 × 100 mm

50. In cavity walls ties are placed to connect two leaves at

	Vertical spacing	*Horizontal spacing*
(a)	600 mm	300 mm
(b)	900 mm	450 mm
(c)	1200 mm	600 mm
(d)	2000 mm	1000 mm

51. In cavity walls the thicknesses of leaves are

(a) equal

(b) inner thinner, outer thicker

(c) inner thicker, outer thinner

(d) any of the above

52. Thumb rule to decide window area for a residential building is there should be 1 m^2 area for every _______ m^3 of internal area

(a) 20 m^3 (b) 30 m^3

(c) 40 m^3 (d) 50 m^3

53. Preferable window area to floor area in a residential building is

(a) 10–15 %

(b) 15–20 %

(c) 20–25 %

(d) 30 %

54. Projection of the frame beyond the opening is known as
   (a) head
   (b) style
   (c) mullian
   (d) horn
55. Which one of the following is not the member of door shutter
   (a) style
   (b) panel
   (c) sash bar
   (d) reveal
56. 1000 × 2000 mm door with double shutter is designated as
   (a) 10 DS 20
   (b) 1000 DS 2000
   (c) 10 DT 20
   (d) 1000 DT 2000
57. Ledge is a
   (a) horizontal member of a shutter
   (b) horizontal member of a door frame
   (c) vertical member of a shutter
   (d) vertical member of door frame
58. The horizontal members of panelled doors are known as
   (a) styles
   (b) rails
   (c) ledges
   (d) bracings
59. Louvered doors are preferred when
   (a) privacy is required
   (b) ventilation is required
   (c) lighting is required
   (d) both privacy and ventilation are required
60. Vertical member employed to subdivide a window opening vertically is called
   (a) mullian
   (b) transome
   (c) louvre (d) style
61. The size of frame of a panel door is
   (a) 80 × 60 mm
   (b) 90 × 60 mm

(c) 100 × 60 mm

(d) 100 × 65 mm

62. Thickness of vertical style, top rail and lock rail of a panelled door should be
(a) 25 mm
(b) 30 mm
(c) 35 mm
(d) 40 mm

63. Thickness of panels in a door should be
(a) 12–15 mm
(b) 15–20 mm
(c) 20–25 mm
(d) 25–30 mm

64. Inclined wooden boards providing additional strength to battens in the battened and ledged door are called
(a) ledges
(b) braces
(c) panels
(d) styles

65. Doors meant to allow fresh air and at the same time prevent entry of insects is known as
(a) lowered door
(b) wire gauzed door
(c) collapsible
(d) rolling shutter

66. 12V6 means a ventilator
(a) 1200 mm wide, 600 mm high
(b) 600 mm wide, 1200 mm high
(c) 120 mm wide, 60 mm high
(d) 60 mm wide, 120 mm high

67. Which one of the following statement is wrong about ventilators?
(a) Opening left may be of brick jali work.
(b) Opening may be with cement mortar jali work.
(c) It is by providing horizontally pivoted shutter.
(d) It is by providing vertically pivoted shutter.

68. The fixture provided on external door for locking is known as
(a) aldrop bolt
(b) flush bolt
(c) barred bolt
(d) tower bolt

69. The end bearing for lintels should be greater than the following
(a) 100 mm

(b) $\frac{1}{12}$th the span

(c) depth of lintel

(d) all the above

70. Arches of centres are built

(a) 1

(b) 3

(c) 5

(d) all of the above

71. The arches made with bricks prepared to the exact shape and size are known as

(a) axed brick arch

(b) gouged brick arch

(c) ashlar brick arches

(d) any of the above

72. The best arrangement for decentring of an arch is

(a) providing wedges between centring and staging

(b) using sand box method

(c) using wood centring

(d) using steel centring

73. The order of placing keystone, voussoirs and skewbacks in which masonry arches are built is

(a) skewback – voussoir – keystone

(b) voussoir – skewback – keystone

(c) voussoir – keystone – skewback

(d) skewback – keystone – voussoir

74. The inclined surface on the abutment which acts as a seat for the arch is known as

(a) springing

(b) haunch

(c) skewback

(d) key

75. Maximum size of coarse aggregate used as base course in ground floor is

(a) 12 mm

(b) 20 mm

(c) 40 mm

(d) 50 mm

76. Materials used for floor finishes are

(a) mud and murram

(b) bricks

(c) marble

(d) all of the above

77. Flooring with marble arrangement in different patterns in lime-surkhi or cement mortar is known as
(a) terrazzo flooring
(b) mosaic flooring
(c) tiled flooring
(d) marble flooring

78. Brick flooring may be made with bricks
(a) laid flat
(b) laid on edges
(c) set at right angle to wall
(d) any of the above

79. Asphalt flooring is
(a) made in different colours
(b) waterproof and jointless
(c) dust and insects free
(d) all the above

80. Linoleum flooring is
(a) durable
(b) cheap
(c) dust free
(d) all the above

81. In jack arch flooring the gap between two adjacent I-sections is covered with
(a) brick arch
(b) concrete arch
(c) timber arch
(d) either brick arch or concrete arch

82. Roof in which slab is directly supported by column is known as
(a) grid floor
(b) flat slab
(c) two-way slab
(d) beam and slab floor

83. In reinforced brick slabs, the brick
(a) resists compression
(b) resists tension
(c) just replaces concrete in tension
(d) resists shear

84. Sides of each unit of precast slab are provided with groove to
(a) insert reinforcements on site
(b) allow drainage of water
(c) interlock with adjacent unit

(d) all the above

85. Roofs are constructed keeping in view

(a) climatic conditions

(b) materials availability

(c) architectural considerations

(d) all the above

86. Which one of the following in not a type of flat roof

(a) Punjab terrace roof

(b) Maharashtra and M.P. terrace roofs

(c) Madras terrace roof

(d) Rajasthan terrace roof

87. In Madras terrace roof, furring pieces are provided

(a) to span between two I-sections

(b) to support brick to be laid

(c) to give required slope to the top surface

(d) to facilitate decentring.

88. Hip is the line formed by the intersection of two sloping roofs, where the exterior angle is

(a) > 180°

(b) < 180°

(c) 90°

(d) < 90°

89. Wooden planks used to fix the ends of common rafters projecting beyond sloping top of a gable wall are known as

(a) eve boards

(b) ridge piece

(c) barge board

(d) battens

90. The limiting span of a couple roof is

(a) 2.5 m

(d) 3.5 m

(c) 4.5 m

(d) 5.5 m

91. The limiting span of a king post truss roof is

(a) 5 m

(b) 6 m

(c) 7 m

(d) 8 m

92. The limiting span of a queen post roof truss is

(a) 6 m

(b) 8 m

(c) 10 m

(d) 12 m

93. Number of vertical posts in a queen post truss is

(a) 1

(b) 2

(c) 4

(d) any number

94. When more lighting is required in a building with fairly large width, the type of truss used is

(a) north-light truss

(b) fan truss

(c) fink truss

(d) pratt truss

95. Steel trusses have almost replaced wooden trusses because

(a) they are light weight

(b) they are fireproof and termite proof

(c) they can be easily built to greater span

(d) all the above

96. Very commonly used covering materials for steel trussed roof is

(a) shingles

(b) tiles

(c) A.C. sheets

(d) G.I. sheets

97. The total length of a stair in a horizontal plane is known as a

(a) run

(b) flight

(c) walk line

(d) flier

98. The type of stairs with curved well formed between the two adjacent flights is known as

(a) open-newel stair

(b) turning stair

(c) dog-logged stair

(d) geometric stair

99. Commonly required width of stair in residential building is

(a) 0.75 m

(b) 0.9 m

(c) 1.2 m

(d) 1.5 m

100. Commonly required width of stair in public building is

(a) 1–1.25 m

(b) 1.5–2.5 m

(c) 2.5–3.5 m
(d) more than 3.5 m

101. The desirable rise of stair in residential and public buildings are respectively.
(a) 150–175 mm and 120–150 mm
(b) 140–150 mm and 100–120 mm
(c) 120–150 mm and 150–175 mm
(d) 100–200 mm and 140–150 mm

102. The goings provided for stairs in residential and public buildings are usually ______ respectively.
(a) 250 mm and 200 mm
(b) 200 mm and 250 mm
(c) 250 and 270 mm
(d) 270 mm and 250 mm

103. If R is rise and G is going of stairs, the empirical formula used to fix rise and going is $2R + G$ and it should be between
(a) 500–600 mm
(b) 550–650 mm
(c) 600–650 mm
(d) 650 to 700 mm

104. Headroom in a staircase should not be less than
(a) 1.8 m
(b) 1.9 m
(c) 2.0 m
(d) 2.1 m

105. The slope of ramp provided to move from one floor to another floor should not be more than
(a) 1 in 15
(b) 1 in 18
(c) 1 in 21
(d) 1 in 24

106. Speed of escalators is usually
(a) 20–25 m/minute
(b) 25–30 m/minute
(c) 30–35 m/minute
(d) 35–40 m/minute

107. The inclination of escalators to horizontal is usually
(a) 20°
(b) 25°
(c) 30°
(d) 35°

108. It is mandatory to provide lifts in a building with more than ______ storeys.

(a) 2
(b) 3
(c) 4
(d) 5

109. The maximum number of steps in a flight should be limited to

(a) 9
(b) 12
(c) 15
(d) 18

110. How many treads should be there in a dog legged stair connecting two floors with a vertical distance of 3.6 m and rise of each step being 150 mm?

(a) 22
(b) 23
(c) 24
(d) 25

111. For designing lifts weight of a person considered is

(a) 62 kg
(b) 65 kg
(c) 68 kg
(d) 72 kg

112. Plastering is done to achieve

(a) decorative effect
(b) to rectify defective workmanship
(c) to protect walls from rodents attack
(d) all the above

113. The thickness of a coat in plaster should not exceed

(a) 8 mm
(b) 10 mm
(c) 12 mm
(d) 15 mm

114. External walls should have a minimum thickness of plaster of

(a) 15 mm
(b) 20 mm
(c) 25 mm
(d) 28 mm

115. In a three-coat plaster, thickness of the finishing coat is

(a) 2–3 mm
(b) 5–6 mm
(c) 8–9 mm

(d) 10–12 mm

116. Swelling in the form of small patches of plastered surface is known as

(a) blistering

(b) efflorescence

(c) cracking

(d) crazing

117. Development of fine hair cracks in plastered surface is known as

(a) cracking

(b) crazing

(c) blistering

(d) flaking

118. Advantage of steel form work is

(a) It can be reused several time.

(b) Erection and removal is easy.

(c) It gives smooth surface finish.

(d) All the above.

119. Formwork for column consists of

(a) wedges

(b) bolts with washers

(c) yokes

(d) all of them

120. Formwork for slab and beam consists of

(a) bearers

(b) ledgers

(c) brackets

(d) all of them

121. The type of formwork preferred for the construction of chimneys is

(a) wooden formwork

(b) steel formwork

(c) slip formwork

(d) any of the above

122. Temporary structure erected to facilitate the construction of walls when the height is more than 1.5 m is known as

(a) scaffolding

(b) formwork

(c) centring

(d) shoring

123. Brick layers scaffolding consists of

(a) only one row of standards

(b) two rows of standards

(c) one or two rows of standards

(d) any number of standards

124. Masons scaffolding consists of
(a) only one row of standards
(b) two rows of standards
(c) one or two rows of standards
(d) any number of rows standards

125. Cantilever scaffolding is used when
(a) the construction is in upper parts of multistorey building
(b) the ground is too weak to receive standards
(c) the space at ground level is required to be free of obstruction
(d) in any of the above situations

126. Scaffolding used for painting is usually
(a) cantilever scaffolding
(b) treste scaffolding
(c) single scaffolding
(d) suspended scaffolding

127. For maintenance works inside the building, the type of scaffolding used is
(a) cantilever scaffolding
(b) trestle scaffolding
(c) single scaffolding
(d) suspended scaffolding

128. Which one of the following is not a type of shoring
(a) raking shore
(b) flying shore
(c) dead shore
(d) running shore

129. Flying shores are used to strengthen
(a) single wall
(b) two adjacent walls
(c) tall walls
(d) any of the above

130. In flying shores struts are provided
(a) in horizontal direction
(b) at 30° to horizontal
(c) at 45° to horizontal
(d) any of the above

131. The flying shores should be provided at a spacing of
(a) 1–1.5 m
(b) 1.5–2.0 m

(c) 2–3 m

(d) 3–4.5 m

132. When large openings are to be made in existing wall, the type of temporary work used is
(a) raking shore
(b) flying shore
(c) dead shore
(d) underpinning

133. Sanitary fittings means various fittings used for
(a) water supply
(b) to drain kitchen and bathroom water
(c) to carry toilet water
(d) all the above

134. Water requirement in a residential building per person per day is about
(a) 45 litres
(b) 135 litres
(c) 270 litres
(d) 340 litres

135. Water requirement per day per bed in a hospital is
(a) 45 litres
(b) 135 litres
(c) 270 litres
(d) 340 litres

136. Water requirement per day per child in a school is
(a) 45 litres
(b) 135 litres
(c) 270 litres
(d) 340 litres

137. All joints in a plumbing should be tested for water pressure of
(a) 30 m head
(b) 45 m head
(c) 60 m head
(d) 75 m head

138. PVC pipes loosely fixed to walls
(a) since tight fitting may damage them
(b) to allow lateral expansion
(c) to allow longitudinal expansion
(d) all the above

139. A water meter measures quantity of water
(a) by measuring velocity and time
(b) by counting filling and emptying of a chamber of known quantity

(c) by measuring weight of water passing per second

(d) any of the above

140. In plumbing for water supply, valves are provided to

(a) avoid wastage of water due to leakage of taps

(b) to avoid wastage due to failures of floats of water tank

(c) to facilitate repairs to plumbing works

(d) all the above

141. Which one of the following is not a type of trap used in plumbing

(a) P-type

(b) Q-type

(c) S-type

(d) Z-type

142. Which one of the following is not a type of trap used in plumbing

(a) floor trap

(b) gully trap

(c) street trap

(d) intercepting trap

143. Which one of the following is not a type of water closet?

(a) Indian type

(b) American type

(c) European type

(d) Anglo-Indian type

144. If sheets or mastic asphalt are used for damp proofing, the lap should not be less than

(a) 100 mm

(b) 125 mm

(c) 150 mm

(d) 200 mm

145. Methods of waterproofing basements is

(a) providing foundation draining and DPC

(b) providing R.C.C. raft and wall slab

(c) asphalt tanking

(d) any of the above

146. Ventilation inside a building is necessary to

(a) remove body odour

(b) remove dust and bacteria-carrying particles

(c) prevent condensation or deposition of moisture in the building

(d) all the above

147. In case of factories, assembly halls and auditoriums, space to be provided for every person for good ventilation is

(a) 8–10 m^3

(b) 10–12 m^3

(c) 12–14 m^3

(d) 14–16 m^3

148. For thermal comfort desirable wind speed

(a) increases with temperature and relative humidity

(b) increases with temperature but reduces with humidity

(c) decreases with both temperature and humidity

(d) decreases with temperature but increases with humidity

149. Natural ventilation is achieved by proper location and size of

(a) doors and windows

(b) ventilations

(c) skylights

(d) all the above

150. Maximum indoor velocity to outdoor velocity that can be achieved by adjusting openings in a building is

(a) 0.25

(b) 0.40

(c) 0.60

(d) 0.75

151. In plenum system, mechanical ventilation is achieved by providing

(a) ordinary fans

(b) exhaust fans

(c) air conditioners

(d) any one of the above

152. Air conditioning system is to

(a) control temperature

(b) control humidity

(c) distribute treated air

(d) all the above

153. In air conditioning comfortable air velocity to be achieved is

(a) 6–9 m/sec

(b) 9–12 m/sec

(c) 12–15 m/sec

(d) 15–18 m/sec

154. The system in which filtration and humidity control are exercised at a central point but heating and cooling systems are installed separately for different rooms is known as

(a) central system

(b) self-contained system

(c) semi-conditioned system

(d) combined system

155. In air conditioners, filter system may be a

(a) viscous filter

(b) dry filter

(c) electrical precipitator

(d) any of the above

156. Humidification system in an air conditioner may be

(a) allowing air to pass on pans of water

(b) allowing air to pass on wet cloth strips

(c) using spray humidifier

(d) any one of the above

157. Dehumidification system in air conditioning system may be

(a) condensation

(b) desiccation using absorbers

(c) desiccation using adsorbents

(d) any of the above

158. Thermal insulation is

(a) conservation of constant heat inside a building

(b) heating a room

(c) cooling a room

(d) all the above

159. Heat transmittance through doors and windows may be reduced by

(a) providing sunshades

(b) using louvered shutters

(c) using double glass with air space between them

(d) using any of them

160. One hertz (Hz) frequency is

(a) 1 cycle/minute

(b) 1 m/minute

(c) 1 cycle/second

(d) 1 m/second

161. Noise level in a building is expressed in terms of

(a) hertz

(b) watts/cm^2

(c) decibels

(d) any of the above

162. The sensation of second persists on ears for a period

(a) $\frac{1}{100}$th of a second

(b) $\frac{1}{30}$th of a second

(c) $\frac{1}{10}$th of a second

(d) $\frac{1}{5}$th of a second

163. To hear an eco the reflecting surface of sound should be at a minimum distance of

(a) 12.15 m
(b) 17.15 m
(c) 27.15 m
(d) 52.15 m

164. Best acoustics is when reverberation time is

(a) 0.5–1.5 seconds
(b) 2–3 seconds
(c) 3–5 seconds
(d) more than 5 seconds

165. Which one of the following has the highest coefficient of absorption?

(a) Brick wall
(b) Marble
(c) Wood veneer
(d) Audience

166. Sound waves are absorbed by

(a) converting into heat energy
(b) damping
(c) resonance of air in containers with small opening
(d) all the above

167. In an auditorium width of a chair should be

(a) 300–350 mm
(b) 350–400 mm
(c) 400–450 mm
(d) more than 450 mm

168. In an auditorium back-to-back distance between the rows of seats should be at least

(a) 400 mm
(b) 450 mm
(c) 500 mm
(d) more than 500 mm

169. In an auditorium ceiling should be at a height that the difference between direct sound path and reflected sound path is less than

(a) 8 m
(b) 12 m
(c) 16 m
(d) 20 m

170. On the basis of fire resistance, National Building Code of India, a building with fire resistance

more than 4 hours is classified as

(a) Type 1
(b) Type 2
(c) Type 3
(d) Type 4

171. Bureau of Indian Standard has divided India into ______ number of earthquake zones

(a) 4
(b) 5
(c) 6
(d) 7

172. From the consideration of earthquake resistance the plan of a building preferred is

(a) square
(b) rectangular
(c) T-shaped
(d) L-shaped

173. From the consideration of earthquake resistance the width of openings in a wall should not exceed ______ of length of wall

(a) $\frac{1}{5}$ th
(b) $\frac{1}{4}$ th
(c) $\frac{1}{3}$ rd
(d) half time

174. To improve earthquake resistance of a building provide

(a) plinth band
(b) lintel band
(c) roof band
(d) all the three

175. Minimum area specified for mass housing is

(a) 15 m^2
(b) 20 m^2
(c) 25 m^2
(d) 30 m^2

176. According to the International Energy Agency, buildings account for ______ per cent of the worlds total primary energy consumption

(a) 24
(b) 30
(c) 40
(d) 50

177. A green building is the

(a) one with green colour

(b) building surrounded with garden

(c) structure that aims to reduce negative environmental effects

(d) all the above

178. The LEED system rates buildings platinum on the basis of

(a) 26–32 points

(b) 33–33 points

(c) 39–51 points

(d) 52 or more

179. Which one of the following is wrong about the bar chart?

(a) It exhibits only major activities.

(b) The effect of delay of an activity on other activities cannot be seen easily.

(c) If does not indicate which activity is critical.

(d) It cannot be understood by all easily.

180. Choose the correct statement about CPM.

(a) A number of small jobs that are to be performed in a sequence to complete the project are known as events.

(b) The tail of an arrow represents the start of an event.

(c) Head of an arrow represents end of the an event.

(d) Dummy activity neither requires any time nor any resource.

II. *Match List - I with List - II by selecting answer Code given below the item*

181.

	List 1		List 2
A.	Combined footing	1.	A row of columns is too close to each other
B.	Cantilever footing	2.	To connect a set of columns of the building
C.	Continuous footing	3.	A column is very close to the boundary and the interior column is nearby
D.	Mat footing	4.	A column is very close to the boundary and interior column is far away

Codes:

(a)	A – 4	B – 3	C – 1	D – 2
(b)	A – 4	B – 3	C – 2	D – 1
(c)	A – 3	B – 4	C – 1	D – 2
(d)	A – 3	B – 4	C – 2	D – 1

182.

	List I		List II
A.	Queen closer	1.	Obtained by cutting triangular portion of half the width but of full length

B.	King closer	2.	Corner splayed at angle 40°–60°
C.	Bevelled closer	3.	Corner is cut to get half header and half stretcher on adjacent faces
D.	Mitred closer	4.	Width is half the original brick

Codes:

(a)	A – 3	B – 4	C – 2	D – 1
(b)	A – 4	B – 3	C – 1	D – 2
(c)	A – 2	B – 3	C – 4	D – 1
(d)	A – 4	B – 1	C – 2	D – 3

183.

	List I		**List II**
	Construction tool		**Used for**
A.	Trowel	1.	To check right angles
B.	Bolster	2.	To maintain the alignment of courses
C.	Masons square	3.	To cut the bricks
D.	Line and pins	4.	To spread the mortar

Codes:

(a)	A – 4	B – 3	C – 2	D – 1
(b)	A – 3	B – 4	C – 2	D – 1
(c)	A – 3	B – 4	C – 1	D – 2
(d)	A – 4	B – 3	C – 1	D – 2

184.

	List I		**List II**
A	Base for placing windows	1	Corbels
B	Face of the wall to fix window frames	2	Copings
C	Bearings for beams	3	Sills
D	Protection to parapet walls	4	Jamb

Codes:

(a)	A – 4	B – 3	C – 2	D – 1
(b)	A – 3	B – 4	C – 1	D – 2
(c)	A – 4	B – 3	C – 1	D – 2
(d)	A – 3	B – 4	C – 2	D – 1

185.

	List 1		List 2
A.	Bay window	1.	Provided on a sloping roof
B.	Clear storey window	2.	Vertical windows on sloping roof
C.	Skylight window	3.	Provided on projected portion of walls
D.	Dormer window	4.	Provided in the wall between the lower and higher level room

Codes:

(a)	A – 3	B – 4	C – 1	D – 2
(b)	A – 3	B – 4	C – 2	D – 1
(c)	A – 4	B – 3	C – 2	D – 1
(d)	A – 4	B – 3	C – 1	D – 2

186.

	List I Type of arch		List II Character of order
A.	Venetian arch	1.	It is built below ground level
B.	Florentine arch	2.	It has 4 centres
C.	Relieving arch	3.	It has 3 centres
D.	Inverted arch	4.	It is built over flat arch

Codes:

(a)	A – 2	B – 3	C – 1	D – 4
(b)	A – 3	B – 2	C – 1	D – 4
(c)	A – 2	B – 3	C – 4	D – 1
(d)	A – 3	B – 2	C – 1	D – 4

187.

	List I Floor finishing		List II Important property to be considered
A.	Railway platform	1.	Resistance to slipperiness
B.	Bathrooms	2.	Resistance to dampness
C.	Ground floor	3.	Resistance to abrasion
D.	Upper floors	4.	Sound insulation

Codes:

(a)	A – 1	B – 3	C – 4	D – 2
(b)	A – 3	B – 1	C – 2	D – 4
(c)	A – 2	B – 3	C – 4	D – 1
(d)	A – 1	B – 2	C – 4	D – 3

188.

	List I		List II
A.	Batten	1.	Run from ridge to eve
B.	Common rafter	2.	Run from ridge to the corners of wall diagonally
C.	Hipped rafter	3.	Run from hip or valley to eve
D.	Jack rafter	4.	Support tiles directly

Codes:

(a)	A – 4	B – 1	C – 2	D – 3
(b)	A – 1	B – 3	C – 4	D – 2
(c)	A – 2	B – 3	C – 4	D – 1
(d)	A – 4	B – 1	C – 3	D – 2

189.

	List I		List II
A.	Wall plate	1.	Horizontally placed members on principal rafters
B.	Cleats	2.	Wooden members provided on wall to the common rafters
C.	Template	3.	Blocks of wood fixed on trusses to prevent sliding of purlins
D.	Purlins	4.	Block of stone or concrete under a beam or truss to spread the load

Codes:

(a)	A – 3	B – 4	C – 2	D – 1
(b)	A – 2	B – 3	C – 1	D – 4
(c)	A – 2	B – 3	C – 4	D – 1
(d)	A – 3	B – 2	C – 4	D – 1

190.

	List I		List II
A.	Lean to roof	1.	Common rafters are connected by a tie beam at their feet
B.	Couple roof	2.	Common rafters are supported on a raised wall at one end and on a post plate at lower level
C.	Couple close roof	3.	Common rafters are connected by a tie beam of higher level
D.	Collar beam roof	4.	A pair of common rafters slope upward from opposite walls and meet on the ridge piece

Codes:

(a)	A – 2	B – 4	C – 3	D – 1
(b)	A – 2	B – 4	C – 1	D – 3
(c)	A – 2	B – 3	C – 4	D – 1
(d)	A – 3	B – 4	C – 1	D – 2

191.

List 1		List 2
A. Step	1.	It is the vertical distance covered in a step
B. Tread	2.	It is horizontal distance between two successive riser faces
C. Going	3.	It is flat-topped unit used for moving from due level to other
D. Rise	4.	It is the upper horizontal portion on which foot is placed while ascending or descending

Codes:

(a)	A – 4	B – 3	C – 1	D – 2
(b)	A – 4	B – 3	C – 2	D – 1
(c)	A – 3	B – 4	C – 1	D – 2
(d)	A – 3	B – 4	C – 2	D – 1

192.

List I		List II
A. Winder	1.	Vertical member supporting handrail
B. Stringer	2.	Ordinary step of rectangular shape in plan
C. Flier	3.	Tapering step used for changing the direction of a stair
D. Baluster	4.	Sloping member supporting steps

Codes:

(a)	A – 4	B – 3	C – 1	D – 2
(b)	A – 4	B – 3	C – 1	D – 2
(c)	A – 3	B – 4	C – 2	D – 1
(d)	A – 3	B – 4	C – 1	D – 2

193.

List I		List II
A. Baluster	1.	This is an additional moulding provided to the nosing
B. Newel post	2.	Vertical member supporting handrail
C. Scotia	3.	The under surface of the stair

D. Soffit 4. Vertical post placed at the end

Codes:

(a)	A – 1	B – 2	C – 4	D – 3
(b)	A – 3	B – 2	C – 4	D – 1
(c)	A – 4	B – 2	C – 3	D – 1
(d)	A – 2	B – 4	C – 1	D – 3

194.

List I	List II
	Defects in plastering
A. Blistering	1. Failure of bond between the coats
B. Crazing	2. Formation of conical holes due to presence of some materials that expand on setting
C. Popping	3. Development of fine hair cracks
D. Flaking	4. Swelling in the form of small patches

Codes:

(a)	A – 2	B – 3	C – 1	D – 4
(b)	A – 4	B – 3	C – 2	D – 1
(c)	A – 4	B – 2	C – 1	D – 3
(d)	A – 3	B – 2	C – 4	D – 1

195.

List I	List II
Temporary works	**Used for**
A. Formwork	1. For arches
B. Centring	2. To prop up for repair works
C. Scaffolding	3. For moulding concrete elements
D. Shoring	4. Platform required for masons and materials

Codes:

(a)	A – 1	B – 2	C – 4	D – 3
(b)	A – 4	B – 2	C – 3	D – 1
(c)	A – 3	B – 4	C – 2	D – 1
(d)	A – 3	B – 1	C – 4	D – 2

196.

List I **List II**

Parts of scaffolding

A	Standards	1	There are horizontal members parallel to well
B	Ledgers	2	These are diagonal members
C	Put logs	3	These are vertical members
D	Braces	4	These are horizontal members normal to the wall

Codes:

(a)	A – 2	B – 1	C – 3	D – 4
(b)	A – 3	B – 1	C – 4	D – 2
(c)	A – 3	B – 4	C – 1	D – 2
(d)	A – 2	B – 3	C – 4	D – 1

197.

List I		List II	
Types of pipes in drainage system		**Purpose**	
A.	Waste pipe	1.	To connect traps and vent pipes
B.	Soil pipe	2.	To carry waste water from sinks and wash basin
C.	Vent pipe	3.	To carry excreta
D.	Anti-syphonage pipe	4.	For escape of foul air

Codes:

(a)	A – 2	B – 3	C – 4	D – 1
(b)	A – 3	B – 2	C – 1	D – 4
(c)	A – 3	B – 1	C – 2	D – 4
(d)	A – 1	B – 2	C – 3	D – 4

198.

List I		List II	
Space to be ventilated		**Air change per hour**	
A.	Living rooms	1.	6–9
B.	Bath rooms	2.	3–6
C.	Kitchen	3.	6–12
D.	Restaurants	4.	12–15

Codes:

(a)	A – 2	B – 3	C – 1	D – 4

(b)	A – 1	B – 2	C – 4	D – 3
(c)	A – 2	B – 1	C – 3	D – 4
(d)	A – 3	B – 2	C – 4	D – 1

199.

	List I		**List II**
	Media		**Velocity of sound**
A.	Air	1.	4900 m/sec
B.	Brick	2.	3600 m/sec
C.	Steel	3.	340 m/sec
D.	Vacuum	4.	Zero

Codes:

(a)	A – 3	B – 4	C – 2	D – 1
(b)	A – 4	B – 3	C – 2	D – 1
(c)	A – 3	B – 2	C – 1	D – 4
(d)	A – 4	B – 2	C – 1	D – 3

200.

	List I		**List II**
	About sound		**Units used**
A.	Velocity of sound	1.	Hz
B.	Frequency of sound	2.	bel
C.	Intensity of sound	3.	Watts/cm^2
D.	Loudness of sound	4.	m/sec

Codes:

(a)	A – 4	B – 3	C – 2	D – 1
(b)	A – 4	B – 2	C – 3	D – 1
(c)	A – 3	B – 2	C – 1	D – 4
(d)	A – 4	B – 1	C – 3	D – 2

201.

	List I		**List II**
	Building		**Acceptable noise level**
A.	Auditoriums	1.	45–50

B.	Music rooms	2.	25–30
C.	Hospital	3.	35–40
D.	Public offices	4.	20–25

Codes:

(a)	A – 4	B – 2	C – 3	D – 1
(b)	A – 3	B – 4	C – 1	D – 2
(c)	A – 3	B – 4	C – 2	D – 1
(d)	A – 4	B – 3	C – 2	D – 1

202.

	List I		**List II**
	Acoustical defect		**Cause**
A.	Excessive reverberation	1.	Concave interior surface
B.	Sound foci	2.	Irregular distribution
C.	Dead spots	3.	Insufficient absorption
D.	Insufficient volume of sound	4.	Excessive absorption

Codes:

(a)	A – 3	B – 1	C – 2	D – 4
(b)	A – 2	B – 3	C – 4	D – 1
(c)	A – 3	B – 2	C – 3	D – 1
(d)	A – 4	B – 2	C – 1	D – 3

203.

	List 1		**List 2**
	Work		**Percentage of total cost**
A.	Foundation	1.	10–15
B.	Walls stairs and roofs	2.	10–20
C.	Doors and windows	3.	30–40
D.	Flooring	4.	12–18

Codes:

(a)	A – 2	B – 1	C – 3	D – 4
(b)	A – 1	B – 3	C – 4	D – 2
(c)	A – 4	B – 2	C – 3	D – 1

(d)	A – 1	B – 1	C – 4	D – 3

III. *For item Numbers 181 to 213 select your answer according to the coding system given for the Assertion A and Reason R*

Coding system

(a) Both A and R are true and R is the correct explanation of A
(b) Both A and R are true but R is not the correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

204. A: Steel columns need grillage foundations.
R: Steel column carry heavy loads per unit area.

205. A: Steel piles are used for pile driving near existing buildings.
R: Strength of steel per unit area is high.

206. A: In case of composite timber and concrete piles, timber piles are provided below the water table.
R: Timber under water do not decay.

207. A: Special techniques are required in laying foundation on black cotton soil.
R: Black cotton soil cracks in summer and swells in rainy season.

208. A: In stone masonry works stones should be properly immersed in water before they are laid.
R: It is to avoid sucking water from mortar.

209. A: Toothing is a method of terminating a wall with alternate courses projecting.
R: Toothing is given so as to ensure proper bond, if the wall is extended at a latter age.

210. A: At the top and bottom of cavity walls terracotta or cast iron bricks are provided.
R: These special bricks provide ventilation to the cavity.

211. A: Ventilators are provided on the underside of top floors.
R: Air exhaled by people in a room is warmer and moves upward.

212. A: It is desirable to provide glass panels in swing doors.
R: Swing doors open on both sides.

213. A: Two days before decentring, the centring of a masonry arch is eased.
R: It is to check whether arch is safely built or not.

214. A: Terrazzo, tiles, marbles and granites are generally preferred for flooring.
R: They give attractive appearance.

215. A: Cork and rubber finishes for floors is desirable in libraries and hospitals.
R: Their thermal resistance is good.

216. A: Lot of care should be taken in providing formworks.
R: Ninety per cent of the failures of structures during construction are due to the failure of formworks.

217. A: It should be easy to remove formwork.
R: Vibrations during stripping should be avoided.

218. A: Instead of seasoned wood, use of plywood is becoming popular.
R: Plywood gives smooth surface finish.

219. A: Sanitary pipes should be laid out straight as for as possible.
R: Straight piping reduces plumbing cost.

220. A: G.I. pipes should not be buried in the ground.
R: It is to avoid corrosion problem.

221. A: In a drainage system in a hause trap should be provided.
R: It is to avoid rodents and foul smell entering hauses.

222. A: A drain of 200–300 mm is constructed parallel to the wall just at top of foundation.
R: It is to make foundation damp proof.

223. A: On sloping R.C.C, if tiles are to be provided mortar bands used as reapers should not be continuous.
R: It is to achieve economy.

224. A: Aldrin and DDT should not be used to prevent growth of termites.
R: These chemicals are not effective to prevent termite for a long time.

225. A: Concentration of carbon dioxide does not form the basis for fixing the rate of ventilation in a residential building.
R: Enough air normally enters the building through crevices and other openings.

226. A: In rooms occupied by few persons ventilation is not a problem.
R: Required air change is automatically attained due to leakage around windows in winter and by keeping windows open during summer.

227. A: There should be a lobby before entering air conditioned rooms.
R: User should not experience a sudden change of temperature.

228. A: Airtight false ceiling are usually provided in air conditioned rooms.
R: By doing so the requirement of conditioned air is reduced.

229. A: External walls should be thicker.
R: Thicker walls give better thermal insulation.

230. A: Ceiling need not be at a height more than 1–1.3 m above the height of occupant.
R: Decrease in radiation emitted by the ceiling behind that distance is negligible.

231. A: Thunder is heard as a continuous rumbling sound.
R: It is due to the successive reflections from cloud, maintains and various strata of air.

232. A: If steel columns are used, they should be encased in brickwork.
R: Brickwork makes the steel corrosion resistant.

233. A: The footings of multistoreyed buildings are rested on flexible pads.
R: It reduces effect of ground shaking on the building.

234. A: PERT is ideally suited for the projects with repetitive nature.
R: In building construction, determining the time for various activities is not a problem.

Answers to Multiple-Choice Questions

I.

1. (b)	2. (a)	3. (a)	4. (b)	5. (d)
6. (d)	7. (a)	8. (b)	9. (a)	10. (a)
11. (d)	12. (c)	13. (c)	14. (b)	15. (d)
16. (d)	17. (c)	18. (c)	19. (d)	20. (a)
21. (c)	22. (d)	23. (d)	24. (d)	25. (b)
26. (a)	27. (b)	28. (c)	29. (d)	30. (b)
31. (b)	32. (c)	33. (d)	34. (d)	35. (d)
36. (c)	37. (a)	38. (d)	39. (c)	40. (b)
41. (d)	42. (a)	43. (d)	44. (d)	45. (b)
46. (d)	47. (d)	48. (c)	49. (c)	50. (b)
51. (c)	52. (b)	53. (b)	54. (d)	55. (d)
56. (c)	57. (a)	58. (b)	59. (d)	60. (a)
61. (d)	62. (d)	63. (a)	64. (b)	65. (b)
66. (a)	67. (d)	68. (a)	69. (d)	70. (d)
71. (b)	72. (b)	73. (a)	74. (c)	75. (c)
76. (d)	77. (b)	78. (d)	79. (d)	80. (d)
81. (d)	82. (b)	83. (c)	84. (c)	85. (d)
86. (d)	87. (c)	88. (a)	89. (c)	90. (b)
91. (d)	92. (c)	93. (b)	94. (a)	95. (d)
96. (c)	97. (a)	98. (d)	99. (b)	100. (b)
101. (a)	102. (c)	103. (b)	104. (d)	105. (a)
106. (b)	107. (c)	108. (c)	109. (b)	110. (a)
111. (c)	112. (d)	113. (c)	114. (b)	115. (a)
116. (a)	117. (b)	118. (d)	119. (d)	120. (d)
121. (c)	122. (a)	123. (a)	124. (b)	125. (d)
126. (d)	127. (b)	128. (d)	129. (b)	130. (c)
131. (d)	132. (c)	133. (d)	134. (b)	135. (d)
136. (a)	137. (c)	138. (c)	139. (b)	140. (d)
141. (d)	142. (c)	143. (b)	144. (a)	145. (d)
146. (d)	147. (d)	148. (a)	149. (d)	150. (b)
151. (a)	152. (d)	153. (a)	154. (c)	155. (d)
156. (d)	157. (d)	158. (a)	159. (d)	160. (c)
161. (c)	162. (c)	163. (b)	164. (a)	165. (d)
166. (d)	167. (d)	168. (b)	169. (a)	170. (a)

171. (b)	172. (a)	173. (c)	174. (d)	175. (b)
176. (b)	177. (c)	178. (d)	179. (d)	180. (d)

II.

181. (c)	182. (b)	183. (d)	184. (b)	185. (a)
186. (c)	187. (b)	188. (a)	189. (c)	190. (b)
191. (d)	192. (c)	193. (d)	194. (b)	195. (d)
196. (b)	197. (a)	198. (a)	199. (c)	200. (d)
201. (a)	202. (a)	203. (b)		

III.

204. (a)	205. (b)	206. (a)	207. (a)	208. (a)
209. (a)	210. (a)	211. (a)	212. (a)	213. (b)
214. (a)	215. (b)	216. (a)	217. (a)	218. (a)
219. (b)	220. (a)	221. (a)	222. (a)	223. (b)
224. (b)	225. (a)	226. (a)	227. (a)	228. (a)
229. (a)	230. (a)	231. (a)	232. (b)	233. (a)
234. (d)				

3

Surveying

3.1 SURVEYING

* Surveying is the art of making measurement of objects on, above or beneath the ground to show their relative positions on paper.
* The earth is an oblate spheroid, the length of equatorial axis being 12,756.75 km and polar axis 12,713.80 km.
* The gravitational force is always directed towards the centre of the earth and the plumb line is known as vertical line. The line perpendicular to vertical is the horizontal line.
* All lines lying on the earth's surface are curved lines and all triangles are spherical triangles. However, the length of an arc of 1.2 km on earth's mean surface is only 1 mm more than the straight line connecting those two points.
* If the area to be surveyed is small, the curvature of earth may be neglected and all plumb lines treated as the parallel to each other. All triangles in survey are treated as plane triangles.
* The survey in which earth's curvature is considered is called *Geodetic Surveying* and the survey in which earth's curvature is neglected is called *Plane Surveying*.

Classification

1. On the basis of nature of the field

(a) Land survey:

(i) Topographic survey

(ii) Cadastral survey

(iii) City survey

(b) Marine or hydrographic survey

(c) Astronomical survey

2. On the basis of object of survey

(a) Engineering survey:

(i) Reconnaissance survey

(ii) Preliminary survey

(iii) Location survey

(b) Military survey

(c) Mine survey

(d) Geological survey

(e) Archaeological survey

3. On the basis of instruments used

(a) Chain survey

(b) Compass survey

(c) Plane table survey

(d) Theodolite survey

(e) Tacheometric survey

(f) Modern surveying

(g) Photographic and aerial surveying

4. Classification on the basis of methods employed

(a) Triangulation

(b) Traversing

Scales

* If 1 mm on the paper represents 1 m on the ground, then the scale is

1 mm = 1 m

or 1 : 1000

or representative factor (RF) = $\frac{1}{1000}$.

* The scale of a map is considered

(i) Large, if it is greater than 1 mm = 1 m. (i.e., RF > 1/1000)

(ii) Intermediate if RF = $\frac{1}{1000}$ to $\frac{1}{10,000}$

(iii) Small if RF = $\frac{1}{10000}$ or less

* Scales recommended for some of the works are

(i) Building sites: RF = $\frac{1}{1000}$ or less

(ii) Town planning schemes: RF = $\frac{1}{5000}$ to $\frac{1}{10000}$

(iii) Cadastral maps: RF = $\frac{1}{500}$ to $\frac{1}{50000}$

(iv) Route surveys: RF = $\frac{1}{10000}$.

* Types of graphical scales:

1. Plain scale 2. Diagonal scale.

In plain scale only units and tenths can be shown whereas in diagonal scales, it is possible to show units, tenths and hundredths.

* Vernier is a device to measure the fractional part of smallest division on main scale. Types of vernier scales are

(i) Direct (ii) Retrograde

In both cases least count = $\frac{d}{3}$

where d = value of smallest division on the main scale

and n = number of divisions on the vernier.

* There are special forms of verniers also

(i) Double vernier

(ii) Double folded vernier

(iii) Extended verniers

* In any map graphical scale as well as RF should be shown, since paper may shrink and actual length may be more than what it shows. In such case

$$\text{Shrinkage factor} = \frac{\text{Calculated length}}{\text{Measured length on the field}}$$

* Methods of locating a point in plain survey.

(i) By linear measurements

(ii) By linear and angular measurements

(iii) By angular measurements only

* Principles of surveying:

(i) Work from whole to part

(ii) Take extra care in fixing positions of new control points, i.e., have check lines and tie lines.

* The Survey of India is the oldest department of Government of India. It was established in 1767 by East India Company. Its headquarters is in Dehradun and has got 18 Directorates. They have prepared topographic map of the whole country and have established GTS (Great Topographic Survey) bench marks at several places all over the country. The entire area covered by India is divided into 4° × 4° longitude and latitude and each grid is numbered. Each grid is further divided into 1° × 1° longitude and they are numbered. The scale used for 4° × 4° grid map is 1 : 25000 and the scale for 1° × 1° grids is 1 : 50,000. The 1° × 1° grid is further divided in 15¢ × 15¢ grids and the scale used are 1 : 50,000 to 1 : 25,000.

3.2 ERRORS IN SURVEYING

* Accuracy is defined as correctness/degree of perfection in reaching an intended target.
* Precision is the degree of perfection used in instruments and the method of observations and calculations.
* Types of errors creeping in surveying are:

1. Mistakes
2. Systematic/cumulative errors
3. Accidental/compensating errors

* The sources of errors are:

1. Instrumental 2. Natural

3. Human limitations 4. Carelessness

* Though accidental errors are unpredictable, the following features are found:

1. Positive and negative errors will occur with equal frequency
2. Small errors occur more frequently
3. Very large errors do not occur

* Principles of least square is applicable to normal distribution.

1. Standard deviation $s = \pm\sqrt{\frac{\Sigma v^2}{n-1}}$

2. Probable error of single observation

$= \pm\, 0.6745\sqrt{\frac{\Sigma v^2}{n-1}}$

3. Most probable error of mean

$= \pm\, 0.6745\,\frac{\sigma}{\sqrt{n}}$

4. Maximum error $= \pm\, 3.29\, s$

where n = the number of observations

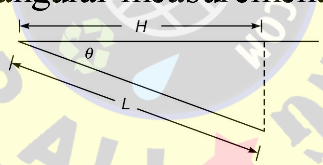
v = difference between any single observation and the mean

* If the relationship between computed and measured quantity is known, error propagation can be calculated. If y is computed quantity, x is measured quantity and $y = f(x)$,

$$dy = \frac{\partial f}{\partial x_1}\delta x_1 + \frac{\partial f}{\partial x_2}\delta x_2 + \frac{\partial f}{\partial x_3}\delta x_3$$

* The permissible errors are:
 1. Measurements with chain on rough ground : 1 in 250
 2. Measurements with chain on average condition: 1 in 500
 3. Measurements with steel tape : 1 in 1000
 4. Base line measurement : 1 in 10,000

* Relative accuracy between linear and angular measurements



$$H = L \cos q$$

$$dH = -L \sin q\, dq$$

$$\frac{\delta H}{H} = \frac{L\sin\theta}{L\cos\theta}\, dq = \tan q\, dq, \text{ if sign is ignored}$$

$$\backslash\ dq = \frac{\delta H}{H}\times\frac{1}{\tan\theta}\text{ radians}$$

$$= \frac{\delta H}{H}\times\frac{1}{\tan\theta}\times\frac{180}{\pi}\times 60\times 60\text{ seconds}$$

Measurements of Horizontal Distance with Chain and Tape

* Methods of measurements:

1. Approximate – pacing
 – with passometer
 – with pedometer
 – with odometer
 – with speedometer

2. Chain and tape – Gunter’s or surveyor’s chain

– Revenue chains

– Engineer’s chains

– Metric chain

– Steel bond

– Cloth or linen tape

– Metallic tape

– Steel tape

– Invar tape

* Accessories required are: arrows, pegs, ranging rods, ranging poles, offset rods, laths, whites, plumb hob and line ranger.
* For ranging a survey line direct method is used. If the two stations are not mutually visible go for reciprocal ranging.
* In surveying all distances measured should be horizontal. If ground is sloping method of stepping or any indirect method may be employed. For base line measurement a wire with spring balance, intermittent stakes and straining poles are used.
* Corrections for absolute length, slope, temperature, pull and sag are made for accurate measurements.
* If A is the measured area with incorrect tape, the corrected area $A¢$ is given by

$$A¢ = \left(\frac{L'}{l}\right)^2 A = \left(1+\frac{c}{l}\right)^2 A \approx (1+2c)\,A \text{ if } c \text{ is small}$$

where $L¢$ is corrected length

and l is designated length

c is correction per chain length

* Correction for slope

$C_{sl} = L\,(1 - \cos q)$

* Correction for temperature

$C_t = L\,\mu\,(T_m - T_o)$

* Correction for pull

$C_p = \frac{(P - P_o)L}{AE}$

* Correction for sag

$C_s = \frac{1}{24}\left(\frac{W}{P}\right)^2 L$

where W = weight of tape per span length

P = pull applied

L = measured length

Chain Surveying

* As far as possible the triangles should have angles close to 60°, in no case less than 30°.
* Offsets taken may be perpendicular or oblique.
* Perpendicular offsets may be set by swinging, using cross staffs, optical square or prism square.
* Fieldwork consists of:
    1. Reconnaissance survey to select stations and prepare typical key plan.
    2. Drawing reference sketches
    3. Line by line surveying
* Office work consists in plotting
* Obstacles to chaining may be grouped as
    1. Obstacles to ranging
    2. Obstacles to chaining
    3. Obstacles to both chaining and ranging

By making suitable alternate measurements, the obstructed length may be calculated.

Angle and Direction Measurements

The direction of a survey line may be defined as the horizontal angle between the line and a reference line. The reference line is known as meridian and the angle as bearing.

* A compass measures bearing of a line w.r.t. magnetic north-south direction whereas it is possible to measure an angle between any two lines using theodolite and sextent.
* In prismatic compass the graduations are shifted by 180° and are written inverted since the angles are read at rear end of line of sight through prism. The markings are from zero to 360°. In surveyor's compass there is no need for writing inverted letters since the reading is not through prism. In this graduation disc is fixed to the box and magnetic needle is free to rotate. The angles are marked from zero to 90° on either side of north and south and noted as

$$N q°E, N q°W, S q°E, S q°W, \text{etc.}$$

* To take magnetic bearing of any line the temporary adjustments required are centring, levelling and focussing.
* The direction shown by a compass in an area affected from local attraction is with respect to magnetic bearing. But at any point the line passing through the point and North-South pole of earth, known as true meridian, may not coincide with the magnetic meridian. The horizontal angle between the magnetic meridian and the true meridian is known as magnetic declination. It is observed that these are small variations in declination which may be classified as secular variation, annual variation, daily variation and irregular variation.
* The vertical angle between the horizontal and the direction shown by a perfectly balanced magnet is known as the dip. It is 0° at the equator while 90° at the magnetic poles.
* For line *AB*, the bearing taken from *A* to *B* is called forebearing while taken from *B* to *A* is called back bearing. In whole circle bearing.

$BB = FB \pm 180°$, plus if FB is less than 180° and minus if FB is more than 180°.

In case of quadrantal bearing system, N (North) and S (South) are to be interchanged.

* Some local objects like steel structures and electric wires influence magnetic needle and attract towards them. This disturbance is called local attraction. It is easily determined by taking fore

bearing and back bearing. If local attraction exists, the difference between the two will not be exactly 180°.

* Fieldwork consists of reconnaissance survey, making location sketches, measurement of distances and directions. Office work consists in plotting by angle and distance method and coordinate method. Closing errors are to be adjusted by Bowditch method, transit method, graphical method or axis method.
* *Limits of precision:* It there are n number of sides is a traverse, the angular error of closure should not exceed $15\sqrt{n}$ minutes. The linear error of closure should not exceed 1 in 300, preferably it should be 1 in 600.
* In a closed traverse the following equations should be satisfied:

$$SL = l_1 \cos q_1 + l_2 \cos q_2 + \ldots = 0$$

$$SD = l_1 \sin q_1 + l_2 \sin q_2 + \ldots = 0.$$

Hence, a maximum two missing measurements may be adjusted. However, in doing so, the change of checking accuracy of measurements is lost.

Plane Table Surveying

* Plane table consists of a board made up of a well seasoned wood mounted on a light tripod with suitable mounting and clamping devices. The table is to be levelled by adjusting tripod.
* Accessories for plane table required are:
  1. Alidade or sight rule—plain or telescopic
  2. Plumbing fork with plumb bob
  3. Spirit level
  4. Trough compass
  5. Drawing sheet and accessories for drawing.
* Working operations are centring, levelling and orientation. Orientation may be achieved by using trough compass, back sighting or by solving two-point or three-point problems.
* Method of plane tabling are radiation, intersection, traversing and resection.
* The problem of finding plotted position of the station point occupied by plane table with the help of two well defined points, the plotted position of which are known, is called two-point problems. Similarly, three-point problem is the problem of locating station point with the help of three plotted positions is known as three-point problem. For this tracing paper method, graphical method or trial and error (Lehman's) method may be employed.
* *Strength of fix:* It is defined as the accuracy with which the point sought p can be fixed with respect to the plotted positions of the three points.

Strength of fix is excellent when:

1. Point P is close to the orthocentre of the great circle
2. The middle station is much nearer
3. Of the two angles subtended at P, one is small and the other is large

The strength of fix is poor when:

1. P is near the circumference of the great circle

2. Both angles subtended at P are small.

• Main advantage of plane table survey is there is no chance of omitting any measurement and plotted plan can be checked in the fieldwork itself. Main disadvantage is that it cannot be conducted in wet weather and on rainy days.

3.3 LEVELLING

* Levelling is the art of determining the elevations of the given point above or below a datum line or establishing given points of required heights above or below the datum line.
* The point or the surface with respect to which levels of other points or planes are calculated is called datum or datum surface.
* Mean sea level (MSL) is the average sea level for all stages of the tides which is established after observing tides for a long period of 19 years. In India MSL is the level established at Karachi, presently in Pakistan.
* The levels of various points taken as height above the datum surface are known as reduced levels (RL).
* Benchmark is a relatively permanent point of reference whose elevation with respect to some assumed datum is known. There are four types of bench marks; namely, GTS (Great Trignometric Survey) benchmarks, permanent benchmarks, arbitrary benchmarks and temporary benchmarks.
* Methods of levelling employed are:
    1. Direct levelling (spirit levelling)
    2. Barometric levelling
    3. Hypsometric levelling
    4. Trigonometric (indirect) levelling
    5. Stadia levelling
* Levelling instrument consists of:
    1. A telescope to provide line of sight
    2. A level tube
    3. Levelling head for levelling the tube
    4. A tripod to support the instrument

• Type of levels available are
    1. Dumpy level
    2. Y-level
    3. Cooke's reversible level
    4. Cushing's level
    5. Telting level
    6. Auto level

• Levelling staff:

A levelling staff is a straight rod with rectangular section having graduations, the foot of the staff represents zero reading.

• *Types of levelling staffs:* Self-reading staff and target staff. There are three types of self-reading staff are: solid staff–single piece of 3 m.

Folding staff–two piece, 2 + 2 m telescopic staff–three piece 2 + 1.25 + 1.25 or 2+ 1.5 + 1.5 m.

Target staff may be single piece or extendable type.

• *Parts of telescope:* Telescope consists of objective, eyepiece, diaphragm and body with focussing device. It may be of external focussing type or internal focussing type.

* Temporary adjustment of level consists of setting, levelling and focussing.
* The following terms are used in levelling:

  1. *Station:* The point over which the level is set.
  2. *Height of instrument:* It is the elevation of plane of sight. It is known as plane of collimation also.
  3. *Back sight:* It is the reading taken on a point of known elevation (bench mark or change point) to find plane of collimation.
  4. *Intermediate sight (IS):* Sight taken on points to establish their reduced level. They are the sights taken after back sight and before foresight.
  5. Foresight: This is the last reading taken from an instrument station before shifting.

* *Types of levelling:* Various types of levelling are simple, differential, fly, profile, cross sectional and reciprocal levellings.
* Methods of reducing levels are height of instrument method and rise and fall method.
* In case of height of instrument methods, there is no check for the levels obtained by intermediate sight whereas rise and fall method gives check for them also.
* *Curvature corrections:* If the sight distance is more, the curvature correction is required because vertical line at the staff point is not at right angle to horizontal line from instrument point. This correction is equal to $\left(\frac{-d^2}{2R}\right)$ where d is the measured distance and R is radius of the earth.
* The line of sight is refracted since when distance is large, it is travelling through denser to thinner air. For average condition, it is assumed to have a radius of curvature 7 times that of the earth. Hence, correction for refraction is $+\frac{1}{7}\frac{d^2}{2R}$.
* Total correction due to curvature and refraction is

$$\frac{-d^2}{2R}+\frac{1}{7}\frac{d^2}{2R} = -\frac{6}{7}\frac{d^2}{2R} = -6.728 \times 10^{-8}\, d^2 \text{ metres}$$

* If P is the position of observation which is h metres above mean see level, distance of visible horizontal in terms of metres after taking into account curvature and refraction, i.e., given by $d = 3855.3\sqrt{h}$.
* By balancing back sights and foresights, the following errors are eliminated:

  1. Error due to non-parallelism of the line of collimation and axis of bubble tube.
  2. Error due to curvature and refraction.

* Errors in levelling may be grouped into the following three categories.

  1. Instrument errors
  2. Natural errors
  3. Personal errors

* After carrying out levelling, if fly levels are taken and ended on the same benchmark closing error can be found. The permissible closing error is

$$e = c\sqrt{k}$$

where c = constant and k = Distance in km

Permissible value of k for different works are:

1. Preliminary survey ± 100
2. Construction survey ± 24
3. For establishing benchmark ± 12
4. Geodetic survey ± 1

Contouring

* A contour line is a imaginary line which connects points of equal elevations.
* The vertical distance between two consecutive contour lines is called contour interval.
* Some important characteristics of contours are:
  1. Widely spaced contour – flat surface
  2. Closely spaced contour – steep ground
  3. Equally spaced – uniform slope
  4. Approximately concentric closed contours with decreasing values towards centre – pond.
  5. Concentric closed contour with increasing values towards centre – hill
  6. V-shaped contours with convexity towards higher ground – valley
  7. U-shaped contour with convexity towards lower ground – ridge
  8. If contour lines meet – existence of cliff or well
  9. If contour lines cross – overhanging cliff or cave
* Methods of contouring:
  1. **Direct method:** In this method vertical and horizontal contours of the points selected on the selected contour lines are established.
  2. **Indirect method:** The points are selected first and their reduced levels are found. Then contour lines are drawn by any one of the following methods.

  (a) Estimation

  (b) Arithmetic calculations

  (c) Graphical method
* Contour maps are useful for the following civil engineering works:
  1. Preliminary selection of project works
  2. Drawing the sections
  3. Determination of intervisibility
  4. Location of routes
  5. Determining catchment area
  6. Calculation of reservoir capacity.

Theodolite Surveying

* Theodolite is used for measuring horizontal and vertical angles. It may be used for prolonging a line, levelling and even for measuring distances indirectly (tacheometry).
* Main parts of a theodolite are telescope, vertical circle, vernier frame, standards (A-frame) upper

plate, lower plate, plate level, levelling head, magnetic compass, tripod, plumb hob and shifting head.

* Fundamental axes of theodolite are:
  1. Vertical axis 2. Trunnion axis
  3. Line of collimation 4. Altitude level axis
  5. Axis of plate level

A theodolite is said to be in proper condition, if the following conditions are satisfied:

1. The axis of the plate is perpendicular to the vertical axis.
2. The trunnion axis is perpendicular to the vertical axis.
3. The line of collimation is perpendicular to the trunnion axis.
4. The axis of the altitude level is parallel to the line of collimation.

* Temporary adjustment involves setting up, levelling and focussing.
* To get more accurate results in measuring angle take readings by method of repetition and face left as well as face right.
* In the method of repetition the following errors are eliminated:
  1. Errors due to inaccurate graduations
  2. Errors due to eccentricity of vernier
  3. Errors due to the line of sight and trunnion axis being out of adjustment
  4. Errors due to inaccurate bisection.

However, the following errors are not eliminated:

1. Error due to dip
2. Error due to displacement of signal
3. Error due to non-verticality of vertical axis

* In the field theodolite is used to measure direct angle or deflection angle. Direct angles are the horizontal angles measured clockwise from the preceding line to the following lines. The angle made by a survey line with the prolongations of the previous line is known as deflected angle.
* Theodolite traversing may be done by the
  1. Included angle method
  2. Direct angle method or
  3. Deflection angle method

Trigonometric Levelling

* This is the method of levelling in which difference between elevation of two points is found by measuring vertical angles and horizontal distances.
* If base of the object is accessible, the distance of the object and vertical angle to the object may be measured to find the RL of the object.
* If base line is inaccessible single plane method or double plane method may be used to find RL of inaccessible object.

3.4 PERMANENT ADJUSTMENTS OF DUMPY LEVEL AND THEODOLITE

* Requirements of dumpy level:

1. The axis of the bubble tube should be perpendicular to the vertical axis.
2. The horizontal cross hair should be in the plane perpendicular to the vertical axis is perpendicular to vertical axis.
3. The line of sight collimination should be parallel to the axis of bubble tube.

* Required permanent adjustments in theodolite
  1. The plate level axis is perpendicular to vertical axis.
  2. The horizontal axis is perpendicular to vertical axis.
  3. The line of sight coincides with the optical axis of the telescope.
  4. The axis of the altitude level is parallel to the line of sight.
  5. When the line of sight is horizontal, vertical circle vernier should read zero.

Computation of Areas

* **Note** 1 hectare = 100 m × 100 m = 1×10^4 m^2

1 square kilometre = 1000 × 1000 m = 1×10^6 m^2 = 100 hectare

* Computation from plotted plans is suitable at planning stage but while executing the works computations of areas from field notes is ideal.
* If boundary of the area has irregular shape, major portion is calculated by dividing area into regular figures and the smaller areas around the boundary is determined from several offsets taken from survey lines close to boundary.
* Areas from offsets taken at regular intervals may be found by

  1. Mid-ordinate rule:

$$A = d\sum_{i=1}^{n} O_i$$

where o_i are mid-ordinates of n number of intervals of size d.

  2. Average ordinate rules:

$$\text{Area} = \frac{O_1 + O_2 + \ldots + O_n}{n} \times L$$

where n is number of ordinates over $L = (n - 1)\, d$ length.

  3. *Area by trapezoidal rule:* In this method, area of each segment is calculated as a trapezoid. If d is the regular interval and total ordinates are n

$$\text{Area} = \left[\frac{O_1 + O_n}{2} + O_2 + O_3 + \ldots + O_n\right] d$$

  4. *Simson's Rule:* In this the boundary line is assumed parabolic. If d is the interval and n is the odd number of ordinates

$$\text{Area} = \frac{d}{3}\left[(O_1 + O_{\underline{n}} + 4\,(O_2 + O_4 + \ldots + O_{n-1}) + 2\,(O_3 + O_5 + \ldots O_{n-2})\right]$$

If there are even number of ordinates, use Simpson's rule upto $n - 1$ ordinates and for last segment use trapezoidal rule.

* Area from coordinates

If (x_i, y_i) are the coordinates of n stations of a closed figure

$$\text{Area} = \tfrac{1}{2}\,[(y_1\,(x_n - x_2) + y_2\,(x_1 - x_3) + y_3\,(x_2 - x_4) + \ldots + y_n\,(x_{n-1} - x_1)]$$

* Computing area from maps: methods used are

1. Give and take method
2. Subdivision into squares
3. Subdivision into trapezoids
4. Using planimeter. In this case

$$\text{Area} = M\,(F - \text{I} \pm 10\,N + C\,)$$

where M = Multiplying constant

F = Final reading

I = Initial reading

N = Number of complete revolutions of the disc. Plus sign, if the zero mark of the dial passes the index mark in clockwise direction and minus if it passes in anticlockwise direction.

C = Area of zero circle. This is added only when the anchor point is inside the area.

M and C are marked by manufacturers on the tracing arm. One can determine them by measuring area of known simple figures also.

Computation of Volumes

The methods employed are

1. From cross-sections
2. From spot levels
3. From contours

1. From cross sections The first step in computation of volumes is to determine the cross-sectional areas.

(a) Level sections:

$A = (b + nh)\,h$

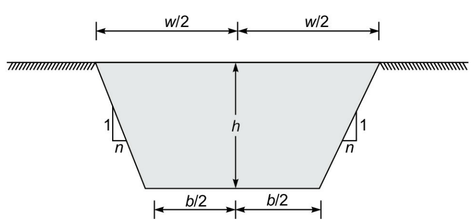


Fig. 3.1 Level section

(b) Two-level section

$$A = \frac{n\,(b/2)^2 + m^2\,(bh + nh^2)}{m^2 - n^2}$$

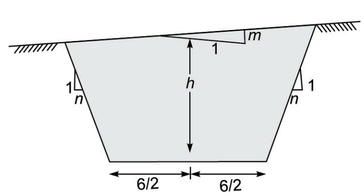


Fig. 3.2 Two-level section

(c) Side hill two-level section:

Area of cutting $A_1 = \frac{(b/2 + mh)^2}{2(m-1)}$

Area of filling $A_2 = \frac{(b/2 - mh)^2}{2(m-n)}$

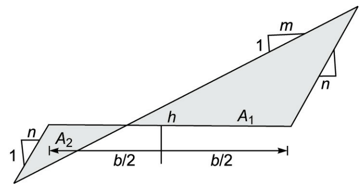


Fig. 3.3 Side hill two-level section

(d) Three-level section:

$A = \frac{b}{4}(h_1 + h_2) + \frac{h}{2}(w_1 + w_2)$

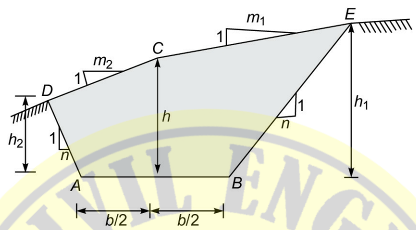


Fig. 3.4 Three-level section

* If cross sections are found at regular intervals volume by trapezoidal rule is

$$V = d\left[\frac{A_1 + A_n}{2} + A_2 + A_3 + \ldots + A_{n-1}\right]$$

Volume by prismoidal rule is

$$V = \frac{d}{3}\,[(A_1 + A_n) + 4\,(A_2 + A_4 + \ldots + A_{n-1}) + 2\,(A_3 + A_5 + \ldots)]$$

It needs odd number of sections.

2. *From spot levels* If a pit of area A is made and the depth of four corners from earth surface is h_1, h_2, h_3 and h_4, then

$$\text{Volume of earth work} = \frac{h_1 + h_2 + h_3 + h_4}{4} \times A$$

3. *Volumes from contours* If h is contour interval and area measured between a set of consecutive contours are A_1, A_2,… A_4, then by trapezoidal rule

$$V = h\left[\frac{A_1 + A_n}{2} + A_2 + A_3 + \ldots A_{n-1}\right]$$

Volume by prismoidal rule is

$$V = \frac{d}{3}\,[(A_1 + A_4) + 4\,(A_2 + A_4 + \ldots + A_{n-1}) + 2\,(A_3 + A_5 + \ldots)]$$

where n is odd number.

Minor Instruments

1. For levelling: hand level, burel hand level
2. For taking horizontal and vertical sights:
Abney level, Indian pattern clinometer, Delisle's clinometer, Foot rule clinometer, Ceylon ghat tracer.
3. Sextants: These are the instruments, which make use of optical principle to measure an angle in single observation. Two types of sextants are nautical sextant and box sextant.
4. Pentagraphs: These are the instruments used to reduce or enlarge the maps.

Tacheometry

* Tacheometry is a method of surveying in which horizontal distances and differences in elevations are determined by measuring intercepts on a graduated scale and angles by using theodolite.
* This method is not tedious and speed of surveying is very high. However, accuracy is less.
* If interval between stadia hairs is i, intercept on staff is s, f is focal length and d is the horizontal distance between the objective and the vertical axis of the instrument, then the distance between instrument station and the position where the staff is held is

$$D = \frac{f}{i} s + (f + d)$$

$$= ks + C$$

where $k = \frac{f}{i}$ and $C = f + d$

k is known as multiplying constant and C is additive constant.

Usually, in all instruments-manufacturers keep k = 100 and C varies from 0.3 to 0.6. These values can be determined by carrying out measurements over known distances. Manufacturers write these values on the instrument also.

* With simple geometric relations, the elevations and distances can be found with inclined sights also.
* Truly speaking C is not constant but varies slightly from sight to sight. By using anallatic lens this value may be made zero. In internal focussing telescopes the value of C can be made as low as 0.05 m to 0.15 m and hence may be taken as zero.
* In movables/substance method, the stadia hairs are made movable and staff intercepts are made constant by using target staffs. The stadia hair interval is read with micrometer screws.
* Since a tacheometry survey involves large observations, instead of calculating each time to get distances and differences in elevations, one can use stadia tables, stadia diagram or stadia slide rules.

3.5 CIRCULAR CURVES

* The circular curves used in roads and railways are of three types, namely, simple, compound and reverse curves.
* Definitions:
  1. *Right hand curve:* It is the curve which deflects to the right of the direction of progress of route. Similarly, left hand curve may be defined.
  2. *Back tangent:* The tangent before the commencement of curve.
  3. *Forward tangent:* The tangent after the end of curve.

4. *Point of intersection:* The intersection of back and forward tangents.
5. *Intersection angle:* Angle of deflection at point of intersection from back to forward tangent.
6. *Point of curve (PC):* The point where curve begins.
7. *Point of tangency:* The point where curve ends.
8. *Apex or summit of curve:* The mid-point of curve.
9. *Mid-ordinate:* Distance between the mid-point of the long chord and apex.
10. *External distance:* The distance between apex and point of intersection.

Elements of Simple Curve

If R is radius of a simple curve and D is angle of deflection

1. Length of curve: $l = R\text{D}$, if D is in radians

   $= R\text{D}\,\frac{\pi}{180}$, if D is in degrees.

2. Tangent length: $T = R \tan \frac{\Delta}{2}$
3. Length of long chord: $L = 2R \sin \frac{\Delta}{2}$
4. Mid-ordinate: $M = R\left(1 - \cos \frac{\Delta}{2}\right)$
5. External distance: $E = R\left(\sec \frac{\Delta}{2} - 1\right)$

Setting out Simple Circular Curves

1. *Linear methods:* (a) Offsets from long chords, (b) successive bisection method, (c) Offsets from the tangent-perpendicular or radial and (d) offsets from the chord produced.
2. *Angular methods:* (a) Rankine's method of tangential angles, (b) two-theodolite method, and (c) tacheometric method.

Compound curves A compound curve consists of two or more simple curves of different radii. In practice it normally consists of two curves. This type of curve is used to avoid the obstruction.

Reverse curves In a reverse curve two circular arcs having radius of curvatures in opposite directions meet at a point tangentially. The common point is called the point of reverse curvature or contrary flexure. As far as possible such curves should be avoided.

Transition curves

* It is a curve provided to bring about a transition between a straight and a circular curve or between two branches of compound or reverse curves. It is also known as a spiral or easements curve. In these curves gradual change of super elevation is introduced.
* Length of transition curve is decided on any one of the following basis:
   1. Uniform rate of 1 in n super elevation $L = ne$ where e is super elevation required in circular curve.
   2. *Time rate:* Super elevation e is applied at a time rate of m units/second. If v is the designed speed of vehicle, then

$$L = \frac{e}{m}v.$$

3. Rate of change of radial acceleration: For comfortable journey of passengers the rate of change of radial acceleration should be 0.3 m/sec^2

From this consideration

$$L = \frac{V^3}{14R} \text{ metres } V \text{ is kmph.}$$

In practice, instead of radial acceleration, the centrifugal ratio (centrifugal force divided by weight of vehicle) $\frac{V^2}{gR}$ is kept constant.

For roads $\frac{V^2}{gR} = \frac{1}{4} \setminus L = 12.80\ \sqrt{R}$

For railway $\frac{V^2}{gR} = \frac{1}{8} \setminus L = 4.525\ \sqrt{R}$

* Clothoid spiral is known as an ideal curve. In such a curve at any point in transition curve

$$l = \frac{V^2}{R}.$$

The coordinates of such curves are

$$x = l\left(1 - \frac{\phi^2}{10} + \frac{\phi^4}{216} \cdots\right)$$

$$y = \frac{l\phi}{3}\left(1 - \frac{\phi^2}{14} + \frac{\phi^4}{440} - \ldots\right) = \frac{l^3}{6RL}\left(1 - \frac{\phi^2}{14} + \frac{\phi^4}{440}\right)$$

where $f = \frac{l^2}{2RL}$

L being total length of transition curve.

If only the first term is taken in the above expression, $y = \frac{l^3}{6RL}$. Such a curve is called cubic parabola.

If only first term of x and y are taken in ideal curve,

$$x = l;\ y = \frac{l^3}{6RL} = \frac{x^3}{6RL}.$$

Such a curve is known as cubic parabola.

* Radius of curvature r in cubic parabola goes on reducing till f 24° 5¢ 41″ and then starts increasing with f and hence do not serve purpose of a transition curve.
* Bernaulli’s lemniscate curve is a transition curve used in roads. It is well adopted when the deflection angle is large. This curve is preferred to the spiral for the following reasons:
  1. In this the radius of curvature decrease more gradually.
  2. Rate of increase of curvature diminishes towards the end of the transition curve.
  3. Its shape correspondence to the actual path traced by a vehicle tuning freely on the curve.
* For small angles, the length of Bernaulli’s lemniscate may be taken as

$$l = 6r\ \mu$$

where μ is in radians

Vertical curves

* The change of grade is made smooth by introducing curves in vertical planes
* To make change of grade uniform,

$$y = ax^2 + bx$$

* The grade is considered +ve, if it is upward
* Types of vertical curves are:
    1. Summit or crest curve
    2. Sag or valley curve

    Length of vertical curve, $L = \frac{g_1 - g_2}{r}$

    where r = rate of change of grade. The recommended rate of change of grade is 0.06% for 20 m station at summit and 0.03% for 20 m station at sags.
* The methods used for setting vertical curves are:
    1. Tangent correction method.
    2. Chord gradients method.
* Length of summit curve is based on the minimum sight distance requirement. It is given by

$$L = \frac{S^2(g_1 - g_2)}{200} \frac{1}{\sqrt{h_1} + \sqrt{h_2}}$$

where S = minimum sight distance

$(g_1 - g_2)$ total change in gradient sign of g_1 is +ve for upward gradient and –ve for downward gradient.

h_1 = Height of driver's eye above the road.

h_2 = Height of obstacle above the road.

* In sag curve, visibility of road is not obstructed but they are to be designed so that headlight of the vehicle illuminates a minimum of stopping sight distance. For this headlight is assumed at a height of 0.75 m above the road and its beam tilled upward by an angle 1° to the horizontal.

From these considerations if $S < L$,

$L = \frac{(g_1 - g_2)S^2}{150 + 3.5S}$

if $S > L$, then

$$L = 2S - \frac{150 + 3.5S}{g_1 - g_2}$$

3.6 PRECISE LEVELLING

* Precise levelling is required for establishing the bench marks. Precise levelling is classified as:
    1. First order: Permissible error = $\pm 4\sqrt{k}$ mm
    2. Second order: Permissible error = $\pm 8\sqrt{k}$ mm
    3. Third order: Permissible error = $\pm 12\sqrt{k}$ mm

    where k is the total distance of the level line in kilometre.
* For this precise levelling precise levels are used. The levelling procedure followed is:

1. Three-wire levelling is carried out.
2. Two-levelling staffs are used.
3. Use of double set of touring points is preferred.
4. Levelling staffs with two scales are preferred.

Precise theodolites Precision of theodolites may be obtained by:

1. Using optical plummet for precise centring.
2. Optical micrometers are used for accurate reading with excellent light on scales.
3. Many are provided with digital display using LEDs or LCDs.
4. If electronic distance measurement (EDM) system is added to the precise theodolite it is known as total station, which have become very popular nowadays.
   * In EDMs distance measurement is based on propagation, reflection and reception of either radio or light of infrared waves. The accuracy achieved is l in 1×10^5 for sights upto 100 km.
   * Electromagnetic waves travel approximately at 3×10^8 m/sec. They are of sinosoidal nature.
   * By phase comparison even fraction of wavelength can be found.
   * Depending upon the carrier waves, EDM instruments are classified as:
     1. Microwave instruments
     2. Infrared instruments and
     3. Visible light instruments

Total station

1. It consists of vertical axis, tilting axis and line of sight.
2. EDM part of a total station uses phase difference technique for measurement.
3. It has keyboard and display keyboard helps in recording vertical angle, horizontal angle and slope distances are electronically recorded.
4. It is provided with internal memories and memory cards for data storage and processing.
5. Microprocessor integrated with the instrument computes average of multiple readings, applies slope corrections and finds horizontal and vertical distances. It also finds coordinates of the points.

The total stations are provided with the following accessories

1. Retroreflector
2. Track light
3. Geotronic unicom—a voice communication system.

Advantages of using total stations:

1. Surveying is very fast
2. Accuracy is high
3. Data can be directly transferred for further processing like plotting contour.

MULTIPLE-CHOICE QUESTIONS

I. Select the appropriate/correct option/options from the following questions.

1. Which of the following scale is the largest?

(a) 1 cm = 10 m

(b) 1 cm = 50 m

(c) 1 : 2000

(d) RF = $\frac{1}{3000}$

2. The length of equatorial axis and polar axis of the earth are respectively

(a) 12713.80 km and 12756.75 km

(b) 12756.75 km and 12713.80 km

(c) 1271.38 km and 1275.675 km

(d) 1275.675 km and 1271.380 km

3. The survey in which earth's curvature is considered is known as

(a) plane surveying

(b) trigonometric surveying

(c) topographic surveying

(d) geodetic surveying

4. The difference in length of an arc and the straight line on the earth's mean surface is only 1 mm in distance of

(a) 1.2 km

(b) 2.4 km

(c) 3.6 km

(d) 4.8 km

5. The sum of the interior angles of a geometrical figure laid on the surface differs from the corresponding plane figure to the extent on 1 second for about _______ square kilometer area.

(a) 50

(b) 100

(c) 150

(d) 200

6. In a diagonal scale only

(a) units can be shown

(b) units, tenths can be shown

(c) units, tenths and hundredths can be shown

(d) units, tenths, hundredths and thousandths can be shown

7. Distance between two points P and Q as found from a shrunk map is 120 m but when measurement is made on the ground it is 125. If A is the area of an estate as found from the same map, the actual area is

(a) $\frac{120}{125}A$

(b) $\frac{125}{120}A$

(c) $\left(\frac{120}{125}\right)^2 A$

(d) $\left(\frac{125}{120}\right)^2 A$

8. If n number of divisions on vernier scales coincide with $n + 1$ divisions on the main scale, the vernier is known as
   (a) direct vernier
   (b) retrograde vernier
   (c) double vernier
   (d) extended vernier
9. If n divisions on vernier coincide with $2n - 1$ divisions on the main scale, the vernier is known as
   (a) direct vernier
   (b) retrograde vernier
   (c) double vernier
   (d) extended vernier
10. If two points are already fixed, with respect to them any number of points may be located by
   (a) two linear measurements
   (b) a linear measurement
   (c) two angular measurements
   (d) any of the above
11. In surveying principle 'work from whole to part is recommended' since
   (a) it is easy to use measurements for plotting
   (b) there is no chance of omitting any required measurement
   (c) it localizes errors
   (d) it leads to errorless maps
12. In a survey A and B are two points already located with respect to A and B point C is located by taking two readings and then line CD is measured, where D is a point on AB. Then line CD is known as
   (a) base line
   (b) check line
   (c) tie line
   (d) additional line
13. The headquarters of Survey of India is located at
   (a) New Delhi
   (b) Mumbai
   (c) Manali
   (d) Dehradun
14. When the length of chain used in measuring distance is shorter than the standard length, the error in measured length is
   (a) positive error
   (b) negative error
   (c) compensating error
   (d) none of these
15. Marking the end of a chain length is an example of
   (a) positive error

(b) negative error
(c) cumulative error
(d) compensating error

16. Pick up the correct feature of accidental error in surveying
(a) positive and negative errors will occur with equal frequency
(b) small errors occur more frequently
(c) large errors do not occur
(d) all the above

17. Significant figure in the number 0.0044 is
(a) 5
(b) 4
(c) 3
(d) 2

18. To minimize rounding off errors, as per the rule the numbers 28.425 and 28.435 are rounded off as
(a) 28.42, 28.43
(b) 28.43, 28.43
(c) 28.42, 28.44
(d) 28.43, 28.44

19. In approximate measurement of a line by pacing, a step length of a normal man is taken as
(a) 0.7 m
(b) 0.75 m
(c) 0.80 m
(d) 0.85 m

20. A watch-like instrument carried in the shirt pocket to count the number of steps taken to measure a line approximately is called
(a) passometer
(b) pedometer
(c) odometer
(d) speedometer

21. The instrument which is attached to the wheel of a cycle to record the number of revolutions made for the purpose of approximate measurement is known as
(a) passometer
(b) pedometer
(c) odometer
(d) speedometer

22. In a 20 m chain the brass tally with two teeth indicates the ______ distance from the nearest end of the chain
(a) 2 m
(b) 4 m
(c) 6 m
(d) 8 m

23. Metallic tapes are made with

(a) varnished linen
(b) varnished linen with steel wires
(c) steel
(d) invar

24. The line to be measured accurately in a chain survey is

(a) main line
(b) base line
(c) check line
(d) detail line

25. If W is the weight of tape per span length, P is the pull applied, the length L measured with a tape is to be corrected by

(a) $+\frac{1}{24}\left(\frac{W}{P}\right)^2 L$

(b) $-\frac{1}{24}\left(\frac{W}{P}\right)^2 L$

(c) $-\frac{1}{12}\frac{W}{P}L$

(d) $-\frac{1}{24}\left(\frac{W}{P}\right)L$

26. The correction to be applied for length L measured along a sloping ground with angle q to horizontal is

(a) $L(1 - \sin q)$
(b) $L(1 - \cos q)$
(c) $L(1 - \tan q)$
(d) $L(1 - \cot q)$

27. In chain survey, as far as possible main triangles should have angles close to

(a) 40°
(b) 50°
(c) 60°
(d) 70°

28. In chain survey a triangle with any angle less than ______ is considered as ill conditioned triangle

(a) 25°
(b) 30°
(c) 35°
(d) 40°

29. Which one of the following is not used in setting perpendicular

(a) line ranges
(b) cross staff
(c) optical square
(d) prism square

30. The bearing S 25° W means ______ in whole circle bearing
   (a) 155°
   (b) 205°
   (c) 115°
   (d) 335°
31. The horizontal angle between the true meridian and magnetic meridian is known as
   (a) magnetic dip
   (b) declination
   (c) local attraction
   (d) magnetic bearing
32. At a place magnetic dip is 15° and declination is 10°E. If the magnetic bearing of a line is 75°, the true bearing is
   (a) 60°
   (b) 65°
   (c) 85°
   (d) 90°
33. In whole circle bearing system, the back bearing of N 20 W line is
   (a) 160°
   (b) 200°
   (c) 340°
   (d) 20°
34. Forebearing of line *AB* is 60° and that of *BC* is 130°, then angle *B* is
   (a) 50°
   (b) 190°
   (c) 110°
   (d) none of the above
35. Forebearing of line *AB* is 80°. Included angle *B* is 100°. Then forebearing of *BC* is
   (a) 160°
   (b) 180°
   (c) 220°
   (d) 240°
36. The following bearings were observed while traversing with a compass.

Line	FB	BB
AB	80°	260°
BC	90°	269°
CD	120°	301
DA	319°	140

Which stations are affected by local attraction?

   (a) *A* and *B*

(b) B and C
(c) C and D
(d) D and A

37. Which one of the following is a wrong statement about plane table surveying
(a) it avoids missing of any measurement required for plotting
(b) it is an accurate method
(c) it is not to be used for locating main stations accurately
(d) it is commonly used for filling details in small or medium scale mapping

38. Which one of the following is not an accessary of plane table?
(a) Plumbing fork
(b) Trough compass
(c) Telescopic alidade
(d) Prismatic compass

39. Which one of the following is not a method of plane tabling?
(a) Orientation
(b) Radiation
(c) Intersection
(d) Resection

40. Three-point problem in plane tabling may be solved by
(a) tracing paper method
(b) graphical method
(c) trial and error method
(d) all of the above

41. Trial and error method of solving three-point problems in plane tabling is also known as
(a) tracing paper method
(b) Bessel's method
(c) Lehman's method
(d) all the above

42. Which one of the following is wrong about level surface?
(a) It is a horizontal plane.
(b) It is a surface parallel to mean spheroid of earth.
(c) All the points lying on this surface are equidistant from the centre of the earth.
(d) It is normal to plumb line at all points.

43. In India mean sea level used for fixing reduced levels is at
(a) Goa
(b) Mumbai
(c) Vishakapatnam
(d) Karachi

44. Which one of the following is not a self-reading staff?
(a) Solid staff
(b) Folding staff

(c) Telescopic staff
(d) Target staff

45. In external focussing telescope for focussing
(a) eyepiece is moved
(b) objective tube is moved
(c) either eyepiece or objective piece is moved
(d) neither eyepiece nor objective piece is moved

46. In levelling height of instrument means
(a) height of telescope from the ground where instrument is set
(b) level of the point with respect to assumed datum
(c) it is the elevation of plane of sight from the assumed datum
(d) none of the above

47. After setting a level, the first sight to be taken is
(a) foresight
(b) back sight
(c) intermediate sight
(d) any of the above

48. The point on which both foresight and back sights are taken is
(a) change point
(b) first station point in the traverse
(c) last station point in a traverse
(d) the point where level is to be set

49. If d is horizontal distance and R is radius of the earth, curvature correction is
(a) $\frac{d^2}{R}$
(b) $-\frac{d^2}{R}$
(c) $\frac{d^2}{2R}$
(d) $-\frac{d^2}{2R}$

50. Correction for refraction is approximately
(a) $+\frac{1}{5}$th curvature correction
(b) $-\frac{1}{5}$th curvature correction
(c) $+\frac{1}{7}$th curvature correction
(d) $-\frac{1}{7}$th curvature correction

51. By balancing back sight and foresight the errors eliminated are
(a) errors due to non-parallelism of line of collimation and axis of bubble tube
(b) error due to curvature and refraction

(c) both (a) and (b)

(d) none of (a) and (*b*)

52. Sensitivity of a bubble tube can be increased by
(a) increasing the length of the tube
(b) increasing the diameter of the tube
(c) decreasing viscosity of liquid
(d) any of the above

53. The rise and fall method of levelling provides a complete check on
(a) back sight
(b) foresight
(c) intermediate sight
(d) all of the above

54. The reading taken from an instrument station on a bench mark of 100.00 RL is 1.2 and the reading taken on next station is 1.70. Then RL of next station is
(a) 98.8 m
(b) 98.30 m
(c) 99.50 m
(d) 100.50 m

55. The reading taken from an instrument station on a benchmark of RL 100.00 is 1.4 and on a chejja reading taken with inverted staff is 2.8 m. Then RL of chejja is
(a) 104.2 m
(b) 101.40 m
(c) 98.6 m
(d) none of the above

56. If height of sight is *h* metres above mean sea level, then the distance *d* of visible horizon is
(a) $10^4\sqrt{\frac{h}{6.728}}$ m
(b) $\frac{h \times 10^4}{\sqrt{6.728}}$ m
(c) $10^4 \frac{h}{6.728}$ m
(d) $\frac{10^4 \times h}{6.728}$ m

57. Contour interval selected is
(a) directly proportional to flatness of ground
(b) larger if the purpose of contouring is for earthwork calculation
(c) inversely proportional to the scale of map
(d) directly proportional to time and fund available

58. Direct method of contouring is suitable for
(a) small areas
(b) large areas
(c) forest areas

(d) hilly areas

59. Method of square is suitable for contouring
    (a) hilly terrain
    (b) forest
    (c) urban area
    (d) plains
60. Pick up the correct statement given below:
    In cross-section method of contouring
    (a) spacing of cross section depends upon the nature of ground
    (b) cross sections need not be always at 90° to main line
    (c) the method is suitable for road projects
    (d) all the above
61. For hilly region the ideal method of contouring is
    (a) direct method
    (b) method of squares
    (c) cross-section method
    (d) radial line method
62. For the purpose of linear interpolation of contour one can use
    (a) estimation
    (b) arithmetic calculations
    (c) graphical method
    (d) all the above
63. Contour maps are useful for
    (a) determining intervisibility between two points
    (b) determining catchment area
    (c) calculation of reservoir capacity
    (d) all the above
64. An imaginary line joining the point of intersection of the cross-hairs of the diaphragm and the optical centre of the object glass is known as
    (a) axis of telescope
    (b) axis of level tube
    (c) line of collimation
    (d) horizontal axis
65. The process of turning the telescope through 180° in vertical plane is known as
    (a) transiting
    (b) plunging
    (c) reversing
    (d) any one of the above
66. The process of rotating the telescope of a theodolite in a horizontal plane is known as
    (a) transiting
    (b) plunging

(c) swinging

(d) any of the above

67. A theodolite is considered to be in proper condition, if
   (a) the axis of the plate is perpendicular to the vertical axis
   (b) the trunnion axis is perpendicular to the vertical axis
   (c) the axis of the altitude level is parallel to the line of collimation
   (d) all the above
68. If the least count of instrument is 20″ , by measuring the horizontal angle n times repeatedly, the accuracy achieved is
   (a) $\frac{20''}{n}$
   (b) $\frac{20''}{2n}$
   (c) 20″
   (d) none of the above
69. By method of repetition in measuring horizontal angle the error that is not eliminated is
   (a) due to inaccurate graduation
   (b) due to the line of sight and trunnion axis being out of adjustment
   (c) due to inaccurate bisection
   (d) due to non-verticality of vertical signal
70. Trigonometric levelling is used when
   (a) base of the object is accessible
   (b) base of the object is not accessible
   (c) in both the above two cases
   (d) in none of the above two cases
71. If the base of the object is inaccessible, in trigonometric levelling method to be used is
   (a) single plane method
   (b) double plane method
   (c) any of the above two
   (d) none of (a) and (b)
72. Two-peg test is conducted to check the following permanent adjustment of dumpy level
   (a) axis of bubble tube is perpendicular to the vertical axis
   (b) horizontal cross-hair lie in a plane perpendicular to the vertical axis
   (c) the line of sight is truly parallel to the axis of bubble tube
   (d) all the above
73. Spire test is to check the following permanent adjustment of theodolite
   (a) plate level axis is perpendicular to vertical axis
   (b) horizontal axis is perpendicular to vertical axis
   (c) the line of sight coincides with the optical axis of the telescope
   (d) the axis of altitude level is parallel to the line of sight

74. If a, b, c are the sides of a triangle and $s = \frac{a+b+c}{2}$, the area of the triangle is

(a) $A = s(s-a)(s-b)(s-c)$

(b) $A = \sqrt{s(s-a)(s-b)(s-c)}$

(c) $A = 3\sqrt{s(s-a)(s-b)(s-c)}$

(d) $A = s(s+a)(s+b)(s+c)$

75. According to Simpson's rule, if there are n number of segments each of width d, in terns of ordinates area of the figure is

(a) $A = \frac{d}{3}[(O_1 + O_n) + 4(O_2 + O_4 + \ldots + O_{n-1}) + 2(O_3 + O_5 + \ldots + O_{n-2})]$

(b) $A = \frac{d}{3}[(O_1 + O_n) + 3(O_2 + O_4 + \ldots + O_{n-1}) + 2(O_3 + O_5 + \ldots + O_{n-2})]$

(c) $A = \frac{d}{3}[O_1 + 4(O_2 + O_4 + \ldots + O_{n-1}) + 2(O_3 + O_5 + \ldots + O_n)]$

(d) $A = \frac{d}{3}[O_1 + 2(O_2 + O_4 + \ldots + O_{n-1}) + 3(O_3 + O_5 + \ldots + O_n)]$

76. To apply Simpson's rule for computation of irregular area, number of segments should be

(a) of equal width and odd number

(b) of equal width and even number

(c) may be of varying width also

(d) may be even or odd

77. If offsets are taken at irregular interval to a boundary from a line the area may be calculated from the equation

(a) $A = \frac{d_1}{2}(O_1 + O_2) + \frac{d_2}{2}(O_2 + O_3) + \frac{d_3}{2}(O_3 + O_n) + \ldots$

(b) $A = \frac{d_1}{3}(O_1 + O_2) + \frac{d_2}{2}(O_2 + O_3) + \frac{d_3}{3}(O_4 + O_n) + \ldots$

(c) $A = \frac{d_1}{3}(O_1 + 2O_2) + \frac{d_2}{3}(O_2 + 2O_3) + \frac{d_3}{3}(O_3 + O_n) + \ldots$

(d) $A = \frac{d_1}{2}\sqrt{O_1^2 + O_2^2} + \frac{d_2}{2}\sqrt{O_2^2 + O_3^2} + \frac{d_3}{2}\sqrt{O_3^2 + O_n^2} + \ldots$

78. If coordinates of stations A, B, C and D are (x_1, y_1), (x_2, y_2), (x_3, y_3) and (x_4, y_4) respectively, the area of $ABCD$ is

(a) $A = \frac{1}{2}[y_1(x_4 - x_2) + y_2(x_1 - x_3) + y_3(x_2 - x_4) + y_4(x_3 - x_1)]$

(b) $A = \frac{1}{2}[y_1(x_1 - x_2) + y_2(x_2 - x_3) + y_3(x_3 - x_4) + y_4(x_4 - x_1)]$

(c) $A = \frac{1}{2}[y_1(x_2 - x_3) + y_2(x_3 - x_4) + y_3(x_4 - x_1) + y_4(x_3 - x_2)]$

(d) none of the above

79. Which one of the following methods is superior in finding area of map?

(a) Give and take rule.
(b) Subdivision into squares.
(c) Subdivision into trapezoids.
(d) Using a planimeter.

80. Which one of the following methods estimates best the area of an irregular curved boundary?

(a) Midordinate method
(b) Average ordinate method
(c) Trapezoidal method
(d) Simpson's method

81. While measuring the area of a plan using a planimeter the following readings were taken. If the anchor point was outside the plan and zero mark of disc crossed the index in clockwise direction, the area of map is ______.

Given Multiplying constant = 100 cm^2
Initial reading = 8.378
Final reading = 1.436

(a) 2694.2 cm^2
(b) 1305.8 cm^2
(c) 694.2 cm^2
(d) none of the above.

82. If L is length of tracing arm, a is the distance of wheel from hinge and R is length of anchor arm, the radius of zero circle of the planimeter is equal to

(a) zero
(b) $\sqrt{l^2 - 2aL + R^2}$
(c) $\sqrt{L^2 + R^2}$
(d) $\sqrt{L^2 + 2aL + R^2}$

83. If A_1, A_2 … A_n are the cross-sectional area of a canal at distances d, $2d$,…, then volume of earthwork involved in making the canal as per trapezoidal rule is

(a) $d[A_1 + A_2 + \ldots + A_n]$
(b) $d\left[\frac{A_1 + A_n}{2} + A_2 + A_3 + \ldots + A_{n-1}\right]$
(c) $d\left[\frac{A_1 + A_n}{2} + A_2 + A_3 + \ldots + A_n\right]$
(d) $\frac{d}{2}[A_1 + A_2 + A_3 + \ldots + A_n]$

84. According to prismoidal rule, the volume of earthwork in terms of cross-sectional area A_1, A_2 … A_n taken at distances d is

(a) $\frac{d}{3}\left[\frac{A_1 + A_n}{2} + A_2 + A_3 + A_3 + \dots A_n\right]$

(b) $\frac{d}{3}[(A_1 + A_n) + 4(A_2 + A_4 + \dots A_{n-1}) + 2(A_3 + A_3 + \dots + A_{n-2})$

(c) $\frac{d}{3}\left[\frac{A_1 + A_n}{2} + A_2 + A_3 + \dots + A_n\right]$

(d) $\frac{d}{2}\left[\frac{A_1 + A_2}{2} + 3(A_2 + A_4 + \dots + A_{n-1}) + 4(A_3 + A_5 + \dots + A_{n-2})\right]$

85. If the depth of excavation of block A at corners a, b, c and d is h_a, h_b, h_c and h_d, the volume of pit is

(a) $\frac{h_a + 2h_b + 2h_c + h_d}{4} A$

(b) $\frac{h_a + 3h_b + 3h_c + h_d}{3} A$

(c) $\frac{h_a + h_b - h_c + h_d}{4} \times A$

(d) $\frac{h_a + 2h_b - 2h_c + h_d}{4} A$

86. The instrument used for reducing a plan is known as

(a) clinometer
(b) planimeter
(c) pantograph
(d) sextant

87. The minor instrument used not only to take horizontal sights but also inclined sights are known as

(a) clinometer
(b) sextant
(c) pantograph
(d) planimeter

88. Minor instruments, which make use of optical principle to measure an angle in a single observations is known as

(a) clinometer
(b) sextant
(c) abney level
(d) pantograph

89. If f is focal length, i is stadia hair interval and d is the distance between the optical centre of the object lense, the multiplying constant is

(a) $\frac{f}{i}$
(b) $f + d$
(c) $\frac{f}{i} + d$
(d) $f + id$

90. In Question 89, the additive constant is

(a) $\frac{f}{i}$

(b) $f + d$

(c) $\frac{f}{i} + d$

(d) $f + id$

91. In a theodolite the multiplying constant for tacheometry is usually
   (a) 10
   (b) 50
   (c) 100
   (d) 200
92. In a tacheometry, if intercept taken on a vertically held staff is inclined at q to horizontal, the horizontal distance is
   (a) $kS + C$
   (b) $kS \cos q + C \cos q$
   (c) $kS \cos^2 q + C \cos q$
   (d) $kS \sin 2q + C \sin q$
93. In Question 92, vertical distance is
   (a) $kS + C$
   (b) $kS \cos q + C \cos q$
   (c) $kS \cos^2 q + C \cos q$
   (d) $kS \sin 2q + C \sin q$
94. In the tachemetry, if inclined sight q is taken on a staff held normal to the sight, horizontal distance is
   (a) $(kS + C) \cos q + r \sin q$
   (b) $(kS + C) \sin q$
   (c) $(kS + C) \cos q \sin q + r \sin^2 q$
   (d) $(kS + C) \tan q$
95. In Question No. 94, the expression for vertical distance is
   (a) $(kS + C) \cos q + r \sin q$
   (b) $(kS + C) \sin q$
   (c) $(kS + C) \cos q \sin q + r \sin^2 q$
   (d) $(kS + C) \tan q$
96. In external focussing telescope with an anallatic lens, for tacheometric survey additive constant is
   (a) zero
   (b) 0.1 m
   (c) 0.3 m
   (d) 0.5 m
97. If the focal length of the object glass is 30 cm and the distance form the object glass to the trunnion axis is 20 cm, the additive constant for telemetry is
   (a) 0.5
   (b) 0.4
   (c) 0.3

(d) 0.1

98. In the substance bar method of tacheometry, the substance bar is held

(a) vertical

(b) horizontal

(c) normal to sight when sight is inclined

(d) any of the above

99. The tangent, which is before the commencement of a curve is called

(a) back tangent

(b) rear tangent

(c) first tangent

(d) all of the above

100. If the degree of curve is 1, then radius of the curve is

(a) $\frac{1800}{\pi}$

(b) $\frac{5400}{\pi}$

(c) $\frac{180}{\pi}$

(d) $\frac{540}{\pi}$

101 The tangent length of a simple curve of radius R and deflection angle D is

(a) $R \sin \frac{\Delta}{2}$

(b) $R \cos \frac{\Delta}{2}$

(c) $R \tan \frac{\Delta}{2}$

(d) $R \cot \frac{\Delta}{2}$

102. The length of long chord of a circular curve of radius R and deflection angle D is

(a) $R \sin \frac{\Delta}{2}$

(b) $2R \sin \frac{\Delta}{2}$

(c) $R \cos \frac{\Delta}{2}$

(d) $2R \cos \frac{\Delta}{2}$

103. Mid-ordinate of a simple curve of radius R and deflection angle D is

(a) $R\left(1-\cos\frac{\Delta}{2}\right)$

(b) $R\left(1-\sin\frac{\Delta}{2}\right)$

(c) $R\left(1-\tan\frac{\Delta}{2}\right)$

(d) $R\left(1-\cot\frac{\Delta}{2}\right)$

104. If point of curve is 521.4 m in setting circular curve with 20 m chain, the first point where peg is

to be fixed on the curve is

(a) 540 m
(b) 541.4 m
(c) 550 m
(d) 551.4 m

105. In linear method of setting out simple circular curves the method to be used is
(a) offset from long chord
(b) successive bisection of chord
(c) offsets from the tangents
(d) any one of the above

106. The radial offset at a distance x from the point of curve in a simple circular curve is
(a) $\sqrt{R^2+x^2}+R$
(b) $\sqrt{R^2+x^2}-R$
(c) $\sqrt{R^2-x^2}+R$
(d) $-\sqrt{R^2-x^2}+R$

107. The perpendicular offset at a distance x from the point of curve in a simple curve is
(a) $\sqrt{R^2+x^2}+R$
(b) $\sqrt{R^2+x^2}-R$
(c) $\sqrt{R^2-x^2}+R$
(d) $R-\sqrt{R^2-x^2}$

108. If obstacles are coming in the alignment of a simple circular curve use
(a) transition curve
(b) compound curve
(c) reverse curve
(d) any one of the above

109. As far as possible reverse curves should be avoided. Reason for it is
(a) puts passengers to discomfort
(b) needs cambers on opposite edges
(c) at the point of reverse curvature, it is not possible to provide camber
(d) all the above

110. In a reverse curve, the super elevation provided at the point of reverse curvature is
(a) minimum
(b) zero
(c) maximum
(d) depends upon the elements of curve

111. If R is radius of curvature and l is the distance from the beginning in a transition curve, then for ideal transition
(a) $l \mu R$

(b) $l \mu R^2$

(c) $l \propto \frac{1}{R}$

(d) $l \propto \frac{1}{R^2}$

112. Which one of the following is not a transition curve?

(a) Cubic spiral
(b) Cubic parabola
(c) Bermalli's leminiscale
(d) Sag curve

113. If the vertical curve connects a 1% upgrade with 1.4% downgrade, and the rate of change of grade is to be 0.06% per 20 m stations, the length of vertical curve is

(a) 133.3 m
(b) 40 m
(c) 400 m
(d) 800 m

114. In a sag curve a minimum of stoppage distance is determined with assumptions of head light ______ and beam tilted at an upward angle of ______

(a) 1.0 m and 2°
(b) 0.75 m and 2°
(c) 1.0 and 1°
(d) 0.75 m and 1°

115. If D is deflection angle, the chord length of a circular curve is

(a) R sin D
(b) R cos D
(c) $2R \sin\frac{\Delta}{2}$
(d) $2R \cos\frac{\Delta}{2}$

116. Two theodolite method of setting out a curve involves

(a) linear measurements only
(b) angular measurements only
(c) both angular and linear measurement
(d) none of the above

117. The necessary super elevation on railway is

(a) $\frac{g v^2}{GR}$

(b) $\frac{G v^2}{gR}$

(c) $\frac{GR}{g v^2}$

(d) $\frac{gR}{G v^2}$

118. If k is the total distance of the level lime in km, the permissible error in the first order precise

levelling is

(a) $\pm 4\sqrt{k}$ mm
(b) $\pm$ 4 k mm
(c) $\pm 8\sqrt{k}$ mm
(d) $\pm$ 8 k mm

119. Electromagnetic distance measurements instruments are
(a) microwave instruments
(b) infrared instruments
(c) visible light instruments
(d) any of the above

120. Total station is
(a) electronic theodolite
(b) electronic distance meter
(c) microprocessor electronic data collector
(d) integration of all the above

II. *Match List I with List II and select the correct answer Code given below the Questions 121 to 127.*

121.

	List I Type of survey		List II Recommended scale
A.	Building survey	1.	1 : 1000
B.	Town planning schemes	2.	1 : 5000
C.	Topographic survey	3.	1 : 10000
D.	Route survey	4.	1 : 25000

Codes:

(a)	A – 1	B – 2	C – 3	D – 4
(b)	A – 2	B – 1	C – 3	D – 4
(c)	A – 1	B – 2	C – 4	D – 3
(d)	A – 2	B – 1	C – 3	D – 4

122.

	List I		List II
A.	Ranging rod	1.	4 – 8 m long with alternate colour bands of 200 mm
B.	Ranging pole	2.	0.5 – 1.0 m long sticks used for ranging
C.	Offset rods	3.	2 to 3 m long with alternate colour bands of 200 mm
D.	Laths	4.	3 m long rods with narrow slights at right angles to each other at a height of eye

Codes:

(a)	A – 1	B – 3	C – 4	D – 2
(b)	A – 3	B – 1	C – 2	D – 4
(c)	A – 3	B – 1	C – 4	D – 2
(d)	A – 1	B – 3	C – 2	D – 4

123.

	List I Types of benchmarks		List II
A.	GTS benchmark	1.	Fixed by a survey team at the end of day work
B.	Permanent benchmark	2.	Fixed by Survey of India
C.	Arbitrary benchmark	3.	Fixed by state PWD
D.	Temporary benchmark	4.	Fixed by a survey team in the beginning of a project

Codes:

(a)	A – 3	B – 2	C – 4	D – 1
(b)	A – 3	B – 2	C – 1	D – 4
(c)	A – 2	B – 3	C – 1	D – 4
(d)	A – 2	B – 3	C – 4	D – 1

124.

	List I Methods of levelling		List II Quantity measured
A.	Direct levelling	1.	Horizontal sight on a staff
B.	Barometric levelling	2.	Boiling point
C.	Hypsometric levelling	3.	Vertical angle and horizontal distances
D.	Trigonometric levelling	4.	Atmospheric pressure

Codes:

(a)	A – 3	B – 2	C – 4	D – 1
(b)	A – 1	B – 4	C – 2	D – 3
(c)	A – 1	B – 2	C – 4	D – 3
(d)	A – 2	B – 4	C – 1	D – 3

125.

List 1		List 2
Type of levelling		
A. Simple levelling	1.	To establish temporary benchmark
B. Differential levelling	2.	For levelling across obstacle like river
C. Profile levelling	3.	For longitudinal sectioning
D. Reciprocal levelling	4.	To find difference in levels of two nearby points

Codes:

(a)	A – 1	B – 2	C – 4	D – 3
(b)	A – 4	B – 2	C – 1	D – 3
(c)	A – 3	B – 2	C – 4	D – 1
(d)	A – 4	B – 3	C – 1	D – 2

126.

List 1		List 2
Nature of contour intervals		**It indicates**
A. Widely spaced contours	1.	Steep ground
B. Closely spaced contours	2.	Uneven surface
C. Irregular contours	3.	Cliff
D. Contours meeting at a point	4.	Flat surface

Codes:

(a)	A – 3	B – 1	C – 2	D – 4
(b)	A – 4	B – 1	C – 2	D – 3
(c)	A – 4	B – 1	C – 3	D – 2
(d)	A – 3	B – 2	C – 4	D – 1

127.

List I		List II
Nature of contour lines		**It indicates**
A. Approximately concentric closed contours with decreasing values towards centre	1.	Ridge
B. Approximately concentric closed contours with increasing values towards centre	2.	Valley
C. V-shaped contours with convexity towards higher ground	3.	Hills
D. U-shaped contours with convexity towards lower ground	4.	Pond

Codes:

(a)	A – 2	B – 3	C – 4	D – 1
(b)	A – 4	B – 3	C – 1	D – 2
(c)	A – 3	B – 4	C – 2	D – 1
(d)	A – 4	B – 3	C – 2	D – 1

III. *Select your answer code according to the coding system given below for the Assertion (A) and Reason (R) given questions 128 to 132.*

(a) Both A and R are true and R is the correct explanation of A.
(b) Both A and R are true but R is not the correct explanation of A.
(c) A is true but R is false.
(d) A is false but R is true.

128. A: Invar tape is more accurate
R: It will not undergo change in length due to creep.
129. A: In radial method of countering hill areas, tacheometry is ideally suited
R: In tacheometry larger area can be easily covered in single setting.
130. A: There is not much advantage for going to the method of repetition when sight distances are less than 100 m.
R: If sighting distances are less than 100 m, the errors in sighting and centring are more significant.
131. A: At the planning stage computation of areas from plotted plans is preferred.
R: This method of computation of area is superior to computation from field notes.
132. A: While executing the works computations of area from field notes is preferred.
R: This method is superior to computation of areas from plotted plans.

IV. *State whether the following statements are True or False. Questions no. 133 to 150*

133. If chain is short, it makes each measured length longer.
134. A normal man takes a step of length 600 mm.
135. Metallic tapes consist of steel tape of 6 to 10 mm width.
136. Optical square is used for levelling.
137. If n is the number of sides in a closed traverse, sum of interior angles is $(n - 4) \times 90°$.
138. Maximum of two omitted measurements can be taken care in office work.
139. Vertical lines to a horizontal line at any distance are parallel to each other.
140. In India GTS benchmark is established with respect to mean sea level at Mumbai.
141. Back sight is always the first reading taken after setting the instrument.
142. The refraction and curvature corrections are positive corrections.
143. Barometric surveying is based on the variation of air pressure with respect to altitude.

144. Hypsometry is the survey based on finding the elevation of a station from the boiling point of water.
145. If contour lines cross each other it shows a vertical cliff.
146. Spire test is to adjust horizontal axis normal to vertical axis.
147. Area of zero circle is added to planimeter calculation only when the anchor point is outside the area of map.
148. In subtense bar method of tacheometry, subtense bar is held horizontal.
149. Clothoid is an ideal transition curve.
150. Vertical curves are generally parabolic curves.

Answer to Multiple-Choice Questions

1. (a)	2. (b)	3. (d)	4. (a)	5. (d)
6. (c)	7. (d)	8. (b)	9. (d)	10. (d)
11. (c)	12. (c)	13. (d)	14. (a)	15. (d)
16. (d)	17. (d)	18. (c)	19. (c)	20. (a)
21. (c)	22. (b)	23. (b)	24. (b)	25. (b)
26. (b)	27. (c)	28. (b)	29. (a)	30. (b)
31. (b)	32. (c)	33. (a)	34. (c)	35. (a)
36. (c)	37. (b)	38. (d)	39. (a)	40. (d)
41. (c)	42. (a)	43. (d)	44. (d)	45. (c)
46. (c)	47. (b)	48. (a)	49. (d)	50. (d)
51. (c)	52. (d)	53. (d)	54. (c)	55. (a)
56. (a)	57. (c)	58. (a)	59. (d)	60. (d)
61. (d)	62. (d)	63. (d)	64. (c)	65. (a)
66. (c)	67. (d)	68. (b)	69. (d)	70. (b)
71. (b)	72. (c)	73. (b)	74. (b)	75. (a)
76. (b)	77. (a)	78. (a)	79. (d)	80. (d)
81. (b)	82. (b)	83. (b)	84. (b)	85. (c)
86. (c)	87. (a)	88. (b)	89. (a)	90. (b)
91. (c)	92. (c)	93. (d)	94. (a)	95. (b)
96. (a)	97. (a)	98. (b)	99. (d)	100. (b)
101. (c)	102. (b)	103. (a)	104. (a)	105. (d)
106. (b)	107. (d)	108. (b)	109. (d)	110. (b)
111. (c)	112. (d)	113. (d)	114. (d)	115. (c)
116. (b)	117. (b)	118. (a)	119. (d)	120. (d)
121. (c)	122. (c)	123. (d)	124. (b)	125. (d)
126. (b)	127. (d)	128. (b)	129. (a)	130. (a)
131. (b)	132. (a)	133. True	134. False	135. False
136. False	137. False	138. True	139. False	140. False
141. True	142. False	143. True	144. True	145. False
146. True	147. False	148. True	149. True	150. True

4

Engineering Mechanics

* Experimental findings developed around the states of rest and state of motion of the bodies by Archemdes, Galilea and Newton is known as classical mechanics/Newtonian mechanics.
* Albert Einstein put forth the theory of relativistic mechanics to explain the behaviour of high speed bodies.
* Schrodinger and Broglie put forth theory of quantum mechanics to explain behaviour of particles when atomic distances are concerned.
* The basic terminolgies in mechanics are
  1. Mass
  2. Time
  3. Space
  4. Length
  5. Displacement
  6. Velocity
  7. Acceleration
  8. Momentum
  9. Continuum
  10. Rigid body
  11. Particle
* The *fundamental laws of* Newtonian mechanics are
  1. Newton's 3 laws
  2. Law of gravitation
  3. Law of transmissibility of forces
  4. Parallelogram law of forces
     1. Newton's first law states that every body continues in its state of rest or of uniform motion in a straight line unless it is compelled by an external agency.
     2. According to Newton's second Law

$$\text{Force } \mu \text{ Mass} \times \text{Acceleration}$$

     3. Newton's third law states action and reaction is equal and opposite.
     4. According to Newton's law of gravitational acceleration the force of attraction between the bodies of mass m_1 and mass m_2 at a distance d is

$$F = G\frac{m_1 m_2}{d^2}$$

     where G is the constant of proportionality.
     5. According to the law of transmissibility of force, the state of rest or motion of the rigid body is unaltered, if a force acting on the body is replaced by another force of the same magnitude and

direction but acting at any other point on the body along the line of action of the replaced force.

6. Parallelogram law of forces states that if two forces acting simultaneously on a body at a point are represented in magnitude and direction by the two adjacent sides of a parallelogram, their resultant is represented in magnitude and direction by the diagonal of the parallelogram which passes through the point of intersection of the two sides representing the forces.

* Triangle law of forces and polygon law of forces are the laws derived from parallelogram law of forces.

* *Unit of force* is so defined that the constant of proportionality in Newton's second law becomes unity. In SI system 1 newton of force moves 1 kg mass at an acceleration of 1m/sec^2.

* 1 kg-wt = 9.81 newton. In practice 1 kg-wt is simply called 1 kg.

* *System of forces*

1. If all forces do not lie in a single plane, it is system or forces in space. If all forces lie in a single plane it is coplanar force system.
2. If all forces in a system pass through a single point it is concurrent force system otherwise it is non-concurreat force system.
3. If all forces in a system are parallel to each other it is parallel force system.

* *Scalars and Vectors:* A quantity is said to be scalar, if it is completely defined by its magnitude alone and it is vector, if it is completely defined only when its magnitude as well as directions are specified.

4.1 RESULTANT AND EQUILIBRIUM OF SYSTEM OF COPLANAR CONCURRENT FORCES

* If F_1 and F_2 are two forces acting on a particle and the angle between them is q, the magnitude of their resultant is

$$R = \sqrt{F_1^2 + 2F_1F_2\cos\theta + F_2^2}$$

and the inclination of resultant to the direction of force F_1 is

$$\alpha = \tan^{-1}\frac{F_2\sin\theta}{F_1 + F_2\cos\theta}$$

* If a force F makes angle q with x-direction,

$$F_x = F\cos q$$

$$F_y = F\sin q$$

* If a system of forces are acting on a particle,

$$R = \left[\left(\sum F_x\right)^2 + \left(\sum F_y\right)^2\right]^{1/2}$$

and its inclination to x-axis a is given by

$$a = \tan^{-1}\left(\frac{\sum F_y}{\sum F_x}\right)$$

* Self-weight ($W = mg$) and reactions from the bodies in contact with the body under consideration

are non-applied forces.

* If body under consideration is freed from contact surfaces of other bodies and the forces on it including self-weight and reactions from contact surfaces is shown, it is known as free body diagram (FBD) of the body.

* Lami's theorem states that if a body is in equilibrium under the action of only three forces, each force is proportional to the sine of the angle between the other two forces.

$$\frac{F_1}{\sin\alpha} = \frac{F_2}{\sin\beta} = \frac{F_3}{\cos\gamma}$$

* If contact surfaces are smooth, reaction between them is normal to the tangent at contact surfaces.

* Equilibrium equations in planar system are,

$$\text{S}F_x = 0, \text{S}F_y = 0.$$

Resultant and Equilibrium of Coplanar Non-Concurrent Forces

* Moment of a force about a point is the measure of rotational effect of the force and is given by

$$M = F \times d$$

where F = the force and d is perpendicular distance of the force from the moment centre.

* Varignon's theorem, also known as principles of moments, states the algebraic sum of moments of a system of coplanar forces about a moment centre is equal to the moment of their resultant force about the same moment centre.

$$R \times d = \text{S}F_i d_i$$

* Two parallel forces equal in magnitude and opposite in direction and separated by a definite distance are said to form a couple.
  1. The translatory effect of a couple on the body is zero.
  2. The rotational effect about any point is a constant.

* Magnitude, direction and the distance of resultant force from the moment centre are given by

$$R = \left[(\Sigma F_x)^2 + (\Sigma F_y)^2\right]^{1/2}$$

$$a = \tan^{-1}\frac{\Sigma F_y}{\Sigma F_x}, \text{ and}$$

$$d = \frac{\Sigma M_o}{R}$$

* x and y intercepts of resultant of non-cocurrent system of forces in a plane are

$$x = \frac{\Sigma M_o}{R_y}, y = \frac{\Sigma M_o}{R_x}$$

* Equations of equilibrium of non-concurrent system of forces are

$$R_x = \text{S}F_x = 0, R_y = \text{S}F_y = 0, \text{S}M_A = 0$$

If points A, B and C are not collinear, the following equations of equilibrium may also be used:

$$\text{S}M_A = 0, \text{S}M_B = 0, \text{S}M_C = 0$$

If line AB is not in y-direction, the following set of equilibrium equations may be used

$$R_y = \Sigma F_y = 0, \Sigma M_A = 0, \Sigma M_B = 0.$$

4.2 BEAMS

* A beam is a structural element which has one dimension (length) considerably larger than the other two dimensions in the cross section and is supported at a few points.
* *Types of supports:* Simple supports, roller supports—hinged support and fixed support

Types of Beams:

1. *Determinate Beams*: cantilever, simply supported, one end hinged and other on roller, overhanging
2. *Indeterminate Beams:* both ends hinged, propped cantilever, continuous.

Statically determinate beams are the beams, in which all reaction components at supports can be found using the equations of equilibrium only.

* **Types of Loadings:** Concentrated load, uniformly distributed load (UDL), uniformly varying load (UVL) general loading, external moments.

Analysis of Pin-Jointed Plane Frames

* A pin-jointed frame is a structure made of slender members pin connected at ends and capable of taking loads at joints.
* A perfect frame is the one which retains its shape with minimum number of members and can carry loads applied at joints.
* A frame is said to be deficient, if the number of members in it are less than that required for a perfect frame.
* A frame is said to be redundant, if the number of members in it are more than that required for a perfect frame.
* The assumptions made in the analysis of pin-jointed frames are:
  1. The ends of members are pin-connected.
  2. The loads act at joints only.
  3. Self weight is negligible.
  4. If there are a number of members along a line of truss, they are located along the same longitudinal line.

4.3 FRICTION

* Friction is the resistance to motion offered by minutely projecting particles at the contact surfaces.
* The limiting value of frictional force when the motion is impending, is known as limiting friction upto this state it is static friction.
* The friction experienced by a body while in motion is known as dynamic friction. It may be sliding friction or rolling friction.
* The ratio of limiting friction to normal reaction is known as coefficient of friction.

$$m = \frac{F_{\text{lim}}}{N}$$

* Coulomb's laws of friction:

1. Friction always opposes motion
2. Till the limiting value is reached, the magnitude of friction is exactly equal to the force which tends to move the body.
3. Coefficient of friction for two contacting surface is constant.
4. Frictional force depends upon the roughness of the surfaces in contact.
5. Force of friction does not depend upon the area of contact.
6. Coefficient of dynamic friction is less than coefficient of static friction.

* The angle of limiting friction is the angle between the resultant reaction and the normal to the horizontal plane on which the motion of the body is impending.
* The maximum inclination of the plane on which a body, free from external forces, can repose (sleep) is called angle of repose.
* The inverted cone with semi-central angle a equal to limiting angle of friction is called as cone of friction.
* Rope/belt friction:

$$T_2 = T_1 e^{mq}$$

where T_1 = force on slack side
T_2 = force on tight side
m = coefficient of friction
q = angle of contact.

Law of Machine

$$P = mW + C$$

where P = effort, W = load
C = constant, $m = \tan q$, the slope of line AB in the effort vs load diagram.

Load This is the resistance to be overcome by the machine

Effort This is the force required to overcome resistance

$$\text{Mechanical advantage} = \frac{\text{Load lifted}}{\text{Effort applied}} = \frac{W}{P}$$

$$\text{Velocity ratio} = \frac{\text{Distance moved by effort}}{\text{Distance moved by load}} = \frac{D}{d}$$

Input It is work done by effort = $P \times D$

Output Useful work got out of the machine = Wd.

Efficiency $h = \frac{\text{Output}}{\text{Input}} = \frac{W \times d}{P \times D} = \frac{MA}{\text{Velocity ratio}}$

Ideal machine $h = 1$, i.e., MA = velocity ratio.

Ideal effort Effort required by ideal machine

$$P_i = \frac{W}{VR}$$

Ideal Load Load that can be lifted by ideal machine

$$W_i = V_R \times P$$

Reversibility of a machine If the removal of effort while lifting results in lowering of the load, the machine is said to be reversible. It can be shown that a lifting machine is reversible, if its efficiency is more than 50 per cent and is self-locking if h < 50%.

* In the first order pulley system $VR = 2^n$

In the second order pulley system $VR = 2n$

In the third order pulley system $VR = 2^{n-1}$

where n is the number of pulleys in the system.

* In wheel and axle,

$VR = \frac{D}{d}$, where D = diameter of wheel

and d = diameter of axle

* In wheel and differential axle,

$$VR = \frac{2D}{d_2 - d_1}$$

where D = diameter of effort wheel

d_1 = diameter of larger axle

d_2 = diameter of smaller axle

* In case of Weston differential pulley block,

$$VR = MA = \frac{2D}{D - d}$$

where D = diameter of larger block

d = diameter of smaller wheel of the block

* In case of inclined plane,

$$VR = \frac{1}{\sin \theta}$$

where q is the inclination of plane to horizontal.

* In case of screen jack, while ascending.

$$P = \frac{d}{2R} W \frac{\mu + \tan \theta}{1 - \mu \tan \theta} = \frac{d}{2R} W \tan(\theta + \phi)$$

where P = effort, W = load,

R = length of lever arm

m = coefficient of friction = tan q

$q = \tan^{-1} \frac{p}{\pi d}$

where p = lead of the screw and

d = mean diameter of screw.

while descending

$$P = \frac{d}{2R} W \tan(\theta - \phi)$$

* In case of differential jack,

$$VR = \frac{2\pi R}{P_A - P_B}$$

where R = length of effort arm

P_A = pitch of outer screw

P_B = pitch of inner screw

* Velocity ratio of winch crab is given by

$$VR = \frac{R}{r} \times \frac{T_2}{T_1}$$

where R = length of lever arm

T_1 = number of teeth on pinion

T_2 = number of teeth on spur wheel.

* In case of double purchases winch crab

$$VR = \frac{R}{r} \times \left(\frac{T_2}{T_1}\right)\left(\frac{T_4}{T_3}\right)$$

where R = length of lever arm

T_1, T_2, T_3, T_4 are teeth on wheels 1 to 4 respectively.

Virtual Work Method

* The work done is virtual if the displacements are virtual or forces acting are virtual.
* Virtual work method consists of:
  1. Give an elemental virtual displacement
  2. Find work done by each force in the system
  3. Equate total work done to zero.
* Many times these equations are identical to the equation of equilibrium.

Centroid and Moment of Inertia

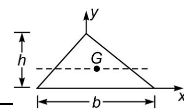
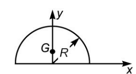
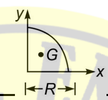
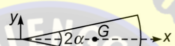
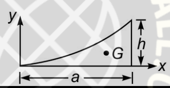
* The term centroid applies to the plane areas and the term centre of gravity applies to the bodies with mass and weight.
* Centre of gravity of a body is the point through which the resultant gravitational force acts.
* Centroid is a point in a plane area such that the moment of area about any axis through that point is

zero.

* Centroid lies on the axis of symmetry, if it exists.
* The distance of centroid from an axis is given by

$$\bar{y} = \frac{\int y\,dA}{A}$$, where y is distance of the element from the axis.

Table 4.1 Centroid of some common figures

Shape	*Figure*	$\bar{x}$	$\bar{y}$	*Area*
Triangle		–	$\frac{h}{3}$	$\frac{bh}{2}$
Semicircle		0	$\frac{4R}{3\pi}$	$\frac{\pi R^2}{2}$
Quarter circle		$\frac{4R}{3\pi}$	$\frac{4R}{3\pi}$	$\frac{\pi R^2}{4}$
Sector of a circle		$\frac{2R}{3\alpha}\sin\alpha$	0	aR^2
Parabolic spandrel		$\frac{3\alpha}{4}$	$\frac{3h}{10}$	$\frac{ah}{3}$

* Centroid of composite figures may be found by

$$\bar{y} = \frac{\sum a_i y_i}{\sum a_i}$$

where a_i = area of ith simple figure

y_i = distance of the centroid of ith simple figure.

* If r is the distance of elemental area dA form the axis AB, the sum of the terms Sr^2dA to cover entire area is called moment of inertia of the area about the axis AB.

$$I_{AB} = \sum r^2 dA = \int r^2 dA$$

* Moment of inertia about an axis perpendicular to the plane of area is known as polar moment of inertia.
* Radius of gyration k is given by

$$k = \sqrt{\frac{I}{A}}$$

where I = moment of inertia

A = area of the cross section.

i.e., $Ak^2 = I$

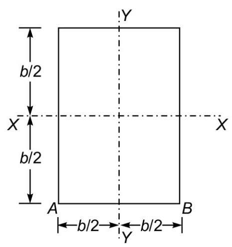
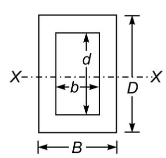
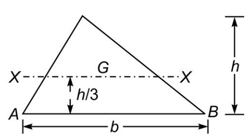
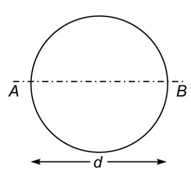
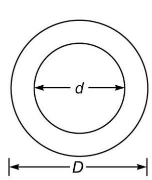
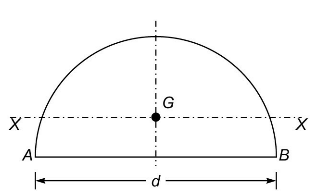
* Perpendicular axis theorem states, 'the moment of inertia' of an area about an axis perpendicular to its plane at any point O, is equal to the sum of moments of inertia about any two mutually perpendicular axes through the same point O and lying in the plane of the area,

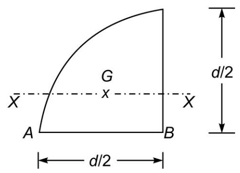
$$I_{zz} = I_{xx} + I_{yy}.$$

* Parallel axis theorem states, 'moment of inertia about any axis in the plane of the area is equal to the sum of moment of inertia about a parallel centroidal axis and the product of area and square of the distance between the two parallel axes.'

$$I_{AB} = I_{GG} + A\,y^2{}_C.$$

Table 4.2 Moment of inertia of standard sections

Shape	*Axis*	*Moment of Inertia*
Rectangle 	(a) Centrodial axis x –x (b) Centroidal axis $y - y$ (c) $A - B$	$I_{xx} = \frac{bd^3}{12}$ $I_{yy} = \frac{db^3}{12}$ $I_{AB} = \frac{bd^3}{3}$
Hollow Rectangle 	Centroidal axis $x - x$	$I_{xx} = \frac{BD^3 - bd^3}{12}$
Triangle 	(a) Centroidal axis $x - x$ (b) Base AB	$I_{xx} = \frac{bh^3}{36}$ $I_{AB} = \frac{bh^3}{12}$
Circle 	Diametral axis	$I = \frac{\pi d^4}{64} = \frac{\pi R^4}{4}$
Hollow Circle 	Diametral axis	$I = \frac{\pi}{64}(D^4 - d^4)$ $= \frac{\pi}{4}(R^4 - r^4)$ where $R = D/2$ and $r = d/2$
Semicircle 	(a) $A - B$ (b) Centroidal axis	$I_{AB} = \frac{\pi d^4}{128}$ $I_{xx} = 0.0068598\ d^4$ $= 0.11\ R^4$ where $R = d/2$

Quarter of a Circle 	(a) $A - B$ (b) Centroidal axis $x - x$	$I_{AB} = \frac{\pi d^4}{256}$ $I_{xx} = 0.00343\ d^4$ $= 0.0055\ R^4$ where $R = d/2$

* Moment of inertia of composite figures
  = sum of moment of inertia of all simple figures about the axis referred.

4.4 CENTRE OF GRAVITY AND MASS MOMENT OF INERTIA

$$W\bar{x} = Sw_i x_i,\ w = \text{weights of elements}$$

$$M\bar{x} = Sw_i x_i,\ m = \text{mass of elements}$$

W – total weight and M – total mass.

* Centre of gravity of right circular cone of base radius r and height h is at a distance $\bar{x} = 3/4\ h$ from apex.
* Centre of gravity of solid hemisphere of radius r from its diametral axis is at $\bar{x} = \frac{3}{8}r$.
* Pappus-Guildinus Theorem–I: The area of surface generated by revolving a plane curve about a non-intersecting axis in the plane of the curve is equal to the length of the curve times the distance travelled by the centroid of the curve in a revolution.
* Pappus-Guildinus Theorem–II: The volume of the solid generated by revolving a plane area about a non-intersecting axis in the plane is equal to the area of the generating plane times the distance travelled by the centroid of the plane area during a revolution.
* Mass moment of inertia of a body about an axis is the sum total of product of its elemental masses and square of their distance from the axis.

$$I_{AB} = \sum r^2\,dm = \int r^2\,dm$$

The unit of mass moment of inertia works out to be N-m-sec^2.

* Radius of gyration of a body is that distance which when squared and multiplied with total mass of the body gives the mass moment of inertia of the body.

$$I = Mk^2 \text{ or } k = \sqrt{I/M}$$

* Mass moment of inertia of a uniform rod of length L and mass M about an axis normal to it at its centroidal axis is

$$I = \frac{ML^2}{12}$$

and about one end is $I = \frac{ML^2}{3}$

* Mass moment of inertia of a rectangular plate of size $a \times b$ and uniform thickness, having total mass M about its centroidal axis is

$$I_{nn} = \frac{Ma^2}{12}, I_{yy} = \frac{Mb^2}{12}$$

$$I_{zz} = \frac{1}{12} M (a^2 + b^2)$$

* Mass moments of inertia of a circular ring of radius R and uniform cross section about a diametral axis is

$$I = \frac{MR^2}{2}$$

* Mass moment of inertia of a solid cone of height h and base radius R

(a) about its axis of rotation $I_{xx} = \frac{3}{10} MR^2$

(b) about an axis through vertex and normal to the axis of rotation $I_{yy} = \frac{3M}{5}\left(h^2 + \frac{R^2}{4}\right)$

* Mass moment of inertia of a solid plate of radius R about its diametral axis

$$I_{yy} = \frac{2}{5} MR^2$$

Dynamics

* A body is said to be in motion, if it is changing its position with respect to a reference point.
* Distance and speed are scalars while displacement and velocity are vectors.
* A motion is said to be translation, if a straight line drawn on the moving body remains parallel to its original position at any time.
* During translation, if the path traced by a point is a straight line, it is called rectilinear translation and if it is curved, it is called curvilinear translation.
* General plane motion is a combination of both translation and rotation.
* If s is displacement, v is velocity and a is acceleration,

$$v = \frac{ds}{dt} \quad a = \frac{dv}{dt} = \frac{d^2s}{dt^2}$$

* If velocity is uniform $a = 0$, and $s = vt$.
* In case of motion with uniform acceleration,

if u – initial velocity, v – final velocity

t – time

$$a = \frac{v-u}{t} \text{ i.e., } v = u + at \text{ i.e., } t = \frac{v-u}{a}$$

$$v^2 - u^2 = 2as, \; s = vt + \frac{1}{2}at^2$$

* In case of motion with varying acceleration,

$$v = \frac{ds}{dt}, \; a = \frac{dv}{dt} = \frac{d^2s}{dt^2} = v\frac{dv}{ds}$$

Projectile If, u = velocity of projection,

a = angle of projection

1. The trajectory is a parabola

$$y = x \tan a - \frac{1}{2}\frac{x^2}{u^2}(1 + \tan^2 a)$$

2. Maximum height reached

$$h = \frac{u^2 \sin^2 \alpha}{2g}$$

3. Time required to reach maximum height

$$t = \frac{u \sin \alpha}{g}$$

4. Time of flight = $\frac{2u \sin \alpha}{g}$

5. Horizontal range $R = \frac{u^2 \sin 2\alpha}{g}$

6. Maximum range is when $a = 45°$

7. Range is the same when $a = 45° + q$ and $45° - q$

Relative velocity Relative velocity of A with respect to B is the vector difference between the velocities of A and B.

$$V_{A/B} = V_A - V_B$$

Resultant velocity It is the vector sum of the velocities caused by different forces acting on a body.

D'Al emberts Principle It states that the system of forces acting on a body in motion is in dynamic equilibrium with the inertia force

$$R - ma = 0$$

The term '$-ma$' is known as inertia force or reverse effective force.

* When a lift is moving downward, with acceleration a

$$R = W(1 - a/g)$$

* When a lift is moving upward, with acceleration a

$$R = W\left(1 + \frac{a}{g}\right)$$

4.5 WORK ENERGY METHOD

* Work done by a force on a moving body is the product of the force and the distance moved by the body in the direction of the force.

* Energy is defined as the capacity to do work.

* Unit of energy and unit of work done are the same, i.e., joules.

$$1 \text{ joule} = 1 \text{ N-m}$$

* Power is defined as rate of doing work. Unit of power is watt.

$$1 \text{ watt} = 1 \text{ N-m/sec.}$$

* Work-energy equation states

Work done = Final K.E – Initial K.E.

i.e., the work done by a system of forces acting on a body during a displacement is equal to the change in kinetic energy of the body during the same displacement.

* Work-energy equation will be more suited if the interest is to find velocity and distance.
* Work done by a spring of stiffness k is

$$= -\frac{1}{2}kx^2$$

where x is distance from normal position of spring.

Impulse Momentum

* Impulse momentum method is more useful in solving problems involving force, time and velocity.
* The equation is

$$\int_{\partial}^{t} R\,dt = mv - mu$$

$$= \text{change in momentum}$$

$\int_{\partial}^{t} R\,dt$ is called impulse

The impulse momentum equation may be stated as the component of the resultant linear impulse along any direction is equal to the change in the component of momentum in that direction.

* The principle of conservation of momentum may be stated as ‘the momentum is conserved in a system in which resultant force is zero. In other words, if the resultant force is zero, the initial momentum will remain equal to the final momentum.

Impact of Elastic Bodies

* A collision between two bodies is said to be impact, if the bodies are in contact for a short interval of time and exert very large force on each other during this short period.
* Common normal to the colliding surface of the two bodies is known as *line of impact*.
* If the motion of the two colliding bodies is directed along the line of impact, the impact is said to be a *direct impact*.
* If the motion of one or both bodies is not directed along the line of impact, the impact is known as *oblique impact*.
* If the mass centres of colliding bodies are on the line of impact, the impact is called *central impact*.
* Even if mass centre of one of the colliding bodies is not on the line of impact, the impact is called *eccentric impact*.
* Period of collision (i.e., time of impact) consists of period of deformation and period of restitution.
* If u_1, u_2 are initial velocities and v_1, v_2 are the final velocities of two colliding bodies along the line of impact, coefficient of restitution

$$e = \frac{v_2 - v_1}{u_1 - u_2}$$

Circular Motion of Rigid Bodies

* When a body moves with uniform velocity v along a curved path of radius r, it has a radical inward acceleration of magnitude v^2/r.

* When a body moves with uniform velocity v along a curved path of radius r, it experiences centrifugal force of magnitude $\frac{w}{g} v^2/r$ in radial outward direction.

* On a circular flat path of radius r, the limiting velocity of a vehicle is $\sqrt{\mu g r}$ to avoid skidding where m is the coefficient of friction between the path and the wheels.

* If h is the height of centre of gravity of vehicle, to avoid overturning it should go at a speed of less than $\sqrt{\frac{gr}{2} \frac{B}{a}}$

  where r = radius of curved path

  B = distance between the wheels of an axle.

* By providing camber/super elevation
  1. Skidding and overturning can be avoided.
  2. Higher speeds can be permitted.
  3. Lateral pressure on wheels may be reduced.
  4. Excess wear and tear of wheels can be avoided.

* The speed on a banked path for which lateral pressure developed is zero is called the design speed on that curve.

4.6 ROTATION OF RIGID BODIES

$$S = rq,\ v_t = r\frac{d\theta}{dt},\ a_t = r\frac{d^2\theta}{dt^2}$$

$$\mathrm{w} = \frac{d\theta}{dt}\ \ a = \frac{d\omega}{dt} = \frac{d^2\theta}{dt^2} = \omega\frac{d\omega}{dt}$$

In case of uniform angular velocity.

$$q = \mathrm{w}t$$

In case of uniformly accelerated angular motion,

$$\mathrm{w} = \mathrm{w}_o + at$$

$$q = \mathrm{w}_o t + \frac{1}{2}\alpha t^2$$

$$\mathrm{w}^2 - \mathrm{w}^2{}_o = 2\ at$$

**** Kinetics of Rigid Body Rotation***

$$M_t = Ia$$

Angular momentum = Iw

$$\text{K.E.} = \frac{1}{2} I\omega^2$$

**** Mechanical Vibration***

* If the disturbing force does not act during vibration, it is called free vibration. If disturbing force

acts at periodical interval on the body, it is called forced vibration.

* Each repetition of motion is called a cycle.
* The time interval required to complete one cycle of vibration is called the *period of vibration* (T)
* The reciprocal of the period is called *frequency* $\left(f = \frac{1}{T}\right)$
* A cycle per second is called one Hertz (Hz)
* The maximum displacement from the equilibrium position is called *amplitude*.
* A motion in which acceleration of the body is directly proportional to its displacement and is directed towards mean position is called *simple harmonic motion* (SHM). Thus, in SHM $a = -kx$
* In case of simple pendulum,

$$T = 2\pi\sqrt{L/g}$$

$$f = \frac{1}{2\pi}\sqrt{g/L},$$

where L is length of pendulum.

General Plane Motion of Rigid Bodies

* A body is said to have general plane motion, if it possesses translation and rotational motion simultaneously.
* For the analysis of general plane motion, it is convenient to split the motion into translational and pure rotation cases.
* At any instant of time it is possible to locate a point in the plane of the motion which has zero velocity and hence plane motion of the other points may be looked upon as pure rotation about this point. Such point is called *instantaneous centre*, and the axis passing through this point and at right angles to the plane of the motion is called *instantaneous axis of rotation*.

MULTIPLE-CHOICE QUESTIONS

I. *Choose the appropriate/correct choice/choices for the following questions.*

1. A particle has
   (a) only mass and no size
   (b) no mass but only size
   (c) neither mass nor size
   (d) none of the above are correct concept of a particle.
2. Newton's law of gravitation in terms of masses m_1, m_2, distance d and constant of gravitation is
   (a) $F = G\frac{m_1}{m_2}d^2$
   (b) $F = G\, m_1\, m_2 d^2$
   (c) $F = G\frac{m_1 m_2}{d^2}$
   (d) $F = \frac{m_1 m_2}{Gd^2}$

3. The law 'the state of rest or motion of the rigid body is unaltered if a force acting on the body is replaced by another force of the same magnitude and direction but acting anywhere on the body along the line of action of the replaced force' is known as
(a) Newton's 4th law
(b) Law of transmissibility
(c) Lami's theorem
(d) D' Alemberts' principle

4. Which one of the following is fundamental law of forces?
(a) Triangle law
(b) Polygonal law
(c) Parallelogram law
(d) Lami's theorem

5. Which one of the following is not a vector?
(a) Distance
(b) Velocity
(c) Acceleration
(d) Momentum

6. Unit of constant of gravitation is
(a) m/sec^2
(b) m-sec
(c) N m^2/kg^2
(d) newton

7. 1 newton is the force required to produce an acceleration of
(a) 9.81 m/sec^2 in a body of mass 1 kg
(b) 1 m/sec^2 in a body of mass 1 kg
(c) 9.81 m/sec^2 in a body of mass 1 kg
(d) none of the above

8. If A = 50 N and B = 120 N and A is at 90° to B, the resultant of AB is
(a) 70 N
(b) 130 N
(c) 190 N
(d) none of the above

9. If a 100 N body rests on a plane inclined at 30° to horizontal the component normal to the plane is
(a) 50 N
(b) 86.6 N
(c) 57.7 N
(d) 75 N

10. The angles between the two forces to make their resultant a minimum and a maximum are respectively

(a) 180° and 0°

(b) 90° and 0°

(c) 180° and 90°

(d) 0° and 180°

11. If two forces P and $P/2$ are acting on a body at right angles to each other the motion of the body will be directed at angle ______ to the direction of the force P.

(a) zero

(b) 30°

(c) 45°

(d) none of above

12. Free-body diagram means

(a) the diagram drawn with free hand

(b) the diagram of a body with applied forces

(c) the diagram of a body with applied forces, self-weight and reactions.

(d) the diagram of a freely suspended body.

13. If a body is in equilibrium under the action of three forces F_1, F_2 and F_3 and a, b and g are the angles between F_2 and F_3, F_3 and F_1, and F_1 and F_2, then according to Lami's theorem

(a) $\frac{F_1}{\sin\alpha} = \frac{F_2}{\sin\beta} = \frac{F_3}{\sin\gamma}$

(b) $\frac{F_1}{\sin\beta} = \frac{F_2}{\sin\gamma} = \frac{F_3}{\sin\alpha}$

(c) $\frac{F_1}{\cos\alpha} = \frac{F_2}{\cos\beta} = \frac{F_3}{\cos\gamma}$

(d) $\frac{F_1}{\cos\beta} = \frac{F_2}{\cos\gamma} = \frac{F_3}{\cos\alpha}$

14. A string is tied to a spindle passing through a smooth ball of weight w and tied to a smooth wall. If the string makes angle q with the wall, reaction of the wall is

(a) $W \sin q$

(b) $W \cos q$

(c) $W \tan q$

(d) $W \cot q$

15. If a roller is to be pulled over a curb with least force q required is

(a) vertical

(b) horizontal

(c) 45° to reaction

(d) 90° to the reaction

16. The law stating that the algebraic sum of moments of a system of coplanar forces about a moment centre is equal to the moment of their resultant force about the same moment centre is known as

(a) Law of transmissibility of forces

(b) Varignon's theorem

(c) Lami's theorem

(d) D'Alembert's principle

17. Which one of the following is the wrong statement about a couple formed by two equal and opposite parallel forces P separated by d. The effect of a couple is unchanged if

(a) the couple is rotated through any angle

(b) the couple is shifted to any position

(c) the couple is replaced by forces $P/2$ magnitude with a separation $d/2$

(d) the couple is replaced by forces of magnitude $2P$ with a separation of $d/2$.

18. If SF_x and SF_y are the summation of forces acting on a body in x and y directions, and SM_o is the sum of the moment of all the forces about the origin o, then x and y intercepts of the resultant are

(a) $\frac{\Sigma M_o}{\Sigma F_x}$ and $\frac{\Sigma M_o}{\Sigma F_y}$

(b) $\frac{\Sigma M_o}{\Sigma F_y}$ and $\frac{\Sigma M_o}{\Sigma F_x}$

(c) $\frac{\Sigma M_o \Sigma F_x}{\Sigma F_y}$ and $\frac{\Sigma M_o \Sigma F_y}{\Sigma F_x}$

(d) none of the above

19. Which one of the following equations is odd in the following group?

(a) $SF_x = SF_y = SF_Z = 0$

(b) $SF_x = SF_y = SM_A = 0$

(c) $SF_y = SM_A = SM_B = 0$, if AB is not in y-direction

(d) $SM_A = SM_B = SM_C = 0$, if A, B, C are not collinear.

20. In a beam of 6 m span with one end hinged and other on roller if 30 kN-m moment is acting at 2 m from support A, then the reaction at A is

(a) 15 kN

(b) 7.5 kN

(c) 5 kN

(d) 4 kN

21. Which one of the following is indeterminate beam?

(a) Simply supported beam

(b) Cantilever

(c) One end hinged, other on roller

(d) Both ends hinged

22. The necessary and sufficient condition for a truss with m number of members and j number of joints to be perfect is

(a) $m = 2j - 3$

(b) $m = 2j + 3$

(c) $j = 2m - 3$

(d) just sufficient members to retain its shape when the load is applied at any joint in any direction

23. Which one of the following is wrong in the list of assumptions for the analysis of pin jointed

tress?

(a) Load acts at joint only

(b) Self-weight neglected

(c) Loads act vertically

(d) Ends of members are pin connected

24. In the method of sections for the analysis of trusses, the section line should

(a) cut at least 3 members

(b) cut only three members

(c) cut 3 members and separate it into two independent parts

(d) cut not more than 3 members and separate the truss into two independent parts.

25. The member force in *AB* of truss shown in the Fig. Q. 25 is

(a) 3 *W*

(b) 4 *W*

(c) 5 *W*

(d) 6 *W*

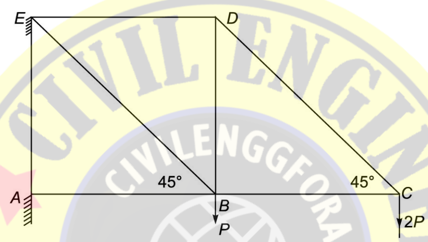


Fig. Q. 25

26. In the truss shown in figure below zero members are

(a) *BC* and *CD*

(b) *BE*, *BC*, *CD*

(c) *BC*, *CD* and *AE*

(d) *BC*, *CD* and *DE*

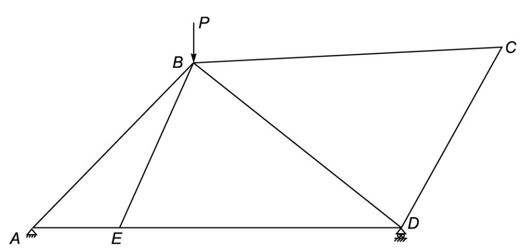


Fig. Q. 26

27. Coefficient of friction is

(a) $\frac{\text{Frictional force}}{\text{Normal reaction}}$

(b) $\frac{\text{Limiting friction}}{\text{Normal reaction}}$

(c) $\frac{\text{Frictional force}}{\text{Total reaction}}$

(d) $\frac{\text{Limiting friction}}{\text{Total reaction}}$

28. The coefficient of friction depends upon

(a) the area of contact
(b) the roughness of the surface
(c) the shape of contact area
(d) all of the above

29. If F is the limiting friction, N is the normal reaction and R is the resultant of F and N, the angle of limiting friction is the

(a) angle between F and N
(b) angle between F and R
(c) angle between N and R
(d) none of the above

30. If f is the angle of repose, then the coefficient of friction m is

(a) tan f
(b) cot f
(c) cos f
(d) sec f

31. The angle of inclined plane with the horizontal when a body placed on it is on the verge of sliding down is known as

(a) angle of friction
(b) cone of friction
(c) coefficient of friction
(d) angle of repose

32. The maximum angle upto which grains can be heaped is known as

(a) angle of friction
(b) cone of friction
(c) coefficient of friction
(d) angle of repose

33. A block weighing W is resting on a plane inclined at q to the horizontal. The coefficient of friction is m. The force P required to pull it up the plane is

(a) $W \sin q - m W \cos q$
(b) $W \sin q + m W \cos q$
(c) $W \cos q - m W \sin q$
(d) $W \cos q + m W \sin q$

34. Compared to static friction, dynamic friction is

(a) more
(b) same
(c) less
(d) depending upon the value of coefficient of friction it may be more or less.

35. Friction is a kind of

(a) active force

(b) reactive force

(c) body force

(d) none of the above

36. If T_1 is the force on slack side and T_2 on tight side of a rape passing over a pulley,

(a) $T_1 = T_2\, e^{mq}$

(b) $T_2 = T_1\, e^{mq}$

(c) $T_1 = mT_2$

(d) $T_2 = mT_1$

37. If P is the effort required to lift a load W, then mechanical advantage is

(a) $\frac{P}{W}$

(b) $\frac{W}{P}$

(c) PW

(d) $\frac{1}{PW}$

38. If D is the distance moved by the effort and d is the distance moved by the load, then the velocity ratio is given by

(a) $\frac{D}{d}$

(b) $\frac{d}{D}$

(c) $d \times D$

(d) $\frac{1}{d \times D}$

39. Efficiency of machine in terms of mechanical advantage (MA) and velocity ratio VR is

(a) $\frac{\text{MA}}{\text{VR}}$

(b) $\frac{\text{VR}}{\text{MA}}$

(c) MA × VR

(d) $\frac{1}{\text{MA} \times \text{VR}}$

40. For the ideal machine,

(a) VR > MA

(b) VR < MA

(c) VR = MA

(d) none of the above

41. If P – actual effort required

P_i – ideal effort required

W – actual load to be lifted.

W_i – ideal load to be lifted

then the efficiency is

(a) $\frac{P_i}{P}$

(b) $\frac{w}{w_i}$

(c) both (a) and (b)

(d) none of the above

42. The law of machine in terms of load (N), effort (P), constants C and m is

(a) $W = mP + C$

(b) $P = mW + C$

(c) $C = mP + W$

(d) $C = mW + P$

43. The efficiency of a self-locking machine is

(a) 100%

(b) more than 50%

(c) less than 50%

(d) none of the above

44. If p is the pitch, d is mean diameter of a screw jack, and P is the effort required for lifting load W, then P is directly proportional to

(a) $W \tan (q - f)$

(b) $W \tan (q + f)$

(c) $W \frac{\tan \theta}{\tan \phi}$

(d) $\frac{W \tan \theta}{\tan \theta}$

where f is angle of friction.

45. Centroid of a semicircle of diameter d from its diametral axis is at a distance

(a) $\frac{d}{3}$

(b) $\frac{d}{\pi}$

(c) $\frac{d}{3\pi}$

(d) $\frac{2d}{3\pi}$

46. Centroid of a sector of circle of radius R and angle $2a$ from its centre of arc is

(a) $\frac{R}{\alpha} \sin \alpha$

(b) $\frac{2R}{\alpha} \sin \alpha$

(c) $\frac{2R}{3\alpha} \sin \alpha$

(d) $\frac{R}{3\alpha} \sin \alpha$

47. Second moment of area of a figure about $x - x$ axis is

(a) Sx^2dA

(b) Sy^2dA

(c) Sr^2dA

(d) S$xydA$

48. Radius of gyration of a section about $x - x$ is

(a) $\sqrt{\frac{I_{xx}}{A}}$

(b) $\sqrt{AI_{xx}}$

(c) $\sqrt{\frac{I_{yy}}{A}}$

(d) $\sqrt{AI_{yy}}$

49. Moment of inertia of a rectangle of side $b \times d$ about its base of width is

(a) $\frac{bd^3}{12}$

(b) $\frac{db^3}{12}$

(c) $\frac{bd^3}{3}$

(d) $\frac{b^3d}{3}$

50. Moment of inertia of a circular section of radius R about its diametrical axis is

(a) $\frac{\pi R^4}{64}$

(b) $\frac{\pi R^4}{32}$

(c) $\frac{\pi R^4}{8}$

(d) $\frac{\pi R^4}{4}$

51. The moment of inertia of a triangle of width b and height h about its base is

(a) $\frac{bh^3}{36}$

(b) $\frac{bh^3}{18}$

(c) $\frac{bh^3}{12}$

(d) $\frac{bh^3}{3}$

52. The centre of gravity of a solid hemisphere of radius R from its diametral axis is

(a) $\frac{4R}{3\pi}$

(b) $\frac{3R}{8}$

(c) $\frac{2R}{\pi}$

(d) $\frac{3R}{4}$

53. The centre of gravity of a semicircular wire of radius R is at a distance ______ from diametral axis.

(a) $\frac{4R}{3\pi}$

(b) $\frac{3R}{4\pi}$

(c) $\frac{R}{\pi}$

(d) $\frac{2R}{\pi}$

54. The unit of mass moment of inertia is

(a) N-m-sec^2

(b) N-m/sec^2

(c) N-m^2/sec

(d) none of the above

55. The mass moment of inertia of a rectangular plate of mass M and sides a and b about an axis perpendicular to plate through its centre is

(a) $\frac{M}{3}(a^2+b^2)$

(b) $\frac{M}{4}(a^2+b^2)$

(c) $\frac{M}{6}(a^2+b^2)$

(d) $\frac{M}{12}(a^2+b^2)$

56. Mass moment of inertia of a uniform rod of mass M and length L about axes normal to it at its centre of gravity is

(a) $\frac{ML^2}{2}$

(b) $\frac{ML^2}{3}$

(c) $\frac{ML^2}{4}$

(d) $\frac{ML^2}{12}$

57. Mass moment of inertia of a uniform rod of mass M and length L about axes normal to it at its end is

(a) $\frac{ML^2}{2}$

(b) $\frac{ML^2}{3}$

(c) $\frac{ML^2}{4}$

(d) $\frac{ML^2}{12}$

58. Mass moment of inertia of a circular cylinder of radius R about its centroidal axis is

(a) $\frac{MR^2}{2}$

(b) $\frac{MR^2}{4}$

(c) $\frac{MR^2}{\pi}$

(d) $\frac{MR^2}{4\pi}$

59. A point on the wheel of a moving vehicle is having
(a) rectilinear translation
(b) curvilinear motion
(c) rotation
(d) general plane motion

60. A body is said to have plane motion when
(a) it moves in a straight line on a plane surface
(b) it moves in a curved path on a plane surface
(c) it rotates around a point
(d) it possesses translation as well as rotation

61. In a velocity time curve the slope represents
(a) velocity
(b) acceleration
(c) displacement
(d) none of the above

62. In a velocity-time curve area under the curve represents
(a) displacement
(b) velocity
(c) acceleration
(d) none of the above

63. In a acceleration-time curve, the velocity is represented by
(a) slope of the curve
(b) ordinate of the curve
(c) area under the curve
(d) none of the above

64. In a displacement-time curve the slope represents
(a) displacement
(b) velocity
(c) acceleration
(d) none of the above

65. A stone is projected vertically upwards from the ground with an initial velocity u m/sec. If g is gravitational acceleration, the stone will come back to the ground after

(a) $\frac{u}{g}$ sec

(b) $\frac{2u}{g}$ sec

(c) $\frac{u}{g}$ sec

(d) $\frac{u_2}{2g}$ sec

66. In the above case, the maximum height reached by the stone is

(a) $\frac{u}{g}$

(b) $\frac{2u}{g}$

(c) $\frac{u^2}{g}$

(d) $\frac{u^2}{2g}$

67. In the above case the velocity at which stone strikes the ground is

(a) more than u
(b) equal to u
(c) less than u
(d) none of the above

68. A stone dropped into a well is heard to strike the water in t_1 second. Then the depth of the well is

(a) $\frac{1}{2}gt_1^2$

(b) less than $\frac{1}{2}gt_1^2$

(c) more than $\frac{1}{2}gt_1^2$

(d) $2gt_1$

69. An automobile starts from rest form a station P and accelerated uniformly to attain a speed of 48 kmph in 30 seconds. Hence, it covers distance ______ to attain this speed.

(a) 200 m
(b) 300 m
(c) 400 m
(d) 450 m

70. The motion of a particle moving in a straight line is given by

$$s = t^3 - 3t^2 + 2t + 5.$$

After 4 seconds, the velocity and accelerations are

(a) 48 m/sec and 40 m/sec^2
(b) 36 m/sec and 24 m/sec^2
(c) 26 m/sec and 18 m/sec^2
(d) none of the above

71. The motion of a particle making in a straight line is given by

$$s = t^3 - 3t^2 + 2t + 5$$

Then the extreme velocity is

(a) 2 m/sec
(b) 1 m/sec
(c) –1 m/sec
(d) –2 m/sec

72. A pilot flying his bomber at a height of 1962 m with a uniform velocity of 720 kmph wants to strike a target. He should release the bomb _______ distance before reaching that target

(a) 4000 m
(b) 3000 m
(c) 2000 m
(d) none of the above

73. If a projectile is fired at angle *a* with initial velocity *u*, it traces the

(a) circular path
(b) parabolic path
(c) catenary path
(d) elliptic path

74. A projectile is fired with initial velocity *u* at an angle 55° to horizontal. Then second projectile was fired with the same velocity but at an angle 35° to horizontal. Then the ratio of horizontal projection of first one to second one is

(a) more than 1
(b) equal to 1
(c) less than 1
(d) May be anything depending upon the value of *u*

75. If air resistance is to be considered, to get maximum range the angle of projection should be

(a) equal to 45°
(b) slightly more than 45°
(c) slightly less than 45° (a) 60°

76. A projectile was fired with initial velocity *u* an angle *a* to horizontal on an inclined plane making angle *b* to horizontal, range is maximum when

(a) $\frac{\pi}{4} + \frac{\beta}{2}$

(b) $\frac{\pi}{4} + \beta$

(c) $\frac{\pi}{4} - \beta/2$

(d) $\frac{\pi}{4} - \beta$

77. A river is flowing at a velocity of 5 kmph. A motor boat can move at a velocity of 10 kmph with uniform velocity. To reach the other bank in minimum time the boat should be set at *q* = … to the direction of flow

(a) 150°

(b) 120°

(c) 90°

(d) 60°

78. The system of forces acting on a moving body is in a dynamic equilibrium with the inertia force of the body. This low is known as

(a) D' Alembert's principle

(b) work-energy principle

(c) impulse momentum theorem

(d) Lami's theorem

79. A man of weight W moves up in a lift. The pressure applied by him on the lift when acceleration is a is,

(a) $W\left(1-\frac{a}{g}\right)$

(b) W

(c) $W\left(1+\frac{a}{g}\right)$

(d) none of the above

80. A block weighing 300 N is attached to one end and a block weighing 450 N is attached to another end of a wire. The system is allowed to move over a smooth pulley. Then the ratio of tension in the wire on 300 N load side to that on 450 N side is

(a) more than 1

(b) less than 1

(c) equal to 1

(d) may be anything depending upon diameter of pulley

81. One Joule of work is equal to

(a) 1 N-mm work

(b) 1 N-m work

(c) 1 kN-m work

(d) none of the above

82. One watt of power is equal to

(a) one joule of work done per second

(b) one kilo-joule of work done per second

(c) one kilo-joule of work done per minute

(d) one joule of work done per minute

83. If v is the final velocity and u is the initial velocity of a body weighing W then work done is

(a) $\frac{W}{g}(v^2-u^2)$

(b) $W(v^2-u^2)$

(c) $\frac{W}{2g}(v^2-u^2)$

(d) $\frac{W}{2}(v^2 - u^2)$

84. In moving a spring of constant k from its undeformed position to displacement x, the work done is equal to

(a) $\frac{1}{2}kx^2$

(b) $-\frac{1}{2}kx^2$

(c) kx

(d) $-kx$

85. The unit of momentum in SI is

(a) N-m/sec

(b) N-m-sec

(c) N/sec

(d) N-sec

86. If R is the resultant force acting on a body of mass m and it is constant during time interval t, then impulse is

(a) mRt

(b) Rt

(c) mt

(d) $\frac{mR}{t}$

87. If a stone of mass m is dropped from a height h on a ground, the velocity of strike is

(a) $\sqrt{2mgh}$

(b) $m\,gh$

(c) $\sqrt{2gh}$

(d) $2\,gh$

88. A glass marble of 0.2 N weight, falls from a height h_1 and rebounds to a height of h_2, the impulse is equal to

(a) $0.2\left[\sqrt{2gh_1} + \sqrt{2gh_2}\right]$

(b) $0.2\left[\sqrt{2gh_1} - \sqrt{2gh_2}\right]$

(c) $\frac{0.2}{g}\left[\sqrt{2gh_1} - \sqrt{2gh_2}\right]$

(d) $\frac{0.2}{g}\left[\sqrt{2gh_1} - \sqrt{2gh_2}\right]$

89. In a system, if the resultant force is zero, initial momentum remains equal to the final momentum. This law is known as

(a) impulse momentum equation

(b) conversation of momentum

(c) work energy equation

(d) equilibrium equation

90. A hammer of weight w falls freely on a pile of weight W from a height h. The velocity of hammer and the pile immediately after the strike is

(a) $\frac{w}{w+W}\sqrt{2gh}$

(b) $\frac{W}{w+W}\sqrt{2gh}$

(c) $\frac{w+W}{w}\sqrt{2gh}$

(d) $\frac{w+W}{W}\sqrt{2gh}$

91. In the above case loss of kinetic energy is equal to

(a) $\frac{w+W}{w}h$

(b) $\frac{W}{w+W}h$

(c) $\frac{wh}{w+W}$

(d) $\frac{wWh}{w+W}$

92. If two bodies moving with velocity u_1 and u_2 start moving with velocities v_1 and v_2 after direct central effect, the coefficient of restitutions is

(a) $\frac{v_1 - v_2}{u_1 - u_2}$

(b) $\frac{v_2 - v_1}{u_1 - u_2}$

(c) $\frac{v_1 - v_2}{u_2 - u_1}$

(d) $\frac{v_2 - v_1}{u_2 - u_1}$

93. Coefficient of restitution in an impact of two bodies is given by

(a) $\frac{\text{Velocity of separation}}{\text{Velocity of approach}}$

(b) $\frac{\text{Velocity of approach}}{\text{Velocity of separation}}$

(c) $\frac{\text{Relative velocity of approach}}{\text{Relative velocity of separation}}$

(d) $\frac{\text{Relative velocity of separation}}{\text{Relative velocity of approach}}$

94. A golf ball is dropped from a height of 10 m on a fixed steel plate. The coefficient of restitution is 0.8. The height to which the ball rebounds after the first bounce is

(a) 8.97 m
(b) 11.21 m
(c) 17.94 m
(d) 22.42 m

95. If a ball is dropped on a smooth ground from a height h and coefficient of restitution is e, after the

second bounce the ball rises to a height of

(a) eh

(b) e^2h

(c) $2eh$

(d) e^4h

96. If W is the weight of the body, v is velocity, S is the distance moved and R is resultant force, work energy equation may be stated as

(a) Kinetic energy = $\frac{1}{2}\frac{W}{g}v^2$

(b) Work done = RS

(c) Work done = Change in kinetic energy

(d) kinetic energy can be changed to other form

97. Unit of momentum is

(a) joule

(b) watt

(c) N-m/sec

(d) n-sec

98. When a body moves in a curved path, centrifugal force to be applied to bring it to dynamic equilibrium is in the direction

(a) radially inward

(b) radially outward

(c) tangentially forward

(d) tangentially backward

99. When a body of mass m moves in a curved path of radius r with velocity v, centrifugal force developed is

(a) $\frac{W}{g}\frac{v^2}{r}$ radially inward

(b) $\frac{W}{g}\frac{v^2}{r}$ radially outward

(c) $\frac{W}{g}vr$ radially inward

(d) $\frac{W}{g}vr$ radially outward

100. If B is base width of vehicle, h height of centre of gravity of the vehicle from road level and r is the radius of curved path, the vehicle is on the verge of overturning when

(a) $\frac{gr}{2}\frac{B}{h}$

(b) $gr\frac{B}{h}$

(c) $\sqrt{\frac{gr}{2}B/h}$

(d) $\sqrt{\frac{gr\,B}{h}}$

101. On curved path banking is provided to
(a) avoid skidding and overturning
(b) permit higher speed
(c) reduce lateral pressure on wheels
(d) all the above

102. Design speed on a banked curved path is
(a) to avoid skidding of the vehicle
(b) to avoid overturning of the vehicle
(c) to avoid lateral pressure on tyres
(d) all the above

103. If a body rotates with uniform angular acceleration a, starting from initial velocity w_o, the velocity w after t seconds and angular distance q, which one of the following is not correct relation?
(a) $w = w_o + at$
(b) $w^2 - w^2_o = 2aq$
(c) $q = \omega_o t + \frac{1}{2}\alpha t^2$
(d) $a = \frac{\omega^2 + \omega_o^2}{2t}$

104. The rotation of a flywheel is governed by the equation $w = 3t^2 - 2t + 2$ where w is in radians per second and t is in second. After 1 second from the start the angular displacement was 4 radians. Then the equation for angular displacement q is
(a) $t^3 - t^2 + 2t + 2$
(b) $t^3 - t^2 + 2t$
(c) $6t - 2$
(d) none of the above

105. If I is mass moment of inertia, a is angular acceleration, w is angular velocity, q is angular distance, angular momentum is
(a) Iw
(b) Ia
(c) $\frac{I\theta}{\omega}$
(d) $\frac{I\alpha}{\omega}$

106. A motion in which acceleration of the body is directly proportional to its displacement and directed towards the origin is called
(a) angular motion
(b) curvilinear motion
(c) circular motion
(d) simple harmonic motion

107. At the instantaneous centre, the velocity of the moving lamina at any instant is

(a) zero
(b) maximum
(c) minimum
(d) varying

108. Instantaneous centre for a wheel rolling on straight road is at
(a) point where it touches ground
(b) at top of the weel
(c) in the forward extreme point
(d) in the backward extreme point

109. Instantaneous centre is at infinity when the angular velocity is
(a) maximum
(b) constant
(c) zero
(d) minimum

110. A 3 m long ladder rests against a wall and makes an angle of 60° with the horizontal. When ladder starts slipping, the instantaneous centre is at
(a) 2.6 m from the floor and 1.5 m from wall
(b) 2.6 m from the wall and 1.5 from floor
(c) 1.73 m from the wall and 1.5 m from floor
(d) 1.73 m from the floor and 1.5 m from wall

II. Match List-I with List-II selecting answer codes given below (questions nos. 111–118).

111.

	List I		**List II**
A.	nano	1.	1×10^{-9}
B.	mega	2.	1×10^{-6}
C.	Giga	3.	1×10^{6}
D.	micro	4.	1×10^{9}

Codes:

(a)	A – 2	B – 1	C – 4	D – 3
(b)	A – 3	B – 2	C – 4	D – 1
(c)	A – 2	B – 3	C – 1	D – 4
(d)	A – 1	B – 3	C – 4	D – 2

112.

	List I		**List II**
A.	Collinear forces	1.	Forces on a uniform rod resting against a wall
B.	Coplanar concurrent forces	2.	A tripod carrying a camera

C.	Non-coplanar parallel forces		3.	Forces on the rope in a tug of war
D.	Non-coplanar concurrent forces		4.	The weight of benches in a classroom

Codes:

(a)	A – 2	B – 3	C – 4	D – 1
(b)	A – 3	B – 1	C – 4	D – 2
(c)	A – 2	B – 4	C – 3	D – 1
(d)	A – 1	B – 2	C – 4	D – 3

113.

	List I Type of beam		List II No. of reactions
A.	Cantilever	1.	6
B.	Simply supported beam	2.	4
C.	Propped cantilever	3.	3
D.	Fixed beam	4.	2

Codes:

(a)	A – 4	B – 3	C – 1	D – 2
(b)	A – 4	B – 3	C – 2	D – 1
(c)	A – 2	B – 3	C – 4	D – 1
(d)	A – 3	B – 4	C – 2	D – 1

114.

	List I Pully system		List II Velocity ratio
A.	Single pulley	1.	$2n$
B.	First order n pulleys	2.	1
C.	Second order n pulleys	3.	$2^n – 1$
D.	Third order n pulleys	4.	2^n

Codes:

(a)	A – 1	B – 2	C – 4	D – 3
(b)	A – 2	B – 4	C – 1	D – 3
(c)	A – 2	B – 4	C – 3	D – 1
(d)	A – 3	B – 4	C – 1	D – 2

115.

List I	List II
Shape of section	**Distance of centroid**
A. Triangle of base width b and height h	1. $3h/10$
B. Parabolic spandrel of the form $y = kx^2$ with $y_{max} = h$	2. $\frac{3}{4}h$
C. Parabolic spandrel of the form $y^2 = kx$ with $y_{max} = h$	3. $h/3$
D. Right circular cone of height h	4. $\frac{3h}{5}$

Codes:

(a)	A – 2	B – 3	C – 4	D – 1
(b)	A – 3	B – 4	C – 1	D – 2
(c)	A – 2	B – 1	C – 4	D – 3
(d)	A – 3	B – 1	C – 4	D – 2

116.

List I	List II
Shape of section	**Moment of inertia**
A. Triangle about its centroid	1. $\frac{\pi R^4}{4}$
B. Triangle about its base	2. $\frac{\pi R^4}{8}$
C. Circle about diametral axis	3. $bh^3/36$
D. Semicircle about diametral axis	4. $\frac{bh^3}{12}$

Codes:

(a)	A – 3	B – 4	C – 1	D – 2
(b)	A – 4	B – 3	C – 1	D – 2
(c)	A – 4	B – 3	C – 2	D – 1
(d)	A – 3	B – 4	C – 2	D – 1

117.

List I	List II
Mass moment of inertia of	**Value of M.M.I.**
A. Circular plate about its diametral axis	1. $\frac{2}{5}MR^2$
B. Circular ring about diametral axis	2. $\frac{3}{10}MR^2$
C. Solid cone about its axis of rotation	3. $\frac{MR^2}{2}$

D. Solid sphere about its diametral axis 4. $\frac{MR^2}{4}$

Codes:

(a)	A – 3	B – 4	C – 2	D – 1
(b)	A – 4	B – 3	C – 2	D – 1
(c)	A – 3	B – 4	C – 2	D – 1
(d)	A – 4	B – 3	C – 1	D – 2

118. A projectile is fired at angle a to horizontal with initial velocity. Match List-I with List-II given below.

	List I		**List II**
A.	Maximum height reached	1.	$\frac{u \sin \alpha}{g}$
B.	Time required to reach maximum height	2.	$\frac{u^2 \sin 2\alpha}{g}$
C.	Total time of flight	3.	$\frac{u^2 \sin^2 \alpha}{2g}$
D.	Horizontal range on flat ground surface	4.	$\frac{2u \sin \alpha}{g}$

Codes:

(a)	A – 3	B – 4	C – 1	D – 2
(b)	A – 3	B – 1	C – 4	D – 2
(c)	A – 4	B – 1	C – 3	D – 2
(d)	A – 4	B – 2	C – 3	D – 1

III. Select your answer according to the coding system given below for the Assertion (A) and Reason (R) given in question Nos. 119 and 120.

(a) Both A and R are true and R is the correct explanation of A.
(b) Both A and R are true but R is not the correct explanation of A.
(c) A is true but R is false.
(d) A is false but R is true.

119. A : In the method of section for the analysis of plane trusses, the section line should cut 3 members and separate the truss into two separate parts.
R : There are only 3 independent equations of equilibrium in a non-concurrent coplanar force system.

120. A : A symmetric axis is a principal axis.
R : Product moment of inertia about a symmetric axis is zero.

IV. State whether the following statements are True (T) or False (F).

121. When a body is taken out in a spacecraft, its mass changes.
122. When a body is taken out in space craft its weight changes.
123. The product of mass and velocity is known as momentum.
124. The term displacement is same as the term distance.
125. A particle has only size and no mass.
126. Newton's first law leads to the definition of force.
127. According to Newton's law of gravitation, the force of attraction between the bodies of mass m_1 and mass m_2 at a distance d is

$$F = G \frac{m_1 m_2}{d^2}$$

where G is constant of gravitation.
128. Law of transmissibility of force is applicable to rigid bodies only.
129. The law of parallelogram of forces cannot be proved theoretically.
130. Triangle law and polygonal law of force are not fundamental laws. They are only derived laws.
131. Unit of a force is kg-m/sec^2.
132. 1 pascal = 1 N/m^2.
133. 1 GN = 1×10^6 kN.
134. The weight of benches in a classroom constitute a system of coplanar parallel forces.
135. If F_1 and F_2 are two forces in a plane and angle between them is q, their resultant is given by

$$R = \sqrt{F_1^2 + 2F_1 F_2 \tan\theta + F_2^2}$$

136. Lami's theorem states that if a body is in equilibrium under the action of only three forces, each force is proportional to the sine of the angle between the other two forces.
137. A 600 N cylinder is supported by the Frame $ABCD$ as shown in Fig. Q. 137. The frame is hinged at D. The direction of reaction at D makes angle 71.56° to horizontal.

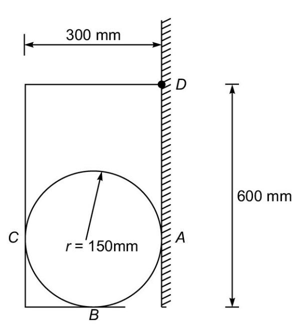


Fig. Q. 137

138. Varignon's theorem states that the sum of momentum of a system of forces is equal to the momentum of their resultant forces.
139. If SM_o is the sum of moments of a system of coplanar forces about O, and SF_x is the summation of x components of all forces, the x intercept of resultant is given by

$$x = \frac{\sum M_o}{\sum F_x}$$

140. A beam with both ends hinged is a statically determinate beam.

141. The compound beam shown in the Fig. Q. 141 is a statically determinate beam.

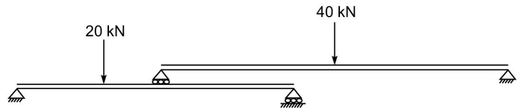


Fig. Q. 141

142. The necessary and sufficient condition for a pin jointed plane frame to be perfect is

$$m = 2J - 3$$

where m = number of members

J = number of joints.

143. The force in the member CD of the truss shown in Fig. Q. 143 is zero.

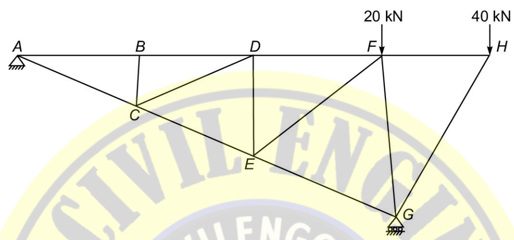


Fig. Q. 143

144. For the analysis of pin jointed truss shown in Fig. Q. 144, the method of joint is ideally suited.

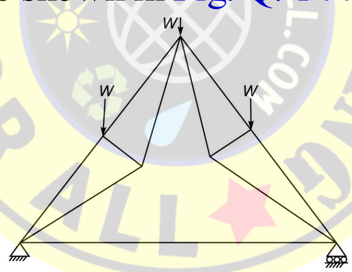


Fig. Q. 144

145. Dynamic friction is more than limiting friction.

146. The force of friction depends on the area of contact between the two surfaces.

147. The maximum inclination of the plane on which a body, free from external forces, can stay is called angle of repose.

148. Efficiency of a lifting machine is equal to the ratio of mechanical advantage to velocity ratio.

149. In an ideal machine velocity ratio is more than mechanical advantage.

150. A machine is reversible, if its efficiency is more than 50%.

151. In a differential screw jack velocity ratio VR is given by

$$VR = \frac{2\pi R}{P_A - P_B}$$

where $P_A - P_B$ is difference in pitches of two screws and R is lower arm of handle.

152. Moment of inertia about an axis perpendicular to the plane of the area is called polar moment of

inertia.

153. In a right circular cone, centre of gravity lies at a distance $\frac{3}{4} \times \text{height}$.

154. Pappus-Guildness theorems are for finding surface area and volumes generated by rotating a curve and a plane area about a non-intersecting axis.

155. To get maximum range a projectile should be thrown at 60° to horizontal.

156. A man exerts more pressure on a lift while the lift is moving downward compared to when lift is moving upward.

157. One joule of work is defined as the amount of work done by one newton force when the particle moves by 1 m in the direction of that force.

158. The work done by a spring of stiffness k when it is compressed by x distance is ($-1/2\ kx^2$).

159. Coefficient of restitution is the ratio of velocity of approach to the velocity of separation.

160. When a body moves with uniform velocity v along a curved path of radius r, it has a radial inward acceleration of magnitude $\frac{v^2}{r}$.

Answers to Multiple-Choice Questions

1. (a)	2. (c)	3. (b)	4. (c)	5. (a)
6. (c)	7. (b)	8. (b)	9. (b)	10. (a)
11. (b)	12. (c)	13. (a)	14. (c)	15. (d)
16. (b)	17. (c)	18. (b)	19. (a)	20. (c)
21. (d)	22. (d)	23. (c)	24. (d)	25. (c)
26. (b)	27. (b)	28. (b)	29. (c)	30. (a)
31. (a)	32. (d)	33. (b)	34. (c)	35. (b)
36. (a)	37. (a)	38. (a)	39. (a)	40. (c)
41. (c)	42. (b)	43. (c)	44. (b)	45. (d)
46. (c)	47. (b)	48. (a)	49. (c)	50. (d)
51. (c)	52. (b)	53. (d)	54. (b)	55. (d)
56. (d)	57. (b)	58. (a)	59. (d)	60. (d)
61. (b)	62. (a)	63. (c)	64. (b)	65. (b)
66. (d)	67. (b)	68. (b)	69. (a)	70. (c)
71. (c)	72. (a)	73. (b)	74. (b)	75. (b)
76. (a)	77. (b)	78. (a)	79. (c)	80. (c)
81. (b)	82. (a)	83. (c)	84. (b)	85. (d)
86. (b)	87. (c)	88. (c)	89. (b)	90. (a)
91. (d)	92. (b)	93. (d)	94. (a)	95. (d)
96. (c)	97. (d)	98. (b)	99. (b)	100. (c)

101. (d)	102. (c)	103. (d)	104. (a)	105. (a)
106. (d)	107. (a)	108. (a)	109. (c)	110. (a)
111. (d)	112. (b)	113. (d)	114. (b)	115. (d)
116. (a)	117. (b)	118. (b)	119. (a)	120. (a)
121. False	122. True	123. True	124. False	125. False
126. True	127. True	128. True	129. True	130. True
131. True	132. True	133. True	134. False	135. False
136. True	137. True	138. False	139. False	140. False
141. True	142. False	143. True	144. False	145. False
146. False	147. True	148. True	149. False	150. True
151. True	152. True	153. True	154. True	155. False
156. False	157. True	158. True	159. False	160. True

5

Strength of Materials

5.1 INTRODUCTION

* Basic assumptions:
  1. Materials are continuous
  2. Material is homogeneous
  3. Material is isotropic
  4. Material is free from internal forces prior to the loading considered (residual stresses are zero).
* Fundamental laws
  1. Elastic behaviour
  2. Law of superposition holds good.
  3. St. Venant principle holds good. In other words stress concentrations at the points of load and geometric discontinuities are not considered in the analysis.

5.2 SIMPLE STRESSES AND STRAINS

* Stress is resistance per unit area.
* Unit of stress is N/m^2 or N/mm^2.
* 1 MPa = 1 N/m^2 \ 1 MPa = 1 N/mm^2.
* In case of direct forces,

$$\text{Stress} = \frac{\text{Force}}{\text{Area}}$$

Strain: Strain is change in dimension for unit of original dimension.

$$\text{Linear strain} = \frac{\text{Change in length}}{\text{Original length}}$$

$$\text{Lateral strain} = \frac{\text{Change is lateral direction}}{\text{Original lateral dimension}}$$

* Behaviour of mild steel in tension:

1. Limit of proportionality: It is the limiting value of the stress up to which stress is proportional to strain.

2. Elastic limit: It is the limiting value of the stress upto which if the material is stressed and then released, the strain disappears completely and the original shape and size is regained.

3. Upper yield point: At this stress the load starts reducing and extension increases.

4. Lower yield point: This is the stress at which the load starts reducing and the extension increases.

5. Ultimate stress: This is the maximum nominal stress the material can resist. At this stage formation of neck starts.

6. Breaking point: The nominal stress at which the specimen finally breaks into two parts is called breaking point.

* If unloading is made within elastic limit, the stress-strain curve follows the original straight portion. If unloading is made after elastic limit, the stress-strain curve traced is parallel to original curve with a certain amount of permanent set.

* In case of aluminium and high strength steel, there is no yield point. The stress at which if unloading is made, there going to be 0.2 % permanent set, is treated as yield point.

* In case of brittle materials, there is no appreciable strain. There is no yield point and no necking. The ultimate and breaking points are one and the same.

* Percentage elongation: It is the ratio of the final extension at rupture to the original length, expressed as percentage.

$$\% \text{ elongation} = \frac{L - L'}{L} \times 100.$$

In case of steel it is 20 to 25%

* Percentage reduction in area: It is the ratio of maximum changes in the cross-sectional area to the original cross-sectional area, expressed as percentage.

$$\% \text{ reduction in area} = \frac{A - A'}{A} \times 100.$$

* Nominal stress = $\frac{\text{Load}}{\text{Original cross-sectional area}}$

True stress = $\frac{\text{Load}}{\text{Actual cross-sectional area}}$

* The maximum stress at which even a billion reversal of stress cannot cause failure of the material is called endurance limit of the material.

$$\text{Factor of safety} = \frac{\text{Ultimate stress}}{\text{Working stress}}$$

In case of elastic materials, instead of ultimate stress, yield stress or 0.2% proof stress is considered in defining factor of safety.

* Hooke's law states, stress is proportional to strain within elastic limit.

$p \propto e$, within elastic limit.

* Elongation $\Delta = \frac{PL}{AE}$

where P = axial load, L = length

A = CS area and E = modulus of elasticity

* The extension of the bar of uniform thickness tapering from width b_1 ro b_2 in a length L, and subject to axial load

$$= \frac{PL}{tE(b_1 - b_2)} \log \frac{b_1}{b_2}$$

* The extension of a bar tapering uniformly from diameter d_1 to d_2 in length L and subject to axial pull

P

$$= \frac{PL}{E\pi/4\, d_1 d_2}$$

* Extension of a bar of uniform cross section A and length L, due to self weight

$$= \frac{\gamma L^2}{2E}$$

where g = unit weight E = Young's modulus.

* The extension of a conical bar of diameter D at one end to zero at the other end in length L due to self-weight only

$$= \frac{\gamma L^2}{6E}$$

where g = unit weight and E = Young's modulus.

* If a compound bar of two materials is subjected to axial force, the conditions to be satisfied are

$$P_1 + P_2 = P \text{ and } \frac{P_1 L_1}{A_1 E_1} = \frac{P_2 L_2}{A_2 E_2}$$

* If a is the coefficient of thermal expansion, t is change in temperature and L is the length, free expansion of the box is

$$\text{D} = a\, t\, L.$$

* Due to change in temperature stresses induced in a bar are so as to cause change in length equal to free expansion prevented.

Simple Shear

* A material is said to be in a state of simple shear, if it is subjected to only shearing stresses.
* Simple shear gives rise to tensile and compressive stresses across planes inclined at 45° to the shearing planes, the intensity of direct stresses being same as the shearing stresses.
* Poisson's ratio: Poisson's ratio is the ratio of lateral strain to linear strain within elastic limit.

$$m = \frac{\text{Lateral strain}}{\text{Linear strain}}$$

* For most of metals Poisson's ratio is between 0.25 to 0.33. For steel its value is 0.3. For concrete its value is 0.15.
* Volumetric strain: The ratio of change in volume to original volume is known as volumetric strain.

$$e_v = \frac{\delta V}{V}$$

* Volumetric strain is equal to the sum of strains in three mutually perpendicular directions $e_v = e_x + e_y + e_z$.

Elastic Constants

* Modulus of elasticity, modulus of rigidity and bulk modulus are the elastic constants.
* Modulus of rigidity is defined as the ratio of shearing stress to the shearing strain within elastic

limit.

$$G = \frac{q}{\phi}$$

where q = shearing stress and f = shearing strain

* Bulk modulus: Bulk modulus is the ratio of identical pressure p acting in three mutually perpendicular directions (hydrostatic pressure) to the corresponding volumetric strain.

$$K = \frac{p}{e_v}$$

* E, G, K and m have the following relations:

$$E = 2G(1 + m) = 3K(1 - 2m)$$

$$\frac{9}{E} = \frac{3}{G} + \frac{1}{K}$$

$$E = \frac{9KG}{G + 3K}$$

Strain Energy

* The energy which is stored in a body duty to straining, is called strain energy.

* Strain energy = $\frac{1}{2} \times \text{Stress} \times \text{Strain} \times \text{Volume}$

$$= \frac{1}{2} \times p \times \frac{p}{E} \times V = \frac{1}{2}\frac{p^2}{E}V$$

* Strain energy per unit volume is known as resilience. Thus,

$$\text{Resilience} = \frac{p^2}{2E}$$

* The maximum strain energy which can be stored by a body without undergoing permanent deformation is called proof résistance. In other words, proof resilience is the strain energy in the body when it is strained to elastic limit.

$$\text{Proof resilience} = \frac{p_y^2}{2E}$$

* Stress developed due to application of a load p suddenly is twice that due to same load applied gradually.

$$p = 2 \times \frac{P}{A}$$

* The stress developed in the material of a bar due to free falling load W from a height h is

$$p = \frac{W}{A}\left[1 + \sqrt{1 + \frac{2AEh}{WL}}\right]$$

where A = Cross-section of the bar

and E = Young's modulus.

Since the term $\frac{2AEh}{WL}$ is very large compared to unity, the above expression for instantaneous stress may be approximated as,

$$p = \sqrt{\frac{2EhW}{AL}}$$

* If U units of shock load is applied to a bar of length L, the stress developed is

$$p = \frac{q^2}{2L} V$$

* Strain energy due to shear stress q is

$$\text{S.E} = \frac{q^2}{2G} V.$$

5.3 COMPOUND STRESSES AND STRAINS

* Stress tensor in 3 dimensions may be represented as

$$\begin{bmatrix} p_x & q_{xy} & q_{xz} \\ q_{yx} & p_y & q_{yz} \\ q_{zx} & q_{zy} & p_z \end{bmatrix} \text{ or } \begin{bmatrix} \sigma_x & \tau_{xy} & \tau_{xz} \\ \tau_{yx} & \sigma_y & \tau_{yz} \\ \tau_{zx} & \tau_{zy} & \sigma_z \end{bmatrix}$$

But $q_{xy} = q_{yx}$, $q_{yz} = q_{zy}$ and $q_{xz} = q_{zx}$.

Hence, stress tensor is $[p_x \; p_y \; p_z \; q_{xy} \; q_{yz} \; q_{zx}]^T$

* In case of uniaxial stress system

$$p_x = p\cos^2 q \text{ and } p_t = \frac{p}{2} \sin 2\, q$$

where q is the inclination of the plane to the plane of uniaxial stress.

\ Shearing stress is maximum at when $q = 45°$.

* In case of biaxial stress,

$$P_x = \frac{p_1 + p_2}{2} + \frac{p_1 - p_2}{2} \cos 2\theta$$

$$\text{and } p_t = \frac{p_1 - p_2}{2} \sin 2\theta$$

where q is the inclination of the plane of stress p_1.

* In case of general two-dimensional stress system

$$p_n = \frac{p_x + p_y}{2} + \frac{p_x - p_y}{2} \cos 2\theta + q \sin 2\theta$$

$$p_t = \frac{p_x - p_y}{2} \sin 2\theta - q \cos 2\theta$$

* The planes on which shearing stresses do not exist are defined as principal planes. Incidentally, they are the planes of maximum and minimum direct stresses.

* Principal plane is given by

$$\tan 2\, q = \frac{2q}{p_x - p_y}$$

* Magnitude of principal stresses are

$$p_1 = \frac{p_x + p_y}{2} + \sqrt{\left(\frac{p_x - p_y}{2}\right)^2 + q^2}$$

$$p_2 = \frac{p_x + p_y}{2} - \sqrt{\left(\frac{p_x - p_y}{2}\right)^2 + q^2}$$

Maximum shear stress occurs at 45° to the principal planes and its magnitude is

$$q_{\max} = \sqrt{\left(\frac{p_x - p_y}{2}\right)^2 + q^2}$$

* Mohr's circle of stress: A circle with centre at $a = \frac{p_x + p_y}{2}$ and radius $R = \sqrt{\left(\frac{p_x - p_y}{2}\right)^2 + q^2}$ in a Cartesian system with direct stress along x-axis and shearing stresses along y-axis is called Mohr's circle.

Principal Strain

* In three-dimensional system strain vector is

$$[e_x\ e_y\ e_z\ g_{xy}\ g_{yz}\ g_{zx}]^T$$

or $[\mathrm{e}_x\ \mathrm{e}_y\ \mathrm{e}_z\ g_{xy}\ g_{yz}\ g_{zx}]^T$

* $e_n = \frac{e_x + e_y}{2} + \frac{e_x - e_y}{2}\cos 2\theta + \frac{1}{2}\gamma_{xy}\sin 2\theta$

$e_t = \frac{e_x + e_y}{2} + \frac{e_x - e_y}{2}\cos 2\theta + \frac{1}{2}\gamma_{xy}\sin 2\theta$

* Principal strain is the normal strain on the plane where shearing strain is zero.

$\tan 2q = \frac{\gamma_{xy}}{e_x - e_y}$, gives the principal shear strain plane.

$$e_{1,2} = \frac{1}{2}\left(\frac{e_x + e_y}{2}\right) \pm \frac{1}{2}\sqrt{(e_x - e_y)^2 + \gamma_{xy}^2}$$

$$g_{\max} = \frac{1}{2}\sqrt{(e_x - e_y)^2 + \gamma_{xy}^2}$$

* Principal strains can be found by constructing Mohr's circle for strains on the same line as Mohr's circle for stresses.

Strain Gauges

* Strain is a physical quantity and stress is only a concept. Hence, in any experimental investigation strain is to be measured not the stress.

To construct Mohr's circle: (Ref Fig. 5.1)

1. Select Cartesian coordinate system with x-axis as direct stress axis and y-axis as shearing stress axis.
2. Locate point D representing state of stress on the plane of p_x.
3. Locate point E to represent state of stress on the plane of p_y.
4. Join DE. Let it intersect x-axis at C.

5. C as centre draw a circle of radius $R = CD = CE$.

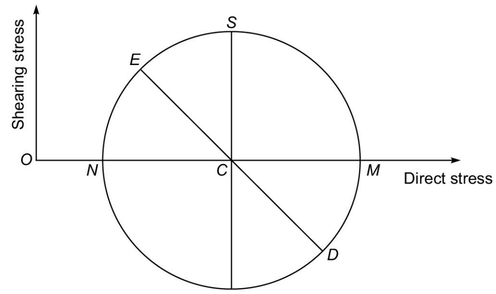


Fig. 5.1 Mohr's circle for stress

Then,

M = Represents maximum principal stress

N = Maximum principal stress

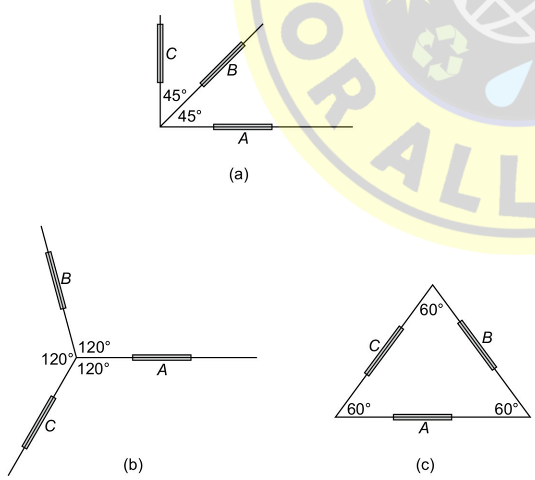
S = Maximum shear stress

* There are mechanical as well as electrical strain gauges. Electrical strain gauges are based on the principle of Wheatstone bridge. It measures the change of resistance in the wire of strain gauge and indicates the strain.

* Shearing strain cannot be measured whereas longitudinal strain can be measured. To overcome this problem, at any point, strains in three directions are measured using strain rosettes. With these measured strains shearing strain can be easily calculated.

* The following types of rosettes are generally used:

1. 45° Rosette



2. 120° Rosette

Fig. 5.2 Strain rosettes

* Generalized Hooke's law is

$$\{p\} = \{D\} \ \{e\}$$

$$6 \times 1 \quad 6 \times 6 \quad 6 \times 1$$

* For isotropic materials, Hooke's law reduces to

$$\begin{Bmatrix} p_x \\ p_y \\ p_z \\ q_{xy} \\ q_{yz} \\ q_{zx} \end{Bmatrix} = \frac{E}{(1+\mu)(1-2\mu)} \begin{bmatrix} 1-\mu & \mu & \mu & 0 & 0 & 0 \\ & 1-\mu & \mu & 0 & 0 & 0 \\ & & 1-\mu & 0 & 0 & 0 \\ \text{Sym.} & & & \frac{1-2\mu}{2} & 0 & 0 \\ & & & & \frac{1-2\mu}{2} & 0 \\ & & & & & \frac{1-2\mu}{2} \end{bmatrix} \begin{Bmatrix} e_x \\ e_y \\ e_z \\ \gamma_{xy} \\ \gamma_{yz} \\ \gamma_{zx} \end{Bmatrix}$$

5.4 THEORIES OF FAILURE

1. ***Maximum principal stress theory (Rankine's Theory)*** According to this theory a material in complex state of stress fails, when the maximum principal stress in it reaches the value of stress at elastic limit in simple tension. This theory is reasonably good for brittle materials.
2. ***Maximum shear stress theory (Coulomb's Theory)*** According to this theory, a material in complex state of stress fails when the maximum shearing stress in it reaches the value of shearing stress at elastic limit in uniaxial tension test.

$$p_1 - p_3 = p_e$$

where p_1 = maximum principal stress

p_3 = minimum principal stress

p_e = stress at elastic limit in uniaxial tension.

This theory gives better results for ductile material with elastic limit same in tension and compression (e.g., steel)

3. ***Maximum strain theory (St. Venant's Theory)*** According to this theory, failure in complex system occurs when the maximum strain in it reaches the value of the strain in uniaxial stress at elastic limit.

$$p_1 - m(p_2 + p_3) = p_e$$

This is suited for materials failing with brittle fractures.

4. ***Maximum strain energy theory (Beltrami and Haigh's Theory)*** According to this theory, a material in a complex stress system fails when the maximum strain energy per unit volume at a point reaches the value of strain energy per unit volume at elastic limit in simple tension test. The condition reduces to

$$p_1^2 + p^2_2 + p^3_3 - 2\,m\,(p_1p_2 + p_2p_3 + p_3p_1) = p_e^2$$

Many investigators have proved that this theory does not predict failure correctly.

5. ***Maximum distortion energy theory (Von-Mises Criteria)*** According to this theory, part of strain energy causes changes only in volume and the rest causes distortion. At failure the energy causing distortion per unit volume is equal to the distortion energy per unit volume at elastic limit in uniaxial tensile test. The condition reduces to

$$(p_1 - p_2)^2 + (p_2 - p_3)^2 + (p_3 - p_1)^2 = 2p_e^2.$$

This is suitable for all ductile materials.

5.5 SHEAR FORCE AND BENDING MOMENT DIAGRAMS

* Shear force at a section in a beam is the force that tries to shear off the section and is obtained as the algebraic sum of all the forces including the reactions acting normal to the axis of the beam either to the left or to the right of the section.

* Bending moment at a section in a beam is the moment that tries to bend it and is obtained as the algebraic sum of the moments of all the forces about the section, including reactions, acting on the beam either to the left or to the right of the section.

* $\frac{dM}{d_x} = -F$ and $\frac{dF}{d_x} = w$

where M = moment; F = shear force and w = load intensity

* A diagram in which the ordinate represents shear force and the abscissa represents the position of the section is known as shear force diagram.

* Bending moment diagram is a diagram in which the ordinate represents bending moment and the abscissa represents the position of the section.

* Bending moment is having extreme values where shear force is zero, since $\frac{dM}{d_x} = -F$.

* At the point of symmetry shear force is zero.

* Point of contraflexure is the point where bending moment changes its sign.

5.6 STRESSES IN BEAMS

* The layer in the loaded beam where stresses are zero is known as neutral layer. The trace of neutral layer in the cross section of the beam is known as neutral axis.

Assumptions

1. Beam is initially straight.
2. Every layer of it is free to expand or contract.
3. Young's modulus is same in tension and compression.
4. Material is homogeneous and isotropic.
5. Stresses are within elastic limit.
6. Plane section remains plane even after bending.
7. The radius of curvature is large compared to the depth of beam.
8. The cross-sectional area is symmetric about an axis normal to the neutral axis.

* Bending equation is

$$\frac{M}{I} = \frac{f}{Y} = \frac{E}{R}$$

* Modulus of section $z = \frac{I}{y_{\max}}$

$$z \text{ for rectangular section} = \frac{1}{6} bd^2$$

$$z \text{ for circular section} = \frac{\pi d^3}{32}$$

$$z \text{ for triangular section} = \frac{bh^2}{24}$$

Composite Beams/Flitched Beams

The beams of different materials rigidly connected are known as composite/flitched beams.
If E_1 and E_2 are the moduli of elasticity of two materials of a flitched beam, it may be looked as a beam of material 1, when its material 2 width is changed to $\frac{E_2}{E_1}$

Beams of Uniform Strength

* A beam in which maximum bending stress at all cross sections is the same, is known as a beam of uniform strength. Since bending moment varies for different loads, any beam may be made beam of uniform strength for a particular loading only.
* For a concentrated load on simply supported beam a beam of uniform strength of constant depth is as shown in Fig. 5.3.

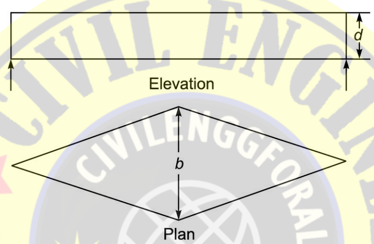


Fig. 5.3 Beam of uniform strength for S.S. beam subject to concentrated load of centre

* Figure 5.4 shows a beam of uniform strength for central concentrated load on a simply supported beam.

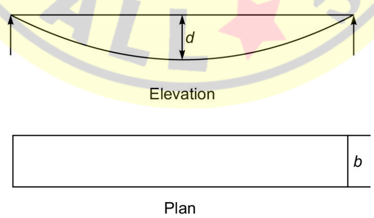


Fig. 5.4 Beam of uniform strength for simply supported beam subjected to UDF

* Leaf spring is a practical example of beam of uniform strength. It consists to of n number of spring plates of different lengths but of the same width b and thickness t joined at the middle. For such springs

$$Z = n \times \frac{1}{6} bt^2$$

Shearing Stresses in Beams

* Shearing stress $q = \frac{F}{bI}(a\bar{y})$

where F = shear force at section
b = width of section

I = moment of inertia of the section

and $a\bar{y}$ = moment of area above the section under consideration about neutral axis.

* Shear stress across a section varies parabolically with zero stress at top and bottom free edges.

* Maximum shearing stresses:

Section	*At*	q_{max}
1. Rectangular	$y = d/2$	$1.5\ q_{av}$.
2. Circular	$y = d/2$	$4/3\ q_{av}$.
3. Isosceles triangle	$y = h/2$	$1.5\ q_{av}$

* In a triangular section, at centroid

$$q = \frac{4}{3} q_{av}.$$

Note. Shearing stress is maximum at neutral axis in case of rectangular and circular sections but in case of triangular section it is at half the depth of the section.

Deflection of Beams

* In a bent beam, radius of curvature of a bent beam is given by

$$\frac{1}{R} = \frac{d^2y/dx^2}{\left[1+\left(\frac{dy}{dx}\right)^2\right]^{3/2}}$$

If deflections are small $\frac{dy}{dx}$ is negligible compared to unity. Hence, in small deflection theory,

$$\frac{1}{R} = \frac{d^2y}{dx^2}$$

* If sagging moment and upward deflections are taken positive,

$$EI\frac{d^2y}{dx^2} = M$$

If sagging moment and downward deflections are taken positive

$$EI\frac{d^2y}{dx} = -M.$$

Other Useful Equations

$$\text{Deflection} = y$$

$$\text{Slope } q = \frac{dy}{dx}$$

$$\text{Moment } M = -\ EI\frac{d^2y}{dx^2}$$

$$\text{Shear force } F = -\frac{dM}{dx} = EI\frac{d^2y}{dx^2}$$

$$\text{Load intensity } w = \frac{dF}{dx} = EI\frac{d^3y}{dx^3}$$

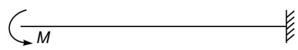
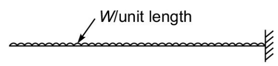
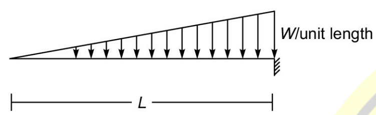
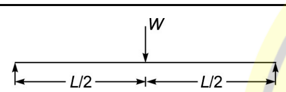
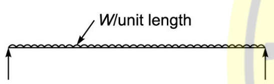
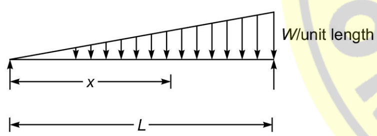
Boundary Conditions

(a) At simply supported/roller ends, $y = 0$

(b) At fixed ends: $y = 0$ and $\frac{dy}{dx} = 0$.

(c) At the point of symmetry $\frac{dy}{dx} = 0$.

Table 5.1 Maximum slopes and deflections in cantilever and simply supported beams subjected to different types of loads

Case	*Max. slope*	*Max. deflection*
	$\frac{ML}{EI}$ at free end	$\frac{ML^2}{2EI}$ at free end
	$\frac{WL^2}{2EI}$ at free end	$\frac{WL^3}{3EI}$ at free end
	$\frac{WL^3}{6EI}$ at free end	$\frac{WL^4}{8EI}$ at free end
	$\frac{WL^3}{24EI}$ at free end	$\frac{WL^4}{30EI}$ at free end
	$-\frac{WL^2}{16EI}$ at support	$\frac{WL^4}{48EI}$ at mid span
	$\frac{WL^3}{24EI}$ at support	$\frac{5}{384}\frac{WL^4}{EI}$ at mid span
	$\frac{WL^3}{45EI}$ at $x = L$	$0.006523\frac{WL^4}{EI}$ at $x = 0.5193\ L$

Moment Area Theorems

1. The change in the slope between two points on a straight member under flexure is equal to the area of $\frac{M}{EI}$ diagram between those two points.

2. Deflection at a point in a beam in the direction perpendicular to its original straight line position measured from the tangent to the elastic curve at another point is given by the moment of $\frac{M}{EI}$ diagram about the point where deflection is required.

Conjugate Beam

Conjugate beam is an imaginary beam of the same span as the original beam loaded with $\frac{M}{EI}$. Diagram of the original beam such that the shear force and bending moment at a section represents the rotation and deflection at the section in the original beam.

Table 5.2 Ends in original and corresponding conjugate beams

Sr. No.	End A in Original Beam	End A in Conjugate Beam
1	A $\theta \neq 0, \Delta = 0$	A $F \neq 0, M = 0$
2	A $\theta \neq 0, \Delta = 0$	A $F \neq 0, M = 0$
3	A $\theta \neq 0, \Delta = 0$	A $F = 0, M = 0$
4	A $\theta \neq 0, \Delta \neq 0$	A $F \neq 0, M \neq 0$
5	$\theta \neq 0, \Delta = 0$ A	$F \neq 0, M = 0$ A
6	$\theta = \neq 0, \Delta \neq 0$ A	$F \neq 0, M \neq 0$ A

Deflections by Energy Methods

* Stain energy due to bending

$$U = \int_0^L \frac{M^2}{2EI} dx$$

* Shear strain energy is very small compared to strain energy due to bending moment. Hence, shear strain energy may be neglected.

* Deflections in beams may be found from the principles of conservation of energy. Thus

$$U = \sum_0^n \frac{1}{2} P\Delta$$

* Bernauli's principle of virtual displacement states: 'If a rigid body is in equilibrium under a system of forces and/or moments, the virtual work done by this system of forces and/or moments during virtual displacement is zero'.

\ Virtual work done by the force system

= Internal virtual strain energy

$$W_g = W_i.$$

* Unit load method of finding deflection is derived from the principle of virtual work. According to it, the deflection at a point D is given by

$$D = \int p' e dv$$

where $p¢$ is stress in the element due to unit load applied.

$e¢$ is strain in the element due to given load system.

Castigliano's Theorem

* Theorem: In a linearly elastic structure, partial derivative of the strain energy with respect to a load

is equal to the deflection of the point where the load is acting, the deflection being measured in the direction of the load.

* If there is a load at the point acting in the desired direction of deflection, write strain expressions in terms of that load. Then differential total energy w.r.t that load, find partial derivative of strain energy to get the desired deflection.
* If no load is acting at the point and in desired direction of deflection, apply dummy load (*P* or *M*), write expression for strain energy, differentiate with respect to dummy load, and then make dummy load zero to get the desired deflection.

Maxwell's Reciprocal Theorem of Displacement

* Displacement at point *A* due to a unit load at point *B* is same as displacement at point *B* due to the unit load at *A*, the displacements being measured in the direction of unit loads.

5.7 TORSION

* A member is said to be in torsion when it is subjected to moment about its axis (twisting moment).
* The torsion equation is derived with the following assumptions:
  1. The material is homogeneous and isotropic.
  2. The stresses are within elastic limit.
  3. The plane cross section remains plane even after twisting.
  4. Radial lines remain radial even after applying torsional moment.
  5. The twist along the shaft is uniform.
* Torsion equation is

$$\frac{T}{J} = \frac{q}{r} = \frac{G\theta}{L}$$

$\frac{J}{R}$ is known as polar modulus of section

where J = Polar moment of inertia, and
R = Radial distance of extreme fibre.

$$\backslash\ Z_p = \frac{\pi}{16} d_1^3 \text{, for circular sections}$$

$= \frac{\pi}{16} \frac{d_1^4 - d_2^4}{d_1}$, for hollow circular sections.

* Power transmitted

$$P = \frac{2\pi NT}{60}$$

where T = Torque
N = RPM

Note 1 watt = 1 N-m/sec work done.
\ 1 kilowatt = 1000 watt.

* Torsional rigidity, *GJ* may be looked as the torque required to introduce a unit angle of twist in a

unit length. since $T = \frac{GJ}{L}\theta$.

* Shear keys are used to connect shafts to flywheels. If L is length and b is width of shear key, torque transferred by key

$$= q_k \, LbR$$

where q_k is shear stress developed in the key.

* The transfer of torque between coupling and shafts is through keys. The two parts of the couplings are held together by a number of bolts, arranged along a circle, called bolt circle.

If n = Number of bolts

R_b = Radius of bolt circle.

d_b = Diameter of bolts

q_b = Stress developed in bolt

the torque transferred by a coupling

$$T = n \cdot \frac{\pi}{4} d_b^2 \, q_b \, R_b.$$

* Strain energy in torsion

$$= \frac{1}{2} \times T \times \theta.$$

\ For solid shafts strain energy

$$U = \frac{q_s^2}{4G} \times \text{Volume.}$$

For hollow shafts

$$U = \frac{1}{4} \frac{d_1^2 + d_2^2}{G d_1^2} \times q_s \times \text{Volume.}$$

* *Closed coiled helical spring:*

The spring is under torsional moment = WR

where W = axial load on spring and

R = radius of spring,

Strain energy of the spring = $\frac{32\,W^2 R^3}{Gd^n} \times n$

where n = total number of coils.

If d is axial deformation

$$d = \frac{64\,WR^3}{Gd^n} \times n$$

\ Stiffness of spring = $\frac{W}{\delta} = \frac{Gd^4}{64\,R^3\,n}$

* For built-up section with rectangular elements, J is not polar modulus of inertia. It is known as torsional constant

$$J = \sum_{i}^{n} \frac{b_i^3 d_i^3}{3.58\,(b_i^3 + d_i^3)} \ldots \text{(A)}$$

$$\text{or } J = \sum_{i=1}^{n} \frac{1}{3} b_i^3 d_i^3 \left(1 - 0.63\frac{b_i}{d_i}\right) \ldots \text{(B)}$$

where b is smaller dimension and d is larger dimension of rectangular section of the element

Equation A gives better results when $\frac{b}{d} \le 1.6$ and Equation B gives better results when $\frac{b}{d} \ge 1.6$.

5.8 THIN AND THICK CYLINDERS AND SPHERES

* Assumptions in the analysis of their cylinders:
  1. Radial stresses are negligible.
  2. The hoop and longitudinal stress distribution across the section is uniform.
* Circumferential stress in thin cylinder

$$f_1 = \frac{pd}{2t}$$

and longitudinal stress

$$f_2 = \frac{pd}{4t}$$

* Strains:
  1. Circumferential strain $e_1 = \frac{Pd}{4tE}[2 - \mu]$
  2. Longitudinal strain $e_2 = \frac{pd}{4tE}[1 - 2\mu]$
  3. Volumetric strain $\frac{\delta V}{V} = \frac{pd}{4tE}[5 - 4\mu]$
  4. Diametral strain = Circumferential strain.
* If h_1 is efficiency of joints in longitudinal direction and h_2 is efficiency of joints in circumferential direction, thickness required is

$$\frac{pd}{2t\eta_1} \text{ or } \frac{pd}{2t\eta_2} \text{ whichever is higher.}$$

Thick Cylinders

When the thickness of a cylinder is more than $\frac{1}{10}$th of the diameter, the assumptions that the radial stress are negligible and hoop stress is uniform across the cross section do not hold good.

* With the assumption 'longitudinal strain is uniform across the cross section' for thick cylinders, Lame's equations are

$$p_x = \frac{b}{x^2} - a \text{ and } f_x = \frac{b}{x^2} + a$$

where p_x = radial stress

and f_x = hoop stress.

$$\text{Hoop stress} = \frac{pd}{4t}$$

Circumferential strain = Diameteral strain

$$= \frac{pd}{4tE}[1 - m]$$

Volumetric strain $= 3e = \frac{3pd}{4tE}[1-\mu]$

If the shell is riveted with efficiency h,

$$f = \frac{pd}{4t\eta}$$

Thick Spherical Shells

$$p_x = \frac{2b}{x^3} - a, f_x = \frac{b}{x^3} + a$$

5.9 COLUMNS AND STRUTS

* Short columns subjected to axial load

$$P = f_c A$$

* Short columns subjected to uniaxial moment

$$f_{max} = \frac{P}{A}\left[1 + \frac{6e}{b}\right]$$

$$f_{min} = \frac{P}{A}\left[1 - \frac{6e}{b}\right]$$

* Short columns subjected to biaxial moments

$$f_{max} = \frac{P}{A}\left[1 + \frac{6e_1}{b} + \frac{6e_2}{d}\right]$$

$$f_{min} = \frac{P}{A}\left[1 - \frac{6e_1}{b_1} - \frac{6e_2}{d}\right]$$

* The area in short column in which if load acts, nowhere in column tension develops, is known as kern of the section.

The kern of rectangular section is of diamond shape with diagonals $\frac{b}{3}$ and $d/3$.

* Kern of a circular section is a circle of radius $\frac{d}{8}$ i.e. of diameter $\frac{d}{4}$.

* For long columns Euler's buckling load is derived with the following assumptions:

1. The material of the column is homogeneous, isotropic and elastic.
2. The section of the column is uniform throughout.
3. The column is initially straight and loaded axially.
4. Self-weight of the column is negligible.
5. Column fails by buckling alone.
6. The end conditions are ideal.

Table 5.3 Euler's buckling loads

End conditions	*Buckling Load*	*Equivalent Length*
1. Both ends hinged	$\frac{\pi^2 EI}{l^2}$	$L = 1$
2. One end fixed, other end free	$\frac{\pi^2 EI}{4l^2}$	$L = 2l$
3. Both ends fixed	$\frac{4\pi^2 EI}{l^2}$	$L = \frac{l}{2}$
4. One end fixed other end hinged	$\frac{2\pi^2 EI}{l^2}$	$L = \frac{l}{\sqrt{2}}$

* Validity of Euler's theory is subject to the condition that the failure of the column is due to buckling.

Hence, it is valid if the slenderness ratio $\frac{L}{K} > \sqrt{\frac{\pi^2 E}{f_c}}$

For steel $\frac{L}{K} > 78.54$

* Rankine's formula:

It is based on the experimental investigation. According to Rankine,

$$\frac{1}{P_{cr}} = \frac{1}{P_C} + \frac{1}{P_E}$$

where P_c = Crushing load $\frac{P}{4}$

$$P_E = \text{Euler's buckling load} = \frac{\pi^2 EI}{L^2}$$

\ $P_{cr} = \frac{f_C A}{1 + a\,(L/K)^2}$

Table: 5.4 Rankine's constant for different materials

S.No.	*Material*	*f_C in N/mm^2*	*$a = f_C/p^2E$*
1.	Mild steel	320	1/7500
2.	Cast iron	550	1/1600
3.	Wrought iron	250	1/9000
4.	Timber	50	1/750

* *Secant Formula*

$$\frac{P}{A} = \frac{f_{\max}}{1 + \frac{ec}{K^2}\sec\left(\frac{1}{2}\sqrt{\frac{P}{E_A}}\frac{L}{r}\right)}$$

IS : 800 accepted this formula for the design of steel structures till 1984. The present formula accepted by IS : 800 is,

$$s_{ac} = 0.6\,\frac{f_{cc}\,f_y}{\left[(f_{cc})^n + (6_y)^n\right]^{1/n}}$$

where s_{ac} = permissible stress in axial compression in N/mm^2.

$$f_y = \text{yield stress}$$

$$f_{cc} = \frac{\pi^2 E}{[L/k]^2}$$

n is a factor assumed as 1.4.

MULTIPLE-CHOICE QUESTIONS

I. *Choose the appropriate correct choice/choices from the following questions (questions 1–126)*

1. Stress at any point in a material is defined as
   (a) load per unit area
   (b) resisting force per unit area
   (c) modulus elasticity times strain
   (d) none of the above

2. 1 mega pascal (MPa) is,
   (a) 1×10^6 N/m^2
   (b) 1 N/m^2
   (c) 1 kN/m^2
   (d) none of the above

3. Simple stress means
   (a) direct tensile stress
   (b) direct compressive stress
   (c) shear stress
   (d) only one type of stress

4. Linear strain is defined as
   (a) change in length per unit original length
   (b) extension per unit original length
   (c) shortening per unit original length
   (d) none of the above

5. In a tension test on a bar, gauge length means
   (a) grip to grip distance
   (b) the length over which extensometer grips
   (c) the length over which extension is measured
   (d) none of the above

6. Elastic limit means
   (a) limiting value of stress upto which stress is proportional to strain
   (b) limiting value of stress upto which if the material is stressed and then released, strain disappears completely
   (c) the stress remains the same but strain increases
   (d) none of the above

7. 0.2 per cent proof stress means
(a) stress corresponding to 0.2 percent strain
(b) 0.2 per cent of ultimate stress
(c) stress at which if unloading is made, there will be 0.2 per cent permanent set
(d) none of the above

8. In case of cast iron
(a) there is no yield point
(b) no necking takes place
(c) ultimate point and breaking point are one and the same
(d) all the above

9. In case of mild steel (i) percentage elongation is 20 to 25 and (ii) percentage reduction in the cross sectional area is 60 to 70.
(a) both (i) and (ii) are correct
(b) (i) is correct and (ii) is wrong
(c) (i) is wrong and (ii) is correct
(d) both (i) and (ii) are wrong

10. In case of steel, the strain at yield point is
(a) 0.0125%
(b) 0.125%
(c) 1.25%
(d) 12.50%

11. In case of brittle materials the ratio of ultimate compressive stress to ultimate tensile stress is
(a) equal to 1
(b) more than 1
(c) less than 1
(d) may be any thing. No definite relation exists.

12. Endurance limit is
(a) the maximum stress a material can sustain for very long time
(b) the maximum stress a material can take under direct loading
(c) the maximum bending stress the material can take
(d) the maximum stress at which even a billion reversal of stress cannot cause failure of the material

13. In case of steel, the factor of safety taken is
(a) 1.85
(b) 2.5
(c) 3.0
(d) 4 to 5

14. According to Robert Hooke, stress is proportional to strain upto
(a) proportionality limit
(b) elastic limit

(c) yield point

(d) ultimate stress

15. Bar A has diameter d and bar B has diameter $2d$. Both are of the same length and are of the same material. If they are subjected to same axial load P, the ratio of extension A to extension of B are

(a) 4

(b) 2

(c) 0.5

(d) 0.25

16. Bar A has diameter d and length L. Bar B has diameter $2d$ and length $2L$. The ratio of extension A to extension B is

(a) 4

(b) 2

(c) 0.5

(d) 0.25

17. A bar of uniform thickness t tapers uniformly from a width of b at one end to b_2 at the other end in a length L. Under axial pull P, the extension of the bar is

(a) $\frac{PL}{tE(b_1 - b_2)} \log(b_2 - b_1)$

(b) $\frac{PL}{tE(b_1 - b_2)}$

(c) $\frac{PL}{tE(b_1 - b_2)} \log\frac{b_1}{b_2}$

(d) $\frac{2PL}{tE(b_1 - b_2)}$

18. A tapering rod has diameter d, at one end and it tapers uniformly to a diameter d_2 at the other end in a length L. If the modulus of elasticity is E, the extension of the rod under axial pull p is

(a) $\frac{PL}{\pi/4(d_1 - d_2)^2 E}$

(b) $\frac{PL}{\pi/4\left(\frac{d_1 d_2}{2}\right)^2}$

(c) $\frac{PL}{\pi/4\left(\frac{d_1 + d_2}{2}\right)^2 E}$

(d) $\frac{PL}{\pi/4 d_1 d_2 E}$

19. A bar of uniform cross section A and length L is suspended from top. The extension of the bar due to self-weight only in terms of Young's modulus E and unit weight g is

(a) $\frac{\gamma L^2}{2E}$

(b) $\frac{\gamma L^2}{AE}$

(c) $\frac{\gamma L}{2E}$

(d) $\frac{\gamma L}{AE}$

20. A solid conical bar of uniformly varying diameter has diameter D at one end and zero at the other end. If the length of the bar is L, modulus of elasticity E and unit weight g, the extension of the bar due to self-weight only is

(a) $\frac{\gamma L^2}{2E}$

(b) $\frac{\gamma L^2}{6E}$

(c) $\frac{\gamma L^2}{2ED}$

(d) $\frac{\gamma L^2}{6ED}$

21. The coefficient of thermal expansion of steel is 12×10^{-6}/°C and that of stainless steel is 18×10^{-6}/°C. Length of steel bar is twice the length of stainless steel bar. The ratio of expansion of steel bar to expansion of stainless steel bar, when there is rise of temperature is

(a) $\frac{1}{3}$

(b) $\frac{2}{3}$

(c) 1.0

(d) 4/3

22. In a rail track, the gap between two rails, each of length L is d. If coefficient of thermal expansion of rails is a, A is the cross-sectional area, t is rise in temperature and E is the Young's modulus, force P developed in the rails is given by

(a) $\frac{PL}{AE} = \alpha t L + \delta$

(b) $\frac{PL}{AE} = \alpha t L - \delta$

(c) $\frac{PL}{AE} = 2\alpha t L + \delta$

(d) $\frac{PL}{AE} = 2t\alpha L - \delta$

23. A bar of brass is enclosed in a steel tube and are rigidly fastened at both the ends. If the coefficient of thermal expansion of brass is more than that of the steel, when temperature rises, the nature of stresses developed are

(a) tensile in steel and compressive in brass bar

(a) compressive in steel and tensile in brass bars

(a) tensile in both steel and brass bars

(a) compressive in both steel and brass bars

24. Figure Q. 24 shows an element in the material subject to shearing stresses of magnitude q. Then stresses along AC and BD are

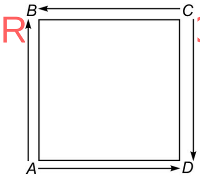


Fig. Q. 24

(a) tensile stresses of intensity q
(b) tensile stresses of intensity $q\sqrt{2}$
(c) tensile stress along AC and compressive stress along BD
(d) compressive stress along AC and tensile stress along BD

25. Poisson's ratio is

(a) $\frac{\text{Linear stress}}{\text{Lateral stress}}$

(b) $\frac{\text{Lateral stress}}{\text{Linear stress}}$

(c) $\frac{\text{Linear strain}}{\text{Lateral strain}}$

(d) $\frac{\text{Lateral strain}}{\text{Linear strain}}$

26. The relationship among modulus of elasticity E, modulus of rigidity G and Poisson's ratio m is given by
(a) $E = 2G(1 - m)$
(b) $E = 3G(1 - m)$
(c) $E = 2G(1 + m)$
(d) $E = 3G(1 + m)$

27. The relationship among modulus of elasticity E, bulk modulus K and Poisson's ratio m is
(a) $E = 3K(1 + 2m)$
(b) $E = 3K(1 - 2m)$
(c) $E = 2K(1 + m)$
(d) $E = 2K(1 - 2m)$

28. The relationship among modulus of elasticity E, modulus of rigidity G and bulk modulus K is

(a) $\frac{3}{E} = \frac{9}{G} - \frac{1}{K}$

(b) $\frac{3}{E} = \frac{9}{G} + \frac{1}{K}$

(c) $\frac{9}{E} = \frac{3}{G} - \frac{1}{K}$

(d) $\frac{9}{E} = \frac{3}{G} + \frac{1}{K}$

29. If a bar of volume V is stressed in axial direction by p and Young's modulus is E, strain energy stored is

(a) $\frac{p^2}{E}V$

(b) $\frac{p^2}{3E}V$

(c) $\frac{p^2}{2E}V$

(d) $\frac{p^2}{4E}V$

30. Bar A and bar B are made up of the same material and are of same length but bar A has diameter d while bar B has diameter $2d$. If both are subjected to same axial load, the ratio of strain energy of bar B to strain energy of bar A is

(a) 8
(b) 4
(c) 2
(d) 1

31. For the bars of A and B referred in Q. No. 30, the ratio of resilience of bar B to bar A is

(a) 1
(b) 1/2
(c) $\frac{1}{4}$
(d) 1/8

32. Stress developed due to application of a load suddenly is _______ times that due to same load being applied gradually.

(a) 0.5
(b) 1.0
(c) 2.0
(d) 4.0

33. A load W falls through a height 'h' before applying load on a bar. Second time it falls from a height $2h$. The ratio of instantaneous stresses developed in case 1 to case 2 is approximately equal to

(a) 4
(b) 2
(c) 1
(d) $1/\sqrt{2}$

34. The instantaneous stress induced in a bar of length L, cross-sectional area A, modulus of elasticity E due to a freely falling weight W from a height h is approximately equal to

(a) $\sqrt{\frac{2EhW}{AL}}$

(b) $\frac{2EhW}{AL}$

(c) $\sqrt{\frac{EhW}{AL}}$

(d) $\frac{EhW}{AL}$

35. Liming value of Poisson's ratio are

(a) 0 and 0.5

(b) –1 and 0.5

(c) –1 and –0.5
(d) 1 and –0.5

36. If a material has identical properties in all directions, it is said to be
(a) elastic
(b) isotropic
(c) orthotropic
(d) homogeneous

37. If a simply supported beam AB of span is subjected to an external moment M at distance a from end A, the reactions R_A and R_B are

(a) $R_A = \frac{M_o}{L}$, $R_B = -\frac{M_o}{L}$

(b) $R_A = \frac{M_o(L-a)}{L}$, $R_B = \frac{M_o a}{L}$

(c) $R_A = \frac{M_o a}{L}$, $R_B = \frac{M_o(L-a)}{L}$

(d) $R_A = \frac{M_o}{L}$, $R_B = \frac{M_o}{L}$

38. In a overhanging beam ABC, $AB = L$ and $BC = a$, C being free end. If it is subjected to a vertical load W at free end, maximum moment occurs at
(a) A
(b) B
(c) C
(d) between A and B

39. A simply supported beam is subjected to a linearly varying load from one end to other end. The nature of variation of shear force diagram is
(a) linear
(b) parabolic
(c) elliptic
(d) 3rd degree curve

40. In the case in Q. No. 39, the variation of bending moment diagram is
(a) linear
(b) parabolic
(c) elliptic (a) 3rd degree curve

41. Point of contraflexure in a beam is the point where bending moment
(a) is zero
(b) changes sign
(c) is maximum
(d) is minimum

42. In a simply supported beam of span L subjected to a concentrated load W at distance 'a' from one end maximum bending moment is

(a) Wa

(b) $\frac{Wa(L-a)}{L}$

(c) $W(L-a)$

(d) none of the above

43. A portion of beam between two sections is said to be in pure bending, when there is

(a) constant bending moment and constant shear force

(b) constant bending moment and zero shear force

(c) zero bending moment and constant shear force

(d) zero bending moment and zero shear force

44. With usual notations for bending moment, bending stress, modulus of elasticity, moment of inertia, radius of curvature and distance of fibre from neutral axis, bending equation

(a) $\frac{M}{R}=\frac{f}{I}=\frac{E}{y}$

(b) $\frac{M}{y}=\frac{f}{R}=\frac{E}{I}$

(c) $\frac{M}{R}=\frac{f}{y}=\frac{E}{I}$

(d) $\frac{M}{I}=\frac{f}{y}=\frac{E}{R}$

45. Section modulus of the breadth with breadth b and depth d is

(a) $\frac{1}{12}bd^3$

(b) $\frac{1}{3}bd^3$

(c) $\frac{1}{6}bd^2$

(d) $\frac{1}{3}bd^2$

46. Modulus of section of beam of circular section of diameter d is

(a) $\frac{\pi d^3}{32}$

(b) $\frac{\pi d^3}{64}$

(c) $\frac{\pi d^4}{32}$

(d) $\frac{\pi d^4}{64}$

47. Section modulus of a triangular cross-section of width b and height h is

(a) $\frac{bh^3}{36}$

(b) $\frac{bh^3}{24}$

(c) $\frac{bh^2}{24}$

(d) $\frac{bh^2}{18}$

48. The maximum flexural stress in timber joist of the flitched beam shown Fig. Q. 48 is 6 N/mm^2, then the maximum stress reached in steel is ______. Given the ratio of Young's modulus of steel to timber is 20.

(a) 60 N/mm^2

(b) 90 N/mm^2

(c) 120 N/mm^2

(d) 180 N/mm^2

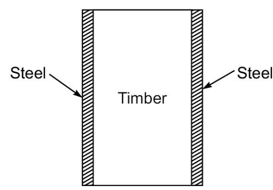


Fig. Q. 48

49. Beam of uniform strength means

(a) a beam with uniform cross section

(b) a beam subjected to same moment throughout

(c) a beam in which maximum bending stress is same at all sections

(d) a beam with same maximum shear stress at all sections

50. A simply supported beam subject to a central concentrated load is to be made beam of uniform strength. If its depth is to be the same throughout, its shape in plan is

(a) rectangular

(b) diamond

(c) parabolic

(d) triangular

51. A leaf spring is a practical example of a beam of uniform strength since

(a) it consists of a number of leaves of same cross section

(b) section modulus is varied in steps depending upon the moment

(c) it absorbs shocks on the body uniformly

(d) it deflects uniformly.

52. In the standard expression for shearing stress in a beam $\left(q = \frac{f}{bI} a\bar{y}\right)$, the term $a\bar{y}$ refers to

(a) moment of area above the section under consideration about neutral axis

(b) moment of area above the neutral axis about neutral axis

(c) moment of the area of the section about the base of the section

(d) none of the above

53. In any beam, shear stress at extreme fibre and neutral axis are respectively

(a) zero and zero

(b) maximum and maximum

(c) maximum and zero

(d) zero and maximum

54. Maximum shear stress in a beam of rectangular cross section is ______ times the average shear stress

(a) 1.25

(b) 1.5

(c) 2.0

(d) 4.0

55. Maximum shear stress in a beam of circular section is ______ times the average stress.

(a) 1.25

(b) 1.33

(c) 1.5

(d) 1.67

56. In case of a beam of triangular section maximum stress occurs at ______ depth and its value is ______ times the average stress.

(a) $\frac{1}{3}$rd, 1.33

(b) $\frac{2}{3}$rd, 2.0

(c) $\frac{2}{3}$rd, 1.5

(d) half, 1.5

57. In case of a beam with triangular section of base width 200 mm and height 100 mm, maximum shear stress due to a shear force of 20 kN is

(a) 2.67 N/mm^2

(b) 3.0 N/mm^2

(c) 1.33 N/mm^2

(d) 1.5 N/mm^2

58. A cantilever of span 1 m has rectangular cross section of size 200 mm × 400 mm. If maximum shear stress permitted is 1.5 N/mm^2, at free end it can carry a maximum load of

(a) 60 kN

(b) 80 kN

(c) 120 kN

(d) 180 kN

59 In case of a cantilever of span L subject to external moment (M) at free end, the deflection (y_{max}) and rotation (q_{max}) at free end are

(a) $q_{max} = \frac{ML}{1.5\,EI}$, $y_{max} = \frac{ML^2}{2\,EI}$

(b) $q_{max} = \frac{ML}{2EI}, y_{max} = \frac{ML^2}{3EI}$

(c) $q_{max} = \frac{ML}{EI}, y_{max} = \frac{ML^2}{2EI}$

(d) $q_{max} = \frac{ML}{EI}, y_{max} = \frac{ML^2}{3EI}$

60. In case of a cantilever of span L subjected to concentrated load W at free end, the rotation (q) and deflection y of free end are

(a) $q = \frac{WL}{EI}, y = \frac{WL^2}{2EI}$

(b) $q = \frac{WL^2}{2EI}, y = \frac{WL^2}{3EI}$

(c) $q = \frac{WL^3}{6EI}, y = \frac{WL^4}{8EI}$

(d) $q = \frac{WL^3}{24EI}, y = \frac{WL^3}{24EI}$

61. A cantilever of span L is subjected to uniformly distributed load of intensity w for half the span from fixed end. Its deflection at free end is

(a) $\frac{wL^4}{192EI}$

(b) $\frac{3\,wL^4}{384EI}$

(c) $\frac{5\,wL^4}{384EI}$

(d) $\frac{7}{384}\frac{wL^4}{EI}$

62. A cantilever of span L is subjected to uniformly distributed load of intensity w from free end up to mid span. Its deflection at free end is

(a) $\frac{5WL^4}{384\,EI}$

(b) $\frac{41WL^4}{384\,EI}$

(c) $\frac{21WL^4}{384\,EI}$

(d) $\frac{5}{192}\frac{WL^4}{EI}$

63. A cantilever carries a uniformly distributed load from fixed end to the midspan in the first case and a UDL of same intensity from midspan to the free end in the second case. The ratio of maximum deflections in the two cases is

(a) 1/3

(b) 3/21

(c) 5/24

(d) 7/41

64. If the deflection at the free end of a cantilever beam of span 1 m, subjected UDL over entire span is 15 mm, then the slope at the free end is

(a) 0.02 radians
(b) 0.03 radians
(c) 0.04 radians
(d) 0.06 radians

65. If the deflection and slope at the free end and of a cantilever beam subjected to uniformly distributed beam are 15 mm and 0.02 radians respectively the length of the beam is

(a) 800 mm
(b) 1000 mm
(c) 1200 mm
(d) 1500 mm

66. A simply supported beam of span L is subjected to a concentrated load W at mid-span. Then in this beam maximum slope and maximum deflection are

(a) $\frac{WL^2}{12EI}$ and $\frac{WL^3}{24EI}$

(b) $\frac{WL^2}{16EI}$ and $\frac{WL^3}{48EI}$

(c) $\frac{WL^2}{24EI}$ and $\frac{WL^3}{48EI}$

(d) none of the above

67. In a simply supported beam of span L subjected to central concentrated load central deflection is 24 mm. Then the slope at supports is

(a) $\frac{24}{L}$ radians

(b) $\frac{36}{L}$ radians

(c) $\frac{48}{L}$ radians

(d) $\frac{72}{L}$ radians

68. In a simply supported beam of span L subjected to uniformly distributed load W per unit length, the deflections at mid-span and slope at end are

(a) $\frac{5}{384}\frac{WL^4}{EI}, \frac{WL^3}{24EI}$

(b) $\frac{5}{384}\frac{WL^3}{EI}, \frac{WL^2}{24EI}$

(c) $\frac{WL^4}{24EI}, \frac{WL^3}{8EI}$

(d) $\frac{WL^3}{24EI}, \frac{WL^2}{8EI}$

69. Which one of the following is not the assumption in the theory of pure torsion?

(a) Shear stress is proportional to shear strain.

(b) No warping takes place.

(c) Radial lines remain radial even after applying torsional moment.

(d) $\frac{T}{J} = \frac{q}{r}$

where T = torsional moment, J = polar moment of inertia, q = shear stress and r = distance of the element from the centre of shaft.

70. With usual notations torsional equation for shafts of circular cross sections is

(a) $\frac{T}{J} = \frac{q}{\theta} = \frac{Gr}{L}$

(b) $\frac{T}{r} = \frac{q}{J} = \frac{G\theta}{L}$

(c) $\frac{T}{J} = \frac{q}{L} = \frac{G\theta}{r}$

(d) $\frac{T}{J} = \frac{q}{r} = \frac{G\theta}{L}$

71. A is a shaft of diameter d and B is a shaft of diameter $2d$. The ratio of polar modulus of section B to section A is

(a) 2

(b) 6

(c) 8

(d) 16

72. A hollow circular shaft has external diameter of $2d$ and internal diameter of d. Its polar modulus of section is

(a) $\frac{\pi d^3}{16}$

(b) $\frac{15\pi}{32} d^3$

(c) $\frac{\pi d^4}{16}$

(d) $\frac{\pi}{32} d^4$

73. If T is torque, G = modulus of rigidity, J = polar moment of inertia, q = angle of twist and L = the length of a circular shaft, its torsional rigidity is

(a) $\frac{G\theta}{L}$

(b) $\frac{GJ\theta}{L}$

(c) $\frac{GL\theta}{L}$

(d) GJ

74. 1 kilowatt power is equal to

(a) 1×10^3 N-mm/sec

(b) 1×10^4 N-mm/sec

(c) 1×10^6 N-mm/sec

(d) 1×10^9 N-mm/sec

75. Bar *AC* shown in Fig Q. 75 is fixed at both ends and is subjected to a torque *T* at *B* where $AB = L/3$. Then torque at end *A* is

(a) $T/3$

(b) $T/2$

(c) $2T/3$

(d) T

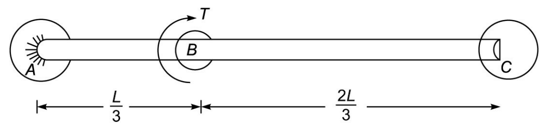


Fig. Q. 75

76. If *L* is the length, *G* = modulus of rigidity *J* = polar modulus of section of shaft subjected to torque *T*, stain energy stored is

(a) $\frac{1}{2}\frac{TL}{GJ}$

(b) $\frac{TL}{GJ}$

(c) $\frac{1}{2}\frac{T^2L}{GJ}$

(d) $\frac{T^2L}{GJ}$

77. If q_s is maximum shear stress due to torque and *G* is the modulus of rigidity of material of solid shaft, strain energy stored is

(a) $\frac{q_s^2}{G} \times \text{Volume}$

(b) $\frac{q_s^2}{2G} \times \text{Volume}$

(c) $\frac{q_s^2}{4G} \times \text{Volume}$

(d) $\frac{q_s^2}{8G} \times \text{Volume}$

78. A closed coil helical spring of radius *R* is subjected to axial load *W*. Any cross section of the spring is subjected to

(a) bending moment *WR*

(b) torsional moment *WR*

(c) bending moment *WR* and torsional moment *WR*

(d) bending moment $\frac{WR}{2}$ and torsional moment $\frac{WR}{2}$

79. A closed coil helical spring of radius *R* with *n* number of coils of diameter *d*. If modulus of

rigidity is G, stiffness of spring is

(a) $\frac{Gd^4}{8R^3n}$

(b) $\frac{Gd^4}{16R^3n}$

(c) $\frac{Gd^4}{32R^3n}$

(d) $\frac{Gd^4}{64R^3n}$

80. Torsion factor for the built up section shown in the Fig. Q. 80 is approximately equal to

(a) $\frac{1}{3}d_1b_1^3+\frac{1}{3}d_2b_2^3+\frac{1}{3}d_3b_3^3$

(b) $\frac{1}{3}b_1d_1^3+\frac{1}{3}b_2d_2^3+\frac{1}{3}b_3d_3^3$

(c) $\frac{1}{3}d_1b_1^3+\frac{1}{3}b_2d_2^3+\frac{1}{3}d_3b_3^3$

(d) $\frac{1}{3}b_1d_1^3+\frac{1}{3}d_2b_2^3+\frac{1}{3}b_3d_3^3$

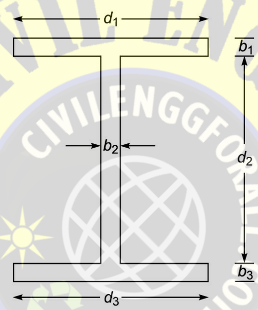


Fig. Q. 80

81. When a cast iron specimen is tested in tension its failure is

(a) at right angles to the axial direction

(b) by formation of cup and cone

(c) at 45° to axial direction

(d) at 30° to axial direction

82. If ultimate strength of a material in tension is 60 N/mm^2, shear strength is 25 N/mm^2, its specimen in tension test fails

(a) at right angle to axial direction

(b) at 45° to axial direction

(c) at 30° to axial direction

(d) there is no definite direction

83. At a point in a stressed material, normal stresses are 120 N/mm^2 in x-direction and 80 N/mm^2 at right angle to that direction. The normal stress on a plane at 30° to the plane of 120 N/mm^2 is

(a) 90 N/mm^2

(b) 100 N/mm^2

(c) 110 N/mm^2

(d) 120 N/mm^2

84. At a point in stressed material normal stress in x-direction is p_x and in y-direction it is p_y. The tangential stress on a plane inclined at q to the plane of p_x is

(a) $\frac{p_x + p_y}{2} \sin 2\theta$

(b) $\frac{p_x - p_y}{2} \sin 2\theta$

(c) $\frac{p_x + p_y}{2} \cos 2\theta$

(d) $\frac{p_x - p_y}{2} \cos 2\theta$

85. In a general two-dimensional element normal stresses ar p_x and p_y while shear stress is q. The principal plane is at q to the plane of p_x, where tan 2q is

(a) $\frac{q}{2(p_x + p_y)}$

(b) $\frac{2q}{(p_x + p_y)}$

(c) $\frac{q}{2(p_x - p_y)}$

(d) $\frac{2q}{p_x - p_y}$

86. In a general two-dimensionally stressed elements the normal stresses are p_x = 120 N/mm^2, p_y = 80 N/mm^2 and shear stress is 15 N/mm^2. The maximum principal stress is

(a) 100 N/mm^2

(b) 125 N/mm^2

(c) 150 N/mm^2

(d) none of the above

87. In Q. No. 86, the maximum shear stress is

(a) 25 N/mm^2

(b) 45 N/mm^2

(c) 60 N/mm^2

(d) 90 N/mm^2

88. In the above case the direction of maximum principal plane is

(a) at 1/2 $\tan^{-1}$ 3/4 to the x-direction

(b) at 1/2 $\tan^{-1}$ 3/4 to the y-direction

(c) at 30° to the x-direction

(d) at 30° to the y-direction

89. The angle between the direction of maximum shear plane and maximum principal plane are

(a) 30°

(b) 45°

(c) 60°

(d) none of the above

90. In a two-dimensional stress system p_x, p_y are normal stresses and q is shear stress. Then centre of Mohr's circle is at

(a) $\frac{p_x + p_y}{2}$

(b) $\frac{p_x - p_y}{2}$

(c) $\sqrt{\left(\frac{p_x - p_y}{2}\right)^2 + q^2}$

(d) none of the above

91. In the above case radius of Mohr's circle is

(a) $\frac{p_x + p_y}{2}$

(b) $\sqrt{\left(\frac{p_x + p_y}{2}\right)^2 + q^2}$

(c) $\sqrt{\left(\frac{p_x - p_y}{2}\right)^2 + q^2}$

(d) none of the above

92. If M is bending moment and T is the torque a section on a circular shaft of diameter d. maximum principal stress is

(a) $\frac{16}{\pi d^3}\left[\frac{M+T}{2} - \sqrt{\left(\frac{M+T}{2}\right)^2 + T^2}\right]$

(b) $\frac{16}{\pi d^3}\left[\frac{M+T}{2} - \sqrt{\left(\frac{M+T}{2}\right)^2 + T^2}\right]$

(c) $\frac{16}{\pi d^3}\left[M - \sqrt{M^2 + T^2}\right]$

(d) $\frac{16}{\pi d^3}\left[M + \sqrt{M^2 + T^2}\right]$

93. If M is the moment and T is the torque acting at a section in circular shaft of diameter d the maximum shear stress is

(a) $\frac{16}{\pi d^3}\sqrt{M^2 + T^2}$

(b) $\frac{32}{\pi d^3}\sqrt{M^2 + T^2}$

(c) $\frac{48}{\pi d^3}\sqrt{M^2 + T^2}$

(d) $\frac{64}{\pi d^3}\sqrt{M^2 + T^2}$

94. A section of a shaft of diameter 100 mm is subjected to a moment of 4 kN-m and a torque of 3 kN-m. Then the ratio of maximum principal stress to minimum is numerically equal to

(a) $\frac{4}{3}$
(b) 5/3

(c) 2
(d) 9

95. A shaft is subjected to a bending stress of 36 N/mm^2 at a point in a shaft. The shaft is also subjected to direct axial tension of 12 N/mm^2. The maximum stress in the section is

(a) 48 N/mm^2
(b) $\sqrt{36^2+12^2}$ N/mm^2

(c) $\frac{36+24}{2}+\sqrt{36^2-24^2}$
(d) none of the above

96. If e_x and e_y are strains in two mutually perpendicular directions and g_{xy} is shear strain at a point in a material, the direction q of the principal plane to the plane of x-direction is

(a) $\frac{\gamma_{xy}}{e_x+e_y}$

(b) $\frac{\gamma_{xy}}{e_x-e_y}$

(c) $\frac{2\gamma_{xy}}{e_x+e_y}$

(d) $\frac{2\gamma_{xy}}{e_x-e_y}$

97. In the above case maximum principal strain is

(a) $\frac{e_x+e_y}{2}+\sqrt{\left(\frac{e_x-e_y}{2}\right)^2+\gamma_{xy}^2}$

(b) $\frac{e_x-e_y}{2}+\sqrt{\left(\frac{e_x-e_y}{2}\right)^2+\gamma_{xy}^2}$

(c) $\frac{1}{2}\left[(e_x+e_y)+\sqrt{(e_x-e_y)^2+\gamma_{xy}^2}\right.$

(d) $\frac{1}{2}\left[(e_x-e_y)+\sqrt{(e_x-e_y)^2+\gamma_{xy}^2}\right]$

98. Radius of Mohr's circle for principal strain in terms of axial strains e_x, e_y and shear strain g_{xy} is

(a) $\sqrt{\left(\frac{e_x-e_y}{2}\right)^2+\gamma_{xy}^2}$

(b) $\frac{1}{2}\sqrt{(e_x-e_y)^2+\gamma_{xy}^2}$

(c) $\frac{e_x+e_y}{2}+\sqrt{\left(\frac{e_x-e_y}{2}\right)^2+\gamma_{xy}^2}$

(d) $\frac{e_x+e_y}{2}-\sqrt{\left(\frac{e_x-e_y}{2}\right)^2+\gamma_{xy}^2}$

99. In a electrical strain gauge, the quantity measured to determine strain is

(a) current
(b) voltage
(c) resistance
(d) none of the above

100. A strain gauge consists of a group of ______ rosetts.

(a) 3
(b) 4
(c) 6
(d) any number

101. A cylinder may be treated as thin when its thickness is less than ______ of its radius.

(a) $\frac{1}{100}$
(b) 1/50
(c) $\frac{1}{20}$
(d) $\frac{1}{10}$

102. In a thin cylinder stress in ______ direction is negligible.

(a) longitudinal
(b) circumferential
(c) radial
(d) any

103. In the analysis of thin cylinders assumptions made are

(i) radial stress is neglected

(ii) the hoop and longitudinal stress distribution across section is uniform.

(a) Both (i) and (ii) are true
(b) (i) is true and (ii) is false
(c) (i) is false and (ii) is true
(d) Both (i) and (ii) are false

104. In a thin cylinder of diameter d, thickness t subject to internal pressure the circumferential stress developed is

(a) $\frac{pd}{t}$
(b) $\frac{pd}{2t}$
(c) $\frac{pd}{4t}$
(d) $\frac{pd}{8t}$

105. In a both end closed thin cylinder of diameter d thickness t subjected to internal pressure. p, the longitudinal stress developed is

(a) $\frac{pd}{t}$

(b) $\frac{pd}{2t}$

(c) $\frac{pd}{4t}$

(d) $\frac{pd}{8t}$

106. In a thin cylinder subjected to internal pressure, if longitudinal stress is 30 N/mm^2, circumferential stress is

(a) 15 N/mm^2

(b) 30 N/mm^2

(c) 60 N/mm^2

(d) 90 N/mm^2

107. In a thin cylinder subject to internal pressure, if circumferential strain is 2.0×10^{-4}, diametral strain is

(a) 1×10^{-4}

(b) 2×10^{-4}

(c) 4×10^{-4}

(d) none of the above

108. In a thin cylinder of diameter d, thickness t, Young's modulus E, Poisson's ratio m, subject to internal pressure p, the volumetric strain is

(a) $\frac{pd}{4tE}(1-2\mu)$

(b) $\frac{pd}{4tE}(5-4\mu)$

(c) $\frac{pd}{2tE}(1-\mu)$

(d) $\frac{pd}{8tE}(4-\mu)$

109. The thickness of a thin cylinder of diameter d, permissible stress f, efficiency of longitudinal joints h_1, circumferential joint of efficiency n_2, subjected to internal pressure p should not be less than

(a) $\frac{pd}{2t\,\eta_1}$

(b) $\frac{pd}{4f\,\eta_2}$

(c) larger of $\frac{pd}{4f\,\eta_1}$ and $\frac{pd}{2t\,\eta_2}$

(d) larger of $\frac{pd}{2t\,\eta_1}$ and $\frac{pd}{4f\,\eta_2}$

110. In a spherical shell of diameter d, subjected to internal pressure p, thickness t, principal stresses f_1 and f_2 developed are

(a) $\frac{pd}{2t}$ and $\frac{pd}{4t}$

(b) $\frac{pd}{t}$ and $\frac{pd}{2t}$

(c) $\frac{pd}{4t}$ and $\frac{pd}{4t}$

(d) $\frac{pd}{2t}$ and $\frac{pd}{2t}$

111. In the above case volumetric strain is

(a) $\frac{pd}{4tE}(1-\mu)$

(b) $\frac{pd}{4tE}(2-\mu)$

(c) $\frac{3}{4}\frac{pd}{tE}(1-\mu)$

(d) $\frac{pd}{tE}(2-\mu)$

112. In the analysis of thick cylinder, the assumption made is
(a) radial stress is negligible
(b) the hoop stress distribution is uniform
(c) the longitudinal stress distribution is uniform
(d) the longitudinal strain is uniform across the section

113. For finding radial and hoop stresses in a think cylinder Lame's equations are ______ and ______ respectively.

(a) $\frac{b}{x^2}-a$ and $\frac{b}{x^2}+a$

(b) $\frac{b}{x^2}+a$ and $\frac{b}{x^2}-a$

(c) $\frac{b}{x^3}-a$ and $\frac{b}{x^3}+a$

(d) $\frac{b}{x^3}+a$ and $\frac{b}{x^3}-a$

114. For finding radial and loop stresses in a thick spherical shell equations to be used are ______ and ______ respectively.

(a) $\frac{2b}{x^3}-a$ and $\frac{b}{x^3}+a$

(b) $\frac{b}{x^3}-a$ and $\frac{b}{x^3}+a$

(c) $\frac{2b}{x^2}-a$ and $\frac{b}{x^2}+a$

(d) $\frac{b}{x^2}-a$ and $\frac{b}{x^2}+a$

115. Kern of rectangular columns is having ______ shape.
(a) rectangular
(b) square

(c) diamond

(d) triangular

116. The diameter of Kern of circular column of diameter d is

(a) d

(b) $\sqrt{d}$

(c) $\frac{d}{2}$

(d) $d/4$

117. Which one of the following is not the assumption in deriving Euler's theory for long columns?

(a) The section of the column is uniform throughout.

(b) The column is initially straight and is loaded axially.

(c) The column fails by buckling alone.

(d) The columns are having hinged ends only.

118. Slenderness ratio is the ratio of

(a) Effective length of column to extreme fibre distance from centroid of the section.

(b) Effective length of column to its radius of gyration

(c) Effective length of column to its cross-sectional area

(d) Effective length of column to its moment of inertia

119. The critical load for a long column is 160 kN. If the same section is to be used for another column of double length, the critical load is

(a) 320 kN

(b) 160 kN

(c) 80 kN

(d) 40 kN

120. The limiting slenderness ratio for applying Euler's theory for columns with Young's modulus E and crushing strength f_c is

(a) $\sqrt{\frac{\pi E}{f_C}}$

(b) $\sqrt{\frac{\pi^2 E}{f_C}}$

(c) $\frac{\pi E}{f_C}$

(d) $\frac{\pi^2 E}{f_C}$

II. *Match List I with List II, selecting answer code given in item 121 to 123*

121.

	List I		**List II**
	Beam of length *L* and load on it		**Maximum bending moment**
A.	Cantilever subject to udl w	1.	$\frac{wL^2}{8}$

B.	Cantilever subject to uniformly varying load zero at free end w/unit length at fixed end	2.	$\frac{wL^2}{6}$
C.	Simply supported beam subjected to udl. w	3.	$\frac{wL^2}{9\sqrt{3}}$
D.	Simply supported beam subjected to uniformly varying load with zero at one end to w/unit length at the other end.	4.	$\frac{wL^2}{2}$

Codes:

(a)	A – 4	B – 2	C – 3	D – 1
(b)	A – 4	B – 2	C – 1	D – 3
(c)	A – 2	B – 1	C – 3	D – 4
(d)	A – 2	B – 1	C – 3	D – 1

122. List I shows the end conditions and the List II effective lengths of column of actual length, l

	List I		**List II**
A.	Both ends hinged	1.	$2l$
B.	Both ends fixed	2.	l
C.	One end fixed, other end hinged	3.	$l/2$
D.	One end fixed, other end free	4.	$l/\sqrt{2}$

Codes:

(a)	A – 2	B – 1	C – 4	D – 3
(b)	A – 2	B – 3	C – 4	D – 1
(c)	A – 3	B – 2	C – 4	D – 1
(d)	A – 3	B – 1	C – 2	D – 4

123.

	List 1		**List 2**
	Material		**Rankine's constant**
A.	Mild steel	1.	1/750
B.	Cast iron	2.	1/1600
C.	Wrought iron	3.	1/7500
D.	Timber	4.	1/9000

Codes:

(a)	A – 3	B – 4	C – 2	D – 1
(b)	A – 2	B – 1	C – 4	D – 3

(c)	A – 3	B – 2	C – 4	D – 1
(d)	A – 4	B – 3	C – 1	D – 2

III. *Select your answer according to the coding system given for the Assertion (A) and Reason (R) given below in the Q. Nos 124 to 129.*

Assertion A

Reason R

Answer Code

(a) Both A and R are true and R is the correct explanation of A.

(b) Both A and R are true but R is not the correct explanation of A.

(c) A is true but R is false.

(d) A is false but R is true.

124. A: In case of steel, stress at breaking point is less than at ultimate point.

R: The above statement refers to nominal stress but not to true stress.

125. A: factor of safety selected for concrete is higher than that for steel.

R: Property of steel is more reliable than that of concrete.

126. A: Volumetric strain of bar of diameter d, length L when subjected to axial load is

$$= \frac{2\delta d}{d} + \frac{\delta L}{L}$$

R: Volumetric strain of a bar is equal to the sum of strain in there mutual perpendicular directions.

127. A: If the sum of stresses on a bar in three mutually perpendicular directions is zero, volumetric change is zero.

R: Volumetric strain is the sum of the strains in three mutually perpendicular directions.

128. A: Bending moment is maximum where shear force is zero.

R: The relationship between bending moment and shear force is $\frac{dM}{d_x} = -F$.

129. A: If shear strength of a material is less than half its strength in tension, it fails at 45° to axial direction under axial tensile test.

R: Axial tension gives rise to maximum shear stress of $\frac{p_t}{2}$ where p_t is axial stress.

IV. *State whether the following statements are True (T) or False (F).*

130. Stress is load per unit area.

131. 1 pascal is equal to 1 N/mm^2.

132. Elastic limit is defined as the stress level up to which stress is proportional to strain.

133. In steel actual stress at breaking point is more than actual ultimate stress.

134. Endurance limit is the maximum stress at which even a billion reverses of stress do not cause failure of the material.

135. Hooke's law assumes stress is proportional to strain up to elastic limit.

136. The extension of a uniformly tapering rod of length L is given by

$$D = \frac{PL}{\frac{\pi}{4} d_1 d_2 E}$$

where p = axial force E = Young's modulus

d_1 = diameter at one end d_2 = diameter at the other end.

137. A bar of uniform cross section A and length L is suspended from the top. The extension of the bar due to self-weight is

$D = \frac{\gamma L^2}{E}$, where g is unit weight of the material of the bar and E is modulus of elasticity.

138. Volumetric strain is equal to the sum of strains in three mutually perpendicular directions.

139. The relationship between modulus of elasticity, modulus of rigidity and bulk modulus is given by

$$E = 2G(1 + m) = 3K(1 - 2m)$$

140. Proof resistance is equal to strain energy in the body corresponding to stress at elastic limit.

141. A freely falling load W, falling from a height h before applying axial force on a bar of length and cross-sectional area A, produces a stress $p = \sqrt{\frac{EhW}{AL}}$, where E is the modulus of elasticity.

142. When a bar is subjected to axial load, there will be maximum shear stress of the magnitude half the axial stress at 45° to the axial direction.

143. If an element in a plane body is subjected to direct stresses p_x and p_y, and shear stress q, the maximum principal stress developed is $p_1 = \frac{p_x + p_y}{2} + \frac{1}{2}\sqrt{(p_x - p_y)^2 + q^2}$.

144. The radius of Mohr's circle of stresses represents, the magnitude of maximum shear stress.

145. An electric strain gauge can measure shear strain.

146. Maximum principal stress theory of failure is known as Rankine's theory also.

147. Rankine's theory of failure is good for brittle materials.

148. Maximum shear stress theory is known as Coulomb's theory also.

149. Maximum shear stress theory is good for brittle materials.

150. Maximum strain theory of failure is known as St. Venant's Theory.

151. Maximum strain energy theory of failure is known as Beltrami and Haigh's theory also.

152. Maximum distortion energy of theory of failure is known as Von-Mises criteria for failure.

153. Maximum distortion energy theory is ideally suited for brittle materials.

154. Bending moment is having maximum value where shear force is zero.

155. On a cantilever of span L, if load varies linearly from zero at free end to W/unit length at support, maximum bending moment is $\frac{WL^2}{6}$.

156. In deriving simple bending theory it is assumed that Young's modulus is same in tension and compression.

157. Simple bending theory is applicable, only if the cross-sectional area is symmetric.

158. Leaf spring is a practical example of beam of uniform spring.

159. In a beam of rectangular section, maximum shear stress is 1.5 times the average shear stress.

160. In a beam of circular section, the maximum shear stress is 4/3 times the average shear stress.

161. The relationship between radius of curvature R and deflection y in a bent beam is

$$R = \frac{\frac{dy^2}{dx^2}}{\left[1+\left(\frac{dy}{dx}\right)^2\right]^{3/2}}$$

162. The maximum slope in a beam of span L, flexural rigidity EI and subjected to central concentrated load W is $\frac{WL^3}{12EI}$.

163. The change in slope between two points on a straight member under flexure is equal to $\frac{M}{EI}$ diagram between these two points.

164. The deflection at a point in a beam in the direction perpendicular to its original straight line position measured from the tangent to the elastic curve at another point is given by the moment of $\frac{M}{EI}$ diagram about the point where the deflection is required.

165. Strain energy in a beam is given by

$$U = \int_0^L \frac{M^2}{EI} dx$$

166. Rotation at A due to unit moment at B is same as rotation at B due to unit moment at A.

167. 1 watt of power is equal to 1 N-m/s.

168. If a rigid body is in equilibrium under the action of a system of forces the virtual work done by this system of forces under virtual displacement is zero.

169. Castigliano's theorem states "in a linearly elastic structure, partial derivative of the strain energy with respect to a load is equal to the deflection of the point where the load is acting, the deflection being measured in the direction of the load.

170. Torsion equation is

$$\frac{T}{J} = \frac{q}{r} = \frac{GL}{\theta}$$

171. In a closed coil helical spring material is subjected to torsional moment.

172. Torsional factor J of a rectangular section of size $b \times d$ is given by

$$J = \frac{1}{12}(bd^3 + db^3)$$

173. A thin cylinder of diameter d and thickness t subjected to internal pressure p is subjected to circumferential stress $= \frac{pd}{4t}$.

174. A thin sperical shell of diameter d and thickness t, subjected to internal pressure p is subjected to hoop stress $= \frac{pd}{2t}$.

175. Lame's equations for thick cylinders are

$$p_x = \frac{b}{x^2} + a$$

$$f_1 = \frac{b}{x^2} - a$$

where p_x = radial stress

f_1 = hoop stress

and a and b are arbitrary constants.

176. In a short column, the area in which if load acts, it does not cause tension at any point is known as kern of the section.

177. Kern of a circular section if diameter d is a circle of diameter $d/4$.

178. The equivalent length of a fixed column of length l is $l/2$.

Answers to Multiple-Choice Questions

1. (b)	2. (a)	3. (d)	4. (a)	5. (c)
6. (b)	7. (c)	8. (d)	9. (a)	10. (b)
11. (b)	12. (d)	13. (a)	14. (b)	15. (a)
16. (b)	17. (c)	18. (d)	19. (a)	20. (b)
21. (d)	22. (b)	23. (a)	24. (d)	25. (d)
26. (c)	27. (b)	28. (d)	29. (c)	30. (d)
31. (c)	32. (c)	33. (d)	34. (a)	35. (a)
36. (b)	37. (d)	38. (b)	39. (b)	40. (d)
41. (b)	42. (b)	43. (b)	44. (d)	45. (c)
46. (a)	47. (c)	48. (c)	49. (c)	50. (b)
51. (b)	52. (a)	53. (d)	54. (b)	55. (b)
56. (d)	57. (a)	58. (b)	59. (c)	60. (b)
61. (d)	62. (b)	63. (d)	64. (a)	65. (b)
66. (b)	67. (d)	68. (a)	69. (d)	70. (d)
71. (c)	72. (b)	73. (d)	74. (c)	75. (a)
76. (c)	77. (c)	78. (b)	79. (d)	80. (a)
81. (c)	82. (b)	83. (c)	84. (b)	85. (d)
86. (b)	87. (a)	88. (b)	89. (b)	90. (a)
91. (c)	92. (d)	93. (a)	94. (d)	95. (a)
96. (b)	97. (c)	98. (b)	99. (c)	100. (a)
101. (d)	102. (c)	103. (a)	104. (b)	105. (c)

106. (c)	107. (b)	108. (b)	109. (d)	110. (c)
111. (c)	112. (d)	113. (b)	114. (a)	115. (c)
116. (d)	117. (d)	118. (b)	119. (d)	120. (b)
121. (b)	122. (b)	123. (c)	124. (a)	125. (a)
126. (a)	127. (a)	128. (a)	129. (a)	130. False
131. False	132. False	133. True	134. True	135. True
136. True	137. False	138. True	139. True	140. True
141. False	142. True	143. False	144. True	145. False
146. True	147. True	148. True	149. False	150. True
151. True	152. True	153. False	154. True	155. True
156. True	157. True	158. True	159. True	160. True
161. False	162. False	163. True	164. True	165. False
166. True	167. True	168. True	169. True	170. False
171. True	172. False	173. False	174. False	175. False
176. True	177. True	178. True		

6

Structural Analysis

6.1 INTRODUCTION

Assumptions

1. Material is homogeneous, isotropic and linearly elastic
2. Boundary conditions are ideal
3. Deflections are small
4. Loads are ideal
5. Structures are idealized as beams, plane frames, three-dimensional frames, etc.

Law of superposition It means the structure can be analysed for different loads separately and the results be superposed to get the final results due to different load combinations.

Conditions of equilibrium In case of three-dimensional structure are

$$\text{S}F_x = 0, \text{S}F_y = 0, \text{S}F_z = 0$$

$$\text{S}M_x = 0, \text{S}M_y = 0, \text{S}M_z = 0$$

where x, y and z are Cartesian coordinate systems in space.

Compatibility conditions It means requirement of continuity at joints.

1. The members meeting at a joint will continue to meet at the same point even after deformation.
2. At rigid-joints, the angle between any two members remains the same even after deformation.

A system is called linear systems if its material has linear stress-strain relation and deflections are small.

If the non-linearity is due to stress-strain relations not being linear, it is material non-linearity problem.

If non-linearity is due to considerable change in the geometry, it is called geometric non-linearity problem.

6.2 INFLUENCE LINES

* The influence line diagram for a stress resultants is the one in which ordinate represents the value of the stress resultant for the position of unit load at the corresponding abscissa.
* Influence line diagrams are used to determine the position of moving loads for the maximum stress resultant and for the maximum value of the stress resultant.

ILD for Simply Supported Beams

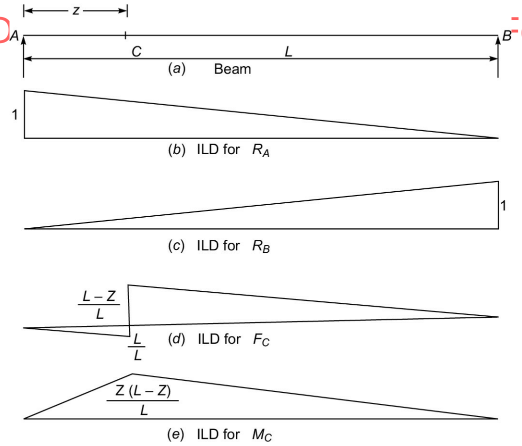


Fig. 6.1 ILD for R_A, R_B, F_C and M_C is simply supported beam

ILD for Cantilever Beams

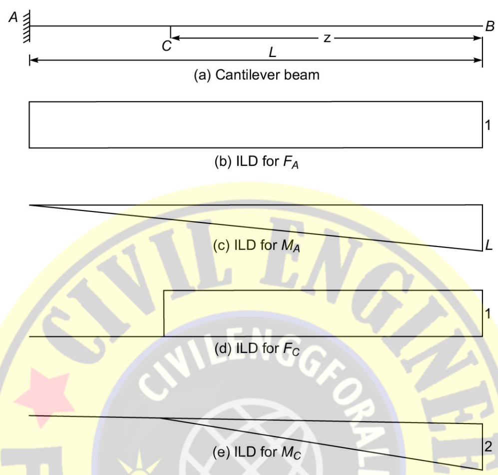


Fig. 6.2 ILD for F_A, M_A, F_C and M_C in a cantilever beam

ILD for Overhanging Beams

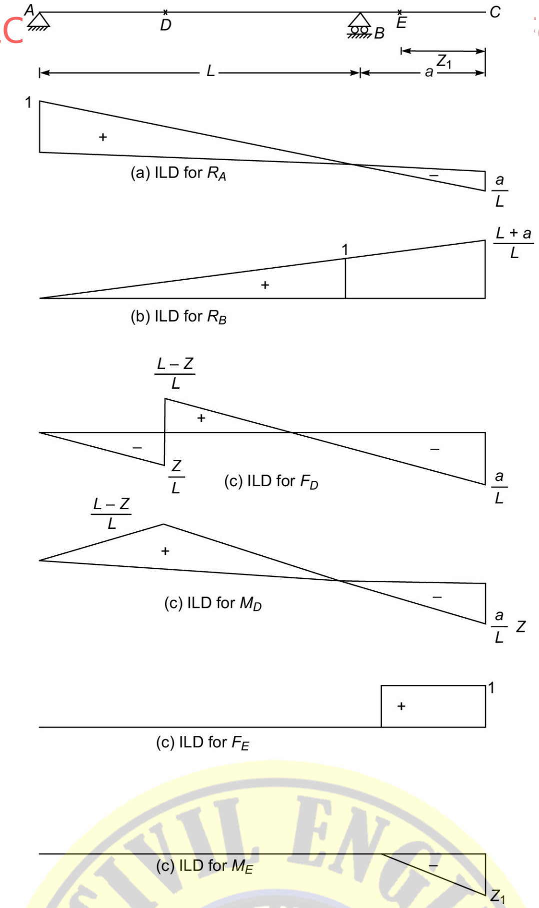


Fig. 6.3 ILD for R_A, R_B, F_D, M_D, F_E and, M_E in overhanging beam

ILD for Double Overhanging Beams

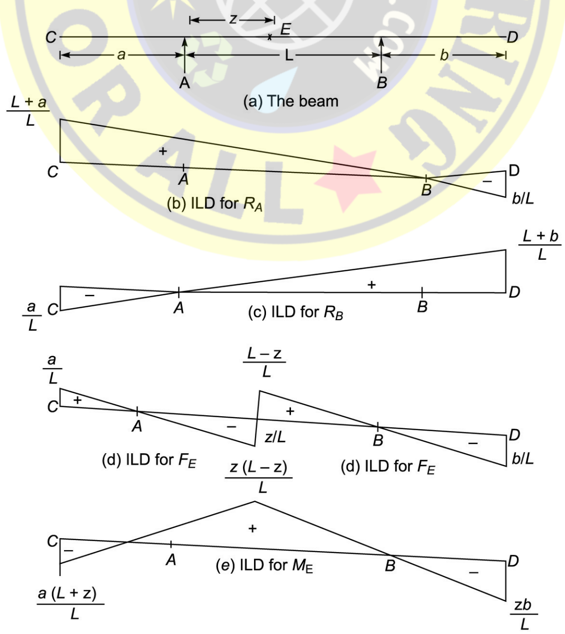


Fig. 6.4 ILD for R_A, R_B, F_E and M_E in double overhanging beam

*** Use of ILD:**

1. In case of concentrated loads for

$$F = SW_i y_i \text{ and } M = SW_i y¢_i$$

where, W_i are concentrated loads, y; are the ordinates to the ILD for shear force and $y¢$; are the ordinates in the ILD for bending moment.

2. In case of udl smaller than the span,

$$SF = \text{Intensity of udl} \times \text{Area of ILD for SF under the load.}$$

Similarly,

$$M = \text{Intensity of load} \times \text{Area of ILD for moment under the load.}$$

*** Maximum SF and BM due to moving loads.**

1. Maximum SF and BM at point z from the end due to single concentrated load:

–ve Max SF = $\frac{Wz}{L}$, when W is just to the left of the section.

+ve Max SF = $\frac{W(L-z)}{L}$, when the load is just to the right of the section.

Max BM = $\frac{Wz(L-z)}{L}$, when the load is on the section.

Absolute max. BM = $\frac{WL}{4}$, occurs at midspan when the load is at that section.

2. Max SF and BM at the given section when UDL is longer than the span

–ve Max SF = $\frac{Wz^2}{2L}$, when load is just to the left of section

+ve Max SF = $\frac{W(L-z)^2}{2L}$, when load is just to the right of the section

Max $M_C = \frac{W_z(L-z)}{2}$, when load covers the entire spam.

Absolute Max $M = \frac{WL^2}{8}$ at midspan when load covers the entire span.

3. UDL smaller than the span

(i) Maximum –ve shear develops when the head of the load reaches the section.

(ii) Maximum positive shear develops when the tail of the udl reaches the section.

(iii) Moment at given section C will be maximum when the ordinates of ILD for M_C at head and tail of the udl are equal which means bending moment at a section is maximum when the load is so placed that the section divides the load in the same ratio as it divides the span.

(iv) Absolute maximum moment occurs at midspan when the C.G. of udl coincides with midspan point.

4. A train of concentrated loads

(i) Shear force has a peak value whenever a load is on the section. Highest value among these values is to be selected to get maximum SF at a given section. It is to be noted that for maximum –ve SF, most of the loads are to the right of the section, and for maximum +ve SF most of the loads are to the right of the section.

(ii) Absolute maximum +ve SF occurs near support A when one of the loads is on A and maximum +ve SF occurs at B when one of the loads is on support B.

(iii) At a given section maximum moment occurs when a concentrated load is on the section and when that load moves from left to right, left side portion becomes heavier to lighter compared to right, side portion.

(iv) Absolute maximum moment occurs under one of the loads when the resultant of all the loads and the load under consideration are equidistant from the centre of the beam.

ILD for Bridge Trusses

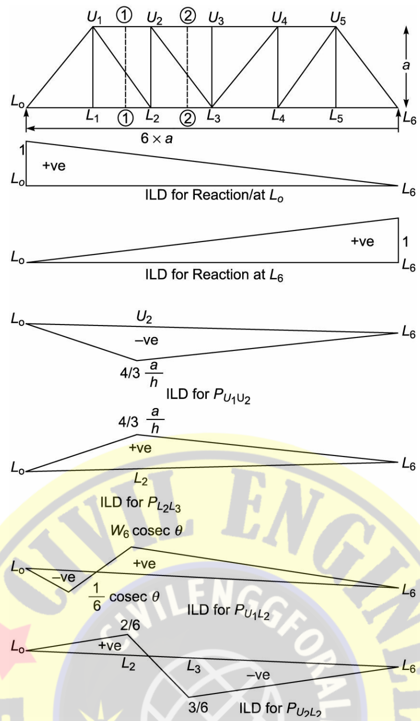


Fig. 6.5

Note:

1. To find ILD for the force in U_1U_2, consider section 1–1, then consider moment about L_2.
2. To find ILD for the force in L_2L_3, consider the section 2–2 and then moment about U_2.
3. To find ILD for inclined member U_1L_2, consider the equilibrium of right hand side portion of section 1–1 and when the load is in portion L_2L_6 consider the equilibrium of left hand portion. When the load is between L_1L_2 it varies linearly.

Three-Hinged Arch

* It is a determinate structure. It may have circular or parabolic shape.

* In case of circular arch of radius R, span L and rise h,

$$\frac{L}{2} \times \frac{L}{2} = h(2R - h) \text{ or } R = \frac{L^2}{8h} + h/2$$

$$x = \frac{L}{2} - R \sin q$$

$$y = R \cos q - (R - h) = h - R\,(1 - \cos q)$$

* In case of parabolic arch

$$y = \frac{4hx}{L^2}\,(L - x), \text{ if springing point is origin}$$

$x^2 = ay$ if the origin is at crown.

* At a section if U is vertical shear, H is horizontal force, Q is radial shear and N is the normal thrust,

$$N = V \sin q + H \cos q$$

and $q = V \sin q - H \cos q$

where q is slope of tangent to horizontal.

* If support A and support B are below crown at distances h_1 and h_2, in a parabolic 3-hinged arch,

$$\frac{L_1}{\sqrt{h_1}} = \frac{L_2}{\sqrt{h_2}} = \frac{L}{\sqrt{h_1} + \sqrt{h_2}}$$

$$\backslash L_1 = L \frac{\sqrt{h_1}}{\sqrt{h_1} + \sqrt{h_2}}$$

$$\text{and } L_2 = L \frac{\sqrt{h_2}}{\sqrt{h_1} + \sqrt{h_2}}$$

* Bending moment in a 3-hinged arch is given by

$$M = \text{Beam moment} - Hy.$$

where H is horizontal thrust

* ILD for 3-hinged arch.

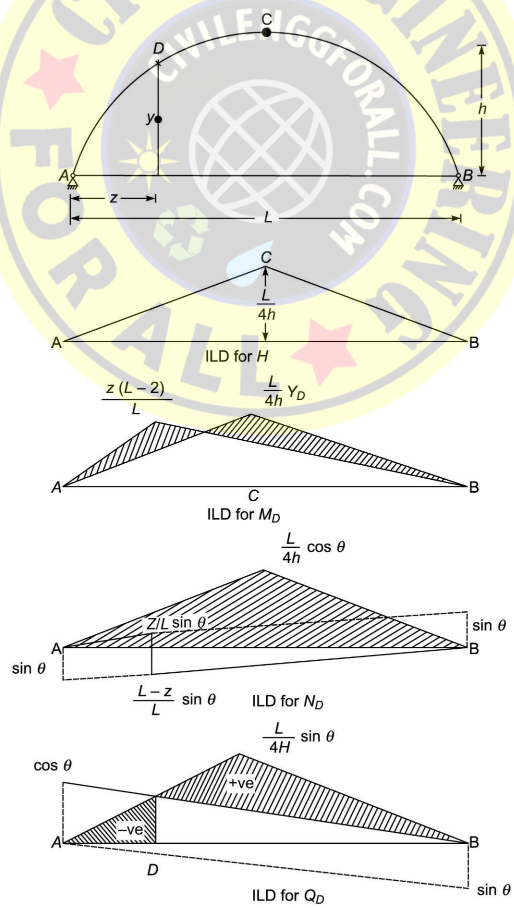


Fig. 6.6 ILD for H, H_D, N_D and Q_D in 3-hinged arch

* Due to concentrated load, maximum moment in 3-hinged parabolic arch occurs when the load is it $x = 0.2113\ L$

$$\text{and } M_{max} = 0.096225\ WL.$$

* Due to moving udl, maximum +ve moment in 3-hinged parabolic arch occurs when the load is up to 0.234 L and its value is 0.01883 wL^2.

6.3 CABLES AND SUSPENSION BRIDGES

* The cables may have either guided pulley support or roller pulley support.

In case of guided pulley support suspension cable continues as anchor cable also and hence tension in the cable on either side of support is same.

In case of roller pulley support, the suspension and anchor cables are connected to a roller. Hence, the horizontal components of tension in suspension cable and anchor cables are the same.

Since cable is flexible,

$$M_x = 0$$

and Hy = beam moment

where H = horizontal force developed at support.

* If the cable is subjected to udl and the supports are at the same level, horizontal thrust developed is given by

$$H = \frac{wl^2}{8h}, \text{ where } l\text{-span}$$

* The length of cable is given by

$$L = l + \frac{8h^2}{3l}, \text{ where } h \text{ is maximum sag.}$$

* If ends arc at different levels, say h_1 and h_2 from the crown point, due to udl

$$H = \frac{wl^2}{2\left(\sqrt{h_1}+\sqrt{h_2}\right)^2}$$

$$L = l + \frac{2}{3}\frac{h_1^2}{l_1} + \frac{2}{3}\frac{h_2^2}{l_2}$$

$$\text{where } l_1 = \frac{L\sqrt{h_1}}{\sqrt{h_1}+\sqrt{h_2}} \text{ and } l_2 = \frac{L\sqrt{h_2}}{\sqrt{h_1}+\sqrt{h_2}}$$

$$V_A = wl_1 \; V_B = wl_2 \; T_{\max} = \sqrt{V_A^2 + H^2}$$

$$H = \frac{wl_1^2}{2h_1}$$

In case of guided pulley support,

Vertical load transmitted to tower = T (sin q + sin a)

Horizontal load transmitted to tower = T (cos q – cos a)

Max bending moment on the tower = T (cos q – cos a) h_1

where q = Angle made by suspension cable with the horizontal

a = Angle made by anchor cable with the horizontal

T = Tension in the cable

and h_1 = Height of tower

Suspension Bridge with Three-Hinged Stiffening Girder

Equivalent load in suspenders is given by $W_e \frac{l^2}{8}$ = Moment in stiffener.

where W_e equivalent udl is suspenders.

ILD for horizontal thrust H and bending moment at any point D are the same as those for 3-hinged arches.

Suspension Cable with Two-Hinged Stiffening Girder

* Equivalent udl in suspenders is equal to the average load on the stiffening girder ILD:

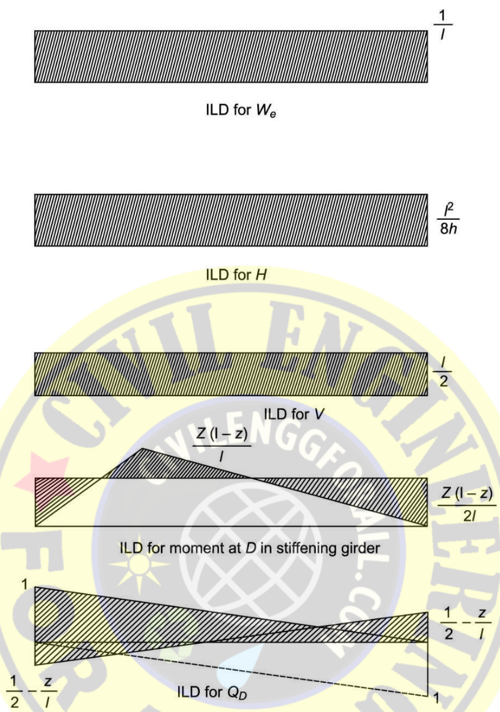


Fig. 6.7 ILD for W_e, H, V, M_D and Q_D in suspension cable with two hinged stiffening girder

Degree of Static Indeterminancy

* Degree of static indeterminancy

= No. of unknowns – No. of independent static equilibrium equations

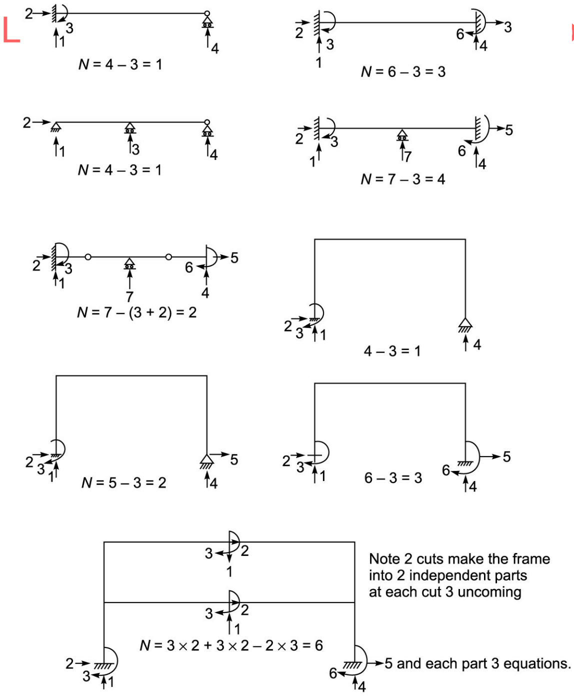


Fig. 6.8 Degree of static indeterminancy

Consistant Deformation Method of Analysing Indeterminate Structures

1. Remove constraints to make the strucuture determinate.
2. Find the displacement of released structure in the direction of released constraints, due to given loading.
3. Determine the expressions for deformation of released structure due to each of released reaction.
4. Impose consistency conditions to get the reactions.

Three-moment equation

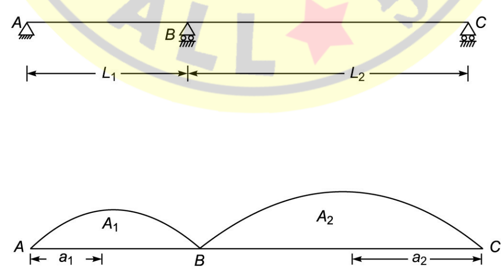


Fig. 6.9 Three-moment equation

If ABC are three continuous supports, $AB = L_1$ and $BC = L_2$,

$$M_A \frac{L_1}{I_1} + 2M_\theta\left(\frac{L_1}{I_1} + \frac{L_2}{I_2}\right) + M_C \frac{L_2}{I_2} = \frac{6A_1 a_1}{L_1} - \frac{6A_2 a_2}{L_2}$$

where M_A, M_B, M_C are moments at A, B and C respectively.

A_1, A_2 area of moment diagram in AB and BC respectively.

a_1 = Distance of C.G. of A_1 from support A

a_2 = Distance of C.G. of A_2 from support C.

If B settles by h_1 below the level of A and h_2 below the level of C, the above equation is

$$M_A\left(\frac{L_1}{I_1}\right)+2M_B\left(\frac{L_1}{I_1}+\frac{L_2}{I_2}\right)+M_C\left(\frac{L_2}{I_2}\right)=-\frac{6A_1a_1}{I_1L_1}-\frac{6A_2a_2}{I_2L_2}+\frac{6Eh_1}{L_1}+\frac{6Eh_2}{L_2}$$

* The three-moment equation is also known as Clapeyron's theorem of three moments.

6.4 SLOPE DEFLECTION METHOD

Slope deflection equations are

$$M_{AB}=M_{FAB}+\frac{2EI}{L}\left(2\theta_A+\theta_B-\frac{3\Delta}{L}\right)$$

$$M_{BA}=M_{FBA}+\frac{2EI}{L}\left(\theta_A+2\theta_B-\frac{3\Delta}{L}\right)$$

where clockwise moments, clockwise rotations are positive. Settlement D is positive if right side support is below the left side support.

If there is sway

$$H_A=\frac{M_{AB}+M_{BA}-Pa}{L_{AB}}$$

$$H_D=\frac{M_{DC}+M_{CD}}{L_{CD}}$$

$$H_A+H_D+P=0$$

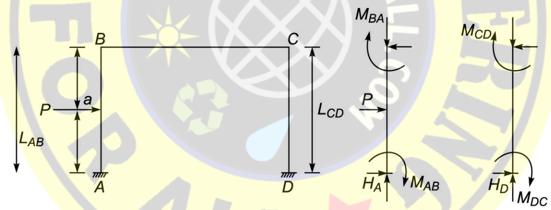


Fig. 6.10 Frame with sway

6.5 MOMENT DISTRIBUTION METHOD

Allowing rotation of the joint A and fixing the far end B, when moment M is applied at joint A, the moment $M¢$ developed at far end B is known as *carry-over moment*.

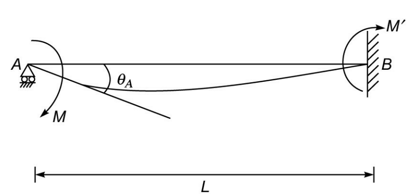


Fig. 6.11 Carry over moment and stiffness

Carry over factor $=\frac{M'}{M}=1/2$

Stiffness of the beam $=\frac{M}{\theta_A}=\frac{4EI}{L}$,

where q_A is the rotation at A.

When a number of members meet at a joint, total moment applied at the joint is shared by each member in proportion to their stiffness. Distribution factor

$$d_i = \frac{M}{M_i} = \frac{k_1}{\Sigma k_i}$$

Moment distribution procedure Find fixed end moments and distribution factors. Balance each joint. Carry-over distributed moment to far ends. Stop the procedure when carry-over moments are negligible.

Note: If the far end is simply supported/hinged it is to be balanced by carrying over 1/2 of it to interior support. If stiffness of end member which has one end simply supported may be balanced once for all and its stiffness modified as $\frac{3EI}{L}$, then no moment is to be carried to the simply supported end.

* If a support sinks

$$M_{FAB} = \frac{6EI\Delta}{L_1^2} = M_{FBA}$$

$$M_{FCD} = \frac{6EI\Delta}{L_2^2} = M_{FDC}$$

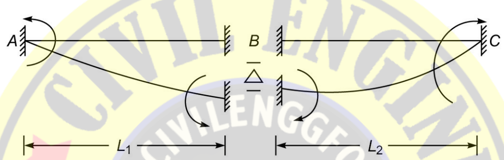


Fig. 6.12 FEM due to settlement of *B*.

If there is sway in the frame

1. Carry out non-sway analysis first.

2. Due to sway only, end moments developed in the columns due to arbitrary sway are proportional to the stiffness of columns. Assume arbitrary but proportional moments in columns. Carry out moment distribution and find sway force. Find the ratio of horizontal force required to prevent sway in non-sway analysis (S) and the sway force ($S¢$) in arbitrary sway cases. Then final moment = Non-sway moment + $\frac{S}{S'}$ arbitrary moment case

* In case of skew frames (Ref. Fig. 6.13)

D = horizontal displacement of *BC*

$$D_{AB} = \frac{\Delta}{S_M \alpha}$$

$$D_{BC} = -(D \cot a + D \cot b)$$

$$D_{CD} = D \cot b$$

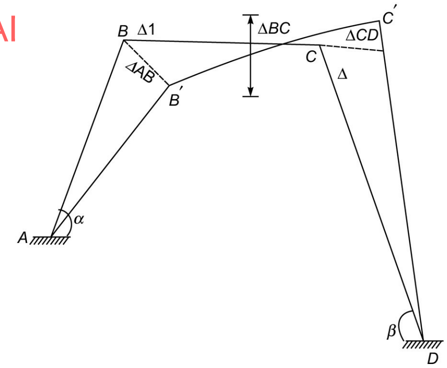


Fig. 6.13 Deformed skew frame

Kani's Method of Rotation Contribution

* The expression $-\frac{1}{2}\frac{k_{AB}}{\sum k_{AB}}$ is called rotation factor for member *AB* at joint *A* and the summation is over various members meeting at *A*.

$$M_{AB} = M_{FAB} + 2 \times \text{Near and moment} + \text{far end moment}$$

* Analysis of symmetric frame taking advantage of symmetry.

(a) **Line of symmetry through columns:** Treat joint at symmetric line as fixed support and analysed half the frame

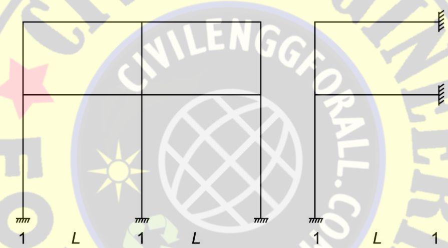


Fig. 6.14 Frame with line of symmetry through columns

(b) When line of symmetry is through the beams (Ref Fig. 6.14), treat beams are fixed at line of symmetry having stiffness = $\frac{1}{2}\times$ actual stiffness of beam in the frame.

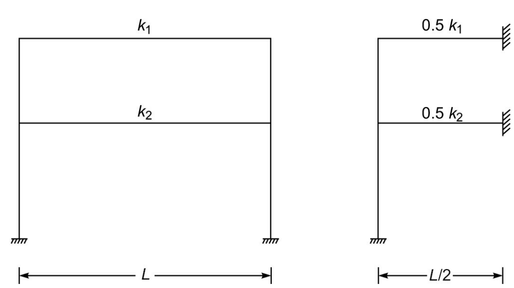


Fig. 6.15 Frame with line of symmetry through beams

* If there is sway in the frame:

Find displacement factors for columns.

$$\text{DF} = -\frac{3}{2}\frac{k}{\sum k},$$

Summation is over the columns in the storey.

Find storey moment = $\frac{S_r h_r}{3}$

Displacement contribution to a column

$$M^*_{AB} = \text{DF}\left[\frac{S_r h_r}{3} + (\Sigma M'_{PQ} + \Sigma M'_{QP})\right]$$

Rotation contributions

$$M¢_{AB} = \text{RF}\ (\text{S}M_{FAB} + \text{S}M¢_{BA} + \text{S}M^*_{PQ})$$

* If the columns in a storey are having different heights,
Choose a convenient height as storey height.

$$C_{PQ} = \frac{h_r}{h_{PQ}}$$

$$\backslash\ M^*_{PQ} = \text{D.F.}\left[\frac{s_r h_r}{3} + \Sigma(M'_{PQ} + M'_{QP})C_{PQ}\right].$$

6.6 COLUMN ANALOGY METHOD

* Method introduced by Hardy Crors is suitable for the analysis of indeterminate beams and columns, with indeterminancy not exceeding three.

* A beam is treated as analogous column of width $\frac{1}{EI}$.

Load on analogous column = Area $\frac{M_s}{EI}$ diagram.

$$M_i = p = \frac{P}{A} + \frac{M_y}{I_{yy}}x$$

where I_{yy} = Moment of inertia of analogous column about $y - y$ axis.

e_y = Eccentricity if load w.r.t. C.G. of analogous column.

$M_y = Pe_y$.

Final moment = $M_s - M_i$

* Column analogy method may be used to
(a) Analyse closed frames
(b) Find stiffness and carry-over factors of beams with variable cross sections.

6.7 INFLUENCE LINE DIAGRAMS FOR STATICALLY INDETERMINATE BEAMS

* It is based on Müller Breslau principle, which states, “If an internal stress component or reaction component is allowed to act through a small distance thereby causing deformation of the structure, the curve of the deformed shape represents to some scale, the influence lines for that stress or reaction component.

* Hence, ILD for indeterminate beams may be found experimentally or by analytically by finding displacements.

6.8 ANALYSIS OF MULTISTOREY BUILDINGS BY APPROXIMATE METHODS

For quick solutions, design engineers use the following approximate methods of analysis:

1. Substitute frame method for vertical loads

2. Any one of the following methods for horizontal loads:
   (i) Portal method (ii) Cantilever method (iii) Factor method

Substitute frame method In this method it is assumed that moment transferred from one floor to another floors are negligible. Hence, a substitute frame consists of floor beams and columns above or below it in a storey. The columns are assumed fixed at top and lower floor levels.

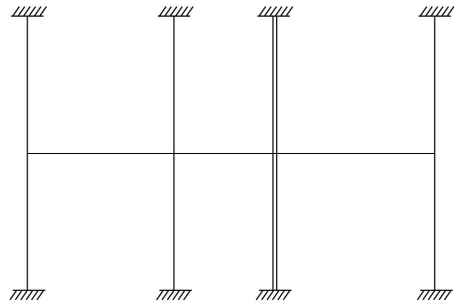


Fig. 6.16 Typical substitute frame

To find design moment due to live load, worst positions of it should be considered as shown in Fig. 6.17.

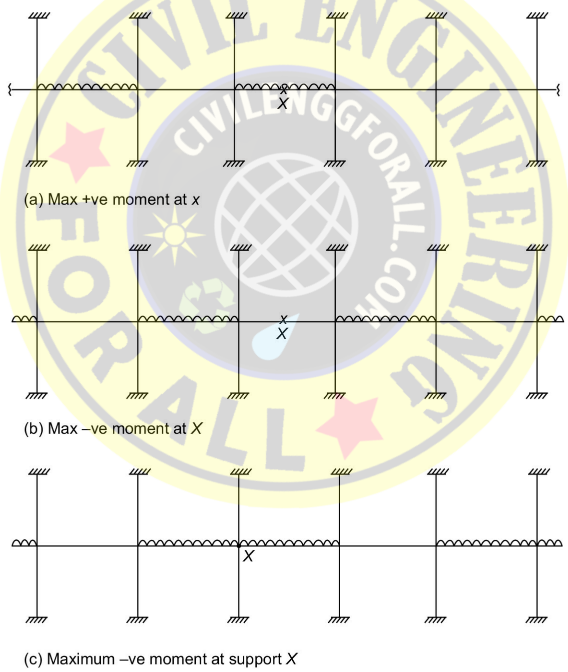


Fig. 6.17 Live load positions for maximum moments at *X*.

Approximate Methods for Horizontal Forces

(i) Portal Method Assumption:

1. Point of contraflexure occurs at the middle of each and every member.
2. Horizontal shear taken by each interior column is twice that by external columns.

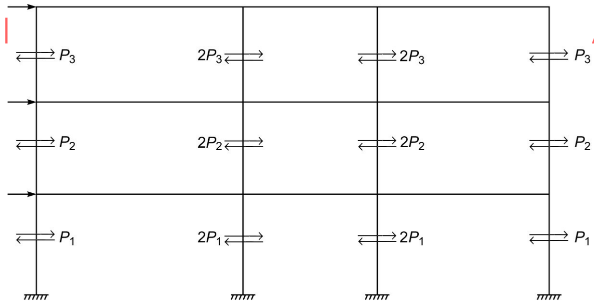


Fig. 6.18 Assumption in portal method

(ii) Cantilever method Assumptions:

1. There is a point of contraflexure at the centre of each member.
2. The intensity of axial stress in each column of a storey is proportional to the horizontal distance of the column from the CG of all columns of the storey under considerations.

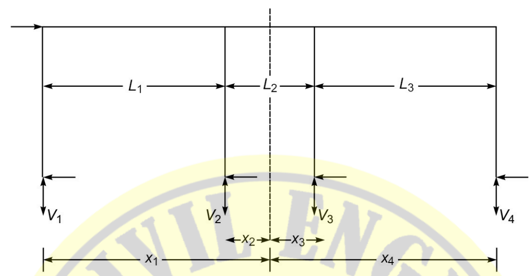


Fig. 6.19 Assumptions in cantilever method

$$\frac{\left(\frac{V_1}{a_1}\right)}{x_1} = \frac{\left(\frac{V_2}{a_2}\right)}{x_2} = \frac{\left(\frac{V_3}{a_3}\right)}{x_3} = \frac{\left(\frac{V_4}{a_4}\right)}{x_4}$$

(iii) Factor method It is an approximate slope deflection method presented in steps using simple instructions like:

(a) Find gird factor $g = \frac{\sum k_c}{\sum k}$

(b) Find column factor $C = 1 - g$

(c) There is a number at each end of column. To the number existing add half the number at the other end.

(d) To the values obtained in step (c) multiply by the relative stiffness of the member to get column moment factors (C) and girder moment factors (G)

(e) Column end moment

$= A \times C$

where constant $A = \frac{Hh}{\Sigma C}$

(f) Girder end moment $= B \times G$

where $B = \frac{\Sigma \text{column moments at joints}}{\Sigma h}$

where $H = H_1 + H_2 + H_3 + \ldots$ = storey shear

h = Storey height

6.9 TWO HINGED ARCHES

* Horizontal thrust may be found by the first theorem of Castigliano (strain energy principle) or by consistent deformation method.

$$H = \frac{\int M'y\, ds/EI}{\int y^2 \frac{ds}{EI}} = \frac{\int M'y\, ds}{\int y^2\, ds}, \text{ if } EI \text{ is constant}$$

where $M¢$ = Beam moment

1. For two-hinged semicircular arch subjected to central concentrated load W,

$$H = \frac{W}{\pi}$$

2. If concentrated load is at a position which makes angle a with vertical line through crown semicircular arch

$$H = \frac{W}{\pi} \cos^2 a.$$

3. In case of udl w throughout,

$$H = \frac{4}{3}\frac{wR}{\pi}$$

4. In case udl is only in one half portion.

$$H = \frac{2}{3}\frac{wR}{\pi}$$

* In case of parabolic arch $y = \frac{4hx(L-x)}{L^2}$,

$$H = \frac{\int My' \frac{dx}{EI} \sec\theta}{\int y^2 \frac{dx}{EI} \sec\theta}$$

$$= \frac{\int M'y\, dx}{\int y^2\, dx}, \text{ if } I = I_o \sec q.$$

1. If load W is at crown,

$$H = \frac{25}{128}\frac{WL}{h}$$

2. In case concentrated load W is at distance from left hand side springing,

$$H = \frac{5}{8}\frac{W}{hL^3}\, a(L-a)(L^2 + La - a^2)$$

3. In case of udl over entire span.

$$H = \frac{WL^2}{8h}$$

4. In case of udl over one half span

$$H = \frac{WL^2}{16h}$$

5. Effects of yielding of supports, rib shortening and temperature, if accounted

$$H = \frac{\int M'y\left(\frac{ds}{EI}\right) + L \propto t - \Delta}{\int y^2 + \left(\frac{ds}{EI}\right) + \left(\frac{L}{E\,A_m}\right)}$$

where L = span a = coefficient of thermal expansion

t = rise in temperature

D = yielding of support

A_m = average area

6. If it is tied arch

$$H = \frac{\int M'y\left(\frac{ds}{EI}\right) + L \propto t - \Delta}{\int y^2 \frac{ds}{EI} + \frac{L}{EA_m} + \frac{L}{A_T\,E_T}}$$

where A_T = cross-sectional area of tie beam

E_T = modulus of elasticity of material of tie beam.

ILD for Two-Hinged Arches

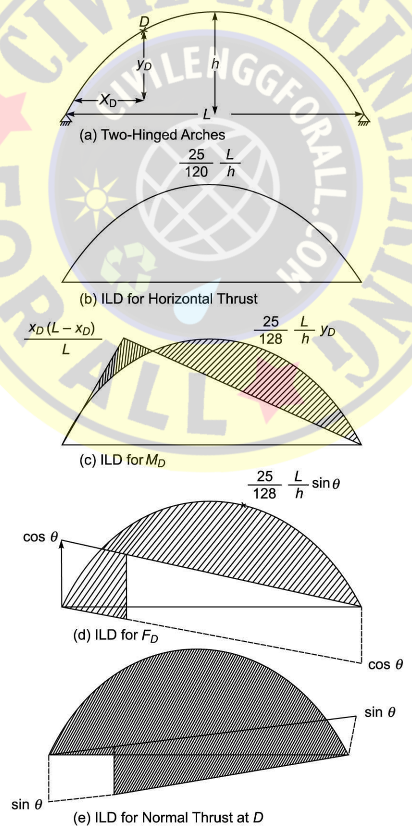


Fig. 6.20 ILD for stress resultants in two-hinged arches

Fixed Arches

To analyse fixed arches the following two methods are available

1. Elastic centre method

2. Column analogy method

Elastic centre method

The elastic centre is defined as the centroid of a analogous column section, the cross section of which is the same as the shape of the given structure with a thickness at any point equal to $\frac{1}{EI}$. Then area, centroidal distances and moment of inertias w.r.t. any axes are given by

$$A = \int \frac{ds}{EI} \quad A\bar{x} = \int x \frac{ds}{EI}$$

$$A\bar{y} = \int y \frac{ds}{EI} \quad I_{xx} = \int y^2 \frac{ds}{EI}$$

$$I_{yy} = \int x^2 \frac{ds}{EI} \text{ and } I_{xy} = \int xy \frac{ds}{EI}$$

If elastic centre is taken as the origin,

$$\int x \frac{ds}{EI} = 0 \text{ and } \int y \frac{ds}{EI} = 0$$

Hence,

$$\int M'x \frac{ds}{EI} + V_A \int x^2 \frac{ds}{EI} + H_A \int xy \frac{ds}{EI} = 0$$

$$\int M'y \frac{ds}{EI} + V_A \int xy \frac{ds}{EI} + H_A \int y^2 \frac{ds}{EI} = 0$$

$$\int M' \frac{ds}{EI} + M_A \int \frac{ds}{EI} = 0$$

where $M¢$ = Moment due to given loading

A = Fixed end A

V_A = Vertical reaction at A

H_A = Horizontal reaction at A

Note: For symmetric arches $\int xy \frac{ds}{EI} = 0$

$$\backslash M_o = -\frac{\int M' \, ds/EI}{\int ds/EI}$$

$$V_o = -\frac{\int M'x \, ds/EI}{\int x^2 \, ds/EI}$$

$$\text{and } H_o = -\frac{\int M'y \, ds/EI}{\int y^2 \, ds/EI}$$

Column analogy method There is hardly any difference between column analogy method and elastic centre method. The difference lies only the way in which equations are looked into. If analogous column is treated as the one which has the same curve as the arch and width at any point equal to $\frac{1}{EI}$ and loaded with $\frac{M'}{EI}$ diagram. For symmetric fixed arch

$$M_o = -\frac{P}{A} \quad V_o = -\frac{M_y}{E_{yy}} \text{ and } H_o = -\frac{M_x}{I_{xx}}$$

where P = The area of $\frac{M}{EI}$ diagram

In case of unsymmetric arches,

$$M_o = -\frac{P}{A},\ V_o = -\frac{M_o - M_x\left(\frac{I_{xy}}{I_{xx}}\right)}{I_{yy} - \left(\frac{I_{xy}^2}{I_{xx}}\right)}$$

$$H_o = -\frac{M_x - M_y\left(\frac{I_{xy}}{I_{yy}}\right)}{I_{xx} - \frac{I_{xy}^2}{I_{yy}}}$$

* In case of symmetric parabolic arch with secant variation, elastic centre is at a depth $\frac{h}{3}$ below the crown where h is the height of crown point from support line.

Beams Curved in Plan

Strain energy due to torsional moment also should be considered. Thus,

$$U = \int \frac{M^2}{2EI} ds + \int \frac{T^2}{2GJ} ds$$

* Deflection at free end in a quarter circle cantilever arch due to load P at free end is

$$D = \frac{PR^3}{EI}(\pi - 2)$$

* In case of semicircular fixed arch subjected to central concentrated load W

Moment at centre = $\frac{WR}{\pi}$

Moment at support = $\frac{WR}{2}$

Torsional moment at support = 0

Torsional moment at support = 0.1817 WR

Torsional moment = 0 at a = 64.96°

where a = measured from centre line OC.

* For circular beam supported at number of equidistant points,

Support moment = kwR^2f

Midspan moment = $k¢wR^2f$

Max. torsional moment = $k\leq wR^2f$

Table 6.1 Coefficients for ring beam stress resultants.

No. of supports	*q*	*k*	*k¢*	*k≤*	*a for max torsional mark*
4	90°	0.137	0.07	0.021	19.25
5	72°	0.108	0.054	0.0148	15.25
6	60°	0.089	0.045	0.009	12.75
8	45°	0.066	0.03	0.005	9.33

10	36°	0.054	0.023	0.003	7.50

Unsymmetric Bending and Shear Centre

The direction of principal planes is given by

$$\tan 2q = \frac{2I_{xy}}{I_{yy} - I_{xx}}$$

where q = inclination of the plane to the direction of I_{xx} plane

Principal moment of inertia are given by

$$I_{uu} = \frac{1}{2}(I_{xx} + I_{yy}) - \sqrt{\left(\frac{I_{yy} - I_{xx}}{2}\right)^2 + I_{xy}^2}$$

$$I_{vv} = \frac{1}{2}(I_{xx} + I_{yy}) + \sqrt{\left(\frac{I_{yy} - I_{xx}}{2}\right)^2 + I_{xy}^2}$$

* Mohr's circles can be drawn to determine principal moment of inertia and principal planes
* Shear centre: The point in the cross section of beam through which if load acts, there will not be any twisting of the section is known as shear centre.
* Shear flow is the shear force resisted per unit length along the centre line of the narrow strip.
* The shear centre of a channel section e from the back of web, is at a distance

$$e = \frac{b/2}{1 + \frac{1}{6}\frac{a_w}{a_f}}$$

where b = width of flange

a_w = area of web

a_f = area of flange

6.10 MATRIX METHOD OF STRUCTURE ANALYSIS

* The number of equations required over and above the equations of static equilibrium for the analysis of a structure is known as the degree of static indeterminacy or degree of redundancy.
* The number of equilibrium conditions required to find the displacement components of all joints of the structure are known as the degree of kinematic indeterminacy or degree of freedom of the structure.
* The systematic development of consistent deformation method has led to flexibility method which is also known as the force method or compatibility method.
* The systematic development of slope deflection method in the matrix form has led to stiffness matrix method which is also known as displacement or equilibrium method.
* The element d_{ij} of a flexibility matrix is the displacement in coordinate i due to a unit force applied at coordinate j.
* The element of stiffness matrix k_{ij} is the force at coordinate i due to unit displacement at coordinate j.

* The flexibility and stiffness matrices are inverse of each other.

Steps involved in flexibility method

1. Determine the degree of static indeterminacy.
2. Choose the redundant.
3. Assign the coordinates to the redundant force directions.
4. Remove the restraints to redundant forces to get basic determinate structure.
5. Determine the deflections in the coordinate directions due to given loading in basic determinate structure.
6. Determine flexibility matrix.
7. Apply the compatibility conditions:

$$P = [d]^{-1} [\mathrm{D} - \mathrm{D}_i]$$

8. Knowing the redundant forces, compute the member forces.

Stiffness matrix method

1. Determine the degree of kinematic indeterminacy.
2. Assign the coordinate numbers to the unknown displacements.
3. Impose restraints in all coordinate directions to get a fully restrained structure.
4. Determine the forces developed in each of the coordinate directions of a fully restrained structure (P_L).
5. Determine stiffness matrix k.
6. Note the final forces.
7. Form and solve the stiffness equation $[k]$ $[\mathrm{D}] = P - P_2$ and find D.
8. Compute member forces using these displacements.

Element approach of stiffness matrix

1. Give coordinate directions to displacements in all Cartesian directions at the end of each element.
2. For each element, find transformation matrix and element stiffness matrix in local coordinate directions.
3. Transform local stiffness matrix to global system by using the relation $[k] = [R]^T [K_e] [R]$ and place it in the global matrix.
4. Assemble load vector of the system.
5. Write stiffness equations.
6. Impose boundary conditions.
7. Solve the equations.
8. Calculate the required member forces.
9. Calculate support reactions.

6.11 PLASTIC ANALYSIS

* Plastic hinge is a section at which all the fibres have yielded and hence for any further load rotations takes place at the section without resisting any additional moment.
* Plastic moment capacity of a section may be defined as the moment which makes all the fibres at that section to yield and thereby form a plastic hinge.
* Assumptions: Apart from usual assumptions in bending theory the following assumptions are also made:

1. Whenever a fully plastic moment is attained at any cross section, a plastic hinge forms which can undergo rotation of any magnitude, but bending moment remains content at fully plastic value (M_P).
2. Effect of axial load and shear on fully plastic moment capacity of the section is neglected.
3. The deflections are small enough for the equations of statical equilibrium to be same as those for undeformed structures.

Shape factor

$$M_y = f_y Z \, M_p = f_y Z_p.$$

\ Shape factor = $\frac{M_p}{M_y} = \frac{Z_p}{Z}$

Shape factor for

1. Rectangular sections = 1.5
2. Circular sections = $\frac{16}{3\pi}$ = 1.698
3. For triangular sections = 2.343
4. Diamond section = 2.0

Basic theorems for finding collapse loads

1. Static theorem For a given structure and loading. If there exists any distribution of bending moment throughout the structure which is both safe and statically admissible with a set of loads W, the value W must be less than or equal to the collapse load W_C.

2. Kinematic theorem For a given structure subjected to a set of loads W, the value of W found to any assumed mechanism must be either greater or equal to the collapse load W_C.

Uniqueness theorem If for a given structure and loading at least one safe and statically admissible bending moment distribution can be found and in this distribution the bending moment is equal to the fully plastic moment at enough cross sections to cause failure of the structure due to unlimited rotations at plastic hinges, the corresponding load will be equal to the collapse load W_C.

Methods of Plastic Analysis

1. Statical method
2. Kinematic method

1. Statical method It consists of drawing statically admissible bending moment diagram and equating bending moment at sufficient points to plastic moment, so that collapse mechanism is formed.

2. *Kinematic method* For assumed mechanisms find collapse load. Try all possible mechanisms, which give least W_C is real collapse load.

* In case of frames try all possible

(i) beam mechanisms
(ii) sway mechanisms and
(iii) combined mechanisms.

MULTIPLE-CHOICE QUESTIONS

I. *Select the correct choice from the following questions (Q. 1-77)*

1. The change in the slope between two points in a straight member under flexure is equal to the area of $\frac{M}{EI}$ diagram between those two points. This statement is known as

(a) Conjugate beam theorem
(b) Mecaulay's theorem
(c) Moment area theorem
(d) Castigliano's theorem

2. Deflection at a point in a beam in the direction perpendicular to its original straight line position measured from the tangent to the elastic curve at another point is given by the moment of $\frac{M}{EI}$ diagram about the point where deflection is required. This statement is known as

(a) Conjugate beam theorem
(b) Mecaulay's theorem
(c) Moment area theorem
(d) Castigliano's theorem

3. The conjugate beam of a cantilever with end A fixed and end B is free is

(a) end A fixed end B is free
(b) end A is hinged end B is simply supported
(c) end A is free end B hinged
(d) end A is free end B is fixed

4. A beam has end A fixed end B is on roller and there is internal hinge at C. Its conjugate beam is

(a) end A free, end B and C on roller
(b) end A is hinged, end B fixed, C on roller
(c) end A is free, end B fixed, C hinged
(d) end A is fixed, and B hinged, C hinged

5. Beam ABC has hinged end at A, simple support at B and free end at C. Its conjugate beam has

(a) fixed end at A, internal hinge at B and hinged end at C
(b) hinged end at A, internal hinge at B and fixed end at C
(c) hinged end at A, roller supports at B and C
(d) roller support at A and B and fixed support at C

6. Which one of the following is wrong with respect to strain energy method for finding deflection?

(a) Structure should be subjected to a single concentrated load.
(b) Deflection can be found only at the loaded point.
(c) Deflection can be found only in the direction of load.
(d) Deflection can be found at any point in desired direction.

7. Virtual work means

A. Work done by real forces due to hypothetical displacements

B. Work done by hypothetical forces during real displacements
(a) Both *A* and *B* correct
(b) *A* is correct and *B* is wrong
(c) *A* is wrong and *B* is correct
(d) Both *A* and *B* are wrong

8. If a rigid body is in equilibrium under a system of forces the virtual work done by this system of forces during virtual displacement is zero. This principle is known as
(a) work energy principle
(b) Mecaulay's principle
(c) Bernauli's principle
(d) Castigliano's principle

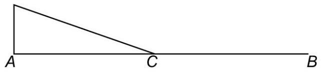
9. If a body in equilibrium under a system of forces is given virtual deformation, the virtual work done by the system of forces is equal to the internal virtual work done by the stresses due to that system of forces'. The above principle is applicable to deformations due to
(a) loads
(b) settlement of support
(c) lack of fit
(d) all the above cases

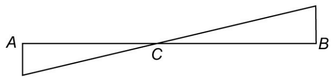
10. 'In a linearly elastic structure, partial derivative of the strain energy with respect to a load is equal to the deflection of the point where the load is acting, the deflection being measured in the direction of the load'. This is known as
(a) Castigliano's theorem
(b) Bernauli's theorem
(c) work energy principle
(d) unit load method

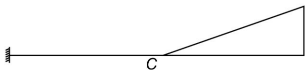
11. Displacement at point *A* due to the load at point *B* is same as displacement of point *B* due to the same load acting at point *A*, the displacement being measured in the directions of the loads'. The above statement is known as
(a) Mecaulay's theorem
(b) Castigliano's theorem
(c) Maxwell's theorem
(d) Bernauli's theorem

12. Influence line diagram for shear force at point *C* in the cantilever beam is having the shape (Ref.

Fig. Q. 12)

(a) 

(b) 

(c) 

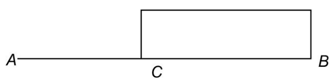
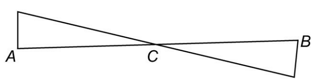
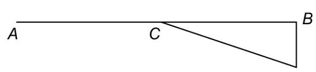
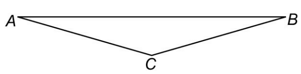
(d) 

Fig. Q. 12

13. Influence line diagram for bending moment at *C* in a cantilever with fixed end at *A* and free at *B* is (Ref Fig. Q. 13)

(a) 

(b) 

(c) 

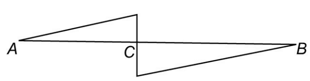
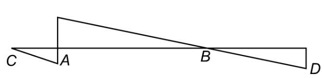
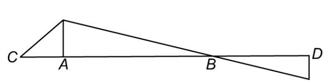
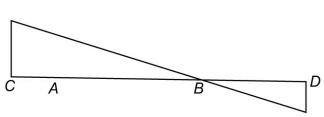
(d) 

Fig. Q. 13

14. In a double overhanging beam with supports at *A* and *B* the shape of influence diagram for reaction at *A* is (Ref. Fig. Q. 14)

(a) 

(b) 

(c) 

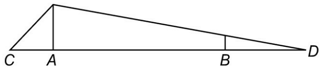
(d) 

Fig. Q. 14

15. The maximum bending moment at 6 m from end *A* in a simply supported beam of span 15 m due to a moving udl, spanning 5 m occurs when the tail of load is at _______ distance from *A*

(a) 1.8 m
(b) 2.0 m
(c) 2.4 m
(d) 4.0 m

16. The absolute bending moment in a simply supported beam of span 10 m due to a moving load of 40 kN/m spanning over 5 m is

(a) 375 kN m at 2.5 m from end *A*
(b) 375 kN m at midpoint
(c) 375 kN m at 3.75 m from end *A*
(d) 500 kN m at midspan

17. In a simply supported beam absolute maximum shear force due to a train of concentrated loads occurs

(a) at support *A* when trailing load is on the support
(b) at support *A* when leading load is on the support
(c) at midspan when leading load is at midspan
(d) none of the above is definite case

18. Four point loads 8, 15, 15 and 10 kN have centre-to-centre spacing of 2 m between consecutive loads and they traverse a girder of 30 m spam from left to right with 10 kN load loading. The maximum shear force at 8 m from left support will be

(a) 8.2 kN
(b) 25.4 kN
(c) 30.2 kN
(d) 42.2 kN

19. In the above case maximum moment at section 8 m from left support occurs when

(a) 10 kN load is on the section
(b) first 15 kN load is on the section
(c) second 15 kN is on the section
(d) 8 kN load is on the section

20. A train of concentrated loads shown in Fig. Q. 20 moves from left to right on a simply supported girder of span 16 m. For maximum moment leading load is at a distance

(a) 8.35 m from *A*
(b) 10.35 m from *A*
(c) 8 m from *A*
(d) 10 m from *A*

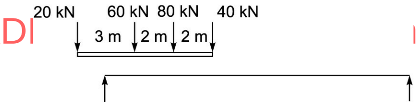


Fig. Q. 20

21. Influence line diagram for a member of the truss is as shown in the Fig. Q.21. What is the maximum direct force in the member when a udl of intensity 20 kN/m, longer than the span moves? (Ref. Fig. Q. 21)

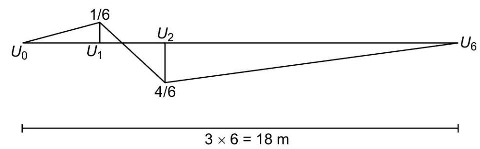


Fig. Q. 21

(a) 6 kN
(b) 48 kN
(c) 64 kN
(d) 96 kN

22. A parabolic arch of span L has central rise h. Taking springing point as the origin its equation is given by

(a) $\frac{hx(L-x)}{L}$
(b) $\frac{hx(L-x)}{L^2}$
(c) $\frac{4hx}{L^2}(L-x)$
(d) $\frac{8hx}{L^2}(L-x)$

23. A parabolic arch has springings A and B are at different levels. The height of crown point C from A is h_1 and from B it is h_2. If L is span, the horizontal distance of AC is

(a) $\frac{L\sqrt{h_2}}{\sqrt{h_1+h_2}}$
(b) $\frac{L\sqrt{h_2}}{\sqrt{h_1}+\sqrt{h_2}}$
(c) $\frac{L\sqrt{h_1}}{\sqrt{h_1+h_2}}$
(d) $\frac{L\sqrt{h_1}}{\sqrt{h_1}+\sqrt{h_2}}$

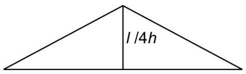
24. In case of a three-hinged arch at a point V is vertical shear, H is horizontal thrust and q is the angle made by tangent to horizontals. The normal thrust N and radial shear Q are given by
(a) $V\cos q + H\sin q$ and $V\cos q - H\sin q$
(b) $V\sin q + H\cos q$ and $V\sin q - H\cos q$
(c) $V\sin q - H\cos q$ and $V\sin q + H\cos q$
(d) $V\cos q - H\sin q$ and $V\cos q + H\sin q$

25. A circular arch of span 25 m with a central rise 5 m is hinged at the crown and springings It

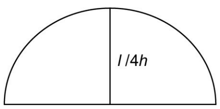
carries a point load of 100 kN at 6 m from the left support. In this case the horizontal thrust is

(a) 45 kN
(b) 60 kN
(c) 75 kN
(d) 90 kN

26. The influence line for horizontal thrust in a three-hinged parabolic arch of span 'l' and size h is as shown in Fig. Q. 26.

(a) 

(b) 

(c) 

(d) none of the above

Fig. Q. 26

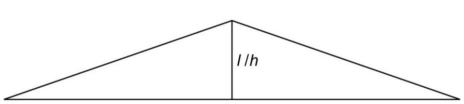
27. Uniformly distributed load w per unit length is suspended from a cable between point A and B. If the points A and B are at same level at distance l and central sag of the cable is h, the horizontal thrust developed of supports is

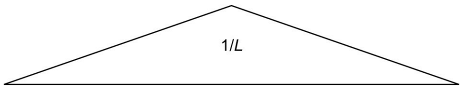
(a) $\frac{wl}{2h}$
(b) $\frac{wl^2}{4h}$
(c) $\frac{wl}{4h}$
(d) $\frac{wl^2}{8h}$

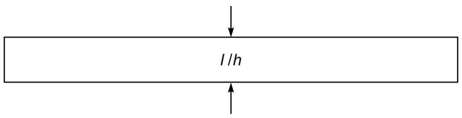
28. In case of a suspension bridge with three-hinged stiffening girder, influence line diagram for equivalent cable load W_e is a symmetric triangle with maximum ordinate _______ at midspan.

(a) $\frac{2}{l}$
(b) $\frac{4}{l}$
(c) $\frac{8}{l}$
(d) none of the above

29. In case of a suspension cable of span l and central sag h with two-hinged stiffening girder, influence line diagram for equivalent cable load W_e is (Ref. Fig. Q. 29).

(a) 

(b) 

(c) 

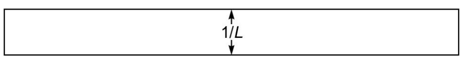
(d) 

Fig. Q. 29

30. The degree of indeterminacy of the beam shown in Fig. Q. 30 is

(a) 3
(b) 4
(c) 5
(d) 6

Fig. Q. 30

31. The degree of static indeterminacy of the frame shown in Fig. Q. 31. is

(a) 4
(b) 5
(c) 6
(d) 7

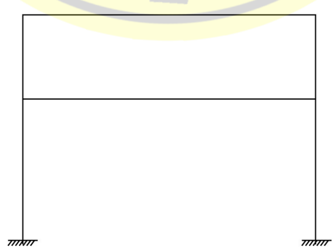


Fig. Q. 31

32. The degree of static indeterminacy of plane frame shown in Fig. Q. 32 is

(a) 14
(b) 16
(c) 18
(d) 20

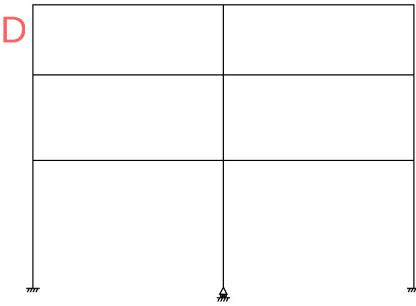


Fig. Q. 32

33. Figure Q. 33 shows a rigid jointed two storey space frame. Its static indeterminacy is

(a) 66
(b) 72
(c) 78
(d) 84

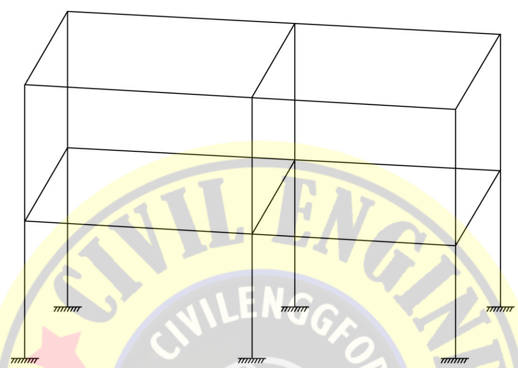


Fig. Q. 33

34. The degree of indeterminacy of pin jointed frame shown in Fig. Q. 34 is

(a) 2
(b) 3
(c) 4
(d) 6

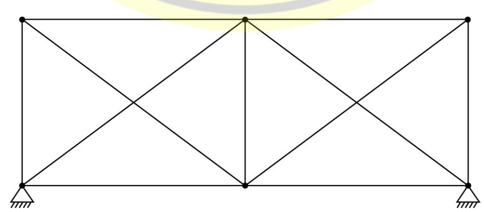


Fig. Q. 34

35. A propped cantilever of span L is fixed at end A and simply supported at end B. It is subjected to udl of intensity w per unit length. Then the reactions at A and B are

(a) $R_A = \frac{5}{8}wL, R_B = \frac{3}{8}wL$

(b) $R_A = R_B = \frac{wL}{2}$

(c) $R_A = \frac{3}{8}wL, R_B = \frac{5}{8}wL$

(d) $R_A = \frac{wL}{4}, R_B = \frac{3wL}{4}$

36. A propped cantilever of span L is fixed at end A and simply supported at end B. Due to a

concentrated load W at midspan, reaction at B is

(a) $\frac{3}{16}W$

(b) $\frac{W}{4}$

(c) $\frac{5W}{8}$

(d) $\frac{7W}{16}$

37. If M_{FBA} and M_{FBA} are the fixed moments in a fixed beam of span L, the rotation at end A is

(a) $\frac{L}{3EI}(M_{FAB} + 2M_{FBA})$

(b) $\frac{L}{3EI}(2M_{FAB} + M_{FBA})$

(c) $\frac{L}{6EI}(M_{FAB} + 2M_{FBA})$

(d) $\frac{L}{6EI}(2M_{FAB} + M_{FBA})$

38. In a fixed beam of span L subject to udl w/unit length, moment at mid-span is

(a) $\frac{wL^2}{8}$

(b) $\frac{wL^2}{12}$

(c) $\frac{wL^2}{24}$

(d) $\frac{wL^2}{48}$

39. In a fixed beam of span L subject to central concentrated load W, the fixed end moment and moment at mid-span are respectively.

(a) $\frac{WL}{12}$ and $\frac{WL}{6}$

(b) $\frac{WL}{8}$ and $\frac{WL}{8}$

(c) $\frac{WL}{6}$ and $\frac{WL}{12}$

(d) none of the above

40. For unyeilding supports, the slope deflection equation for the beam shown in Fig. Q. 40 is

(a) $M_{BC} = M_{FBC} + \frac{2EI_2}{L_2}(2\theta_B + \theta_c)$

(b) $M_{BC} = M_{FBC} + \frac{2EI_2}{L_2}(\theta_B + 2\theta_c)$

(c) $M_{BC} = M_{FBC} + \frac{2EI_2}{L_2}(2\theta_B + \theta_C) + \frac{1}{2}M_{FCB}$

(d) $M_{BC} = M_{FBC} + \frac{2EI_2}{L_2}(\theta_B + 2\theta_C) + \frac{1}{2}M_{FCB}$

Fig. Q. 40

41. In the beam shown in Fig. Q. 41 support B yields by D, the slope deflection equation for M_{BA} is

(a) $M_{BA} = M_{FBA} + \frac{2EI}{L^2}\left(\theta_A + 2\theta_B - \frac{\Delta}{L}\right)$

(b) $M_{BA} = M_{FBA} + \frac{2EI}{L^2}\left(2\theta_A + \theta_B - \frac{\Delta}{L}\right)$

(c) $M_{BA} = M_{FBA} + \frac{2EI}{L^2}\left(\theta_A + 2\theta_B - \frac{3\Delta}{L}\right)$

(d) $M_{BA} = M_{FBA} + \frac{2EI}{L^2}\left(2\theta_A + \theta_B - \frac{3\Delta}{L}\right)$

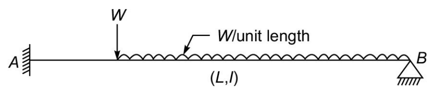


Fig. Q. 41

42. For the analysis of continuous beam shown by the slope deflection method, the conditions to be used are (Ref. Fig. Q. 42)

(a) $q_A = 0$, $M_{BA} = M_{BC}$, $q_C = 0$

(b) $q_A = 0$, $M_{BA} + M_{BC} = 0$, $q_C = 0$

(c) $q_A = 0$, $M_{BA} + M_{BC} = 0$, $M_{CB} = 0$

(d) $q_A = 0$, $M_{BA} = M_{BC}$, $M_{CB} = 0$

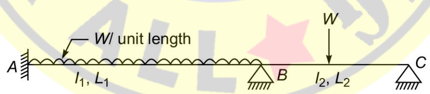


Fig. Q. 42

43. Which of the frame shows in Fig. Q. 43 experience sway?

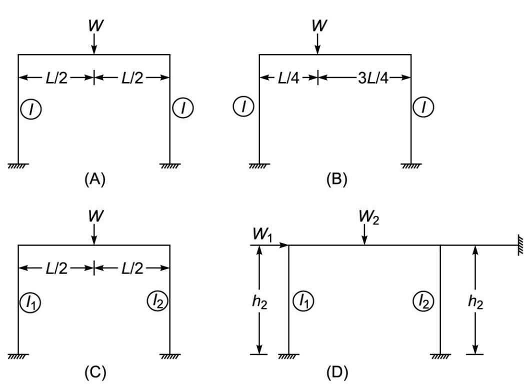


Fig. Q. 43

Select the correct answer using the codes

(a) A and B

(b) A and C

(c) B and C

(d) B and D

44. Figure Q. 44 shows a frame to be analysed by moment distribution. The distribution factors for members EB, ED and EF will be respectively

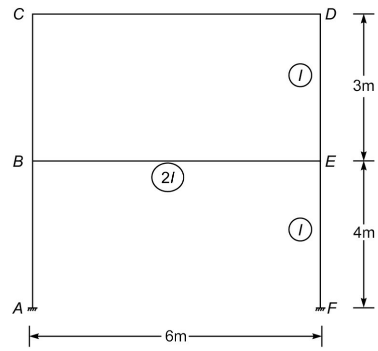


Fig. Q. 44

(a) $\frac{2}{9}, \frac{4}{9}, \frac{1}{3}$

(b) $\frac{8}{13}, \frac{3}{13}, \frac{4}{13}$

(c) $\frac{3}{10}, \frac{4}{10}, \frac{3}{10}$

(d) $\frac{4}{11}, \frac{4}{11}, \frac{3}{11}$

45. The ratio of fixed end moments developed in columns AB and DC in the frame shown Fig. Q. 45 due to sway is

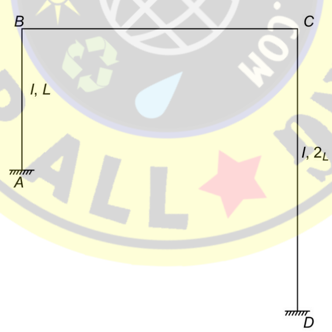


Fig. Q. 45

(a) 4 : 1
(b) 2 : 1
(c) 1 : 2
(d) 1 : 4

46. 'If an internal stress component like shear force, bending moment or reaction component is allowed to act through a small distance thereby causing deformation of the structure, the curve of the deformed shape represents to some scale, the influence line diagram for that stress or the reaction component. The above statement is known as

(a) Mecaulay's theorem
(b) Müller–Breslau principle
(c) Castigliano's theorem
(d) Maxwell's theorem

47. Which one of the following methods is more accurate for the analysis of rigid frames?

(a) Substitute frame method
(b) Portal method
(c) Factor method
(d) Slope deflection method

48. In a two-hinged semicircular arch of radius R subjected to a central concentrated load W, the horizontal thrust developed is

(a) $\frac{W}{2}$
(b) $W/4$
(c) $\frac{3WR}{4\pi}$
(d) $\frac{W}{\pi}$

49. A semicircular two hinged arch of radius R is subjected to a udl w/unit length over entire span. Assuming EI to be constant, horizontal trust developed is

(a) $\frac{3}{4}\frac{wR}{\pi}$
(b) $\frac{wR}{\pi}$
(c) $\frac{4}{3}\frac{wR}{\pi}$
(d) none of the above

50. The horizontal thrust developed in a two-hinged semicircular arch subjected to a udl on only one half of arch is

(a) $\frac{WR}{\pi}$
(b) $\frac{2}{3}\frac{WR}{\pi}$
(c) $\frac{4}{3}\frac{WR}{\pi}$
(d) $\frac{WR}{2\pi}$

51. The horizontal thrust in a two-hinged parabolic arch of span h with equation $y = \frac{4hx\,(h-x)}{L^2}$ with $I = I_o$ sec q, subject to beam moment $M¢$

(a) $H = \frac{\int M'y\,dx}{\int y^2\,dx}$
(b) $H = \frac{\int M'\,dx}{\int y\,dx}$
(c) $H = \frac{\int M'y\,dx}{\int y\,dx}$
(d) $H = \frac{\int M'\,dx}{L}$

52. A two-hinged parabolic arch of span L and rise h carries a concentrated load W at the crown. The expression for horizontal thrust developed is

(a) $\frac{5}{64}\frac{WL}{h}$

(b) $H = \frac{25}{128}\frac{WL}{h}$

(c) $\frac{5}{16}\frac{WL}{h}$

(d) $\frac{WL}{h}$

53. A two-hinged parabolic arch of span L and rise h carries udl w/unit length over the whole span. Assuming $I = I_o \sec q$, horizontal thrust developed is

(a) $H = \frac{wL^2}{16h}$

(b) $H = \frac{wL^2}{12h}$

(c) $H = \frac{wL^2}{8h}$

(d) $H = \frac{wL^2}{24h}$

54. In a two-hinged parabolic arch,

A. if support yields horizontal thrust increases

B. if, ribshortening is considered, horizontal thrust reduces

Select your answer code from the following:

(a) Both A and B are true
(b) A is true but B is false
(c) A is false but B is true
(d) Both A and B are false

55. In case of a symmetric, fixed parabolic arch of span L and rise h, elastic centre is at a depth ______ below the crown.

(a) $\frac{h}{4}$

(b) $\frac{h}{3}$

(c) $\frac{h}{2}$

(d) h

56. The point in the cross section of beam through which if load acts there will not be any twisting of the beam but there will be only bending is known as

(a) centre of gravity
(b) centroid
(c) shear centre
(d) all the above

57. A. The number of equilibrium equations needed to find the displacement components of all joints

of the structure is known as the degree of kinematic indeterminacy.

B. The kinematic indeterminacy is also known as degree of redundancy.

Select your answer code from the list below:

(a) Both A and B are true
(b) A is true but B is false
(c) A is false but B is true
(d) Both A and B are false

58. The systematic development of slope deflection method in the matrix form is known as to

(a) stiffness matrix method
(b) displacement matrix method
(c) equilibrium method
(d) all the above

59. Flexibility matrix method is known as

A. Force method
B. Compatibility method
C. Displacement method
D. Equilibrium method

Select your answer code from the list given below:

(a) A and B are true
(b) B and C are true
(c) C and D are true
(d) A and D are true

60. End *A* of beam *AB* is hinged and end *B* is on roller. The degree of kinematic indeterminacy is

(a) 3
(b) 2
(c) 1
(d) zero

61. Degree of kinematic indeterminacy of the trust shown is Fig. Q. 61. is

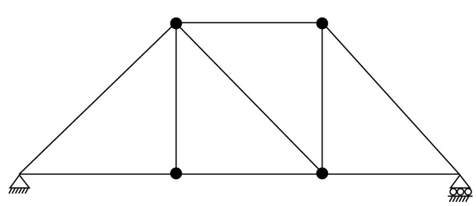


Fig. Q. 61

(a) zero
(b) 3
(c) 6
(d) 9

62. The degree of freedom of the frame shown in Fig. Q. 62.

(a) 18

(b) 24

(c) 28
(d) 36

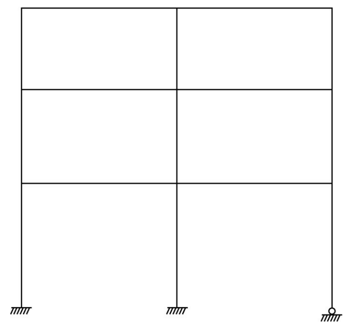


Fig. Q. 62

63. The degree of freedom of the rigid frame shown in Fig. Q. 63 is

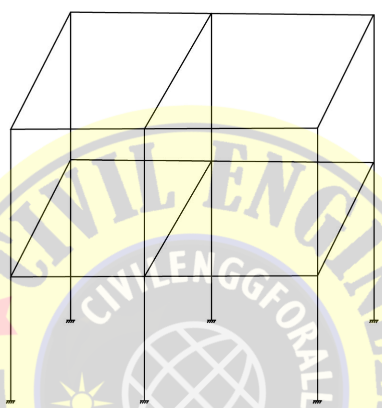


Fig. Q. 63

(a) 36
(b) 48
(c) 72
(d) 96

64. The element d_{ij} if a flexibility matrix is
(a) the displacement at coordinate j due to a unit force at coordinate i
(b) the displacement at coordinate i due to a unit force at coordinate at j
(c) the force at coordinate j due to a unit displacement at coordinate at i
(d) the force at coordinate i due to a unit displacement at coordinate at j

65. Figure shown in Fig. Q. 65 is a continuous beam with uniform flexural rigidity. Options (a) to (d) represent shapes of bending moment diagrams. Select the correct options

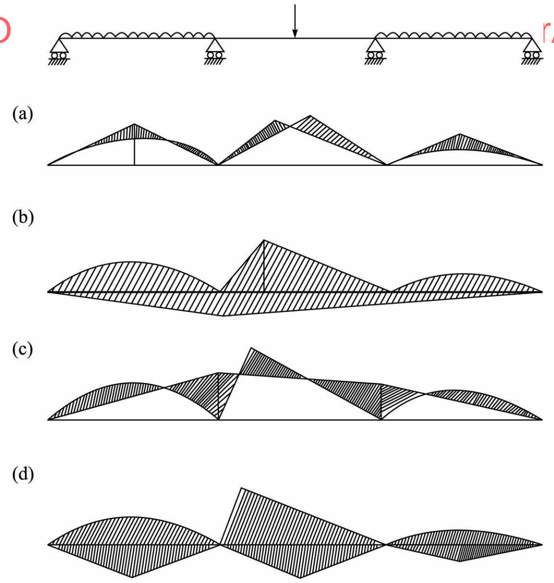


Fig. Q. 65

66. The moment which makes all the fibres at the section to yield is known as
   (a) flexural rigidity
   (b) moment of resistance
   (c) plastic moment capacity
   (d) yield moment

67. In plastic analysis of structures the following assumptions are made:
   A. Plane section before bending, remains plane even after bending.
   B. The relationship between compressive stress and compressive strain is the same as between tensile stress and tensile strain.
   C. The defections are small.
   Select the correct answer code from below:
   (a) A and B are true but C is wrong
   (b) A and C are true but B is wrong
   (c) B and C are true but A is wrong
   (d) A, B and C are true

68. The shape factor of a rectangular section is
   (a) 1.0
   (b) 1.5
   (c) 2.0
   (d) 3.6

69. The shape factor of a circular section with radius R is
   (a) $\frac{4R}{3\pi}$
   (b) $\frac{4R}{\pi}$
   (c) $\frac{16}{3\pi}$
   (d) $\frac{8}{3\pi}$

70. The shape factor of a diamond shaped section for bending about its diametral arise is
   (a) 1.2
   (b) 1.5
   (c) 2.0
   (d) none of the above

71. The shape factor of a I section is
   (a) 1.2
   (b) 1.5
   (c) 2.0
   (d) none of the above

72. For the section shown in Fig. Q. 72, the plastic neutral axis is

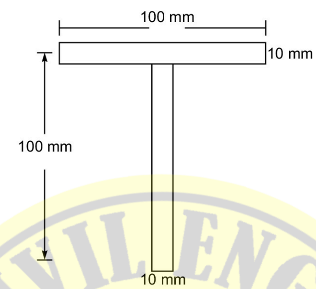


Fig. Q. 72

   (a) in the flange
   (b) at the junction of flange and web
   (c) in the web
   (d) at the top of flange

73. Plastic neutral axis of the section shown in the Fig. Q. 73 from topmost fibre is at a distance

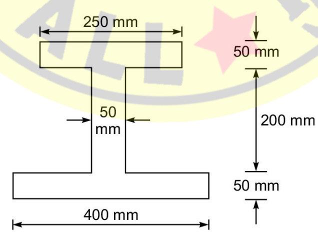


Fig. Q. 73

   (a) 210 mm
   (b) 225 mm
   (c) 237.5 mm
   (d) 262.5 mm

74. ‘For a given structure and loading, if these exist any distribution of bending moment throughout the section which is both safe and statically admissible with a set of loads W, the value of W must be less than or equal to the collapse load W_c’. The above theorem is known as
   (a) kinematic theorem
   (b) static theorem
   (c) uniqueness theorem
   (d) none of the above

75. The collapse load for a propped cantilever of span L subjected to a concentrated load W at mid-span is

(a) $\frac{2M_p}{L}$
(b) $\frac{3M_p}{L}$
(c) $\frac{4M_p}{L}$
(d) $\frac{6M_p}{L}$

76. Collapse load in a fixed beam of span L, carrying udl over entire span and having plastic moment capacity M_p is

(a) $\frac{6M_p}{L}$
(b) $\frac{8M_p}{L}$
(c) $\frac{8M_p}{L^2}$
(d) $\frac{16M_p}{L^2}$

77. For the frame of uniform section shown in the Fig. Q. 77, if combined mechanism is considered plastic moment is

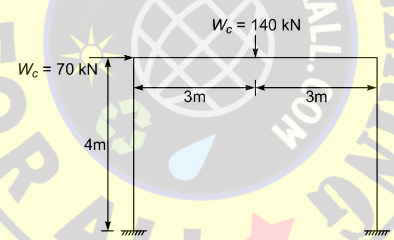
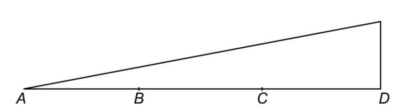
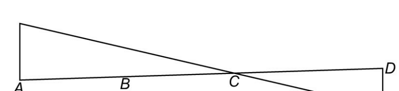


Fig. Q. 77

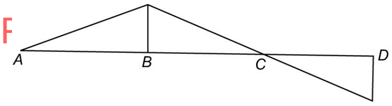
(a) 175 kN-m
(b) 125 kN-m
(c) 116.67 kN-m
(d) 97.67 kN-m

II. *Match List I with list II selecting answer code given below the item nos. 78 to 81.*

78.

	List I		List II
A.	ILD for R_4	1.	
B.	ILD for R_C	2.	

C. ILD for SF at *B*

3. 

D. ILD for bending moment at *B* in

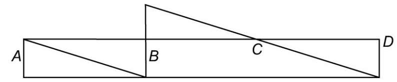
4. 

Fig. Q. 78

Codes:

(a)	A – 1	B – 2	C – 3	D – 4
(b)	A – 1	B – 3	C – 2	D – 4
(c)	A – 2	B – 3	C – 1	D – 4
(d)	A – 2	B – 1	C – 4	D – 3

79. In the simply supported beam shown in Fig. Q. 79 when 10 kN moving load moves from left to right, match list I with list II

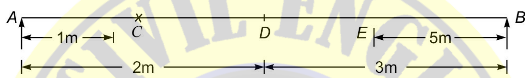


Fig. Q. 79

List I		List II	
A.	Absolute Maximum moment At *C*	1.	8 kN-m
B.	Maximum moment at *D*	2.	10.5 kN-m
C.	Maximum moment at *E*	3.	12 kN-m
D.	Absolute maximum moment	4.	12.5 kN-m

Codes

(a)	A – 3	B – 2	C – 1	D – 4
(b)	A – 1	B – 3	C – 2	D – 4
(c)	A – 2	B – 1	C – 3	D – 4
(d)	A – 1	B – 2	C – 4	D – 3

80. Figure Q. 80 shows a typical truss List I shows its member and List II shapes of influence line diagrams for the forces in the member. Match List I with List II by selecting answer code given.

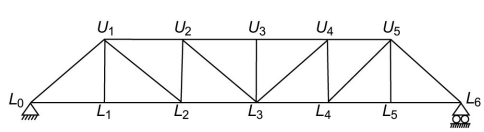
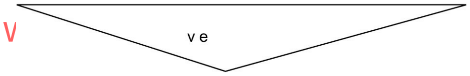


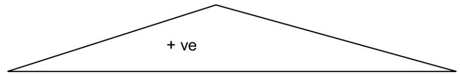
Fig. Q. 80

List I **List II**

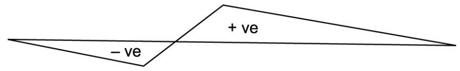
A. L_1U_1 1.



B. U_2L_3 2.



C. L_2L_3 3.



D. U_2U_3 4.

Codes:

(a)	A – 3	B – 4	C – 2	D – 1
(b)	A – 4	B – 3	C – 2	D – 1
(c)	A – 3	B – 2	C – 1	D – 4
(d)	A – 2	B – 3	C – 1	D – 4

81. For the beam *ABC* shown in Fig. Q. 81, List I shows stress resultant and List II, the shapes of influence line diagrams. Match List-I with List-II by selecting answer code given

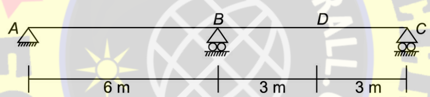
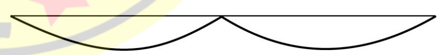


Fig. Q. 81

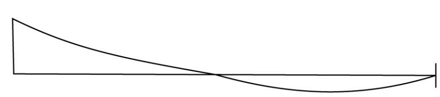
List I **List II**

A. R_A 1.

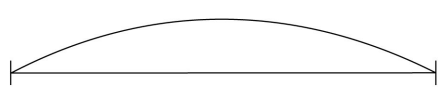


B. R_B 2.

C. M_B 3.



D. M_D 4.



Codes:

(a)	A – 1	B – 2	C – 4	D – 3
(b)	A – 2	B – 4	C – 3	D – 1
(c)	A – 3	B – 2	C – 1	D – 4
(d)	A – 3	B – 4	C – 1	D – 2

III. *select your answer according to the coding system given for the Assertion (A) and Reason (R) given below the questions 82 to 86.*

Assertion A

Reason R

(a) Both A and R are true and R is the correct explanation of A.

(b) Both A and R are true but R is not the correct explanation of A.

(c) A is true but R is false.

(d) A is false but R is true.

82. A: In a cable structure horizontal thrust increases with rise in temperature.
R: Due to rise in temperature the length of cable increases.

83. A: Flexibility and stiffness matrices are inverse of each other.
R: If $[I]$ is identity matrix, $[k]$ is stiffness matrix and $[d]$ is flexibility matrix

$$[I] = [k]\,[d]$$

84. A: At plastic hinge rotation takes place without resisting any additional moment.
R: Plastic hinge is the section at which all fibres have yielded.

85. A: Shape factor is defined as the ratio of plastic moment capacity of the section to yield moment capacity of the section.
R: The shape factor is the property of the section and it will not depend upon the property of the material.

86. A: Plastic neutral axis is also known as equal area section.
R: Plastic neutral axis divides the section into areas of tension and compression equally.

Answers to Multiple-Choice Questions

1. (c)	2. (c)	3. (d)	4. (a)	5. (b)
6. (d)	7. (a)	8. (c)	9. (d)	10. (a)
11. (c)	12. (d)	13. (b)	14. (c)	15. (d)
16. (b)	17. (d)	18. (c)	19. (c)	20. (b)
21. (d)	22. (c)	23. (d)	24. (b)	25. (b)
26. (a)	27. (d)	28. (a)	29. (d)	30. (b)
31. (c)	32. (b)	33. (d)	34. (b)	35. (a)
36. (c)	37. (d)	38. (c)	39. (b)	40. (a)
41. (c)	42. (c)	43. (c)	44. (d)	45. (a)
46. (b)	47. (d)	48. (d)	49. (c)	50. (b)
51. (a)	52. (b)	53. (c)	54. (c)	55. (b)

56. (c)	57. (b)	58. (d)	59. (a)	60. (a)
61. (d)	62. (c)	63. (c)	64. (b)	65. (b)
66. (c)	67. (d)	68. (b)	69. (c)	70. (c)
71. (d)	72. (a)	73. (b)	74. (b)	75. (d)
76. (d)	77. (c)	78. (d)	79. (b)	80. (b)
81. (d)	82. (d)	83. (a)	84. (a)	85. (a)
86. (a)				

R.C.C. Design (As Per IS : 456-2000)

* Concrete is good in resisting compressive stress but is very weak in resisting tensile stress. Hence, concrete structure is reinforced with steel wherever tension develops. Steel is the best reinforcement since its tensile strength is quite high and the bond between steel and concrete is excellent.

* Characteristic strength of concrete is defined as the compressive strength of 150 mm concrete cubes at 28 days in N/mm^2, below which not more than 5 per cent cubes give the result. Table 7.1 gives grades of concrete.

Table 7.1 Grades of concrete

Group	*Grade Designation*	*Characteristic strength in N/mm^2*
Ordinary concrete	M 10	10
	M 15	15
	M 20	20
Standard concrete	M 25	25
	M 30	30
	M 35	35
	M 40	40
	M 45	45
	M 50	50
	M 55	55
High strength concrete	M 60	60
	M 65	65
	M 70	70
	M 75	75
	M 80	80

* Nowadays ultra high strength concrete of M 500 are also produced in the laboratories and M 250 concrete has been used in bridge construction.

* Minimum grade of concrete for different exposure with normal weight aggregates of 20 mm nominal maximum size are as shown below:

Mild – M : 20 Moderate M 25

Severe – M : 30 Very severe M 35

Extreme – M : 40

* Tensile strength: A designer may use the following expression for finding flexural tensile strength of

concrete.

$F_t = 0.7\sqrt{f_{ck}}$ N/mm^2

* As per IS 456–2000, modulus of elasticity for concrete

$E_c = 5000\sqrt{f_{ck}}$

* Poisson's ratio: $m = 0.1$ for high strength concrete

= 0.2 for weak concrete

Usually, $m = 0.15$ for strength calculation

and = 0.20 for serviceability calculation

* *Shrinkage:* Approximate value of the total shrinkage strain may be taken as 0.0003.
* *Creep:* The creep coefficient is defined as the ratio of ultimate creep strain to elastic strain at the age of loading and it may be taken as given below:

7 days 2.2

28 days 1.6

1 year 1.1

* *Grades of steel:*

yield/0.2 % proof stress

Mild steel 255 N/mm^2

HYSD bars 415 N/mm^2 and 500 N/mm^2

Hard drawn steel 480 N/mm^2

* Characteristic strength f_y in tension and compression is taken equal.
* Young's modulus: It is taken as 2×10^5 N/mm^2 for all grades of steel.
* Available diameter of bars in mm are:

Mild steel:	6,	10,	12,	16,	20,	25,	and	32	
HYSD bars:	8,	10,	12,	16,	20,	22,	25,	28	and	32

* Arrangement of bars: They may be arranged singly or in pairs. Use of 3 to 4 bundled bars is also permitted.
* Loads to be considered and their combinations are as per the IS 875–1987.
* Structural analysis may be by linear elastic theory. Classical methods or finite element method may be used. Standard packages may be used.

7.1 METHODS OF R.C.C. DESIGN

* With an appropriate safety the structure should
  1. sustain all loads expected in its life cycle
  2. sustain deformations during and after construction
  3. have adequate durability

4. have adequate resistance to misuse and fire.

Methods used for design are given below.

1. ***Working Stress Method*** The designer aims at keeping stresses at working loads as close to permissible stresses as possible but without exceeding them. Permissible stress is defined as the ultimate stress divided by a factor of safety in case of concrete. Factor of safety in concrete is taken as 3. In case of steel permissible stress is yield stress or 0.2% proof stress divided by factor of safety. Factor of safety is taken as 1.75 to 1.85 only, since steel is a more reliable material. Modular ratio is taken as

$$m = \frac{E_s}{E_c} = \frac{280}{3\sigma_{ebc}}.$$

where s_{ebc} = permissible compressive stress in bending.

Working stress method is conservative and hence being given up. However, for checking serviceability conditions this method is also used now.

2. ***Load Factor Method (LFM)*** In this method ultimate load is used as design load and the collapse criteria for the design. Ultimate load is defined as load factor times the working load. A load factor of 2 was used.

3. ***Limit State Method (LSM)*** This is a comprehensive method which takes care of the structure not only for its safety but its fitness throughout the period of service. Various limit states to be considered are:

(a) Limit states of collapse: Tension, compression, flexure, tension and shear.

(b) Limit states of serviceability: Limit states of deflection and cracking.

(c) Other limit states: Limit states of vibration, fire resistance, chemical and environmental actions, accidental or catastrophic collapse.

Characteristic Load

Characteristic load means the value of the load above which not more than 5 per cent results are expected to fall. It may be taken as

$$\text{Characteristic load} = \text{Mean load} + kS$$

when for normal distribution $k = 1.64$ and S is standard deviation.

IS code 456–2000 permits use of the values given in IS 875 as characteristic loads.

Characteristic Strength

The strength that one can safely assume for a material is known as characteristic strength. It may be taken as

$$\text{Characteristic strength} = \text{Mean strength} - kS$$

when $k = 1.64$ and S is standard deviation

Partial Safety Factor for Loads

$$g_f = \frac{F_d}{F}$$

where F_d = Design load and F = characteristic load.

Table 18 of IS 456–2000 gives the values for various loads and load combinations for limit state of collapse and the limit state of serviceability.

Partial Safety Factor for Materials

$$g_m = \frac{f}{f_d}$$

where f = characteristic strength of the material

f_d = design strength of material

Partial safety factor for material are as given in Table 7.2.

Table 7.2 Partial safety factor for material strength.

Material	*Limit state of*	
	Collapse	*Deflection*
Concrete	1.5	1.0
Steel	1.15	1.0

Idealized Stress-Strain Curves

Irrespective of grade, stress strain curve for concrete is taken as:

1. Parabolic for 0 to 0.002 strain
2. Constant for 0.002 to 0.0035 strain set
3. Ultimate strain 0.0035.

* Strength achieved in the structure in the field may be taken as 0.67 for (i.e., 2/3 f_{ck}).

* In addition to the above, code recommend use of partial safety factor of 1.5 for concrete.

Hence, design stress in concrete = $\frac{0.67 f_{ck}}{1.5} = 0.446\, f_{ck}$.

$$= 0.45\, f_{ck}$$

\ Stress block for a beam is as shown in Fig. 7.1.

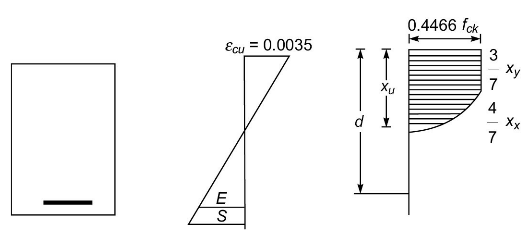


Fig. 7.1 Stress block

* For steel, partial safety factor used is 1.15:

\ Max stress in steel is restricted to

$$\frac{f_y}{1.15} = 0.87 f_y.$$

* The maximum strain in the tensile reinforcement of failure

$$\frac{f_y}{1.15 E_s} + 0.002, \text{ i.e., } 0.87 f_y + 0.002$$

* For balanced section $e_{su} = \frac{0.87 f_y}{E_s} + 0.002$.

* If strain in steel reach $0.002 + \frac{0.87 f_y}{E_s}$ earlier to compressive strain in concrete reaching 0.0035 the section is called under reinforced section. The excess strain in steel beyond critical strain amounts to considerable cracks in concrete. The deflection increases. They serve as warning. This type of failure in under reinforced section is called primary tensile failure. Code recommends design should be to such failures only.

Stress block parameters:

$$\text{Area of stress block} = 0.36 f_{ck}\, x_u$$

where x_u depth of neutral axis.

\ Compressive force in section

$$C = 0.36 f_{ck}\, b x_u$$

Distance of centroid of compressive force from extreme compression flange

$$\bar{x} = 0.42\, x_u.$$

Limiting value of x_u is given by

$$\frac{x_{u\,\text{lim}}}{d} = \frac{0.0035}{0.87 \frac{f_y}{E_s} + 0.0055}$$

$$\backslash \text{ For mild steel } \frac{x_{u\,\text{lim}}}{\text{d}} = 0.93$$

$$\text{For Fe 415 } \frac{x_{u\,\text{lim}}}{d} = 0.48$$

$$\text{For Fe 500 } \frac{x_{u\,\text{lim}}}{d} = 0.46.$$

For under reinforced sections

$$\frac{x_u}{d} = \frac{0.87 f_y A_{st}}{0.36 f_{ck}\, bd}$$

Strength of rectangular section in flexure

$$M_u = 0.36 f_{ck} \frac{x_u}{d}\left(1 - 0.42 \frac{x_u}{d}\right) bd^2$$

$$= k f_{ck}\, bd^2 \text{ for balanced section}$$

where $k = 0.36 \frac{x_{u\,\text{lim}}}{d}\left(1 - 0.42 \frac{x_{u\,\text{lim}}}{d}\right)$

\ For mild steel $M_{u\ \text{lim}} = 0.148\, f_{ck}\, bd^2$

For Fe 415, $M_{u\ \text{lim}} = 0.138\, f_{ck}\, bd^2$

For Fe 500, $M_{u\ \text{lim}} = 0.133\, f_{ck}\, bd^2$.

Approximate expression for moment of resistance

$$M_u = 0.87\, f_y\, A_{\text{st}}\, d\left[1 - \frac{A_{\text{st}}}{bd}\frac{f_y}{f_{ck}}\right]$$

However, to avoid compression failures, the strength of such sections should be considered as that of balanced section, i.e.,

$$M_u = M_{u\ \text{lim}} = 0.36\, f_{ck}\, x_{u\ \text{lim}}\, (d - 0.42\, x_{u\ \text{lim}}).$$

Flanged Section in Flexure

* Effective width of flanges:

For T-beams $b_f = \frac{l_o}{6} + b_w + 6D_f$

For L-beams $b_f = \frac{l_o}{12} + b_w + 3\, D_f$

where l_o = distance between points of zero moments in the beam.

Note: For continuous beams and frames l_o may be taken as 0.7 × the effective span.

* Strength of flanged section in flexure: Based on the value of x_u, the following three cases arise:

1. x_u £ D_f.

$M_u = 0.36\, f_{ck}\, b_f\, x_u\, (d - 0.42\, x_u)$.

2. $\frac{3}{7}\, x_u > D_f$.

IS 456 says, if $\frac{D_f}{d}$ £ 0.2, treat that it belongs to this case. In this case

$$C = C_w + C_f$$

where $C_w = 0.36\, f_{ck}\, b_w\, x_u$.

and $C_f = 0.446\, (b_f - b_w)\, f_{ck}\, D_f$

To find depth of neutral axis

$$0.36\, f_{ck}\, b_w\, x_u + 0.446\, (b_f - b_w)\, f_{ck}\, D_f = 0.87\, f_y\, A_{\text{st}}.$$

\ $M_u = 0.36\, f_{ck}\, b_w\, x_u\, (d - 0.42\, x_u) + 0.446\, f_{ck}\, (b_f - b_w) \times D_f\, (d - D_f/2)$

3. $\frac{3}{7}\, x_u < D_f$ or $\frac{D_f}{d} < 0.2$ and $x_u > D_f$.

$0.36\, f_{ck}\, b_w\, x_u + 0.45\, f_{ck}\, y_f\, (b_f - b_w) = 0.87\, f_y\, A_{\text{st}}$

where $y_f = 0.15\, x_u + 0.65\, D_f$

From it x_u may be found.

$M_u = 0.36\, f_{ck}\, b_w\, x_u(d - 0.42\, x_u) + 0.45\, \underline{f_{ck}}\, y_f(b_f - b_w) \times (d - 0.5\, y_6)$

$M_{u\text{lim}} = 0.36\, f_{ck}\, b_w\, x_{u\text{lim}}\, (1 - 0.42\, x_{u\text{lim}}) + 0.45\, f_{ck}\, y_f(b_f - b_w)\, (d - 0.5\, y_f)$.

where $y_f = 0.15\, x_{u\ \text{lim}} + 0.65\, D_f$ but not more than D_f.

7.2 STRENGTH OF DOUBLY REINFORCED SECTIONS

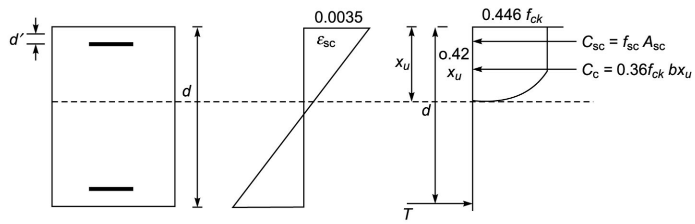


Fig. 7.2 Doubly reinforced section

* Compressive force

$$C = C_c + C_s$$

$$C_c = 0.36\, f_{ck}\, b\, x_u - f_{cc}\, A_{\text{sc}}$$

$$= 0.36\, f_{ck}\, b\, x_u.$$

$$Cs = f_{\text{sc}}\, A_{\text{sc}} \text{ and } T = 0.87\, f_y\, A_{\text{st}}.$$

$$C = T \text{ gives}$$

$0.36\, f_{ck}\, b\, x_u + f_{sc}\, A_{\text{sc}} = 087\, f_y\, A_{st}.$

From it x_u may be found.

* The strain at the level of compression steel

$$e_{\text{sc}} = 0.0035 \left(1 - \frac{d'}{x_u}\right)$$

The corresponding stress in compression steel may be obtained from stress-strain curve. Then

$$f_{\text{sc}} = e_{\text{sc}}\, E_s = 0.0045 \left(1 - \frac{d'}{x_u}\right) \times 2 \times 10^5$$

$$= 700 \left(1 - \frac{d'}{x_u}\right), \text{ subject to maximum of } 0.87\, f_y.$$

$$M_u = C_c(d - 0.42\, x_u) + C_s(d - d¢)$$

$$= 0.36\, f_{ck}\, b\, x_u\, (d - 0.42\, x_u) + f_{ck}\, A_{\text{sc}}\, (d - d¢).$$

Strength of R.C. Section in Shear, Torsion and Bond

* Design procedure is given by IS: 456–2000 based on average shear stress across the section.

Average shear stress $T_v = \frac{V_u}{bd}$

where V_u = factored (design) shear force

b = bredth

d = effective depth

In case of varying depth,

$$t_v = \frac{V_u \pm \frac{M_u}{d} \tan \beta}{bd}$$

where M_u = factored bending moment

b = angle between the top and bottom edges.

* Table 19 in IS 456–2000 gives design shear strength (t_c) for various mixes for different percentage of reinforcements.

* Shear strength V_u can be enhanced by providing shear reinforcement in any one of the following:

1. Vertical stirrups
2. Bent up bars
3. Inclined stirrups.

If a is the angle between the inclined stirrup or bent up bar and the axis of the member, then total vertical shear force resisted is given by

1. Vertical stirrups: $V_{us} = \frac{0.87 f_y}{S_v} A_{sv} d$

2. Bent up bars: $V_{us} = \frac{0.87 f_y}{S_v} A_{su} d (1 + \cos\alpha) \sin\alpha$

3. Inclined stirrups: $V_{us} = \frac{0.87 f_y}{S_v} A_{su} d (\sin\alpha + \cos\alpha)$

However, code specifies wherever bent up bars are provided, their contribution towards shear resistance shall not be more than half that of the total shear reinforcement. Code also specifies that to avoid compression failure of the section in shear, under no circumstances, even with shear reinforcement nominal shear stress t_v exceeds $t_{c\,max}$, given in Table 7.3.

Table 7.3 $T_{c\,max}$ values in N/mm^2

Concrete Gauge	M 20	M 25	M 30	M 35	M 40 onwards
$t_{c\,max}$	2.8	3.1	3.5	3.7	4.0

* *Torsional Shear Strength:* IS code recommends the effect of torsional moment T_u, may be split into a bending moment and a shear force as given below:

$$M_u = T_u \frac{1 + D/b}{1.7}$$

$$V_u = 1.6 \frac{T_u}{b}$$

where b = bredth of beam or breadth of web in case of flanged sections

D = overall depth of beam

\ If a beam is subjected to M_{us}, T_u and V_u

$$M_{\text{equivalent}} = M_u + T_u \frac{1 + D/b}{1.7}$$

$$V_{\text{equivalent}} = V_u + 1.6 \frac{T_u}{b}.$$

* Bond strength:

$$T_{bf} = \frac{V}{d_j \Sigma o}$$

where d_j is lever arm.

\ Bond length L_d is given by

$L_d = \frac{0.87 b_y \phi}{4 \tau_{bd}}$ where f = Diameter of bar.

The values for different grade of concrete are as given in Table 7.4.

Table 7.4 Design bond stress in plain bars in tension

Grade of Concrete	M 20	M 25	M 30	M 35	M 40 and above
t_{bd} in N/mm^2	1.2	1.4	1.5	1.7	1.9

* Equivalent Development Lengths: For standard hooks and bends the equivalent development bends may be taken as given below:

1. U-type bends: 16 × diameter of bar
2. For standard bends, it shall be 4 times the diameter of the bar for each 45° bend subject to a maximum of 16 times the diameter of the bar.

7.3 LIMIT STATE OF SERVICEABILITY

* Deflection limits:

$$\text{Final deflection} \ngtr \frac{\text{Span}}{250}.$$

Final deflections due to partitions and finishes $\ngtr \frac{\text{Span}}{350}$ or 20 mm whichever is less

For calculating deflections, take

$$E = E_c = 5000 \sqrt{f_{ck}}$$

$$\text{and } I = I_{\text{eff}} = \frac{I_r}{1.2 - \frac{M_r}{M}\frac{z}{d}\left(1 - \frac{n}{d}\right)\frac{b_w}{b}}$$

$$\text{but } I_r £ I_{\text{eff}} < I_{gr}.$$

where $M_r = f_{cr} \frac{I_{gr}}{y_t}$.

I_{gr} = M.I. of gross section

I_r = M.I. of cracked section.

For singly reinforced sections,

$$I_r = \frac{bx^3}{3} + m\,A_{\text{st}}\,(d - x)^2$$

where x = distance of NA from compression flange

For doubly reinforced sections

$$I_r = \frac{bx^3}{3} + (m - 1)\,A_{\text{st}}\,(d - d)^2 + m\,A_{\text{st}}\,(d - x)^2$$

* *Crack width:*

Acceptance limits are:

1. 0.3 mm in members if cracking is not harmful to the durability of structure.
2. 0.2 mm in members continuously exposed to moisture or in contact with soil.
3. 0.1 mm in aggressive environment.

* Cracks due to bending in a compression member subjected to axial load of 0.2 $f_{ck}\,A_c$ need not be checked, if

1. Spacing between adjacent bars > dia. of larger bar

and 5 mm more than size of coarse aggregate

2. If there are two or more number of rows of bars the spacing between the rows should be larger of the following.

(a) 15 mm

(b) $\frac{2}{3}$ × nominal size of aggregates

(c) Size of bar

* Crack width may be calculated from the following formula:

$$W_{cr} = \frac{3a_{cr}\,\varepsilon_m}{1 + \frac{2(a_{cr} - c_{\min})}{h - x}}$$

where a_{cr} = Distance of the point from the surface of nearest longitudinal bars

$C_{\min}$ = Minimum cover to the longitudinal bar

e_m = Average strain in longitudinal bar

h = Overall depth of the section

x = Depth of NA from compression edge

Design of Beams

* Effective span

1. Simply supported beams or slabs

l_{eff} = Clear span + Effective depth or centre-to-centre distance between the supports whichever is less

2. Continuous beams or slabs

(a) If width of support, $w < \frac{1}{12} \times$ clear span, the effective span is same as for simply supported case

(b) For end span with one end simply supported and the other end continuous.

l_{eff} = Clear span + $\frac{1}{2}d$ or

= Clear span + $\frac{1}{2}$ Width of support whichever is less.

3. In case of roller supports,

l_{eff} = distance between the supports

4. Cantilevers:

l_{eff} = Clear span + $d/2$

5. Overhanging beams:

l_{eff} = Centre of support to free end.

6. Frames:

l_{eff} = Centre-to-centre distance.

Size of Beam

* If we select depth of beam $\frac{1}{12}$ th to $\frac{1}{15}$ th of span for simply supported beams and $\frac{1}{15}$ th to $\frac{1}{20}$ th of span for continuous beams. Normally, it will be under reinforced and do not violate deflection criteria. From the consideration of standardizing form works, overall depth is kept in multiples of 50 mm usually 250 mm to 700 mm in multiples of 50 mm.
* The width is normally kept as 200 mm, 250 mm, 300 mm and 350 mm. Use of 230 mm is also practised where 230 mm (9≤) brick walls are built.

Cover to Reinforcement

Minimum nominal cover to meet durability requirements as per IS 456 are:

Exposure condition	*Minimum cover*
Mild	20 mm

Moderate	30 mm
Severe	45 mm
Very severe	50 mm
Extreme	75 mm

7.4 REQUIREMENTS OF REINFORCEMENTS

1. Main reinforcements

(a) At least 2 bars and not more than 6 bars in one layer.

(b) 8 or 10 mm dia. bars for slabs. For beams 12, 16, 20, 22, 25 or 36 mm bars may be used.

(c) Minimum reinforcements

$$p_{t,\,\min} = \frac{A_{st}}{bd} = \frac{0.85}{f_y}$$

(d) Maximum reinforcement = 4.0% of gross area.

(e) Bars less than 32 mm dia. may be bundled but bars larger than 32 mm shall not be bundled.

2. Shear reinforcement:

(a) Should go around outermost tension and compression bars.

(b) If no compression steel is used, provide two suspender bars of diameter 10 mm.

(c) Maximum spacing shall be: 0.75 d for vertical shear reinforcement, and d for inclined stirrups at 45°. In no case it should not be more than 300 mm.

(d) Minimum reinforcement shall be such that $\frac{A_{sv}}{b_{sv}} \geq \frac{0.4}{0.87 f_y}$.

(e) 6, 8, 10, 12 mm bars are used for shear reinforcement.

(f) Usually 2 legged reinforcements are provided. Sometimes to avoid too close spacing 4 or 6 legged bars are provided.

(g) If depth of beam exceeds 750 mm, side reinforcements are provided at the rate of 0.1% of web area. Spacing shall not exceed 300 mm.

Design of Slab

* If $\frac{l_y}{l_x} \geq 2$, design as one way slab

< 2, design as two way slab.

* In case of simply supported slab if $\frac{l}{d} \geq 25$, there is no need to check for deflections.

* Spacing of bars may be found using the relation $S = \frac{\frac{\pi}{4}\phi^4}{A_{st}} \times 1000$.

* Spacing should not exceed 3 × depth of slab or 300 mm whichever is smaller.

* A minimum of 0.15% of total cross section distribution steel is provided if mild steel is used and it is 0.12%, if Fe 415 steel is used.

* In case of continuous slab, assume a depth of $\frac{1}{30}$th span and design moment at support next to end support is

$$M_{\max} = \frac{W_d l^2}{12} + \frac{W_L l^2}{9}$$

* In case of cantilever assume depth of slab as $\frac{l}{7}$. In this case $M_u = \frac{W_L l^2}{2}$ and $V_u = w_{uL}$ and reinforcements are required at top. Sufficient anchorage depth should be provided at the support.
* In case of simply supported slabs with two adjacent edges at corner, if there is discontinuity, torsional reinforcements are required. Torsional reinforcement consists of a mesh of reinforcements at top and bottom of slab, the area of reinforcement in each layer shall be 3/4th of the area required at mid-span of slab. The length shall be $\frac{1}{5}$th of shorter span.

Design of Columns

* Table 28 of IS 456–2000 gives the effective lengths for columns with various end conditions.
* Slenderness ratio limits prescribed for columns are:
  (i) Unsupported length, l shall not be more than 60 times the least lateral dimension.
  (ii) If in any given plane, one end of the column is unrestricted $l \ngtr 100 \frac{h^2}{D}$.
* Minimum eccentricity to be considered is

$$e_{\min} = \frac{l}{500} + \frac{\text{Lateral dimension}}{30}$$

* The assumptions made are
  1. The maximum compressive strain in axial compressive is 0.002.
  2. In case of column subjected to axial load and bending, maximum strain permitted is
  $e_{\max} = 0.0035 - 0.75\, e_2$
  where e_2 = strain at the least compressed extreme fibre.
* Design:

$$P_u = 0.4 f_{ck} A_c + 0.67 f_y A_{sc}.$$

The above value may be multiplied by 1.05 if helical reinforcements are provided, if the volume of helical reinforcement to the volume of core is greater than or equal to $0.36 \left(\frac{A_g}{A_c} - 1\right)\frac{f_{ck}}{f_y}$.

* Reinforcement: Maximum 0.8%
Minimum 6%.
It is preferable to use from 0.8% to 4%
* Minimum number of bars: 4 for rectangular sections and 6 for circular sections
* Minimum diameter of bars to be used is 12 mm.
* Spacing of longitudinal bars measured along the periphery should not exceed 300 mm.

* The pattern of transverse reinforcement should be as shown in Fig. 7.3.

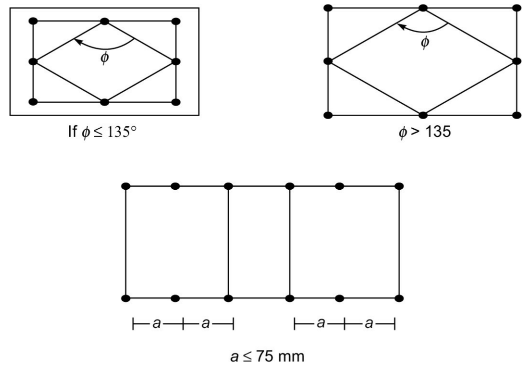


Fig. 7.3

* Diameter of transverse reinforcement should not be less than

    1. $\frac{1}{4}$ th of larger main reinforcement
    2. 5 mm

* Pitch shall not be more than
    1. Least lateral dimension
    2. 16 × dia. of smallest longitudinal bar
    3. 300 mm.
* Pitch of helical spring should not be
    1. more than 75 mm
    2. more than $\frac{1}{6}$ th core diameter
    3. less than 25 mm
    4. less than 3 × diameter of helix.
* Design of columns subjected to combined axial load and uniaxial moment: Use interaction chart given in SP–16 in which interaction diagrams are available for $\frac{P_u}{f_{ck}\,D}$ vs. $\frac{M_u}{f_{ck}\,bD^2}$ for different values of $\frac{p}{f_{cu}}$, where p is the percentage reinforcement.

Design of Isolated column footing

* For masonry walls, footing is one way reinforced type and for columns, it is two-way reinforced footing.
* Column footing may be isolated, combined or raft
* Minimum depth of footing is given by

$$h = \frac{p}{w}\left[\frac{1-\sin\phi}{1+\sin\phi}\right]^2$$

where p = SBC, w = Unit weight of soil and f = Angle of friction of soil.

* Minimum cover to reinforcement shall be 50 mm. If plain concrete bed is not provided it shall be 75 mm.

* Minimum thickness shall be
  – 150 mm for footing on soil
  – 300 mm for footing on piles.
* To find area of footing, add 10% of vertical load to account for self-weight. Then

$A = \frac{1.1P}{\text{SBC of soil}}$

* Soil reaction for the factored load

$q_u = \frac{P_u}{A} = \frac{1.5\,P}{A}$.

* Determine the minimum depth required from the consideration of bending moment, single shear and double shear.
* Bending moment is maximum at the face of column.
* Critical section for one way shear is at a distance d from the face of column.
* Double shear is critical at distance $d/2$ from the face of column. Thus, if $b \times d$ is size of column, area of concrete resisting punching shear is

$$A = 4(b + d)d.$$

Punching shear $S = B \times D - h \times d$.
where $B \times D$ = area of footing.

* Footing may be of uniform thickness or sloping.
* Bending moments and shear forces may be found by the direct design method or by equivalent frame method
* The direct design method is applicable, only if the following conditions are satisfied:
  1. There are at least three continuous spans in each direction.
  2. $\frac{\text{Longer span}}{\text{Shorter span}}$ £ 2.
  3. The successive span length in each direction shall not differ by more than $\frac{1}{3}$ × longer span.
  4. The design live load $\ngtr$ 3 × design dead load
* Total design moment

$M_o = \frac{WL_n}{8}$

where W = Design load on the area $L_2 \times L_n$

L_n = Clear span but not less than 0.65 L_1

Note: Circular supports shall be treated as square supports having the same area for finding clear span. If transverse span on either side varies it shall be taken as the average.

In an interior span,

$$\text{–ve design moment} = 0.65\,M_o$$

$$+\text{ve design moment} = 0.35\, M_o.$$

In an end span,

$$\text{Interior –ve design moment} = \left[0.75 - \frac{0.10}{1+\alpha_c}\right]M_o$$

$$\text{Interior +ve design moment} = \left[0.63 - \frac{0.28}{1+\frac{1}{\alpha_c}}\right]M_o$$

$$\text{Exterior –ve design moment} = \left[\frac{0.65}{1+\frac{1}{\alpha_c}}\right]M_o$$

where $a_c = \frac{\sum k_c}{\sum k_s}$

k_c = Flexural stiffness of columns meeting at joint

k_s = Flexural stiffness of the slab

* In the column strip the distribution of moment is

–ve moment at exterior support = 100%

–ve moment at interior support = 75%

+ve moment = 60%

* The critical section for shear shall be at a distance $d/2$ from the periphery of the column/capital drop.

Design of Stairs

* The accepted relation between a tread and rise are:
  1. 2 × rise + tread = 600 to 640 mm.
  2. Rise × tread = 40,000 to 42000 mm^2.

  In public buildings tread may be kept about 270 mm to 300 mm. However, in commercial complexes steeper stairs are used. Slope of stairs should be between 25° to 40°.

* Loads on stairs:
  1. 5 kN/m^2, if crowded
  2. 3 kN/m^2, if not crowded.

* Stairs are designed for flexure.

* While detaining reinforcement, care should be taken to see that at junctions the resultant tension is not directed towards the cover to reinforcement.

Design of flat slabs

1. It may be without drop and column head.
2. With drop and without column head
3. With drop and column head.

* *Drops:* Drops when provided shall be rectangular in plan and have length in each direction not less than $\frac{1}{3}$ of the panel in that direction. For exterior columns the width of drop at right angles to the non-continuous edge and measured from the centre line of the column shall be equal to one half of the width of drop for interior panels.
* *Column head:* It shall slope at 45°.
* Thickness of flat slab: If drops are provided

$$\frac{\text{Thickness}}{\text{Larger span}} = 40, \text{ if mild steel is used}$$

$$= 32, \text{ if Fe 415 or Fe 500 steel is used}$$

If drops are not provided the above values for mild steel and Fe 415 steel are 36 and 28.8 respectively.

It is also suggested that in no case, the thickness shall be less than 125 mm.

* Minimum reinforcement: At least 50 per cent of bottom bars should be from support to support. If adjacent spans are not equal, the extension of –ve reinforcement beyond each face shall be based on the longer span.

7.5 DESIGN OF CIRCULAR AND ODD SHAPED SLABS

* $M_r = C_1 qR^2$ $M_q = C_2 qR^2$ and D = $C_3 qR^4$

where C_1, C_2 and C_3 are constants as shown in Table 7.5.

Table 7.5 Coefficients for moments and deflections.

Support condition	*Location*	C_1	C_2	C_3
Simply supported	Centre	3/16	3/16	5/64
	Support	0	2/16	0
Fixed support	Centre	1/16	1/16	1/64
	Support	-2/16	0	0
Partially fixed	Centre	2/16	2/16	3/64
	Support	–1/16	1/16	0

The critical section for shear is at a distance *d* from the support where *d* is the effective depth.

* The reinforcements may be in radial and circumferential directions or in any two mutually perpendicular directions. The simply supported edges are rarely perfect simple supports. Hence, provide 10 mm ring bars at 300 mm spacing upto approximately to a distance of 1 m from inside of support.

* Design of slabs with openings:

1. Small openings: Opening size is less than three times the thickness of slab. If reinforcement is to be distributed for making the hole, provide a ring around the hole.
2. Medium size openings: In such case edge thickening is made. The material added for edge thickening should not be less than the material removed for making hole.

3. Large openings: In such case provide edge beam and secondary beams around the opening.

7.6 YIELD LINE ANALYSIS OF SLABS

* It is based on the following assumptions:
  1. There will be tension failure only.
  2. The yield lines are straight lines.
  3. Compared to plastic deformations elastic deformations are negligible.
  4. After collapse mechanism is formed each segment of slab acts as rigid body and rotates around the yield line.

* Characteristic features of yield lines:
  1. Yield lines are straight.
  2. Yield lines terminate at the boundary of slab or at the intersection of yield lines.
  3. Yield lines act as axes of rotations
  4. Axes of rotations are along the lines of support and pass on columns.
  5. Each segment will be having axes of rotations (natural or yield line) all along its periphery.

* Moment capacity across a yield line:

Moment capacity per unit length of slab

$$M_u = 0.87 f_y A_{st}\, d\left[1 - \frac{A_{st}}{bd}\frac{f_y}{f_{ck}}\right]$$

If yield line makes angle *a* with reinforcement.

$$M_{ux} = 0.87 f_y A_{stx}\, d\left[1 - \frac{A_{st\,x}}{bd}\frac{f_y}{f_{ck}}\right]$$

$$\text{and } M_{uy} = 0.87 f_y A_{sty}\, d\left[1 - \frac{A_{st\,y}}{bd}\frac{f_y}{f_{ck}}\right].$$

* Analysis may be made by the method of virtual work.

Design of Continuous Beams

* Effective span:

  (a) If width of support is less than $\frac{1}{12}$ th clear span l, $l_e = l$ + effective depth.

  (b) If width of support is more than $\frac{1}{12}$ th the clear span l:

    (i) For end span with fixed end and for intermedial spans $l_e = l$.

    (ii) For end span with one end simply supported and the other continuous,

    $l_e = l + \frac{1}{2}$ effective depth.

    $= l + \frac{1}{2} \times$ width of support, whichever is less

    (iii) In case of spans with rollers and rockers

l_e = distance between centres of supports.

* Loading patterns for design moment due to live loads.
  1. For midspan moment: The panel and the alternate panel loaded.
  2. For –ve moment at support adjoining panels loaded.
* Moment redistribution: Since there will be moment redistribution before ultimate failure, IS code permits a maximum of 30% redistribution of moment. However, it is to be remembered that if moment is reduced at end span, it is to be increased by the same amount at midspan.

Design of Grid Floors

* Spacing of beams is usually at 0.75 to 1.5 m. The depth is $\frac{1}{25}$ to $\frac{1}{20}$ th of span. Width is kept $\frac{1}{3}$ to $\frac{1}{4}$ th depth but in no case less than 65 mm. In topping slab reinforcements are kept at middle of slab since slab dimension is very small. To find design moment and shear in beams central strip of the slabs are assumed to have load shared in two directions so as to maintain continuity at midpoint. Then

$$M_x = \frac{q_x l_x^2}{8} \quad M_y = \frac{q_y l_y^2}{8}$$

and $q_x + q_y = q$.

Design of Portal Frames

A portal frame is a frame with rigid joints at the junction of beams and columns. They are commonly used for construction of industrial slabs. Near the support if hinges are to be achieved reinforcement shall be as shown in Fig. 7.4.

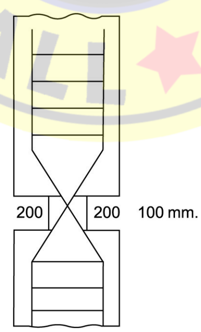


Fig. 7.4

Combined Footings

A combined footing may be supporting

1. Two columns 2. A row of columns 3. A group of columns

1. Combined footing supporting two columns may be of the following types:
   (a) Rectangular slab footing
   (b) Trapezoidal slab type
   (c) Beam and slab type
   (d) Strap footing.

The principle to be followed in these footing designs is the centre of gravity of footing coincides with the centre of gravity of the load on the two footings. Combined footings are required

(i) if individual footings overlap

(ii) a column may be near property line.

2. If a row of columns is to be provided with combed footing it becomes a strip footing.

3. If a group of columns are to be provided with combined footing, it becomes mat/raft footing.

Retaining Walls

* The walls built to retain filled earth of greater heights are known as retaining walls. R.C.C. retaining wall may be cantilever type or counterfort type.
* In cantilever retaining wall, stem, heal slab and toe slab are all acting as cantilevers. In counterfort retailing wall stem and heal slab act as continuous slab while toe slab acts as a cantilever.
* Retaining walls should be checked for their stability against overturning and sliding.
* Counterforts should be provided with horizontal and vertical reinforcement to bind it with stem and footing, apart from designing it for bending moment.

Bunkers and Silos

Bunkers and silos, known as bins are used to store large quantities of materials like grains, cement, coal, etc. The shallow bins are known as bunkers and deep bins as silo.

* The lateral pressure p exerted by filled material on the wall is given by:

$$p = g\,h \cos b \,\frac{\cos\beta - \sqrt{\cos^2\beta - \cos^2\phi}}{\cos\beta + \sqrt{\cos^2\beta - \cos^2\phi}}$$

where g = unit weight of material stored

h = Depth measured from top

b = Angle of surcharge and

f = Angle of repose

\ Horizontal pressure = $p \cos b$.

Maximum angle of surcharge is naturally f.

\ $p_{max} = g\,h \cos b = g\,h \cos f$ parallel to top of stored material

\ $p_{h\,max} = p_{max} \cos b = g\,h \cos^2 f$

If $b = 0$,

$$P_h = g\,h \,\frac{1-\sin\phi}{1+\sin\phi}$$

* Hopper bottoms are subjected to direct tension and bending moment. Tension reinforcement is designed to take full tension. To limit crack width concrete should be limited to permissible tensile stress.

* Walls of circular bunkers are subjected to hoop tension $T = 0.5\, P_h\, D$. A minimum thickness of 120 mm should be provided to the wall.

Design of Chimneys

* In many industries chimneys are required to leave hot waste gases at greater heights. Chimneys of 50–100 m are common. The outer diameter of chimney may be constant or varied linearly. Thickness of wall may be varied linearly or in steps. Concrete chimneys are provided with lining of 100–150 mm.
* Chimneys are designed for self-weight, wind load and temperature variations. Shape factor for wind load may be taken as shown in Table 7.6.

Table 7.6 Shape factors

Ratio of height to base width *Shape*	*0 to 4*	*4 to 8*	*8 or above*
Circular	0.7	0.7	0.7
Octagonal	0.8	0.9	1.0
Square, wind perpendicular to diagonal	0.8	0.9	1.0
Square, wind perpendicular to face	1.0	1.15	1.3

Water Tanks

* Types: Surface water tanks, underground water tanks and overhead water tanks.
* To make water tanks impervious crack widths should be restricted. To achieve it:
  1. Use richer concrete mix (M 25 or M 30)
  2. Give at least clear cover of 25 mm
  3. Use smaller diameter bars at closer intervals
  4. Keep tensile stresses low
  5. Follow good construction practices
  6. Use working stress method for design
* Minimum reinforcement to be provided is

$p_{\min} = 0.3$ up to 100 mm thick sections

$= 0.3 - 0.1\, \frac{t - 100}{450 - 100}$ for $t = 100$ to 450 mm.

If thickness of section is more than 225 mm, layers of bars are required near both the faces.

* For surface water tanks the walls may have sliding base or rigid base (Fig. 7.5).

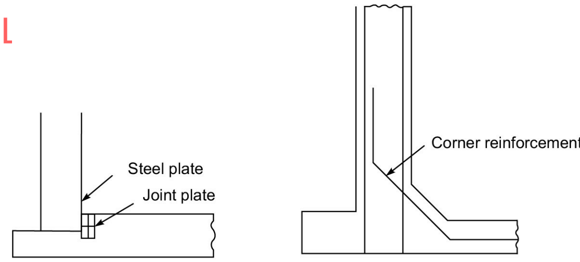


Fig. 7.5

* In all water tanks a free board of about 200 mm is to be given, in other words depth of water tank is kept 200 mm more than the required depth for the capacity.

* Rectangular water tanks:

1 tank with $\frac{L}{B} < 2$.

MULTIPLE-CHOICE QUESTIONS

I. *Select correct option/options from the following questions. (1 to 196)*

1. Minimum grade of concrete for moderate exposure with normal weight aggregates is
   (a) M 15
   (b) M 20
   (c) M 25
   (d) M 35
2. Concrete surfaces exposed to sea water spray is considered exposure condition
   (a) extreme
   (b) very severe
   (c) severe
   (d) moderate
3. Concrete surface buried under non-aggressive soil/groundwater is considered exposed to condition
   (a) moderate
   (b) severe
   (c) very severe
   (d) extreme
4. M 45 concrete is regarded as
   (a) ordinary concrete
   (b) standard concrete
   (c) high strength concrete
   (d) ultra-high strength concrete
5. M 75 concrete is regarded as
   (a) ordinary concrete
   (b) standard concrete
   (c) high strength concrete
   (d) ultra-high strength concrete

6. For strength calculations and serviceability calculations, Poisson's ratio of concrete is taken respectively as
(a) 0.15 and 0.1
(b) 0.1 and 0.15
(c) 0.2 and 0.15
(d) 0.15 and 0.2

7. In the absence of data the approximate value of the total shrinkage strain may be taken as
(a) 0.0001
(b) 0.0003
(c) 0.001
(d) 0.003

8. If age of loading on concrete structure is 28 days, the creep coefficient may be taken as
(a) 2.2
(b) 2.0
(c) 1.8
(d) 1.6

9. Yield strength of mild steel is
(a) 250 N/mm^2
(b) 415 N/mm^2
(c) 500 N/mm^2 (c) 480 N/mm^2

10. The Young's modulus for all grades of steel is
(a) 180 kN/mm^2
(b) 200 kN/mm^2
(c) 210 kN/mm^2
(d) 200 kN/cm^2

11. Which one of the following is not the diameter of market form of reinforcing bar?
(a) 16 mm
(b) 18 mm
(c) 20 mm
(d) 22 mm

12. Bars larger than _______ diameter should not be bundled.
(a) 22 mm
(b) 25 mm
(c) 28 mm
(d) 32 mm

13. Which one of the following is not the diameter of the market form of reinforcing bars?
(a) 28 mm
(b) 30 mm
(c) 32 mm

(d) 36 mm

14. If a roof is sloping at 12°, imposed load to be considered in the design is

(a) 1.5 kN/m^2

(b) 1.0 kN/m^2

(c) 0.75 kN/m^2

(d) 0.71 kN/m^2

15. In design of a flat R.C.C. roof without access except for maintenance, imposed load to be considered is

(a) 1.5 kN/m^2

(b) 1.25 kN/m^2

(c) 1.0 kN/m^2

(d) 0.75 kN/m^2

16. In the design of a seven-storey building, while designing the columns of 5th storey reduction in imposed loads on floor is

(a) 0%

(b) 10%

(c) 20%

(d) 30%

17. In designing a structure at a height 25 m in a region with wind velocity V, the wind pressure to be considered in

(a) 0.45 V^2

(b) 0.5 V^2

(c) 0.6 V^2

(d) 0.75 V^2

18. Upto a height of ______ wind pressure on a structure is considered to be uniform.

(a) 20 m

(b) 30 m

(c) 40 m

(d) 50 m

19. Snow load need not be considered in the design of structures in cold regions, if slope of the roof is more than

(a) 25°

(b) 30°

(c) 45°

(d) 60°

20. Which one of the following is not correct load combination in structural design

(a) $DL + WL$

(b) $DL + WL + IL$

(c) $DL + WL + SL$

(d) $DL + WL + IL + SL$

where DL = dead load

WL = wind load

IL = imposed load

SL = wind load

21. A structure design should

(a) sustain all loads

(b) sustain the deformation

(c) should have adequate resistance to misuse and fire

(d) all the above

22. In the working stress method of R.C.C. design which one of the following is correct?

(a) Shear deformations are neglected.

(b) Stress-strain relation is linear, both for steel and concrete.

(c) The modular ratio between steel and concrete remains constant.

(d) All the above.

23. In the working stress method of R.C.C. design factor of safety used for concrete and steel are respectively

(a) 3 and 1.85

(b) 4 and 1.85

(c) 4 and 2

(d) 3 and 1.5

24. In the working stress method of R.C.C. design, modular ratio between steel and concrete used is

(a) $\frac{230}{3\sigma_{bc}}$

(b) $\frac{230}{\sigma_{bc}}$

(c) $\frac{280}{3\sigma_{bc}}$

(d) $\frac{280}{\sigma_{bc}}$

where s_{bc} is permissible compressive stress in bending for concrete.

25. In working stress method of design, factor of safety is

A. $\frac{\text{Ultimate stress}}{\text{Working stress}}$ B. $\frac{\text{Ultimate load}}{\text{Working load}}$

(a) Both A and B are true

(b) A is true and B is false

(c) A is false and B is true

(d) Both A and B are false

26. The failure criteria in the ultimate load method of design is

(a) stress

(b) strain
(c) load
(d) all the above

27. Limit state method of R.C.C. design takes care of structure

A. Its safety

B. Its fitness throughout its designed life. Select your answer code from the list given below:

(a) Both A and B are true
(b) A is true but is not true
(c) A is not true but B is true
(d) Both A and B are not true.

28. Limit state method is based on probable

A. Load

B. Strength.

Select your answer code from the list given below:

(a) Both A and B are true
(b) A is true and B is false
(c) A is false and B is true
(d) Both A and B are false

29. Characteristic load means

(a) maximum load
(b) mean load
(c) mean load + 5 % of standard deviation
(d) mean load + 10 % of standard deviation

30. Characteristic strength is

(a) minimum assured strength
(b) minimum assured strength +1.64 times standard deviation
(c) mean strength
(d) mean strength + 1.64 times standard deviation

31. If standard deviation is 4 N/mm^2, the mean strength of M : 20 concrete should be

(a) 16 N/mm^2
(b) 20 N/mm^2
(c) 24 N/mm^2
(d) 26.4 N/mm^2

32. Partial safety factors for dead load and imposed load combination for limit state of serviceability are

(a) 1.0 and 1.0
(b) 1.5 and 1.5
(c) 1.2 and 1.2
(d) 1.0 and 0.8

33. Partial safety factor for dead load, imposed load and wind load for limit state of collapse are respectively
   (a) 1.5, 1.5, 1.0
   (b) 1.5, 1.2, 1.0
   (c) 1.2, 1.2, 1.5
   (d) 1.2, 1.2, 1.2

34. Partial safety factor for steel for limit state of collapse is
   (a) 1.0
   (b) 1.15
   (c) 1.2
   (d) 1.5

35. Partial safety factor for steel for limit state of deflection is
   (a) 1.0
   (b) 1.15
   (c) 1.2
   (d) 1.5

36. The stress strain curve for concrete is considered parabolic by I.S. code upto a strain of
   (a) 0.0015
   (b) 0.0020
   (c) 0.0030
   (d) 0.0035

37. IS code considers concrete has reached its limit state of collapse when the strain is
   (a) 0.0015
   (b) 0.0020
   (c) 0.0030
   (d) 0.0035

38. Which one of the following is the correct shape of stress block showing distribution of compressive stress in concrete beam at limit state across the depth (Ref Fig. Q. 38).

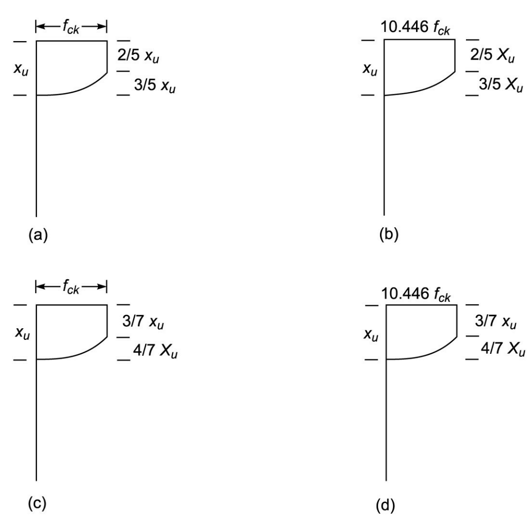


Fig. Q. 38

39. The centroid of a compression block representing stress in concrete at limit state, the distance being measured from extreme compression edge is
(a) 0.36 x_u
(b) 0.42 x_u
(c) 0.48 x_u
(d) 0.53 x_u
where x_u = depth of compression cone.

40. Limiting value of depth of neutral axis in R.C. beam of depth d with Fe 415 steel is
(a) 0.36 d
(b) 0.42 d
(c) 0.48 d
(d) 0.53 d

41. For a rectangular beam of size $b \times d$, with yield stress of steel f_y, area of steel A_{st}, concrete with characteristic strength f_{ck}, for under-reinforced section, neutral axis to depth ratio is given by

(a) $\frac{x_u}{d} = \frac{0.87 f_y A_{st}}{0.36 f_{ck} bd}$
(b) $\frac{x_u}{d} = \frac{0.36 f_{ck} bd}{0.87 f_y A_{st}}$
(c) $\frac{x_u}{d} = \frac{f_y A_{st}}{f_{ck} bd}$
(d) none of the above

42. Limiting moment carrying capacity
A. If Fe 415 steel is used is 0.138 $f_{ck}\, bl^2$,
B. If Fe 500 steel is used is 0.148 $f_{ck}\, bl^2$.
Select your answer code from the following.
(a) Both A and B are true
(b) A is true but B is false
(c) A is false but B is true
(d) Both A and B are false

43. In a beam and slab structure, if width of beam is b_w, depth of slab D_f, l_o is the distance between points of zero moments in the beam, effective width of intermediate flange is given by

(a) $b_f = \frac{l_o}{6} + b_w + 6D_f$

(b) $b_f = \frac{l_o}{3} + b_w + 6D_f$

(c) $b_f = \frac{l_o}{6}\, b_w + 3D_f$

(d) $b_f = \frac{l_o}{3} + b_w + 3D_f$

44. In the end beam of beam and slab construction with above notations effective width of flange is

(a) $b_f = \frac{l_o}{12} + b_w + 6D_f$

(b) $b_f = \frac{l_o}{6} + b_w + 3D_f$

(c) $b_f = \frac{l_o}{12} + b_w + 3D_f$

(d) $b_f = \frac{l_o}{12} + b_w + 6D_f$

45. One can go for doubly reinforced section

(a) to restrict depth of beam from architectural consideration

(b) to improve ductility of beam

(c) to reduce long-term deflections

(d) all the above

46. The Fig. Q. 46 shows a cantilever of width b and varying depth d. If V_u is factored shear force and M_u is factored bending, average shear stress T_v is given by

(a) $\frac{V_u}{bd}$

(b) $\frac{V_u + d\tan\beta}{bd}$

(c) $\frac{V_u + M_u\tan\beta}{bd}$

(d) $\frac{V_u + \frac{M_u}{d}\tan\beta}{bd}$

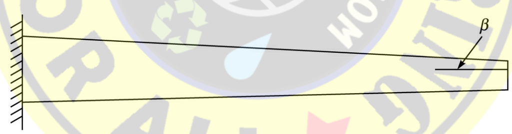


Fig. Q. 46

47. At section A in a beam $100 \times \frac{A_{st}}{bd}$ is 3.0 and in another section B this value is 3.5. The design shear strength of concrete t_c

(a) at section A > at section B

(b) at section A = at section B

(c) at section A < at section B

(d) nothing can be said without knowing the loading pattern

48. In beam A 100 $\frac{A_{st}}{bd}$ is same as in beam B. If beam A is of M 40 concrete and beam B of M 50 concrete, design shear strength t_c

(a) of beam A > that of beam B

(b) of beam A is same as that of beam B

(c) of beam A < that of beam B

(d) nothing can be said definitely

49. In a R.C. beam shear reinforcement should be always in the form of

(a) vertical stirrups
(b) inclined stirrups
(c) bent up bars with stirrups
(d) any one of the above

50. Vertical component of shear resisted by vertical stirrup in a R.C. beam is given by

(a) $\frac{0.87 f_y A_{sv}}{S_v} d$

(b) $\frac{f_y A_{sv}}{S_v} d$

(c) $\frac{0.87 f_y A_{sv}}{S_v}$

(d) $\frac{0.87 f_y A_{sv}}{S_v}$

where f_y, A_{sv}, d and S_v have usual meaning.

51. Vertical component of shear resisted by stirrups inclined at a to vertical in a R.C. beam is

(a) $\frac{0.87 f_y A_{sv}}{S_v} d (\sin\alpha + \cos\alpha)$

(b) $\frac{0.87 f_y A_{sv}}{S_v}$ $(\sin a + \cos a)$

(c) $\frac{f_y A_{sv}}{S_v} d \tan\alpha$

(d) $\frac{f_y A_{sv}}{S_v} \tan\alpha$

52. In a rectangular section depth to width ratio is 2. Which one of the following expression is appropriate to judge torsional factor J?

(a) $J = \frac{1}{12} (bd^3 + db^3)$

(b) $J = \frac{b^3 d^3}{3.58 (b^2 + d^2)}$

(c) $J = \frac{b^3 d}{3}\left(1 - 0.63\frac{b}{d}\right)$
(d) none of the above

53. If M_u is design bending moment, V_u is design shear due to flexure and T_u is design torsional moment the section should be designed for

(a) $M_e = M_u + \frac{1 + D/b}{1.7}$
(b) $M_e = M_u + T_u$

(c) $M_e = M_u + \frac{D/b}{7}$

(d) $M_e = M_u + \frac{D/b}{1.7}$

54. If a section of overall depth D and width b is subjected to design moment M_u, design bending shear V_u and design torque T_u, the section should be designed for

(a) $V_e = V_u + \frac{T_u}{1.6b}$

(b) $V_e = V_u + 1.6\ \frac{T_u}{b}$

(c) $V_e = V_u + T_u\ \frac{d}{1.6b}$

(d) $V_e = V_u + 1.6\ T_u\ \frac{d}{b}$.

55. A R.C. beam has cross section 300 × 600 mm and is subjected to
bending moment M_u = 115 kN-m
shear force V_u = 95 kN
and torsional moment T_u = 51 kN-m.
The equivalent bending moment and shear force for design are
(a) 196 kN-m and 340 kN
(b) 205 kN-m and 367 kN
(c) 221 kN-m and 375 kN
(d) none on the above

56. In a beam of depth D reinforced with 2 bars of mild steel of diameter d, the bond stress developed is

(a) $\frac{V}{jD \times 2\pi d}$

(b) $\frac{V}{jD \times 4\pi d}$

(c) $\frac{V}{jD \times \frac{\pi d^2}{2}}$

(d) $\frac{V}{jD \times \pi d^2}$

where jD is the depth of neutral axis.

57. If f_y is yield stress, f the diameter and T_{bd} design bond stress in plain bar, the bond length required is given by

(a) $\frac{0.87 f_y \phi}{\tau_{bd}}$

(b) $\frac{f_y \phi}{4\tau_{bd}}$

(c) $\frac{0.87 f_y \phi}{4\tau_{bd}}$

(d) $\frac{f_y \phi}{\tau_{bd}}$

58. The anchorage value of a standard U-type hook is equivalent to ______ times the diameter of the bar

(a) 4
(b) 8
(c) 12
(d) 16

59. Pick up the incorrect statement

A: Standard hooks are provided in plain bars.
B: Standard bends are provided in high yield bars.
C: Standard hook or bend is provided in plain bars.

(a) A and B are correct C is false.
(b) A and C are correct B is false.
(c) A is false B and C are correct.
(d) All the three are correct.

60. Figure Q. 60 shown below shows four methods of end reinforcements in a continuous beam in its end span. Which one is correct?

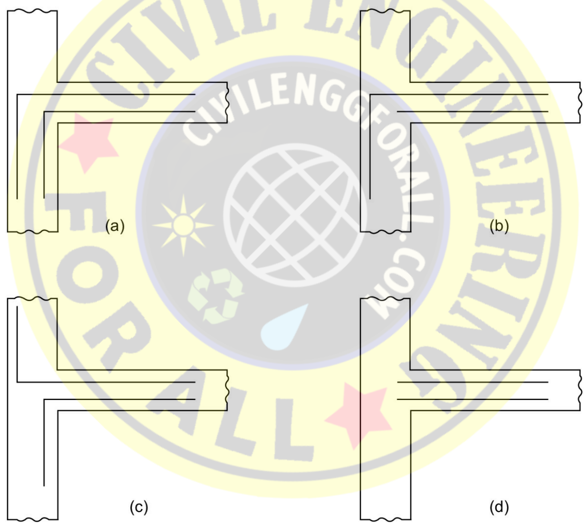


Fig. Q. 60

61. For deflection calculation of a R.C. beam of size $b \times d$ with reinforcement on one side only, depth of neutral axis from compression flange x is given by

(a) $\frac{bx^2}{6} = m\, A_{st}\, d$
(b) $bx = m\, A_{st}$
(c) $\frac{bx^2}{2} = m\, A_{st}(d - x)$
(d) $bx^2 = m\, A_{st}(d - x)$

62. For the R.C. beam shown in Fig. Q. 62 the depth of neutral axis x for serviceability calculations is given by

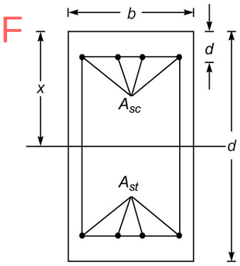
 

Fig. Q. 62

(a) $\frac{bx^2}{2} + m\,A_{st}\,(x-d) = m\,A_{st}(d-x)$

(b) $\frac{bx^2}{2} + (m-1)\,A_{st}\,(x-d) = m\,A_{st}\,(d-x)$

(c) $bx^2 + A_{st}\,(x-d) = A_{st}\,(d-x)$

(d) $\frac{bx^3}{3} + (m-1)\,A_{st}\,(d-d¢)^2 + m\,A_{st}\,(d-x)^2$

63. Crack width limitations are imposed in R.C. design, keeping in mind that it should not affect

A: The appearance

B: The durability.

Select your answer code from below:

(a) Both A and B are true.

(b) A is true but B is false.

(c) A is false but B is true.

(d) Both A and B are false.

64. In a R.C. beam main reinforcement consists of 16 mm bars and coarse aggregate size used is 20 mm. The horizontal distance between two parallel reinforcing bars should not be less than

(a) 16 mm

(b) 20 mm

(c) 21 mm

(d) 25 mm

65. If there are two rows of bars, the minimum vertical distance between the two rows shall not be less than

(a) 15 mm, size of aggregates and diameter of largest bar

(b) 20 mm, 1.5 times size of aggregates and diameter of the largest bar

(c) 15 mm, $\frac{2}{3}$rd the size of aggregate and diameter of largest bar

(d) 20 mm, $\frac{2}{3}$rd the size of aggregate and diameter of largest bar

66. A simply supported beam of size 400 × 600 mm is supported on walls of 300 mm width the clear span is 4 m. The effective span of the beam is

(a) 4.6 m

(b) 4.4 m

(c) 4.3 m

(d) none of the above

67. A cantilever beam of size 230 × 400 mm has a clear span of 2.5 m and is supported on a 400 × 400 mm column. The effective span of the cantilever is
   (a) 2.615 mm
   (b) 2.7 m
   (c) 2.9 m
   (d) 3.3 m
68. Not more than ______ number of bars should be used in one layer in a beam
   (a) 4
   (b) 5
   (c) 6
   (d) 8
69. If Fe 415 steel bars are used as tensile reinforcement, minimum percentage of steel to be used is
   (a) 0.2
   (b) 0.205
   (c) 0.25
   (d) 0.30
70. The maximum area of tensile reinforcement to be used in a beam is to be restricted to
   (a) 0.04 × gross area of the section
   (b) 0.04 × effective area of the section
   (c) 0.057 × gross area of the section
   (d) 0.057 × effective area of the section
71. The bars larger than ______ diameter should not be bundled.
   (a) 24 mm
   (b) 28 mm
   (c) 32 mm
   (d) 36 mm
72. If no compression steel is used, two suspended bars of minimum ______ diameter should be used to support shear reinforcement
   (a) 8 mm
   (b) 10 mm
   (c) 12 mm
   (d) 16 mm
73. The maximum spacing of vertical shear reinforcement for a beam of size 250 × 360 mm is
   (a) 250 mm
   (b) 270 mm
   (c) 300 mm
   (d) 360 mm
74. If shear reinforcement in a beam is provided at 45° to horizontal and beam cross section is 250 ×

360 mm, spacing shall not exceed

(a) 250 mm
(b) 270 mm
(c) 300 mm
(d) 360 mm

75. When the depth of a beam exceeds ______, side face reinforcement be provided

(a) 500 mm
(b) 600 mm
(c) 750 mm
(d) 800 mm

76. While designing a beam, if design moment M_u exceeds limiting moment $M_{u\lim}$,

A: Depth of the beam may be increased
B: Doubly reinforced section may be tried
C: Reinforcement may be increased and tried

(a) Only A is correct
(b) Only B is correct
(c) A and B are correct but C is not correct
(d) All the three are correct methods

77. Which one of the following statement is not correct about curtailment of positive reinforcement in a continuous member?

(a) Minimum two bars should extend throughout.

(b) At least one-third bars should extend into the support for a $\frac{1}{3}$ rd development length.

(c) Cut-off bars shall extend for a distance not less than effective depth of the member beyond theoretical cut-off point.

(d) Cut-off bars shall extend for a distance not less than 12 times the bar diameter beyond theoretical cut-off point.

78. Pick up the correct statement about the design of a slab of dimension 7 m × 3 m.

(a) Main reinforcement will be in the direction 7 m and distribution reinforcement in 3 m.
(b) Main reinforcement will be in 3 m direction and distribution in 7 m direction.
(c) Provide main reinforcement in 7 m direction and there is no need of distributions steel.
(d) Provide main reinforcement in 3 m direction and there is no need of distribution steel.

79. In one-way slab distribution steel is to be provided

A: To distribute load properly
B: To distribute secondary stresses

Pick up the correct statement:

(a) Both A and B are correct.
(b) A is correct but B is false.
(c) A is false and B is correct.
(d) Both A and B are false.

80. A slab may be designed as one-way slab if the ratio of its longer dimension to shorter direction exceeds
(a) 1.5
(b) 1.75
(c) 2.0
(d) 2.5

81. If Fe-415 steel is used, minimum distribution steel to be provided is ______ per cent of main reinforcement
(a) 0.12
(b) 0.15
(c) 0.18
(d) 0.2

82. If A_{st} is the area of steel required per 1 m width of slab, f is the diameter of bar in mm, the maximum spacing to be provided is found from the relation
(a) $\frac{A_{st}}{\pi/4\phi^2} \times 1000$
(b) $\frac{\pi/4\phi^2}{A_{st}} \times 1000$
(c) $\frac{A_{st}}{\pi/4\phi^2}$
(d) $\frac{\pi/4\phi^2}{A_{st}}$

83. In a slab design, if design shear stress (t_v) exceeds permissible shear stress in concrete (t_c).
A: Increase slab thickness and redesign.
B: Provide shear reinforcement.
Select the correct answer:
(a) Both A and B are correct.
(b) A is correct but B is false.
(c) A is false and B is correct.
(d) Both A and B are false.

84. To satisfy deflection criteria, the span l to depth d ratio in a simply supported slab shall be not less than
(a) 15
(b) 20
(c) 25
(d) 36

85. If b_1 is centre-to-centre distance between compression bars is the direction of width, d_1 is centre-to-centre distance between corner bars in vertical direction, the spacing of stirrups of diameter f shall not exceed the following
(a) $b_1 + f$

(b) $\frac{b_1 + d_1 + 2\phi}{4}$

(c) 300 mm

(d) none of the above

86. In a continuous slab, if all spans are equal to l, due to dead load w_d and live load w_L, per unit length, the maximum moment for design is

(a) $(w_d + w_L)\,\frac{l^2}{8}$

(b) $(w_d + w_L)\,\frac{l^2}{10}$

(c) $(w_d + w_L)\,\frac{L_2}{12}$

(d) $\frac{w_d\, l^2}{12} + \frac{w_L\, l^2}{9}$

87. In the above case maximum shear for design is

(a) $0.5\,(w_d + w_L)l$

(b) $0.6\,(w_d + w_L)l$

(c) $(0.5\,w_d\; 0.6\,w_L)l$

(d) $(0.6\,w_d + 0.5\,w_L)l$

88. While designing a continuous slab, to start with depth of slab is to be assumed as

(a) $\frac{\text{Span}}{20}$

(b) $\frac{\text{Span}}{25}$

(c) $\frac{\text{Span}}{30}$

(d) $\frac{\text{Span}}{36}$

89. In designing a cantilever slab of span l, to start with, depth of slab may be assumed as

(a) $\frac{l}{7}$

(b) $\frac{l}{12}$

(c) $\frac{l}{15}$

(d) $\frac{l}{25}$

90. Which one of the following statement is not correct regarding the torsional reinforcements to be provided in a slab with two adjustment edges discontinuous?

(a) It consists of two layers of reinforcements one at top and other at bottom.

(b) It consists of total four layers.

(c) The total area of reinforcement shall be 3/4th the area required for the maximum moment at mid span.

(d) The length of each layer shall be of length $\frac{1}{5}$ th of the shorter span.

91. A column is considered long, if the effective length to least lateral dimension is more than
(a) 10
(b) 12
(c) 15
(d) 18

92. In case of a flat slab construction with column capital, unsupported length l of the column is the distance between the lower floor and
(a) the top floor
(b) the bottom of drop panel
(c) half the depth of column capital
(d) the lower extremity of the column capital

93. In case of beam and slab construction, if the two beams of different depth meet in the same direction (Ref. Fig. Q. 93), the unsupported length l in that direction is the distance between the floor and

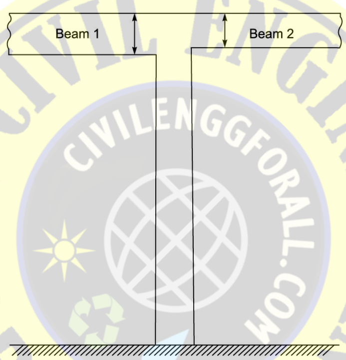


Fig. Q. 93

(a) lower side of beam 1
(b) middle of beam 1
(c) lower side of beam 2
(d) average level of beam 1 and 2

94. IS 456–2000 recommends that the unsupported length of any column should not exceed _______ times the least lateral dimension of the column.
(a) 15
(b) 25
(c) 36
(d) 60

95. The maximum eccentricity to be considered in a R.C. column of length l is

(a) $\frac{l}{400} + \frac{\text{Lateral dimension}}{30}$
(b) $\frac{l}{500} + \frac{\text{Lateral dimension}}{30}$
(c) $\frac{l}{500} + \frac{\text{Lateral dimension}}{25}$

(d) $\frac{l}{400}+\frac{\text{Lateral dimension}}{25}$

subject to a minimum of 20 mm.

96. In the limit state of collapse-flexure, the maximum compressive strain in concrete, in axial compression is

(a) 0.0015
(b) 0.002
(c) 0.003
(d) 0.0035

97. In limit state design as per IS recommendation when minimum eccentricity does not exceed 0.05 times the lateral dimension, the factored load carrying capacity of the column with usual notation is

(a) $P_u = 0.4\, f_{ck}\, A_c + 0.67\, f_y\, A_{sc}$
(b) $P_u = 0.45\, f_{ck}\, A_c + f_y\, A_{sc}$
(c) $P_u = 0.445\, f_{ck} + 0.67\, f_y\, A_{sc}$
(d) $P_u = 0.67\, f_{ck}\, A_c + 0.87\, f_y\, A_{sc}$

98. Instead of laterals, if helical reinforcements are used the strength of the column

(a) is decreased by 1.05 times
(b) is increased by 1.05 times
(c) is increased by 1.1 times
(d) is decreased by 1.1 times

99. IS 456–2000 recommends that in any column a minimum of ______ reinforcement should be used

(a) 0.8%
(b) 1.0%
(c) 1.2%
(d) 1.5%

100. IS 456–2000 recommends that in any column reinforcement shall not be more than

(a) 3%
(b) 4%
(c) 6%
(d) 8%

101. Where bars from the column below are to be lapped with those in the column under consideration, the steel shall usually not exceed

(a) 3%
(b) 4%
(c) 6%
(d) 8%

102. Minimum number of bars to be provided in a rectangular section column are

(a) 4

(b) 6

(c) 8
(d) 12

103. The minimum number of bars to be provided in a circular column is
(a) 4
(b) 6
(c) 8
(d) 12

104. In a column minimum diameter of the bar to be used is
(a) 10 mm
(b) 12 mm
(c) 16 mm
(d) 20 mm

105. Spacing of longitudinal bars measured along the periphery of R.C. column shall not exceed
(a) 200 mm
(b) 300 mm
(c) 400 mm
(d) 450 mm

106. The internal angle *f* of the transverse reinforcement shown in the Fig. Q. 106 should not exceed
(a) 120°
(b) 135°
(c) 150°
(d) 165°

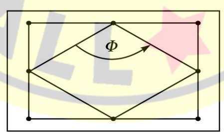


Fig. Q. 106

107. If spacing of longitudinal bars is less than ______ alternate bars may be unsupported. (Fig. Q. 107)

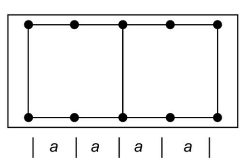


Fig. Q. 107

(a) 45 mm
(b) 60 mm
(c) 75 mm
(d) 90 mm

108. Diameter of transverse reinforcement in a R.C. column should be

A: $\frac{1}{4}$ th of largest diameter of longitudinal bars

B: 6 mm

Select your answer code:

(a) Both A and B are true.

(b) A is true but B is false.

(c) A is false but B is true.

(d) Both A and B are false.

109. The pitch of ties in the R.C. column should not be more than

(a) least lateral dimension of the column

(b) 16 × the diameter of smallest longitudinal bar

(c) 300 mm

(d) all the above

110. If the strength of the column is to be enhanced by 1.05, the pitch of helical reinforcement should satisfy

(a) not more than 75 mm

(b) not more than $\frac{1}{6}$ th core diameters of helix.

(c) not less than 3 times the diameter of helix bar

(d) all the above should be satisfied.

111. If B is width of wall footing and b_w is the width of wall, the footing is designed as a cantilever of span (Ref Fig. Q. 111)

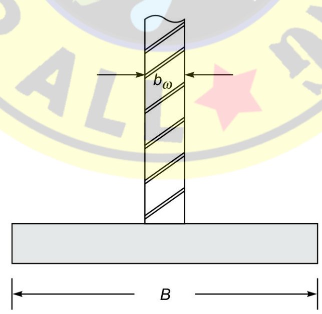


Fig. Q. 111

(a) $\frac{B}{2}$

(b) $\frac{B}{2}-\frac{b_w}{2}$

(c) $\frac{B}{2}-\frac{b_w}{4}$

(d) $\frac{B}{2}-\frac{b_w}{6}$

112. If plain concrete bed is provided to a column footing, the minimum cover to main reinforcement shall be

(a) 25 mm

(b) 40 mm

(c) 50 mm

(d) 75 mm

113. If plain concrete bed is not provided to a concrete column footing, minimum cover to main reinforcement shall be

(a) 25 mm
(b) 40 mm
(c) 50 mm
(d) 75 mm

114. Minimum thickness of footing shall be

A: for footing on soil –150 mm

B: for footing on piles –250 mm

Select your answer code

(a) Both A and B are true.
(b) A is true but B is true.
(c) A is false but B is true.
(d) Both A and B are false.

115. If P is the axial load and P_u is the factored axial load on the footing, area of footing required is

(a) $\frac{P}{\text{SBC of soil}}$

(b) $\frac{P_u}{\text{SBC of soil}}$

(c) $\frac{1.1P}{\text{SBC soil}}$

(d) $\frac{1.1P}{\text{SBC of soil}}$

116. The depth of footing required for an isolated column depends upon

(a) bending moment
(b) single shear
(c) double shear
(d) all the three above

117. In the design of isolated column footing, of thickness d the critical section from the consideration of single shear is

(a) at column face
(b) at distance $d/4$ from the column face
(c) at distance $\frac{d}{2}$ from the face of column
(d) at distance d from the face of column

118. If the size of the column is 250 × 300 mm and depth of footing is 400 mm, the perimeter of critical section for two way shear is

(a) 1100 mm
(b) 1500 mm

(c) 2700 mm

(d) none of the above

119. Figure Q. 119 shows a sloping footing with depth d at column face. The reinforcement to resist bending may be found by assuming bending moment about section x–x is resisted by the section $b_e \times d_e$ where $d_e = d$ and b_e is

(a) $b + \frac{1}{2}(B - b)$

(b) $b + \frac{1}{4}(B - b)$

(c) $b + \frac{1}{6}(B - b)$

(d) $b + \frac{1}{8}(B - b)$

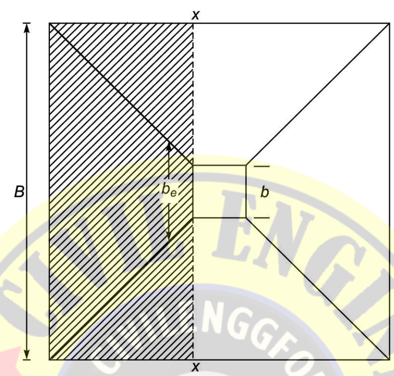


Fig. Q. 119

120. For designing square footing for a circular column of diameter d, equivalent square column has side

(a) d

(b) 0.8 d

(c) 0.75 d

(d) 0.707 d

121. For a circular column of 200 mm radius a circular footing of radius 1.25 m is provided. If the depth of footing is 600 mm and factored earth pressure is q_u, the design two way shear will be

(a) 1.5225 $p\, q_u$

(b) 1.44 $p\, q_u$

(c) 1.3125 $p\, q_u$

(d) 0.9225 $p\, q_u$

122. A square column is provided with a square footing of size $B \times B$. The axial load on the footing is W and the column is subjected to uniaxial moment M. The maximum earth pressure under the footing is

(a) $\frac{W}{B^2} + \frac{M}{B^3}$

(b) $\frac{W}{B^2} + \frac{3M}{B^3}$

(c) $\frac{W}{B^2} + \frac{4M}{B^3}$

(d) $\frac{W}{B^2} + \frac{6M}{B^3}$

123. The width of stairs in a residential building should be at least

(a) 600 mm
(b) 750 mm
(c) 900 mm
(d) 1200 mm

124. In a public building width of stair should be at least

(a) 1000 mm
(b) 1200 mm
(c) 1500 mm
(d) 1800 mm

125. The width of landing in stairs should be at least

(a) 0.5 × width of stairs
(b) 0.75 × width of stairs
(c) width of stairs
(d) 1.5 × width of stairs

126. IS code recommends that the slope of stairs should be between

(a) 25° to 40°
(b) 20° – 35°
(c) 20° – 30°
(d) 15° – 30°

127. The accepted relations between rise R and tread T in a step are

(a) $R + 2T = 700$
(b) $2R + T = 600$ to 640 mm
(c) $R + 2T = 650$
(d) $2R + T = 750$

128. In a public building ideal tread is

(a) 200 to 250 mm
(b) 220 to 260 mm
(c) 270 to 300 mm
(d) 300 to 350 mm

129. Ideal rise in a stair is

(a) 100 mm
(b) 120 mm
(c) 150 mm
(d) 165 mm

130. In the design of stairs spanning longitudinally shown in Fig. Q.130 depth of section for resisting

moment is

(a) d_1

(b) d_2

(c) d_3

(d) none of the above

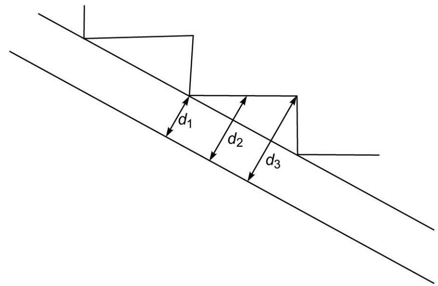


Fig. Q. 130

131. For the stairs shown in Fig. Q. 131, span to be taken while designing stairs is

(a) 8.6 m
(b) 6.3 m
(c) 6.0 m
(d) 4.0 m

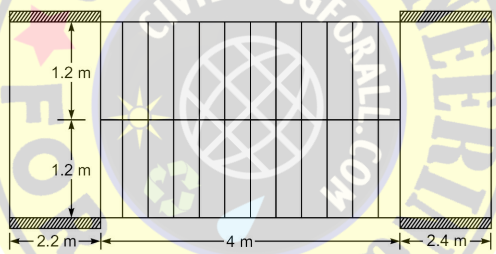


Fig. Q. 131

132. In a residential building, while designing stairs, live load to be taken is

(a) 3 kN/m^2

(b) 4 kN/m^2

(c) 4.5 kN/m^2

(d) 5 kN/m^2

133. While designing a stair for a college building, the live load to be considered is

(a) 3 kN/m^2

(b) 4 kN/m^2

(c) 5 kN/m^2

(d) 6 kN/m^2

134. Figure Q. 134 shows main reinforcement details of a stair. The bar bending near sections

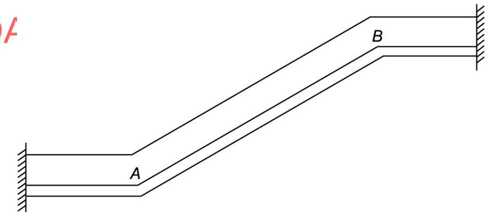


Fig. Q. 134

(a) *A* and *B* is not correct
(b) *A* it is correct but not at *B*.
(c) *A* it is not correct but it is correct at *B*.
(d) *A* as well as *B* it is not correct

135. In flat slab construction, column head is widened. The reason for widening is
(a) aesthetic consideration
(b) to get more depth to resist moment
(c) to reduce two-way shear
(d) all the above

136. Figure Q. 136 shows 4 sections in a flat slab with column head. The critical section for shear is

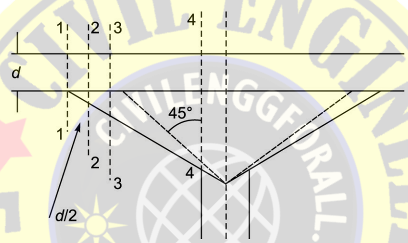


Fig. Q. 136

(a) 1 – 1
(b) 2 – 2
(c) 3 – 3
(d) 4 – 4

137. Figure Q. 137 shows the position of columns supporting a flat slab. In this case width of middle strip shown is

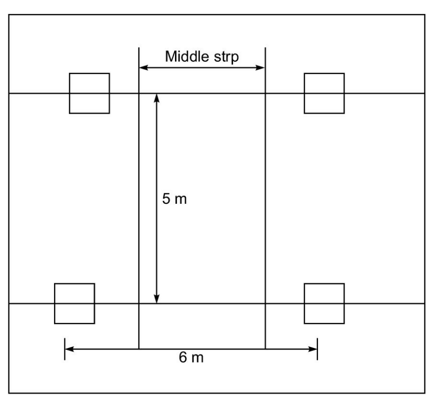


Fig. Q. 137

(a) 2.0 m
(b) 2.5 m

(c) 3.0 m

(d) 3.5 m

138. In flat slabs the drop provided shall be rectangular in plan and have a length in each direction not less than ______ time of the panel in that direction.

(a) 0.2
(b) 0.25
(c) 0.33
(d) 0.35

139. The thickness of flat slab of 5 m × 6 m, which is provided with standard drop and is to be designed with Fe-415 should not be less than

(a) 125 mm
(b) 150 mm
(c) 155
(d) 187.5 mm

140. In the above case, if standard drop is not provided, the thickness of slab should not be less than

(a) 135 mm
(b) 170 mm
(c) 175 mm
(d) 209 mm

141. In the direct design method of flat slab, if W is the design load on the panel and L_n is the effective length, the absolute sum of the positive and negative moment in that direction is

(a) $\frac{WL_n}{4}$
(b) $\frac{WL_n}{8}$
(c) $\frac{WL_n}{10}$
(d) $\frac{WL_n}{12}$

142. If M_o is the total design moment in a panel of flat slab, in the direct design method of an interior span, negative and positive design moments are respectively

(a) 0.65 M_o and 0.35 M_o
(b) 0.55 M_o and 0.45 M_o
(c) 0.45 M_o and 0.55 M_o
(d) 0.35 M_o and 0.65 M_o

143. If M is the positive moment across the column strip in a panel of flat slab, found as per the direct design method, distribution of moments at exterior and interior supports are respectively

(a) M and 0.75 M
(b) M and 0.5 M
(c) 0.5 M and 0.5 M
(d) 0.75 M and M

144. If q is the load intensity on a simply supported circular slab of radius R, the maximum radial moment and circumferential moment are respectively

(a) $\frac{qR^2}{8}$ and $\frac{qR^2}{8}$

(b) $\frac{3}{16}qR^2$ and $\frac{3}{16}qR^2$

(c) $\frac{qR^2}{8}$ and $\frac{3qR^2}{16}$

(d) $\frac{3}{16}qR^2$ and $\frac{qR^2}{8}$

145. If q is the udl acting over the entire surface of simply supported circular slab of radius R, the maximum deflection is

(a) $\frac{3}{64}qR^4$

(b) $\frac{1}{16}qR^4$

(c) $\frac{5}{64}qR^4$

(d) $\frac{3}{32}qR^4$

146. In a fixed circular slab of radius R subject to udl q over the entire surface maximum deflection will be

(a) $\frac{qR^4}{64}$

(b) $\frac{qR^4}{32}$

(c) $\frac{3}{16}qR^4$

(d) $\frac{qR^4}{16}$

147. In a fixed circular slab of radius R subject to udl q over the entire surface, moment at centre in any direction is

(a) $\frac{1}{16}qR^2$

(b) $\frac{1}{8}qR^2$

(c) $\frac{3}{16}qR^2$

(d) $\frac{qR^2}{4}$

148. In a fixed circular slab of radius R subject to udl q over the entire surface, the fixed end moment in radial direction is numerically equal to

(a) $\frac{1}{16}qR^2$

(b) $\frac{1}{8}qR^2$

(c) $\frac{3}{16} qR^2$

(d) $\frac{qR^2}{4}$

149. The assumptions made in the yield line theory are

A: Slab is under-reinforced.

B: The yield lines are straight.

C: Elastic deformation is negligible.

Which one of the following is correct?

(a) A, B and, C correct all
(b) Only A and B.
(c) Only B and C
(d) Only A and C

150 The following statements are about characteristics of yield line pattern in a slab.

A: Yield lines are straight lines.

B: Yield lines either terminate at the boundary of the slab or at the intersection of other yield lines.

C: Each segment of slab will be having axes of rotation all along its periphery.

In the above statements

(a) A, B and C are correct
(b) Only A and B are correct
(c) Only B and C are correct
(d) Only A and C are correct

151. When yield line is at right angles to the main reinforcement, the ultimate moment capacity per unit width of slab, with usual notations is

(a) $0.87 f_y A_{st} d$

(b) $0.87 f_y A_{st} d \left[1 - \frac{A_{st}}{bd} \frac{f_y}{f_{ck}}\right]$

(c) $f_y A_{st} d$

(d) $f_y A_{st} d \left[1 - \frac{bd}{A_{st}} \frac{f_y}{f_{ck}}\right]$

152. The ultimate moment of any yield line in orthotropically reinforced slab at angle a to x-axes, with usual notation, is given by

(a) $m_{ux} [\sin^2 a + m \cos^2 a]$
(b) $m_{ux} [\sin 2 a + m \cos 2 a]$
(c) $m_{ux} [\cos^2 a + m \sin^2 a]$
(d) $m_{ux} [\cos 2 a + m \sin 2 a]$

153. The yield line pattern for 6 m × 4 m, slab with three edges simply supported and one edge free is as shown in Fig. Q. 153

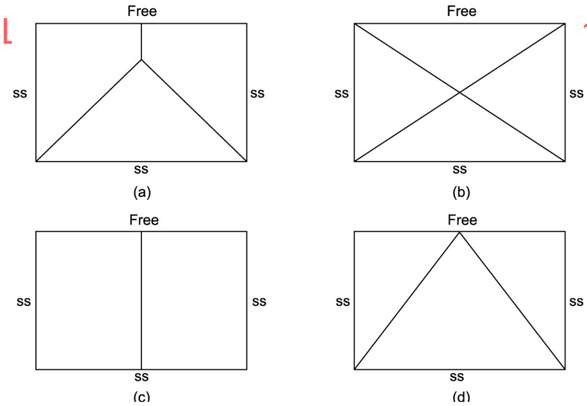
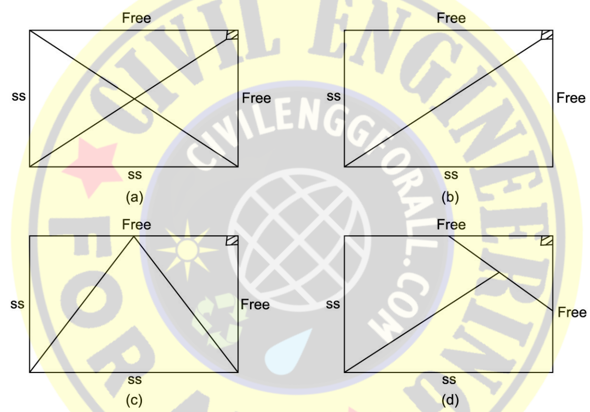


Fig. Q. 153

(a) ☐
(b) ☐
(c) ☐
(d) ☐

154. Which one of the following is the correct yield line pattern for a slab simply supported along two edges and supported by column as shown in the Fig. Q. 154.



Fig, Q. 154

(a) ☐
(b) ☐
(c) ☐
(d) ☐

155. To get maximum positive moment at x_1, the midspan of interior span in a continuous beam, live load should be as shown in Fig. Q. 155.

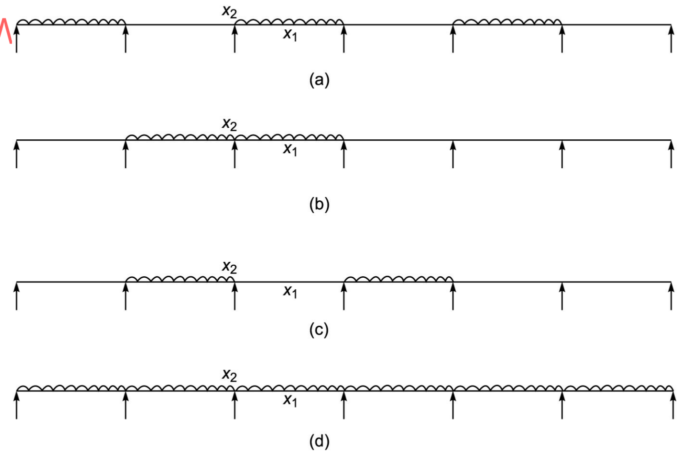


Fig. Q. 155

156. To get maximum moment at support x_2, the live loads should be considered as shown in Figure (Ref Q. 155).

(a) ☐
(b) ☐
(c) ☐
(d) ☐

157. IS: 456–2000 permits redistribution of moments in continuous beam to a maximum extent of

(a) 15%
(b) 20%
(c) 25%
(d) 30%

158. Figure Q. 158 shows a multistorey building column and the live load coming on it from the roof and floors. The live load to be considered for the design of ground floor column is

(a) 115 kN
(b) 138 kN
(c) 230 kN
(d) none of the above

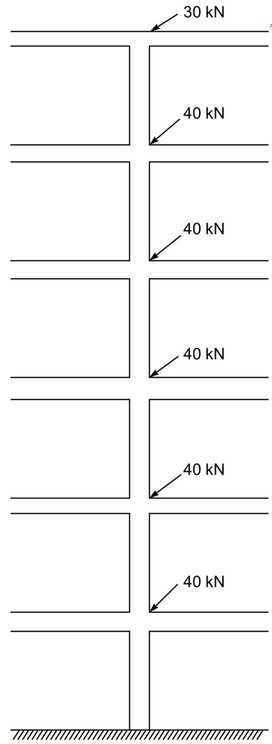


Fig. Q. 158

159. On back fill of retaining walls drains are provided to
   A: improve drainage in longitudinal direction
   B: reduce water pressure on the stem
   C: reduce frictional force on stem
   (a) A and B are correct and C is wrong.
   (b) A and C are correct and B is wrong.
   (c) B and C are correct and A is wrong.
   (d) A, B and C are correct.

160. In cantilever retaining walls
   (a) both toe and heal slab bend up
   (b) toe slabs bend up and heal slab bends down
   (c) tow slab bends down and heal slab bends up
   (d) both slabs bend down

161. If g is the unit weight of flat back fill, k_a is coefficient of active earth pressure on a cantilever retaining wall of height H, the maximum moment on the stem is
   (a) $\frac{1}{2} k_a g H^2$
   (b) $\frac{1}{6} k_a g H^2$
   (c) $\frac{1}{3} k_a g H^3$
   (d) $\frac{1}{6} k_a g H^3$

162. In a retaining wall, if b is surcharge angle and f is angle of friction, the coefficient of active earth pressure is

(a) cos $b\ \frac{\cos\beta-\sqrt{\cos^2\beta-\cos^2\phi}}{\cos\beta+\sqrt{\cos^2\beta-\cos^2\phi}}$

(b) cos $b\ \frac{\cos\beta+\sqrt{\cos^2\beta-\cos^2\phi}}{\cos\beta-\sqrt{\cos^2\beta-\cos^2\phi}}$

(c) sin $b\ \frac{\cos\beta+\sqrt{\cos^2\beta-\cos^2\phi}}{\cos\beta-\sqrt{\cos^2\beta-\cos^2\phi}}$

(d) sin $b\ \frac{\cos\beta-\sqrt{\cos^2\beta-\cos^2\phi}}{\cos\beta+\sqrt{\cos^2\beta-\cos^2\phi}}$

163. The relationship between coefficient of passive earth pressure k_p and active earth pressure k_a is

(a) $k_p = \frac{1}{1.1\,k_a}$
(b) $k_p = 1.25\ k_a$

(c) $k_p = \frac{1}{k_a}$

(d) $k_p = \frac{1}{1.25\,k_a}$

164. In a reinforced concrete retaining wall, a shear key is provided, if the
(a) shear stress in the vertical stream is excessive
(b) shear force in the toe slab is more than that in the heel slab
(c) retaining wall is not safe against sliding
(d) retaining wall is not safe against overturning

165. In the design of R.C. retaining wall the minimum factor of safety against over turning should be
(a) 1.4
(b) 2.0
(c) 2.5
(d) 3.0

166. Which one of the following is the correct statement about R.C. retaining wall
(a) toe slab and heel slab are provided with reinforcements at top face
(b) toe slab and heel slab are provided with reinforcement at bottom face
(c) toe slab is provided with reinforcement at top face and heel slab at bottom face
(d) toe slab is provided at bottom face and heel slab at bottom face

167. In a cantilever retaining wall of height h bending moment in stem varies as
(a) h
(b) h^2
(c) h^3
(d) h^4

168. If h is the height of retaining wall, the base width is generally
(a) 0.3 h
(b) 0.5 h

(c) 0.75 h

(d) 0.2 h

169. If base width of a cantilever retaining wall is b, its toe projection is generally

(a) 0.2 b
(b) 0.3 b
(c) 0.4 b
(d) 0.5 b

170. If height of back fill in a retaining wall is more than ______ counterfort retaining wall should be preferred.

(a) 4.5 m
(b) 6.0 m
(c) 7.5 m
(d) 9.0 m

171. In the stem of counterfort retaining wall main reinforcements are

(a) vertically upward on the face away from earth fill
(b) vertically upward on earth face
(c) horizontally on earth face
(d) horizontally away from earth face in some portion and on earth face in some other position

172. The spacing of counterforts usually varies from ______, where h is the height of wall.

(a) $\frac{1}{8}$ to $\frac{1}{6}$
(b) $\frac{1}{6}$ to $\frac{1}{3}$
(c) $\frac{1}{4}$ to $\frac{1}{3}$
(d) $\frac{1}{2.5}$ to $\frac{1}{2}$

173. The counterfort in a retaining wall need reinforcement

(a) along its slopping edge
(b) horizontal direction
(c) vertical direction
(d) all the above

174. In counterfort retaining walls

(i) the vertical slab is designed as a horizontal continuous slab
(ii) the toe slab is designed as a continuous slab
(iii) the heel slab is designed as a continuous slab
(iv) the vertical slab is designed as a cantilever

The correct answer is

(a) (i) and (ii)
(b) (i) and (iii)

(c) (ii) and (iii)

(d) (iii) and (iv)

175. The principle of prestressed concrete is to introduce calculated ______ stresses in the zones wherever ______ stresses are expected when the concrete structure is put to use.

(a) tensile, compressive
(b) compressive, tensile
(c) compressive, shear
(d) tensile, shear

176. The cube strength of concrete used for a prestressed concrete member should not be less than

(a) 20 N/mm^2
(b) 25 N/mm^2
(c) 35 N/mm^2
(d) 50 N/mm^2

177. The ultimate strength of steel used for prestressing is nearly

(a) 250 N/mm^2
(b) 415 N/mm^2
(c) 600 N/mm^2
(d) 1400 N/mm^2

178. Mild steel cannot be used for pressing since

(a) its strength is low
(b) percentage loss of prestress is high
(c) it cannot be anchored easily
(d) both (a) and (c)

179. Advantage of prestressed concrete member over equivalent strength R.C.C. member is

(a) more durable
(b) dead weight is less
(c) deformation is much less
(d) all the above

180. Disadvantages of PSC over RCC are

(a) it requires skilled labour
(b) it needs special techniques for prestressing
(c) it needs special techniques to anchorage wires
(d) all the above

181. Which one of the following is not a post-tensioning method?

(a) Freyssinet system
(b) Gifford udall system
(c) Long line method
(d) Lee-Macall system

182. Which of the following losses of prestress occur only in pretensioning and not in post-

tensioning?

(a) Creep of concrete.

(b) Shrinkage of concrete.

(c) Elastic shortening of concrete.

(d) Slip in anchorages.

183. Loss of prestress due to friction occurs

(a) only in pre-tensioned beams

(b) only in post-tensioned beams

(c) in both pre-tensioned and post-tensioned beams

(d) none of the above

184. The loss of pre-stress with time at constant strain is called

(a) shrinkage

(b) relaxation

(c) creep

(d) all the above

185. The coefficient of shrinkage for high grade concrete used for pretensioned work is

(a) 0.0003

(b) 0.003

(c) $\frac{0.0003}{10g_{10}(t+2)}$

(d) $\frac{0.003}{10g_{10}(t+2)}$

where t is age of concrete at transfer in days.

186. Loss in pre-stressed beam and post-tensioned members may be takes as ______ and ______ respectively.

(a) 15–20; 20–25

(b) 20–25, 15–20

(c) 10–15, 15–20

(d) 15–20, 10–15

187. Which of the following has high tensile strength?

(a) Mild steel

(b) Plain hot rolled wires

(c) Cold drawn wires

(d) Thermo mechanically treated bars

188. High carbon content in the steel causes

(a) increase in tensile strength and ductility

(b) decrease in both tensile strength and ductility

(c) increase in tensile strength but decrease in ductility

(d) decrease in tensile strength but increase in ductility

189. If elastic modulus of high tensile steel is E_{ts} and that of mild steel is E_{ms}, then

(a) $E_{ts} > E_{ms}$

(b) $E_{ts} = E_{ms}$

(c) $E_{ts} < E_{ms}$

(d) any of the above depending upon carbon content

190. For water retaining structures, minimum grade of concrete to be used is

(a) M 15
(b) M 20
(c) M 25
(d) M 40

191. Water tanks should be designed by

(a) working stress method
(b) ultimate load method
(c) limit state method
(d) any of the above

192. For design of water tank permissible direct tension in mild steel is

(a) 115 N/mm^2
(b) 140 N/mm^2
(c) 190 N/mm^2
(d) 225 N/mm^2

193. Upto 100 mm thickness of water tank minimum reinforcement to be provided is

(a) 0.3%
(b) 0.5%
(c) 0.8%
(d) 1.0%

194. If thickness of water tank wall is more than ______ reinforcement should be provided on both faces

(a) 125 mm
(b) 175 mm
(c) 225 mm
(d) 275 mm

195. Maximum reinforcement in water tank walls of 100 mm and 450 mm should be respectively

(a) 0.3 and 0.2%
(b) 0.2 and 0.3%
(c) 0.3 and 0.4%
(d) 0.4 and 0.3%

196. Rise of spherical domes of diameter d in water tanks should be

(a) $\frac{1}{7}d$

(b) $\frac{1}{5}\,d$

(c) $\frac{1}{3}\,d$

(d) $\frac{1}{2}\,d$

II. *Match List-I width List-II selecting the answer code given below each question no. 197 to 204*

197.

	List I		List II
	Material		**Unit weight**
A.	A.C. sheets	1.	20 kN/m^3
B.	R.C.C.	2.	24 kN/m^3
C.	Brick masonry	3.	25 kN/m^3
D.	Granite stone masonry	4.	0.13 kN/m^3

Codes:

(a)	A – 4	B – 2	C – 1	D – 3
(b)	A – 4	B – 3	C – 1	D – 2
(c)	A – 4	B – 3	C – 2	D – 1
(d)	A – 4	B – 2	C – 2	D – 3

198.

	List I		List II
	Occupancy		**Udl to be considered**
A.	Both rooms and toilets	1.	5 kN/m^2
B.	Assembly buildings	2.	4 kN/m^2
C.	Dining rooms in hotels	3.	3.5 kN/m^2
D.	Assembly halls with fixed seats	4.	3 kN/m^2
		5.	2 kN/m^2

Codes:

(a)	A – 5	B – 3	C – 2	D – 1
(b)	A – 5	B – 4	C – 2	D – 1
(c)	A – 4	B – 3	C – 2	D – 1
(d)	A – 4	B – 2	C – 1	D – 3

199. Figure Q. 199 shown below is that of a simply supported beam. In this four critical points are

shown. List 2 gives the failure criteria to be considered at the critical points. Match List-1 with List-2.

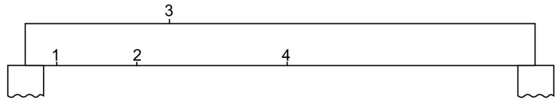


Fig. Q. 199

	List I		**List II**
A.	Point 1	1.	Flexure failure
B.	Point 2	2.	Shear failure
C.	Point 3	3.	Shear plus tensile failure
D.	Point 4	4.	Shear plus compression failure

Codes:

(a)	A – 4	B – 3	C – 1	D – 2
(b)	A – 2	B – 3	C – 1	D – 4
(c)	A – 2	B – 3	C – 4	D – 1
(d)	A – 3	B – 2	C – 4	D – 1

200. List I shows loading and the section in a continuous beam and List II moment coefficient. Match List I and List II.

	List I		**List II**
A.	Fixed type *DL* + *IL* – At middle of interior	1.	$\frac{1}{9}$
B.	Fixed type *DL* + *IL* – At middle of end support	2.	$\frac{1}{10}$
C.	Fixed type *DL* + *IL* – At support next to end	3.	$\frac{1}{12}$
D.	Imposed load (not fixed) At support next to end support	4.	$\frac{1}{16}$

Codes:

(a)	A – 2	B – 4	C – 1	D – 3
(b)	A – 4	B – 2	C – 1	D – 3
(c)	A – 3	B – 4	C – 1	D – 2
(d)	A – 4	B – 3	C – 2	D – 1

201. List-I shows the section in a continuous beam. List II shows shear coefficient due to *DL* and *IL*. Match List-I with List-II

	List I		**List II**
A.	At end support	1.	0.4

B.	At support next to end support outer side	2.	0.5
C.	At support next to end support inner side	3.	0.55
D.	At all other interior supports	4.	0.6

Codes:

(a)	A – 2	B – 3	C – 4	D – 1
(b)	A – 1	B – 4	C – 3	D – 2
(c)	A – 1	B – 2	C – 4	D – 3
(d)	A – 2	B – 4	C – 3	D – 1

202. List-I shows the end conditions of a column and List-II recommended value of effective length. Match List-I with List-II.

	List I		**List II**
A.	At both ends effectively held in position and rotation.	1.	0.65 l
B.	Effectively held in position at both ends but not restrained against rotation.	2.	0.80 l
C.	Effectively held in position and restrained at one end at the other end restrained in rotation but not held in position.	3.	1.0 l
D.	Effectively held in position at both ends but restrained against rotation at only one end.	4.	1.2 l

Codes:

(a)	A – 1	B – 3	C – 4	D – 2
(b)	A – 1	B – 3	C – 2	D – 4
(c)	A – 2	B – 1	C – 3	D – 4
(d)	A – 2	B – 3	C – 1	D – 4

203. List-I shows the end conditions of a column and List-II theoretical effective length. Match List-I with List-II.

	List I		**List II**
A.	Fixed–Fixed	1.	2.0 l
B.	Fixed–Free	2.	1.0 l
C.	Fixed–hinged	3.	0.707 l
D.	Hinged–Hinged	4.	0.50 l

Codes:

(a)	A – 3	B – 4	C – 2	D – 1
(b)	A – 4	B – 1	C – 3	D – 2

(c)	A – 3	B – 1	C – 2	D – 3
(d)	A – 4	B – 2	C – 3	D – 1

204. Figure Q. 204 shows a typical interaction curve for column design. Match List-I with List-II

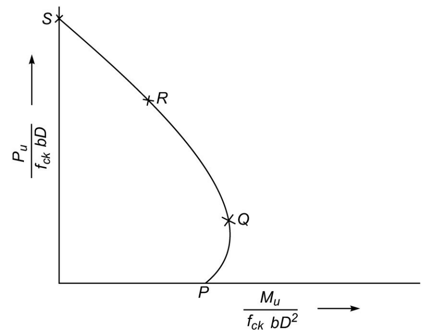


Fig. Q. 204

	List I		**List II**
A.	Point P	1.	Pure compression failure
B.	Point Q	2.	Pure moment case
C.	Point R	3.	Compression failure
D.	Point S	4.	Balanced failure

Codes:

(a)	A – 2	B – 3	C – 1	D – 4
(b)	A – 1	B – 2	C – 4	D – 3
(c)	A – 1	B – 3	C – 2	D – 4
(d)	A – 2	B – 4	C – 3	D – 1

III. *Select your answer according to the coding system given for the Assertion A and Reason R given below in questions nos. 205 to 213.*

Assertion A

Reason R

(a) Both A and R are true and R is the correct explaination of A

(b) Both A and R are true but R is not the correct explaination of A

(c) A is true but R is false

(d) A is false but R is true

205. Assertion: In working stress method of design there is no need to check for serviceability requirement

Reason: The working stresses considered are low.

206. Assertion: I.S. code permits design of over-reinforced sections

Reason: Over-reinforced sections are not economical sections

207. Assertion: Shear reinforcement is designed for yielding.

Reason: R.C. members are to be designed for ductile failure and not for compression failure of concrete.

208. Assertion: In R.C. design, the nominal shear stress t_v should not exceed $t_{c\ \max}$ specified by code.

Reason: If t_v exceeds $t_{c\ \max}$, there will be compression. Failure of concrete instead of ductile failure of steel.

209. Assertion: For simply supported beam up to span 12 m minimum width provided is 200 mm

Reason: According to code, if width provided is 200 mm, there is no need to check for lateral stability of the beam.

210. Assertion: In column transverse reinforcements should be provided.

Reason: If transverse reinforcements are net provided column will buckle and fail.

211. Assertion: At junction B in the stairs shown Fig. Q. 211, reinforcement is not bent properly.

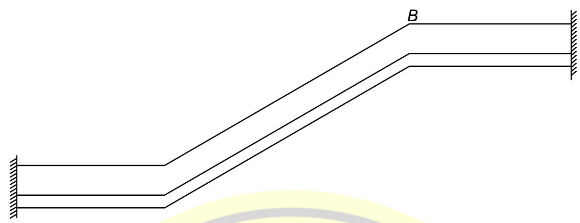


Fig. Q. 211

Reason: The resultant tension in the reinforcement will burst the concrete.

212. Assertion: The minimum thickness for topping slab in grid floors is equal to twice the cover plus the diameter of the bar.

Reason: Topping slab in grid floors are provided with reinforcement at their mid depth.

Answers to Multiple-Choice Questions

1. (c)	2. (b)	3. (a)	4. (b)	5. (c)
6. (d)	7. (b)	8. (d)	9. (a)	10. (b)
11. (b)	12. (d)	13. (b)	14. (d)	15. (d)
16. (c)	17. (c)	18. (b)	19. (d)	20. (d)
21. (d)	22. (d)	23. (a)	24. (c)	25. (b)
26. (b)	27. (a)	28. (a)	29. (c)	30. (b)
31. (d)	32. (a)	33. (d)	34. (b)	35. (a)
36. (b)	37. (d)	38. (d)	39. (b)	40. (d)
41. (a)	42. (b)	43. (a)	44. (c)	45. (d)
46. (d)	47. (b)	48. (b)	49. (d)	50. (a)
51. (a)	52. (c)	53. (a)	54. (b)	55. (b)
56. (a)	57. (c)	58. (d)	59. (a)	60. (b)
61. (c)	62. (b)	63. (a)	64. (d)	65. (c)
66. (c)	67. (b)	68. (b)	69. (b)	70. (a)
71. (c)	72. (b)	73. (b)	74. (c)	75. (c)
76. (c)	77. (b)	78. (b)	79. (a)	80. (c)
81. (a)	82. (b)	83. (b)	84. (c)	85. (d)
86. (d)	87. (b)	88. (c)	89. (a)	90. (c)
91. (b)	92. (d)	93. (c)	94. (d)	95. (b)
96. (b)	97. (a)	98. (b)	99. (a)	100. (c)

101. (b)	102. (a)	103. (b)	104. (b)	105. (b)
106. (b)	107. (c)	108. (b)	109. (d)	110. (d)
111. (c)	112. (c)	113. (d)	114. (b)	115. (c)
116. (d)	117. (d)	118. (c)	119. (d)	120. (d)
121. (c)	122. (d)	123. (c)	124. (d)	125. (c)
126. (a)	127. (b)	128. (c)	129. (c)	130. (a)
131. (c)	132. (a)	133. (c)	134. (b)	135. (d)
136. (b)	137. (d)	138. (c)	139. (d)	140. (d)
141. (b)	142. (a)	143. (a)	144. (b)	145. (c)
146. (a)	147. (a)	148. (b)	149. (a)	150. (a)
151. (b)	152. (c)	153. (a)	154. (d)	155. (a)
156. (b)	157. (d)	158. (b)	159. (a)	160. (b)
161. (d)	162. (a)	163. (c)	164. (c)	165. (a)
166. (d)	167. (c)	168. (b)	169. (b)	170. (a)
171. (d)	172. (c)	173. (d)	174. (b)	175. (b)
176. (c)	177. (d)	178. (b)	179. (d)	180. (d)
181. (c)	182. (d)	183. (b)	184. (d)	185. (a)
186. (a)	187. (c)	188. (c)	189. (b)	190. (c)
191. (a)	192. (a)	193. (a)	194. (c)	195. (a)
196. (a)	197. (b)	198. (b)	199. (b)	200. (d)
201. (b)	202. (a)	203. (b)	204. (d)	205. (a)
206. (c)	207. (a)	208. (a)	209. (a)	210. (c)
211. (a)	212. (a)			

8

Steel Structures (As Per IS 800-2007)

8.1 ADVANTAGES AND DISADVANTAGES

Advantages It has high strength per unit mass. Its quality is assured speed of construction is high. It can be strengthened at any other time, if there is need. It can be fabricated in workshop and transported to site. Material is reusable.

Disadvantages It is susceptible to corrosion. Maintenance cost is high.

Types of Steel

Structural steel – Rolled steel sections are made of such steel. It is also known as Fe-410 or E-250 steel. Fe – 410 – Cu – S means copper bearing steel with ultimate tensile strength of 410 MPa. Weldable quality steel Fe 540 (E 410), Fe - 570 (E 450) and Fe 590 (E 450) steel are also available.

Properties of Steel

Irrespective of its grade physical properties of steel may be taken as given below:

Unit mass $r = 7850$ kg/m^3

$$E = 2 \times 10^5 \text{ N/mm}^2$$
$$m = 0.3$$
$$G = 0.769 \times 10^5 \text{ N/mm}^2$$
$$a = 10 \times 10^{-6}/°\text{C}$$

Rolled Steel Sections

Rolled steel sections are available in the form of I–sections, channel sections, angle sections, T–sections, bars, tubes, plates, flats and strips.

Various types of sections and their properties may be seen in steel tables.

Considerations in Steel Design

It involves

1. Selecting suitable size and shape
2. Avoiding buckling
3. Providing minimum thicknesses
4. Detailing and designing connections

Loads

1. Dead loads
2. Imposed loads which include live load, crane load, snow load, dust load, impact loads

horizontal loads on parapets, hydrostatic and earth pressure.

3. Wind loads
4. Earthquake loads
5. Erection loads
6. Accidental loads
7. Secondary effects

IS 875 may be referred to get magnitude of loads

Methods of Design

IS 800–2007 suggests use of limit state design widely and restricts working stress method only wherever limit state design cannot be applied.

8.2 PRINCIPLE OF LIMIT STATE DESIGN

Design Requirements

1. Structure should remain fit with adequate reliability during its lifetime.
2. Should have adequate durability under normal maintenance.
3. Should not suffer overall damage or collapse disproportionately under accidents.

To achieve all the above it is not enough if the members are designed to take the expected internal forces for load transfer. It is necessary that all structural elements are suitably connected and anchored.

Limit States

* The major categories of limit states are limit state of strength and limit state of serviceability.

* ***Characteristic actions*** It is defined as the values of different actions which are not expected to be exceeded with more than 5 per cent probability, during the life of the structure. In the absence of statistical analysis, the loads presented in IS 875 and other codes may be considered as characteristic actions.

* ***Design Actions (Loads)*** To take care of uncertainties involved in analysis, design and construction, code specifies taking design actions as partial safety factor times the characteristic actions. Table 4 of IS 800–2007 gives partial safety factor g_f for limit state.

* ***Design strength*** To take care of manufacturing defects, IS 800–2007 recommends reduction in the strength of material by a partial safety factor g_m, where

$$g_m = \frac{S_u}{S_d}$$

where S_u = ultimate strength and

S_d = Design strength

These values are given in Table 5 of IS. 800–2007.

* ***Deflection Limits***

• Deflection limits are specified with the consideration that excess deformations do not cause damage to finishing. Deflections are to be checked to adverse but realistic combinations of service loads.

• Table No. 6 of IS 800–2007 gives deflection limits.

Fire Resistance Fire resistance level is specified in terms of minutes depending upon the purpose for which the structure is used and the line taken to evacuate in case of fire. For detailed specifications refer to section 16 of IS. 800–2007.

8.3 BOLTED CONNECTIONS

* Riveted connections were made by inserting ductile metal pins called red hot rivets into holes and hammering to form heads. Rivet hole diameter is 1.5 to 2.0 mm larger than rivets and after forming the connection it is assumed that rivet fills the hole completely and hence effective diameter is 1.5 to 2.0 mm more than nominal diameter. After weldable quality steel is introduced and high strength friction grip bolts are developed riveting is given up.

* Bolted connections are preferred for making connections at site.

* Bolts are classified as

1. Unfinished (black) bolts
2. Finish (turned) bolts
3. High strength friction grip (HSFG) bolts

1. Unfinished Bolts The shank is unfinished, i.e., it is rough as rolled. These bolts are designated as M 16, M 20, M 24, etc., in which the number indicates diameter of bolts. The yield strength of commonly used bolts is 240 N/mm^2 and ultimate strength 400 N/mm^2.

2. Finished Bolts These bolts are formed from hexagonal rods, which are finished by turning to a circular shape. Actual dimensions of these bolts are 1.2 mm to 1.3 mm larger than nominal diameter. Bolt hole is kept 1.5 mm larger than nominal diameters. These bolts are used in special jobs like connecting machine parts subjected to dynamic loading. Black bolts and turned bolts are also known as bearing type bolts.

3. HSFG Bolts Instead of mild steel, for these bolts high strength steel rods are used. These bolts are tensioned using calibrated wrenches and then bolts are tightened. As a result of it bolts exert high pressure on plates connected and friction grip is achieved. Bolts are subjected to shear, only after friction grip force is exceeded. Commonly available nominal diameter HSFG bolts are 16, 20, 24, 30 and 36 mm.

* Advantages of bolted connections:

1. Easy to make connections, even with ordinary labour.
2. Making joints is noiseless and quick.
3. Accommodates minor discrepancies in dimensions.
4. Alteration, if any can be easily done.

* Disadvantages of bolted connection

1. Strength is reduced considerably due to reduction of area and stress concentrations at the root of threads.

2. Joints are not very rigid.

3. Due to vibrations nuts are likely to loosen.

* Terminology

1. Pitch of the bolts (p) It is centre-to-centre spacing of bolts in a row, measured along the direction of load.

2. Gauge distance (g) It is the distance between the two consecutive bolts of adjacent rows and is measured at right angles to the direction of load.

3. Edge distance (e) It is the distance of centre of bolt hole from the adjacent edge of plate.

4. End distance (e) It is the distance of the nearest bolt hole from the end of the plate.

5. Staggered distance (P_s) It is the centre-to-centre distance of staggered bolts measured obliquely.

* Specifications for spacing and edge distances of bolt holes.

1. Pitch p shall not be less than 2.5 d
2. Pitch p shall not be more than
   (a) 16 t or 200 mm, whichever is less, in tension members
   (b) 12 t or 200 mm, whichever is less, is case of comp. members.
   (c) In case of staggered pitch, pitch may be increased by 50% provided gauge distance is less than 75 mm.
3. In case of butt joints maximum pitch is to be restricted to 4.5 d for a distance of 1.5 times the width of plate, from the butting surface.
4. The gauge length g should not be more than 100 + 4 t or 200 mm whichever is less.
5. Minimum edge distance shall not be
   (a) less than 1.7 × hole diameter in case of hand flame cut edges.
   (b) less than 1.5 × hole diameter in case of rolled machine flame cut, sawn and planed edges.
6. Minimum edge distance should not exceed
   (a) 12 t e where e = $\sqrt{\frac{250}{f_y}}$
   (b) 40 + 4 t, if exposed to corrosive influences.
7. In case of a member made up of two flats, or angles or tees or channels, tacking rivets/bolts are to be provided along the length:
   (a) not exceeding 1000 mm, if it is tension member
   (b) not exceeding 600 mm, if it is compression member.

Design of Bolted Connections

* Assumption in design of bearing bolted connections:

1. The friction between the plates is negligible.
2. Shear is uniform over the cross section of the bolt
3. The stress distribution between bolt holes is uniform
4. Bolts in a group subjected to direct loads share the load equally.

* Principles observed in design:
   1. The centre of gravity of bolts should coincide with the centre of gravity of connected members.
   2. The length to connection should be as small as possible.
* Design tensile strength of a joint is least of the following:

1. Tensile strength of plate

$$T_{dn} = \frac{0.9 A_n f_u}{\gamma_{mc}}$$

where g_{mc} = partial safety factor = 1.25

f_u = ultimate stress

A_n = net area of the plate

$$= \left[b - nd_o + \sum \frac{P_{s_i}^2}{ng_i} \right] t$$

where h = width of plate

t = thickness of thinner plate

d_o = diameter of bolt hole

g = gauge length

P_s = staggered pitch

n = number of bolt holes at critical section

2. Shear capacity of bolts

$$V_{dsb} = \frac{V_{nsb}}{\gamma_{mb}} = \frac{1}{r_{mb}} \times \frac{f_{ub}}{\sqrt{3}} (n_n A_{nb} + n_s A_{sh})$$

where f_{ub} = ultimate tensile strength of bolt

n_n = number of shear planes with threads

n_s = number of shear planes with threads intercepting shear planes (in shank)

A_{sb} = nominal shank area of the bolts

A_{nb} = net area of the bolt at threads

$= \frac{\pi}{4}(d - 0.9382\,p)^2$, where p = pitch of thread

$= 0.78\ \frac{\pi}{4} d^2$ for ISO threads.

Reduction factors for shear strength:

(a) For long joints: If the distance between first and least bolt exceed 15 d, the reduction factor

$$b_{lj} = 1.075 - 0.005 \frac{l_i}{d}$$

Subjected to 0.75 £ b_{ij} £ 1.0

(b) Reduction factor, if grip length is larger, i.e., total thickness for connected plates is more than 5 d

$$blg = \frac{8d}{3d + l_g}$$

(c) Reduction factor if packing plates used are more than 6 mm thick:

$$b_{pk} = 1 - 0.0125\ t_{pk}$$

where t_{pk} = thickness of thicker packing in mm

Thus, the bearing capacity of the bolts in shear is $\frac{f_u}{\sqrt{3}}(n_u\ A_{snb} + n_s\ A_{sb})\ \beta_{ij}\ \beta_{lg}\ \beta_{pk}$

3. Bearing capacity of bolts

$$V_{dpb} = \frac{V_{npf}}{\gamma_{mb}} = \frac{2.5\, k_b\, dt\, f_u}{\gamma_{mb}}$$

where g_{mb} = partial safety factor of material = 1.25

and k_b is smaller of $\frac{e}{3d_o}, \frac{p}{3d_o} - 0.25, \frac{f_{ub}}{f_u}, 1.0$

where e = end distance

p = pitch distance

d_o = diameter of hole

d = nominal diameter of bolt

t = thickness of the connected plates experiencing bearing stress in the same direction.

Nominal diameter of bolts (d):	12	14	16	20	22	24	30	36
Diameter of bolt hole:	13	15	18	22	24	26	33	39

* Efficiency of Joint :

$$h = \frac{\text{Strength of joint}}{\text{Strength of solid plate}} \times 100$$

where strength of solid plate = $\frac{f_y}{1.1} \times b \times t$

Eccentric Connection

(a) Line of action of load is in the plane of group of bolts

Direct shear $F_1 = \frac{p}{n}$

Due to bending $F_2 = \frac{p \cdot e \cdot r_i}{\Sigma r_1^2}$

If F_2 acts at q to line joining CG of bolts and the point,

\ $F = \sqrt{F_1^2 + F_2^2 + 2F_1 F_2 \cos\theta}$

This value should be within the limit.

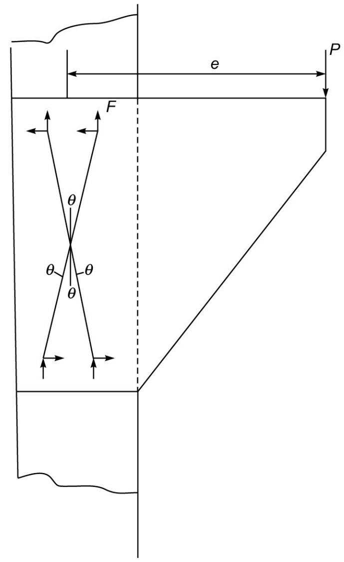


Fig. 8.1 Line of action of load in the plane of group of bolts

(b) **Load causing moment in the plane perpendicular to the plane of group of bolts**

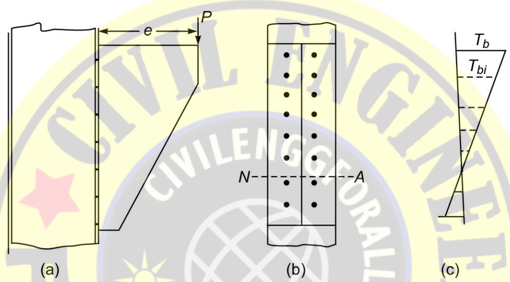


Fig. 8.2 Load causing moment in the plane perpendicular to the plane of group of bolt

On compression side the connecting angle assists in transferring load to column while on tension side only bolts have to resist. Hence, $N - A$ is assumed at a distance $\frac{1}{7}$ th depth of the bracket.

\ Total moment resisted by bolts on tension side

$$M' = \frac{M}{\left[1 + \frac{2h}{2l}\frac{\Sigma y_i}{\Sigma y_i^2}\right]}$$

\ Tensile force in a bolt at distance y_i from CG of bolts

$$T_{bi} = \frac{M' y_i}{\Sigma y_i^2}$$

Design requirement for bolts in combined action of shear and moment is

$$\left(\frac{V_{sb}}{V_{ab}}\right)^2 + \left(\frac{T_b}{T_{dh}}\right)^2 \leq 1$$

* If bolts are to be provided in 2 vertical rows, number of bolts in each row required is

$$n = \sqrt{\frac{6M}{(2V)p}}$$

where M at joint and V is design shear strength of bolt and p is pitch.

Try the above number and check with interaction formula.

HSFG Bolts

Nominal shear capacity of HSFG bolts

$$V_{nsf} = m_f \, n_e \, k_h \, F_o$$

where m_f = coefficient of friction, as given in Table 20 in is 800–2007 for different surfaces.

n_e = number of effective interfaces offering frictional resistance to the slip

(n_e = 1 for lap joint, 2 for double cover butt joint)

k_h = 1.0 for fasteners in clearance holes.

= 0.85 for fasteners in oversized and short slotted holes and long slotted holes loaded perpendicular to the slot

= 0.70 for fasteners in long slotted holes parallel to the slot

$$F_o = A_{nb} \, F_o$$

where A_{nb} = net area of the bolt in threads

= 0.78 $\frac{\pi}{4} d^2$

and f_o = proof stress = 0.70 f_{ub}

$$\text{Slip resistance } V_{sf} = \frac{V_{nsf}}{\gamma_{mf}}$$

in which g_{mf} = 1.10, if slip resistance is designed at service load

= 1.25 if designed at ultimate load

Tension capacity of HSFG bolts

$$T_{nf} = 0.9 \, f_{ub} \, A_n \, £ \, f_{yb} \, A_{sb} \, \frac{\gamma_{mb}}{\gamma_{mo}}$$

Hence, $T_{af} = \frac{0.9 \, f_{ub} \, A_n}{\gamma_{mb}} \leq f_{yp} \frac{A_{sh}}{\gamma_{no}}$

$$g_{mb} = 1.25, \; g_{mo} = 1.1$$

f_{ub} for holts of grade 8.8 i.e., 800 MPa

$$\text{and } f_{yh} = 640 \text{ MPa}$$

* Interaction formula for combined shear and tension

$$\left(\frac{V_{sf}}{V_{df}}\right)^2 + \left(\frac{T_f}{T_{df}}\right)^2 \leq 1.0$$

Prying Forces

* If HSFG bolts are used, additional forces develop at connected point due to the flexibility of connected plates.

$$q = \frac{l_v}{2l_c}\left[T_e - \frac{\beta\eta f_o b_e t^4}{27 l_c l_v^2}\right]$$

where l_v = distance from bolt centre line to the toe of the fillet weld or half the root radius for rolled sections.

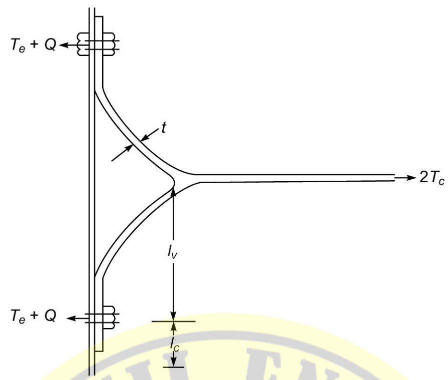


Fig. 8.3 Prying forces Q

l_c = distance between the prying forces and bolt centre line is the minimum of either the end distance on the value given by

$$l_c = 1.1t\sqrt{\frac{\beta f_o}{f_y}}$$

where b = 2 for non-pre-tensioned bolts and 1 for pre-tensioned bolts

h = 1.5, be = effective width of flange per pair of bolts

f_o = proof stress, t = thickness of end plate.

8.4 WELDED CONNECTIONS

Advantages

1. Welded structures are lighter due to absence of gusset plates, connecting angle, etc.
2. Absence of making holes for bolts, etc.
3. More adoptable and 100% efficiency can be achieved
4. Good aesthetic appearance
5. Less noise
6. Alterations in connections can be easily made
7. No problem of mismatching of holes.

Disadvantages

1. Needs skilled workers
2. Not good to resist fatigue stresses
3. Likely to get distorted due to uneven heating and cooling

4. Inspection of joints is difficult and expensive
5. Proper welding in the field is difficult

Types of Welded Joints

* ***Butt welds*** Square, *V*, *U*, *J* welds, may be single or double.

* ***Fillet welds*** Approximately triangular connections when the cross section of fillet weld is isoceles triangle with face at 45°, it is known as a standard fillet weld. In this case $t = \frac{s}{\sqrt{2}} = 0.7s$ where s is size and t is throat thickness.

* ***Slot weld and plug weld*** To make slot weld a circular hole is made in one plate, kept on another plate and fillet welding is made along the periphery of the hole.

Plug weld is made by making small holes in one of the plates to be connected, and then weld material is filled in the holes after keeping the plate on the other plate to be connected.

Important Specifications for Welding

Butt weld It is specified by throat thickness

1. In case of double *U*, double *V*, double *J* and double level butt welds, the thickness of weld, is taken as complete penetration of butt weld and hence it is equal to the thickness of thinner plate
2. In case of single *U*, single *V*, single *J* and single level, it is taken as $\frac{5}{8}$ × thickness of thinner plate connected.
3. Minimum weld length shall be 4 × the size of weld.
4. If intermittent butt welding is used, it shall have an effective length of not less than 4 × the weld size and space between the consecutive weld shall not be more than 16 times the thickness of thinner plate joined.

Fillet Weld

1. The size of normal fillet weld shall be taken as the minimum leg size.
2. Minimum size of s, specified are:

For less than 3 mm plates	3 mm
For 10 to 20 mm plates	5 mm
For 20 to 32 mm plates	6 mm
For 32 to 50 mm plates	8 mm

3. Effective throat thickness shall be ks where s is size and k is constant, depending upon angle between fusion faces as given below

Angle of fusion face	60° – 90°	91° – 100°	101° – 106°	107° – 10°	114° to 120°
k	0.7	0.65	0.60	0.55	0.5

4. In the drawing only effective lengths are shown. It is to be noted that actual length shall be equal to the effective length + twice the size of weld.
5. Lap joint shall be a minimum of 4 times the thickness of thinner member or 40 mm which-ever is more.
6. If intermittent weld is used it shall not be less than 4 times the weld size or 40 mm whichever is more.

Plug weld The effective area of a plug weld shall be considered the nominal area of the hole.

**** Design stresses***

1. In butt weld, same as that in parent metal.
2. In fillet, slot or plug welds $f_{wd} = \frac{f_u}{\sqrt{3}\gamma_{mw}}$

where f_u = smaller of ultimate stress in weld or of the parent metal

g_{mw} = 1.25 for shop welds

= 1.5 for field welds

The following provisions are made in the code :

(i) If fillet weld is to the square edge,

$$\text{max size} = t - 1.5 \text{ mm}$$

(ii) If fillet weld is to the rounded toe of rolled section

$$s = \frac{3}{4} \times \text{thickness of section at toe}$$

(iii) Reduction in design stresses for long joints:

If the length of welded joint l_j, is greater than 150 t, where t is throat thickness, the design capacity of weld f_{wd} shall be reduced by the factor

$$B_{lw} = 1.2 - \frac{0.2 l_j}{150 t} \leq 1.0$$

(iv) Combined axial and shear stress

The equivalent stress f_e shall satisfy the following:

$$f_e = \sqrt{f_a^2 + 3q^2} \leq \frac{f_u}{\sqrt{3}\gamma_{mw}}$$

where f_a = axial stress

q = shear stress

\ If eccentric connection gives rise to moment at right angle to the plane of weld.

Direct shear stress

$$q = \frac{P}{2ht}$$

Bending stress

$$f = \frac{6Pe}{2th^2}$$

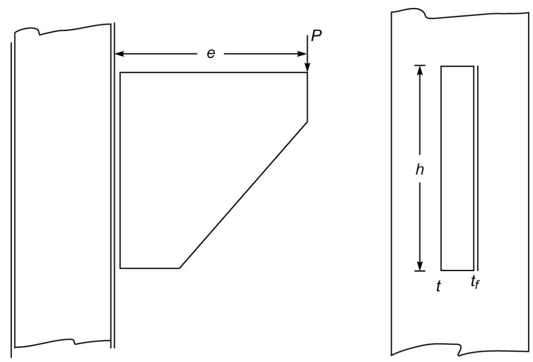


Fig. 8.4 Combined axial and shear stresses on welds

Take trial depth take $h = 1.1\ h¢$ where

$$h¢ = \sqrt{\frac{6M}{2t\, f_{wd}}}$$

8.5 DESIGN OF TENSION MEMBER

* The section should be compact and in order to minimize stress concentration, it should be so arranged that as large portion of it as possible is connected to the gusset plate.

* Design strength is the lowest of the following:

1. Design strength due to yielding of gross section T_{dg}.
2. Rupture strength at critical section T_{dn}
3. The block shear T_{dh}

1. Design strength due to yielding of gross area:

$$T_{dg} = \frac{A_g\, f_y}{\gamma_{mo}}$$

2. Design strength due to rupture of critical section

$$T_{dn} = \frac{0.9\, A_g\, f_y}{\gamma_{ml}}$$

where $A_n = \left[b - nd_o + \Sigma \frac{p_{s_i}^2}{4\, g_i}\right] t$

For threaded rods and bolts, $A_n = \frac{0.9\, A_u\, f_u}{\gamma_{ml}}$

3. Design strength due to block shear

$$T_{db} = \frac{A_{vg}\, f_y}{\sqrt{3}\,\gamma_{mo}} + \frac{0.9\, A_{tn}\, f_u}{\gamma_{ml}}$$

or $T_{db} = \frac{0.9\, A_{vn}\, f_u}{\sqrt{3}\,\gamma_{mf}} + \frac{A_{tg}\, f_g}{\gamma_{mo}}$, whichever is smaller

where A_{vg} and A_{vn} = Minimum gross and net area in shear

and A_{tg} and A_{tn} = minimum gross and net area in tension

* Design procedure:

1. Find $A_g = \frac{1.1T_u}{f_y}$ where T_u = factored tensile force
2. Take A = 25 to 40 % more than A_g.
3. Select the section, design the connection and find the strength.
4. Redesign, if strength is less or too much higher compared to the load.
5. Check for slenderness ratio which should be within the limits specified in Table 3 of IS 800–2007.

Tension member splices

* Strength of splice plate and joint should be at least equal to the design load.

* If packing thickness in connection exceeds 6 mm, the design shear capacity of bolts in shear should be reduced by a factor

$$b_{pk} = 1 - 0.0125\, t_{pk}.$$

Lug Angles

* Length of end connection of a heavily loaded tension member may be reduced by using lug angles.

* Use of lug angle may reduce the size of gusset plate, but it adds to the cost of connection.

8.6 DESIGN OF COMPRESSION MEMBERS

1. Determine slenderness ratio of the member. If end conditions can be assessed, refer Table 11 in IS code to get effective length. In case of bolted, riveted or welded trusses effective length shall be taken as 0.7 L to 1.0 L where L is the actual length, depending upon the degree of end restraint provided.
2. Various shapes of cross section are divided into buckling classes a, b, c and d for which Table 10 in IS 800–2007 may be referred.
3. Find imperfection factor a which is 0.21, 0.34, 0.49 and 0.76 for buckling class a, b, c and d respectively.
4. Then, design compressive stress f_{cd} of axial loaded column is given by

$$f_{cd} = \frac{f_y/\gamma_{mo}}{\phi + (\phi^2 - \gamma^2)^{0.5}} \le \frac{f_y}{\gamma_{mo}}$$

where $a = 0.5\,[1 + a\,(l - 0.2) + l^2]$

and l = non-dimensional effective slanderners ratio

$$= \sqrt{\frac{f_y\left(\frac{KL}{r}\right)^2}{\pi^2 E}}$$

KL = Effective length

5. One can refer to Table No. 9 in IS 800–2007 also and use f_{cd} straightaway.

Design of Laced Columns

1. Lacing may be single or double.

2. Thickness of flats for lacing shall not be less than $\frac{1}{40}$th of its effective length for single lacing and $\frac{1}{16}$th of the effective length for double lacing.

3. Lacing bars shall be at 40° to 70° to the axis of column.

4. The distance between the two members should be such that $r_{yy} > r_{xx}$.

5. Lacing shall be designed to resist shear V_t = 2.5 % of axial load in columns.

6. Effective length of laced column shall be taken as 1.05 times the actual maximum slenderness ratio.

7. Effective length of single laced column = L and that of double laced column = 0.7 L, where L is actual length.

8. The slenderness ratio of lacing bars should not exceed 145.

Design of Battened Column

1. The number of battens should be such that the member is divided into not less than three bays.

2. r_{yy} should be more than r_{xx}.

3. Effective slenderness ratio = 1.1 × Actual slenderness ratio.

4. Battens shall be designed to carry moments and shear forces arising from transverse shear force V_t = 2.5% of axial load.

5. The effective depth of end battens shall not be less than the distance between the centroids of main members.

6. The effective depth of intermediate battens shall not be less than 3/4 th of the above distance.

7. Thickness of battens shall not be less than $\frac{1}{50}$th of the distance between the innermost connecting lines of rivets/bolts/welds.

8.7 COLUMN SPLICE

* Ideal place for splicing in multistorey frames is at the point of inflection which is usually at 150 to 300 mm from the floor line.

* If ends are not milled, the joint is designed to transmit all forces. If ends are milled connection may be designed for 50% of axial load.

* Types of column splices:
  1. When the column are of the same size, milled ends are provided.
  2. When the columns are of slightly different sizes, filler plates are used.
  3. When the columns are of considerably different sizes, bearing plates are used.

Column Bases

Two types, 1. Slab base 2. Gussetted base

1. Slab-base If the load carried by column is not much, the column is directly connected to the base plate through cleat angles

Design procedure is:

(i) Bearing strength of concrete pedestal = 0.45 f_{ck}

(ii) Area of base plate required

$$= \frac{P_u}{0.45\, f_{ck}}$$

(iii) Select size of the base plate. As far as possible the projection in x and y directions should be the same.

(iv) Find intensity of pressure

$$w = \frac{P_u}{\text{Area of base plate}}$$

(v) Thickness required

$$t_s = \left[\frac{2.5w(a^2 - 0.36^2)\gamma_{mo}}{f_y}\right]^{0.5} > t_f$$

where t_f = thickness of flange

Connection: Use 2 ISA 6565, 6 mm for connecting column to base plate. Use four 20 mm dia. and 300 mm anchor bolts to connect base plate to concrete foundation.

2. Gussetted Base For columns carrying heavy loads gussetted bases are used. In this case the column is connected to the base through gussets, which transfers the load to the base party through bearing and partly through gussets. Design procedure is as follows:

(i) Area of base plate = $\frac{\text{Factored load}}{0.45\, f_{ck}}$

(ii) Assume various members of gusseted base

(a) Thickness of gusset plate = 16 mm

(b) Size of the gusset angle selected is such that the leg connected to column should accommodate two bolts in one vertical line and the other leg should accommodate one bolt in a row, say ISA 150 115, 15 mm thick.

(c) Width of gusset base is kept such that it will just project outside the gusset angle and hence length = $\frac{\text{Area of plate}}{\text{Width}}$

(d) When the end of the column is machined for complete bearing on the base plate, 50% of the total load is assumed to be transformed by the bearing and 50 per cent by fastening.

(e) The thickness of the base plate is computed by flexural strength at the critical sections.

8.8 DESIGN OF BEAMS

* Plastic neutral axis divides the cross section into two equal areas.

* When plastic hinge is formed at all fibres at the section all fibres are having yield stress, with opposite nature on either side of $N–A$

* $Z_p = \frac{1}{4} bt^2$, for rectangular sections.

* The sections are classified as class 1 (plastic), class 2 (compact) and class (3 semi-compact) classification of various sections into class 1 to class 3 may be found in Table 2 of IS 800–2007.

Design procedure

1. Select a trial section assuming it is going to be plastic section.
2. Find the class to which it belongs.
3. Check for bending strength, shear strength and deflection. Revise the section if necessary.

Bending strength

If $\frac{d}{tw} < 67\varepsilon$, two cases

(a) If V £ 0 .6 V_d

$$M_d = b_b f_y \times \frac{1}{\gamma_{mo}} \leq 1.2\, z_e f_y \times \frac{1}{\gamma_{mo}} \text{ for simply supported beams}$$

$$= \beta_b z_p f_y \frac{1}{\gamma_{mo}} \leq 1.5\, z_e \frac{f_y}{\gamma_{mo}} \text{ for cantilever beam}$$

where b_b = 1.0 for plastic and compact sections

$$= \frac{z_e}{z_p} \text{ for semi-compact sections}$$

(b) If $V > 0.6\ V_d$

(i) Plastic or compact sections

$$M_{dv} = M_d - \beta (M_d - M_{fd}) \leq 1.2\, z_e f_y \frac{1}{\gamma_{mo}}$$

where $b = \left(\frac{2V}{V_d} - 1\right)^2$

M_d = Plastic design moment of the whole section

M_{fd} = plastic design strength of the area of the cross section excluding the shear area considering partial safety factor g_{mo}

(ii) Semi-compact section:

$$M_{dv} = \frac{z_e f_y}{\gamma_{mo}}$$

Shear strength of a laterally supposed beams:

$$V_d = \frac{A_v f_{yw}}{\sqrt{3}} \times \frac{1}{\gamma_{mo}}$$

where A_v = shear area f_{yw} = yield strength of web. Shear area is given by

(i) I and channel sections:

Major axis bending: Hot rolled, $A_v = h\, t_w$

Welded, $A_v = d\, t_w$

Minor axis bending $A_v = 2b\, t_f$

(ii) Rectangular hollow sections:

Loaded parallel to depth: $A_v = \frac{A+h}{b+h}$

Loaded parallel to width $A_v = \frac{Ab}{b+h}$

(iii) Circular: Hollow tubes $A_v = \frac{2A}{\pi}$

(iv) Solid bars and plates $A_v = A$

Deflection limits: Refer Table 6 in IS 800–2007.

Web Buckling Strength Certain portion of beam at support acts as a column to transfer the load from beam to support and hence there is a chance for buckling of web. In this case dispersion angle of beam may be taken as 45°. There is no need to check it for rolled section since the web thickness are sufficient to avoid such buckling failures web buckling strength is given by

$f_{cdw} = (b_1 + n_1)\, t_w f_c$

where b_1 = width of stiff bearing on the flange

$n = \frac{h}{2}$ which h is the depth of section

f_c = allowable compressive strength ratio corresponding to slenderness ratio

$$= 2.5\, \frac{d}{t_w}$$

Web crippling Near the support web of the beam may cripple due to lack to bearing capacity. Crippling occurs at the root of the radius.

$$F_w = (b_1 + n_2)\, t_w \frac{f_{yw}}{\gamma_{mo}}$$

where b_1 = stiff bearing length

n_c = length obtained by assuring dispersion at a slope 1 in 2.5

f_{yw} = yield strength of the web

* IS Table No. 15 gives effective length for simple beams with different end conditions.

Design of Purlins

* The effective length may be taken as centre-to-centre distance between the supports.

* Bending moment

$$M = \frac{WL^2}{8} \text{ in case of simply supported beams}$$

$= \frac{WL^2}{10}$ in case of continuous purlins.

* Design procedure:

1. Resolve factored forces parallel and perpendicular to sheeting
2. Find moment and shear forces about $z-z$ and $y-y$ axis.
3. Z_{pz} required $= \frac{M_z}{fy}\gamma_{mo} + 2.5\frac{d}{b}\frac{M_y}{f_y}\, g_{mo}$

where $g_{mo} = 1.1$

4. Check for shear capacity

$$V_{dz} = \frac{f_y}{\sqrt{3}} \times \frac{1}{\gamma_{mo}} \times A_{Vz}$$

$$V_{dy} = \frac{fy}{\sqrt{3}} \times \frac{1}{\gamma_{mo}} \times A_{Vy}$$

where $A_{Vz} = h\, t_w$ and $A_{vy} = 2b_f\, t_f$

5. Compute the design capacity of the section in both axes.

$$M_{dz} = \frac{Z_{pz}\, f_y}{\gamma_{mo}} \le 1.2\, Z_{ey}\frac{f_y}{\gamma_{mo}}$$

$$M_{dy} = \frac{Z_{Py}}{\gamma_{mo}} \times f_y \le 1.5\, Z_{ey}\frac{f_y}{\gamma_{mo}}$$

6. The condition to be satisfied is

$$\frac{M_z}{M_{dz}} + \frac{M_y}{M_{dy}} \le 1.0$$

7. Check for deflection. Simplified method of design of purlins: It assumes that the load normal to sheeting is resisted by purlin and the load parallel to sheeting is resisted by sheeting, if

   1. Roof slope is less than 30°
   2. Width of angle leg perpendicular to sheeting $\ge \frac{L}{45}$
   3. Width to angle leg parallel to sheeting $\ge \frac{L}{60}$

In such case bending moment about $z-z$ axis should be taken as $\frac{W_z L}{10}$ and there is need to check for deflection.

Design of Bolted Beam Connections

Connection may be

1. Simple connection/flexible connection
2. Moment resistant/rigid connection.

1. Flexible Connection Types

(a) Framed connection

(b) Unstiffened seated connection

(c) Stiffened seated connection.

(a) Framed connection If the shear to be transferred is less, the beam may be connected to the main beam or column using cleat angles only.

(b) Unstiffened seated connection If shear force is larger the depth of cleat angle required for framed connection may become more than the depth of beam to be connected. In such case seat angle is connected to column over which beam rests. At top nominal cleat angles are provided.

(c) Stiffened seated connection If the shear to be transferred is still larger seat angles are stiffened with angles.

2. Rigid/Moment Resistant Connection If moment to be transferred is small clip angle or split beam connection may be made. If moment to be transferred is large, bracket connection may be used.

Design of Welded Beam Connections

For flexible connection framed connection, unstiffened seated connection or stiffened seated connections can be used.
For rigid/moment resistant connections, double plated framed connections or double angle framed connections may be used.

Design of Plate Girders

* Plate girder is a built up I-section beam with two flange plates connected to a web plate of required depth.

* A plate girders need stiffeners to avoid buckling of web. Types of stiffeners used are:

(a) Transverse (vertical stiffeners)

(i) Bearing stiffeners

(ii) Intermediate stiffeners.

(b) Longitudinal (horizontal) Stiffeners

* If only one horizontal stiffener is provided, it will be at a depth $0.2d$ from compression flange. If another horizontal stiffener is to be provided it will be at mid-depth of web.

* Self-weight of plate girder:

$$w = \frac{W}{200} \text{ kN/m}$$

where w = factored self-weight

W = total factored load on the girder.

* Economical depth: It is given by

$$d = \left(\frac{Mk}{f_y}\right)^{\frac{1}{3}}$$

where $k = \frac{d}{t_w}$, M = factored maximum moment and f_y = yield strength.

* Another practical guideline for selecting depth of plate girder is

$$\frac{D}{L} = \frac{1}{15} \text{ to } \frac{1}{25} \text{ for girders in building}$$

$$= \frac{1}{12} \text{ to } \frac{1}{18} \text{ for highway bridges}$$

$$= \frac{1}{10} \text{ to } \frac{1}{15} \text{ for railway bridges.}$$

* Flange thickness may be found by assuming that only flanges resist moment. Hence,

$$\frac{A_f f_y d}{1.1} = M$$

To keep the section semi-compact $\frac{b}{t_f}$ should be 9.4 e to 13.6 e where $e = \sqrt{250/f_y}$

Hence, minimum is found from

$$13.6\, t\, t_f^2 = A_f$$

* If $\frac{d}{t_w}$ £ 67 e, design as ordinary beam

  If $\frac{d}{t_w} \geq 67\, e$, provide stiffeners.

* Shear buckling strength may be found by simple post-critical method or tension field method.

* End panel may be provided with a single stiffener at the end or with double stiffeners.

* Buckling resistance of stiffeners is found taking effective section is full area or core area of the stiffener together with an effective length of 20 t_w of web on each side.

Design of Gantry Girders

* Gantry girders support a travelling bridge girder provided with crane and a control cabin. They are commonly used in factories for moving heavy loads within the factory.

* The following imposed loads should be considered in the design:
  1. Vertical load from crane.
  2. Impact load from crane.
  3. Longitudinal horizontal force along the crane rail.
  4. Lateral thrust across the crane rail.

* Position of crane hook for maximum shear on gantry girder should be considered.

* On gantry girder the position of crane girder for maximum shear and bending moment should be considered.

* The ideal profile for gantry girder is a I-section strengthened with a channel section on compression flange. If necessary additional flange plates also may be used.

* Limitations on vertical deflections are as shown in Table 8.1.

Table 8.1 Limitations on deflections of gantry girders

Category	*Max. deflection*
Vertical deflection:	
(a) Manually operated cranes	$L/500$
(b) Electrically operated cranes upto 500 kN	$L/750$
(c) Electrically operated cranes over 500 KN	$L/1000$
Lateral deflection	$L/400$

Design of Roof Trusses

*** *Roof trusses are supported on walls or a series of columns***

* ***Bracings*** In the end panel of roof level bracings are to be provided using ISA 9060, 8 mm. Diagonal bracings are provided in the last but one panel at bottom chord level. For very long buildings additional diagonal bracings are provided at every 4 to 5 days.

*** *Members of Trusses***

1. Top chord members
2. Bottom chord members
3. Struts: Compression members not belonging to top or bottom chords
4. Slings: Tension members not belonging to top or bottom chord.
5. Sag tie: Member subjected to zero forces but provided to reduce sag of bottom chord member.

*** *Pitch of truss***

1. Minimum pitch for GI sheeting = $\frac{1}{6}$.
2. Minimum pitch for A.C. sheeting = $\frac{1}{12}$.
3. Preferable pitches: $\frac{1}{4}$, if snow load is expected $\frac{1}{6}$, if snow is not expected

*** *Spacing***

(a) 3 to 4.5 m upto 15 m span

(b) 4.5 to 6.0 m for 15 to 30 m span

(c) More than 40 m span, spacing of 12 to 15 m may be used with cross trusses replacing purlins.

*** *Purlins***

1. As far as possible should be located on panel joints of top chord members.
2. Angle iron purlins if spacing is 3 to 4 m.
3. Channels if spacing is 4 to 5 m.

4. For still larger spans use I-sections

**** If angles are used outstanding legs should be at top***

**** Sheetings*** 1 G.I. sheets

1. *Common size*

(i) 8 corrugation, 75 mm wide and 19 mm deep, overall width 660 mm

(ii) 10 corrugations, 75 mm wide and 19 mm deep, overall width 810 mm

2. *Gauges* 16, 18, 20, 22 and 25

3. *Lengths* 1.8 m, 2.2 m, 2.5 m, 2.8 m, and 3.0 m

4. *Overlaps* 1, $1\frac{1}{2}$ or 2 corrugations

5. *End laps* 100 mm, if slope is more and 150 mm, if slope is less than 20°.

6 *Hooks* 8 mm dia at a maximum pitch of 350 mm.

**** A.C. sheets***

Shapes Corrugated or trafford

Lengths 1.75 m, 2.0 m, 2.5 m and 30 m

Thickness 6 mm or 7 mm

Maximum permissible spacing 1.4 m for 6 mm sheets and 1.6 m for 7 mm sheets

Overlap Longitudinal 150 mm

Side One corrugation

End Bearings

1. One end fixed or hinged. This is achieved by anchor bolt holes of circular shape.

2. Sliding end bearing is achieved by providing oval shaped holes for anchor bolts.

3. Foundation bolts embedded in concrete are used for anchoring.

MULTIPLE-CHOICE QUESTIONS

I. *Choose the correct options given in questions nos 1 to 157.*

1. The advantage of steel structure is
   (a) needs less space
   (b) quality is assured
   (c) speed of construction is high
   (d) all the above

2. Weldability of steel is enhanced by alloying it with ______.
   (a) carbon
   (b) sulphur
   (c) chrome
   (d) nickel

3. Irrespective of grade, the following properties of steel are same

(a) unit weight
(b) modules of elasticity
(c) Poisson's ratio
(d) all the above

4. The lightest I-section for the same depth is
(a) ISMB
(b) ISLB
(c) ISJB
(d) ISWB

5. The heaviest I-section for the same depth is
(a) ISMB
(b) ISJB
(c) ISWB
(d) ISHB

6. A channel section has
(a) two webs one flange
(b) one web two flanges
(c) one web one flange
(d) two webs and two flanges

7. Rolled steel tubes are referred by their
(a) outer diameters
(b) inner diameter
(c) average diameter
(d) outer radius

8. Maximum thickness of rolled steel strip are
(a) 2.45 mm
(b) 4.5 mm
(c) 6.0 mm
(d) 8.0 mm

9. Minimum thickness of rolled steel flats available is
(a) 5 mm
(b) 6 mm
(c) 8 mm
(d) 12 mm

10. Maximum width of steel plates manufactured are
(a) 1 m
(b) 1.5 m
(c) 2.0 m
(d) 2.5 m

11. IS 800–2007 recommends use of ______ connections as far as possible.

(a) riveted
(b) bolted
(c) welded
(d) any of the above

12. Limit state of strength includes
(a) loss of equilibrium of whole or part of structure
(b) fracture by excessive deformations
(c) fracture due to fatigue
(d) all the above

13. Which one of the following is not limit state of serviceability?
(a) Vibration
(b) Corrosion
(c) Loss of stability
(d) Fire

14. Which one of the following is not a variable action?
(a) Handling and erection loads
(b) Wind loads
(c) Earthquake loads
(d) Self-weight

15. Characteristic actions are those which do not exceed ______ percent probability.
(a) 5%
(b) 10%
(c) 12%
(d) 15%

16. Partial safety factors for dead load and live load for limit state of strength are
(a) 1.5 and 1.5
(b) 1.5 and 1.0
(c) 1.5 and 1.05
(d) 1.0 and 1.05

17. Partial safety factor for limit state of serviceability for live load and dead load are
(a) 1.5 and 1.3
(b) 1.5 and 1.2
(c) 1.2 and 1.0
(d) 1.0 and 1.0

18. Partial safety factor for shop welding and field welding are
(a) 1.10 and 1.25
(b) 1.25 and 1.25
(c) 1.25 and 1.5
(d) 1.5 and 1.5

19 Size of rivet hole is kept ______ more them size of rivet
(a) 1 to 1.5 mm

(b) 1.5 to 2 mm

(c) 2–3 mm
(d) 3–4.5 mm

20. The effective diameter of a rivet is taken as
(a) nominal diameter of rivet
(b) rivet hole diameter
(c) rivet hole diameter +1.5 mm
(d) rivet hole diameter –1.5 mm

21. Which one of the following is not a type of bolt?
(a) Black bolt
(b) Turned bolt
(c) High strength friction grip bolt
(d) Hot rolled bolt

22. The yield strength and ultimate strength of M20 bolts are
(a) 20 N/mm^2 and 28 N/mm^2
(b) 200 N/mm^2 and 280 N/mm^2
(c) 200 N/mm^2 and 400 N/mm^2
(d) 240 N/mm^2 and 400 N/mm^2

23. Actual dimension of turned/finished bolts is
(a) nominal diameter –1.2 to 1.3 mm
(b) nominal diameter
(c) nominal diameter +1.2 to 1.3 mm
(d) diameter of bolt hole

24. To connect members subjected to dynamic loads which one of the following type of bolts is preferable?
(a) black bolts
(b) turned bolts
(c) HSFG bolts
(d) both (b) and (c) types

25. The successful introduction of ______ bolts resulted into replacement of rivets.
(a) black bolt
(b) turned bolt
(c) HSFG bolts
(d) all of the above

26. The following types of bolts may be classified as bearing types bolts
(a) black bolt
(b) turned bolt
(c) HSFG bolt
(d) both black and turned bolt

27. Which one of the following is not the advantage of HSFG bolt?

(a) No slip takes place in the joint.
(b) Bolts are not subjected to shearing and bearing stresses.
(c) The load transfer is by shearing stresses.
(d) Less stress concentration.

28. Which one of the following is not an advantage of bolted connection over welded connection?
(a) Making joint is noiseless.
(b) Connection can be made easily.
(c) Accommodates minor discrepancies in dimensions.
(d) Alterations in connections can be made easily in the field.

29. If *p* is the pitch, *d* is nominal diameter and *d*¢ bolt hole diameter, minimum pitch is
(a) 3*d*
(b) 3*d*¢
(c) 2.5*d*
(d) 2.5*d*¢

30. If *t* is the thickness of thinner plate in a bolted connection of tension member, pitch shall not be more than the
(a) 16*t* or 200 mm whichever is less
(b) 16*t* or 200 mm whichever is more
(c) 12*t* or 150 mm whichever is less
(d) 12*t* or 150 mm whichever is more

31. If *t* is the thickness of thinner member and *p* is the pitch in bolted connection of a compression member, pitch shall not be more than
(a) 16*t* or 200 mm whichever is less
(b) 16*t* or 200 mm whichever is more
(c) 12*t* or 200 mm whichever is less
(d) 12*t* or 180 mm whichever is less

32. Minimum edge distance, in case of hand flame cut edges, shall not be less than ______times bolt hole diameter.
(a) 1.2
(b) 1.5
(c) 1.7
(d) 1.8

33. In case of planed edges, minimum edge distance shall not be less than ______ times bolt hole diameter.
(a) 1.25
(b) 1.5
(c) 1.75
(d) 2.0

34. In double angle tension member of a truss tacking bolts are provided at a distance not exceeding
(a) 600 mm
(b) 800 mm

(c) 1000 mm

(d) 1200 mm

35. In a compression member of a truss, consisting of double angle, tacking bolts should be provided at a distance not more than

(a) 600 mm
(b) 800 mm
(c) 1000 mm
(d) 1200 mm

36. The assumptions made in the design of bearing bolted connections are

(i) the friction between the plates is negligible
(ii) the shear is uniform over the cross section
(iii) bolts in a group subject to direct load share the load equally

(a) (i) and (ii) are correct
(b) (ii) and (iii) are correct
(c) (i) and (iii) are correct
(d) all the three are correct

37. The principle to be observed in bolted connection are:

(i) the centre of gravity of bolts should coincide with the centre of gravity of connected members
(ii) the length of connection should be kept as small as possible

(a) only (i) is correct
(b) only (ii) correct
(c) both (i) and (ii) are correct
(d) none is correct

38. Minimum edge distances specified by the code should be maintained to avoid

(a) rupture of plate
(b) shearing of plate
(c) crushing of plate
(d) both (b) and (c)

39. If g_{ml} is partial safety factor, f_u ultimate stress and A_n net effective area, the tensile strength of a bolted connection is

(a) $0.8 \frac{A_n f_u}{\gamma_{ml}}$

(b) $0.9 \frac{A_n f_u}{\gamma_{ml}}$

(c) $\frac{A_n f_u}{\gamma_{ml}}$

(d) $1.1 \frac{A_n f_u}{\gamma_{ml}}$

40. In a width of plate b, thickness t, number of bolts n of diameter d, with hole diameter d_o net effective area is

(a) $(b - nd_o)\, t$

(b) $(b - nd)\ t$

(c) $(b - 1.1\ n_{do})\ t$

(d) $(b - 1.1d)\ t$

41. In case of standard bolts of diameter d, the cross-sectional area at threads is approximately

(a) $0.78\ p/n\ d^2$

(b) $0.85\ p/n\ d^2$

(c) $0.9\ p/n\ d^2$

(d) $0.95\ p/n\ d^2$

42. In a bolt of diameter d, effective area for resisting single shear is

(a) $0.78\ \frac{\pi}{4}\ d^2$

(b) $0.85\ \frac{\pi}{4}\ d^2$

(c) $0.9\ \frac{\pi}{4}\ d^2$

(d) $\frac{\pi}{4}\ d^2$

43. In double shear a bolt of diameter d has effective area resisting shear is

(a) $1.5\ \frac{\pi}{4}\ d^2$

(b) $1.6\ \frac{\pi}{4}\ d^2$

(c) $1.78\ \frac{\pi}{4}\ d^2$

(d) $2.0\ \frac{\pi}{4}\ d^2$

44. The code does not suggests reduction factor for shear capacity in the case

(a) if the joint is too long

(b) if number of bolts exceed a specified number

(c) if the grip length is large

(d) if packing plate thickness exceeds 6 mm

45. If packing plate thickness t_{pk} exceeds 6 mm the shear capacity is to be reduced by a factor

(a) $1 - 0.25\ t_{pk}$

(b) $1 - 0.100\ t_{pk}$

(c) $1 - 0.0125\ t_{pk}$

(d) $1 - 0.01\ t_{pk}$

46. With usual notations, bearing capacity of bolt is given by

(a) $1.5\ k_b\ dt\ f_u$

(b) $2.5\ k_b\ dt\ f_u$

(c) $1.5\ k_b\ dt\ f_y$

(d) $2.5\ k_b\ dt\ f_y$

47. In calculating bearing capacity of bolts constant k_b to be used need not be smaller of

(a) $\frac{e}{3d_o}$

(b) $\frac{p}{3d_o} - 0.25$

(c) $\frac{f_u}{f_{ub}}$

(d) 1.0

48. In a bracket, if load p acts at an eccentricity e producing moment in the plane of group of bolts, the stress induced in a bolt at distance r from the centroid of the group due to moment alone is

(a) $\frac{per}{\Sigma r}$

(b) $\frac{per}{\Sigma r^2}$

(c) $\frac{pe}{\Sigma r^2}$

(d) none of the above

49. In a bolt used for connecting a bracket, moment is in the plane of group of bolts. If F_1 is direct shear stress and F_2, the stress due to moment, resultant stress is

(a) $\sqrt{F_1^2 + F_2^2 + 2F_1F_2 \tan\theta}$

(b) $\sqrt{F_1^2 + F_2^2 + 2F_1F_2 \sin\theta}$

(c) $\sqrt{F_1^2 + F_2^2 + 2F_1F_2 \cos\theta}$

(d) $\sqrt{F_1^2 + F_2^2 + 2F_1F_2 \cot\theta}$

50. In a bracket, if groups of bolts are subjected to moment M in their plane approximate number of bolts of design shear strength V, provided at pitch p required are

(a) $\sqrt{\frac{M}{VP}}$

(b) $\sqrt{\frac{4M}{VP}}$

(c) $\sqrt{\frac{6M}{VP}}$

(d) $\sqrt{\frac{8M}{VP}}$

51. If V_{sb} is the factored shear force, T_b the factored tensile force, V_{db} is design shear force and T_{db} is design tensile force, design requirement of bolted connection subjected to direct shear and axial tension is

(a) $\left(\frac{V_{sb}}{V_{db}}\right)^2 + \left(\frac{T_b}{T_{db}}\right)^2$ £ 1.0

(b) $\left(\frac{V_{db}}{V_{sb}}\right)^2 + \left(\frac{T_{db}}{T_b}\right)^2$ £ 1.0

(c) $\frac{V_{sb}}{V_{db}} + \frac{T_b}{T_{db}}$ £ 1.0

(d) $\frac{V_{db}}{V_{sb}} + \frac{T_{db}}{T_b}$ £ 1.0

52. In the design of a bracket subjected to moment in the plane at right angles to the plane of bolts, neutral axis is assumed to lie at a distance ______ of the depth of bracket, measured from the bottom edge of the angle

(a) $\frac{2}{3}$

(b) $\frac{1}{2}$

(c) $\frac{1}{3}$

(d) $\frac{1}{7}$

53. If M is the moment to be resisted by bolts in a bracket subjected to moment normal to the plane of bolts, total moment $M¢$ resisted by bolts in tension in terms of the distance y_i of bolts from the centroid of bolts is

(a) $\frac{M}{1+\frac{h}{21}\frac{\Sigma y_i}{\Sigma y_i^2}}$

(b) $\frac{M}{1+\frac{2h}{21}\frac{\Sigma y_i}{\Sigma y_i^2}}$

(c) $\frac{M}{1+\frac{h}{7}\frac{\Sigma y_i}{\Sigma y_i^2}}$

(d) $\frac{5M}{7}$

where h is the depth of the bracket.

54. For HSFG bolts, partial safety factor designed at service load and at ultimate load are respectively

(a) 1.10 and 1.25

(b) 1.2 and 1.4

(c) 1.25 and 1.4

(d) 1.25 and 1.5

55. HSFG bolts transfer load mainly due to

(a) friction

(b) shearing

(c) bearing

(d) none of the above

56. Prying forces should be considered in designing

(a) black bolts

(b) turned bolts

(c) all bearing bolts

(d) HSFG bolts

57. For connecting circular tubes in tension, the best connection is by

(a) riveting

(b) bolting

(c) using HSFG bolts

(d) welding

58. Under fatigue stresses, which one of the following joint fails earlier?

(a) black bolted

(b) turned bolted.

(c) HSFG bolted

(d) welded.

59. If a plate with small hole is kept over another plate and the entire hole is filled with weld material, the welded joint is known as

(a) fillet weld

(b) butt weld

(c) plug weld

(d) slot weld

60. The minimum length of butt weld shall be ______ times the size of weld

(a) 4

(b) 5

(c) 6

(d) 8

61. If intermittent butt welding is used, the space between two welds should not be more than ______ times the thickness of the thinner member connected.

(a) 12

(b) 16

(c) 20

(d) 24

62. For connecting 10 to 20 mm plates minimum size of fillet weld is

(a) 5 mm

(b) 6 mm

(c) 8 mm

(d) 10 mm

63. In showing welded connection the length of the weld shown should be

(a) effective length only

(b) effective length + size of weld

(c) effective length + 2 × size of weld

(d) effective length + 4 × size of weld

64. When welding is carried out, the length of the weld should be

(a) length shown in drawing

(b) length shown in drawing + size of weld

(c) length shown in drawing + 2 × size of weld

(d) length shown in drawing + 4 × size of weld

65. In lap joints with welding, lap should not be less than

(a) $4 \times t$ or 40 mm

(b) 5 t or 50 mm

(c) 6 t or 60 mm

(d) 100 mm

66. If t is the thickness of thinner plate jointed by intermittent weld, minimum spacing recommended in tension and compression joints are respectively

(a) 12 t and 16 t

(b) 16 t and 12 t

(c) 16 t and 20 t

(d) 20 t and 16 t

67. Design strength of shop weld in terms of ultimate stress of f_u weld is

(a) $\frac{f_u}{\sqrt{3}}$

(b) $\frac{f_u}{1.25}$

(c) $\frac{f_u}{1.5\sqrt{3}}$

(d) $\frac{f_u}{1.25\sqrt{3}}$

68. If a fillet weld is to the square edge, the size of weld shall be at least ______ less than the edge thickness

(a) 1.5 mm

(b) 2.0 mm

(c) 2.5 mm

(d) 3.0 mm

69. If fillet weld is to the rounded toe of thickness t, a rolled steel section, the size of weld generally not to exceed

(a) t – 1.5 mm

(b) t – 2.0 mm

(c) $\frac{4}{5}\, t$

(d) 3/4 t

70. If the length of welded joint l_j is greater than 150 t, where t is the throat thickness, the design capacity of weld shall be reduced by

(a) 0.8

(b) $1.2 - \frac{0.2\, l_j}{150t}$

(c) $1 - \frac{0.25}{150t}$

(d) $1.2 - \frac{0.3\, l_j}{150\, t}$

71. Figure Q. 71 shown below is a welded connection of a bracket. In this if throat thickness of weld

is t, the direct shear stress is

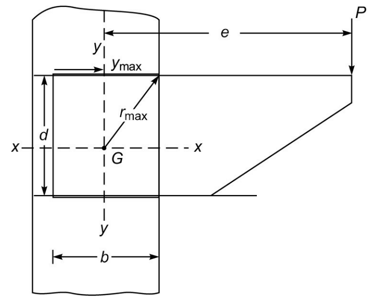


Fig. Q. 71

(a) $\frac{p}{dt}$

(b) $\frac{p}{(b+d)t}$

(c) $\frac{p}{(2b+d)t}$

(d) none of the above

72. In Fig. Q. 71, maximum bending stress in weld is

(a) $\frac{pe(d/2)}{I_{xx}}$

(b) $\frac{pe}{I_{yy}} y_{\max}$

(c) $\frac{pe\,r_{\max}}{I_{zz}}$

(d) None of the above

73. If a weld is subjected to axial stress f_a and shear stress q, equivalent stress f_c to be considered is

(a) $\sqrt{f_a^2 + q^2}$

(b) $\sqrt{f_a^2 + 2q^2}$

(c) $\sqrt{2f_a^2 + q^2}$

(d) $\sqrt{f_a^2 + 3q^2}$

74. In the welded bracket connection shown in Fig. Q. 74 direct shear stress in weld is

(a) $\frac{P}{2ht}$

(b) $\frac{P}{2h(0.7t)}$

(c) $\frac{P}{ht}$

(d) $\frac{P}{4ht}$, where t is thickness of weld

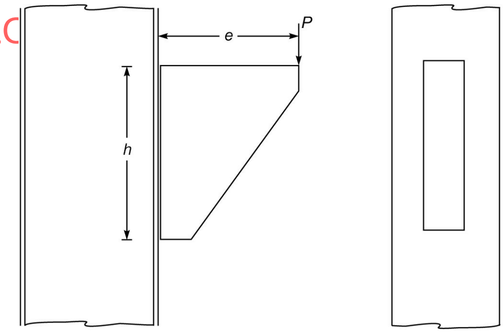


Fig. Q. 74

75. In the bracket shown in Fig. Q.74 maximum bending stress in the weld is

(a) $\frac{pe}{6th^2}$

(b) $\frac{pe}{4th^2}$

(c) $\frac{3pe}{th^2}$

(d) $\frac{6pe}{th^2}$

76. In the design of a connection of tension member to a gusset plate, the principle to be followed is
(a) section should be compact
(b) as large portion of it as is possible is connected
(c) centre of gravity of member should be through the middle of thickness of gusset plate
(d) all the above

77. The design strength of tension member is
(a) design strength of gross section due to yielding
(b) rupture strength of section
(c) block shear strength
(d) lowest of the above

78. In the four bolt connection shown is Fig. Q. 78, block shear strength is along
(a) 1 – 2 – 3 – 4
(b) 1 – 2 – 3 – 5
(c) any one of (a) and (b)
(d) none of the above

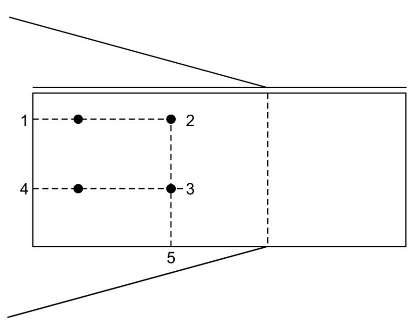


Fig. Q. 78

79. From the consideration of tearing of section strength of an unequal angle section in tension is _______ when short leg is connected compared to when its long leg is connected.

(a) more

(b) less
(c) equal
(d) may be any one of above depending upon the ratio of length of the legs

80. In a roof truss a member normally acting as tension member but occasionally subjected to compression due to wind load, slenderness ratio should not exceed
(a) 150
(b) 250
(c) 350
(d) 450

81. The following are the statements about lug angle used to connected heavily loaded tension member to gusset plates.
(i) The length of end connection is reduced
(ii) By using lug angles there will be saving in the gusset plate
(iii) Cost of connection increases due to additional fasteners and angle required
(a) only (i) and (ii) are correct.
(b) only (i) and (iii) are correct.
(c) only (ii) and (iii) are correct.
(d) all the three are correct.

82. Which one of the following is not a correct statement about lug angle connection?
(a) By using lug angle, there will be saving in gusset plate.
(b) The connection of lug angle to main member shall preferably start in advance of the member to the gusset plate.
(c) Minimum of two bolts are used for connecting lug angle to the gusset plate.
(d) Maximum of five bolts should be used in the connection.

83. Load carrying capacity of compression member depends upon
(a) cross-sectional area
(b) end condition
(c) slenderness ratio
(d) all the above

84. IS 800–2007, divides sections into ______ number of buckling classes.
(a) 3
(b) 4
(c) 5
(d) 6

85. The most economical section for a compression member is
(a) rectangular
(b) I-shaped
(c) circular (d) hollow circular

86. For compression members most preferable I-section is

(a) light beam (b) junior beam

(c) medium beam (d) heavy beam

87. Lacing and battening of columns is to increase ______ of column.

(a) sectional area

(b) least radius of gyration

(c) section modulus

(d) none of the above

88. In case of bolted lacing, the width of lacing bars shall be ______ times the nominal diameter of the bolt.

(a) 2

(b) 3

(c) 4

(d) 6

89. For single lacing the thickness of flat lacing bars shall not be less than ______ times the effective length.

(a) $\frac{1}{25}$

(b) $\frac{1}{30}$

(c) $\frac{1}{35}$

(d) $\frac{1}{40}$

90. For double lacing the thickness of lacing bar shall not be less than ______ times the effective length.

(a) $\frac{1}{16}$

(b) $\frac{1}{20}$

(c) $\frac{1}{24}$

(d) $\frac{1}{30}$

91. Maximum spacing of lacing bars shall be such that the maximum slenderness of the main member between consecutive lacing connection is not more than

(a) 30

(b) 40

(c) 50

(d) 60

92. Lacing shall be designed to resist transverse shear V_t equal to

(a) 2.5% of P

(b) 4.0% of P

(c) 5.0% of P

(d) 10.0% of P

where P is axial compression.

93. For welded and double laced joints, effective length of lacing is ______ times the actua1 1ength.
 (a) 0.5
 (b) 0.6
 (c) 0.7
 (d) 0.85

94. The slenderness ratio of lacing bars should not exceed
 (a) 105
 (b) 125
 (c) 145
 (d) 160

95. The effective slenderness ratio of laced columns shall be taken as ______ times the actual maximum slenderness ratio, in order to account for shear deformation effect.
 (a) 1.05
 (b) 1.10
 (c) 1.15
 (d) 1.20

96. The number of battens should be such that the member is divided into not less than ______ bays.
 (a) 3
 (b) 4
 (c) 5
 (d) 6

97. The effective slenderness ratio of battened columns shall be taken as ______ times the maximum slenderness ratio of the column
 (a) 1.05
 (b) 1.10
 (c) 1.15
 (d) 1.20

98. Effective depth of intermediate battens shall not be less than ______ of the distance between the centroid of main members.
 (a) $\frac{1}{2}$
 (b) $\frac{2}{3}$
 (c) $\frac{3}{4}$
 (d) $\frac{7}{8}$

99. Thickness of battens shall not be less than ______ of the distance between the innermost connecting lines of bolts.
 (a) $\frac{1}{30}$

(b) $\frac{1}{40}$

(c) $\frac{1}{50}$

(d) $\frac{1}{60}$

100. The length of the weld connecting batten plate to the member shall not be less than ______ the depth of batten plate.

(a) $\frac{1}{3}$

(b) $\frac{1}{2}$

(c) $\frac{3}{4}$

(d) 1

101. It is recommended that columns should preferably spliced at
(a) point of maximum shear
(b) point of zero shear
(c) point of contraflexure
(d) anywhere

102. In a column splice, if ends are milled, the connection and splice plates may be designed for only ______ percent of axial load.
(a) 50
(b) 60
(c) 70
(d) 80

103. When the two columns to be spliced are of slightly different size
(a) milled ends are provided
(b) filler plates are used
(c) bearing plates are used
(d) milled end and bearing plated are used

104. Column splice plates may be assumed to act as columns with slenderness ratio
(a) zero
(b) 40
(c) 80
(d) 120

105. The beam sections in which the extreme fibre in compression can yield stress, but cannot develop the plastic moment of resistance, due to local buckling are classified as
(a) plastic sections
(b) compact sections
(c) semi-compact sections
(d) slender sections

106. In a beam if the elements of cross sections buckle locally even before reaching yield stress, it

belongs to

(a) plastic section

(b) compact section

(c) semi-compact section

(d) slender section

107. The shear area of a rolled steel I-section for minor axis bending is

(a) $h\ t_w$

(b) $b\ t_f$

(c) $2\ b\ t_f$

(d) $h\ t_f$

where

h = overall depth

b = breadth

t_w = thickness of web

t_f = thickness of flange

108. In an industrial building with brittle cladding, vertical deflection of beams should not exceed

(a) $\frac{\text{Span}}{150}$

(b) $\frac{\text{Span}}{180}$

(c) $\frac{\text{Span}}{240}$

(d) $\frac{\text{Span}}{300}$

109. Figure Q. 109 shows a top layer of grillage foundation. Length of beams is L and top plate in that direction is a. The beams of top layer should be designed for moment M and shear force V where M and V are

(a) $\frac{P(L-a)^2}{4}$ and $P(L-a)$

(b) $\frac{P(L-a)}{8}$ and $\frac{P(L-a)}{2L}$

(c) $\frac{P(L-a)^2}{8}$ and $\frac{P(L-a)^2}{2L}$

(d) $\frac{P(L-a)}{4}$ and $\frac{P(L-a)}{L}$

where P is total load from column.

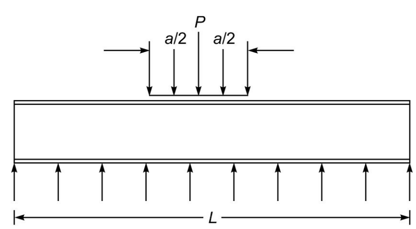


Fig. Q. 109

110. Minimum cover beyond the edges of steel beams in a grillage foundation should be
(a) 25 mm
(b) 50 mm
(c) 75 mm
(d) 100 mm

111. In a grillage foundation a minimum clear space of ______ should be maintained
(a) 50 mm
(b) 75 mm
(c) 100 mm
(d) 125 mm

112. Which one of the following is not a flexible connection of beams?
(a) Web angle connection
(b) framed connection
(c) unstiffened seated connection
(d) stiffened seated connection

113. Economical depth of a girder is given by

(a) $\left[\frac{Mk}{f_y}\right]^{1/2}$

(b) $\left[\frac{Mk}{f_y}\right]^{1/3}$

(c) $\left[\frac{Mk}{f_u}\right]^{1/2}$

(d) $1.2\left[\frac{Mk}{f_u}\right]^{1/3}$

where M is maximum moment

$k = \frac{d}{t_w}$ assumed

t_w = thickness of web

f_u and f_y = ultimate and yield stresses respectively

114. In a plate girder, when transverse stiffeners are not provided, minimum thickness of web to be used is

(a) $\frac{d}{200}$

(b) $\frac{d}{250}$

(c) $\frac{d}{415}$

(d) $\frac{d}{500}$

115. In a plate girder if vertical stiffeners are provided at distances less than the depth of the girder, minimum thickness of web to be used is

(a) $\frac{d}{200}$

(b) $\frac{d}{250}$

(c) $\frac{d}{270}$

(d) $\frac{d}{340}$

116. In a plate girder with vertical stiffeners at less than 0.74 depth of girder and a horizontal stiffener, web thickness should be at least

(a) $\frac{d}{200}$

(b) $\frac{d}{250}$

(c) $\frac{d}{300}$

(d) $\frac{d}{340}$

117. In a plate girder with vertical stiffeners and two horizontal stiffeners, minimum thickness of web is

(a) $\frac{d}{200}$

(b) $\frac{d}{250}$

(c) $\frac{d}{340}$

(d) $\frac{d}{400}$

118. In a plate girder of depth *d*, if one horizontal stiffener is to be provided, it should be at ______ below compression flange.

(a) 0.2 *d*

(b) 0.25 *d*

(c) 0.3 *d*

(d) 0.5 *d*

119. In a plate girder, if two horizontal stiffeners are to be used they should be at depth ______from compression flange.

(a) 0.2 *d* and 0.4 *d*

(b) 0.2 *d* and 0.5 *d*

(c) 0.33 *d* and 0.67 *d*

(d) 0.4 *d* and 0.8 *d*

120. Assuming moment is resisted by flanges only, flange area of a plate girder may be found by using the equation

(a) $A_f = \frac{1.1\,M}{f_y\,d}$

(b) $A_f = \frac{M}{f_y\,d}$

(c) $A_f = \frac{1.1M}{f_u d}$

(d) $A_f = \frac{M}{f_u d}$

where M is the moment, d depth of plate girder, f_y and f_u yield and ultimate stresses respectively.

121. Simple post-critical method may be used for finding shear buckling resistance of web in case of plate girder

(a) without vertical stiffeners only

(b) with vertical stiffeners only

(c) with or without vertical stiffeners

(d) with vertical and horizontal stiffeners.

122. The following are the statements about tension field method of finding shear buckling resistance of plate girded: which one of them is correct statement?

(a) It may be used if end and intermediate vertical stiffeners are provided.

(b) As the web begins to buckle, it loses the ability to resist diagonal compression.

(c) It gives higher value of shear buckling strength of web compared to simple post-critical method.

(d) All the above.

123. According to tension field method as web begins to buckle

(a) horizontal component of diagonal compression in web due to shear is resisted by flange

(b) vertical component of diagonal compression in web due to shear is resisted by vertical stiffener

(c) web resists only diagonal tension

(d) all the above statements are correct

124. In designing connection between web plate and flange plate, shear stress is calculated using moment of inertia of

(a) web plate only

(b) web plate and flange plates

(c) half the web plate and a flange plate

(d) one flange plate only

125. Slenderness ratio l of a vertical stiffener in a plate girder may be taken as

(a) $0.5 \frac{L}{r}$

(b) $0.7 \frac{L}{r}$

(c) $0.75 \frac{L}{r}$

(d) $\frac{L}{r}$

126. For finding buckling resistance of a stiffener in a plate girder the area of web to be added is

(a) 20 t_w from one side of stiffner

(b) 20 t_w from each side

(c) 28 t_w from one side

(d) 28 t_w from each side

127. Bearing stiffeners are provided at
(i) supports (ii) the mid span
(iii) the point of application of concentrated loads
The correct answer is
(a) only (i)
(b) both (i) and (ii)
(c) both (i) and (iii)
(d) all the three

128. Gantry girders are designed to resist
(a) vertical load from cranes
(b) longitudinal and vertical loads
(c) lateral, longitudinal and vertical loads
(d) lateral and longitudinal loads

129. In the design of gantry girders impact factor for vertical loads for electrically operated cranes is taken as
(a) 10%
(b) 15%
(c) 20%
(d) 25%

130. In the design of hands operated gantry girders, the impact factor for vertical loads to be considered is
(a) 10%
(b) 15%
(c) 20%
(d) 25%

131. In designing gantry girders impact factor for horizontal force along rails is taken as
(a) 5%
(b) 10%
(c) 15%
(d) 25%

132. In manually operated gantry girders vertical deflection is limited to

(a) $\frac{\text{Span}}{250}$
(b) $\frac{\text{Span}}{500}$
(c) $\frac{\text{Span}}{750}$
(d) $\frac{\text{Span}}{1000}$

133. In gantry girders lateral deflection should be restricted to

(a) $\frac{\text{Span}}{200}$

(b) $\frac{\text{Span}}{300}$

(c) $\frac{\text{Span}}{400}$

(d) $\frac{\text{Span}}{500}$

134. In roof trusses bracings should be provided at top chord level in the
(a) end panels using flats
(b) end panels using angles
(c) last but one panel using flats
(d) last but one end panel using angles

135. In roof trusses bracings should be provided at bottom chord level in the
(a) end panels using flats
(b) end panels using angles
(c) last but one panel using flats
(d) last but one panel using angles

136. The type of trusses shown in Fig. Q. 136 is known as
(a) King post
(b) Howe
(c) Fink
(d) Pratt

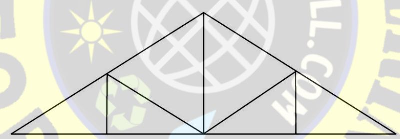


Fig. Q. 136

137. The truss shown in Fig. Q. 137 is known as
(a) King post
(b) Howe
(c) Fink
(d) Pratt

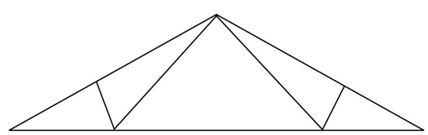


Fig. Q. 137

138. The truss shown in Fig. Q. 138 is known as
(a) King post
(b) Howe
(c) Fink
(d) Pratt

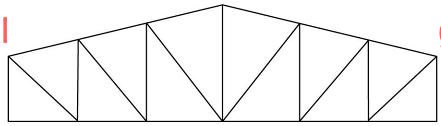


Fig. Q. 138

139. Pitch of a roof truss means

(a) $\frac{\text{Height}}{\text{Span}}$

(b) $\frac{\text{Height}}{\frac{1}{2}\text{span}}$

(c) inclination of top chord

(d) none of the above

140. Minimum pitch, if AC sheets are used is

(a) $\frac{1}{4}$

(b) $\frac{1}{6}$

(c) $\frac{1}{8}$

(d) $\frac{1}{12}$

141. Minimum pitch if GI sheets are used is

(a) $\frac{1}{4}$

(b) $\frac{1}{6}$

(c) $\frac{1}{8}$

(d) $\frac{1}{12}$

142. Preferable pitch, if snow load is expected is

(a) $\frac{1}{4}$

(b) $\frac{1}{6}$

(c) $\frac{1}{8}$

(d) $\frac{1}{12}$

143. If span of a roof truss is between 15–30 m, preferable spacing is

(a) 3.0 to 4.5 m

(b) 4.5 to 6.0 m

(c) 6 to 8 m

(d) 10–12 m

144. If span of truss is 40 m and above, preferable spacing of trusses is

(a) 4.5 to 6 m

(b) 6 to 8 m

(c) 8 to 10 m

(d) 12–15 m

145. For spacing of trusses 3 to 4 m, purling used are
(a) angle iron with outstanding leg at top
(b) angle iron with outstanding leg at bottom
(c) channel sections
(d) I-sections

146. For 4 to 5 m spacing of trusses purling used are
(a) angles with outstanding leg at top
(b) angles with outstanding leg at bottom
(c) channel sections
(d) I-sections

147. 8 corrugation A.C. sheets are having width of
(a) 500 mm
(b) 660 mm
(c) 810 mm
(d) 1000 mm

148. 10 corrugation A.C. sheets have width of
(a) 600 mm
(b) 810 mm
(c) 1020 mm
(d) 1240 mm

149. In A.C. sheet roofing side lap should be at least
(a) 1 corrugation
(b) $1\frac{1}{2}$ corrugation
(c) 2 corrugation
(d) more than 2 corrugations

150. In A.C. sheet roofing, if slope is more than 20°, end lap should be at least
(a) 100 mm
(b) 125 mm
(c) 150 mm
(d) 175 mm

151. In A.C. sheet roofing, if slope is less than 20°, end lap should be at least
(a) 125 mm
(b) 150 mm
(c) 175 mm
(d) 200 mm

152. The A.C. sheets should be fastened to purlins by 8 mm hook bolts at a maximum pitch of
(a) 300 mm
(b) 350 mm

(c) 400 mm

(d) 500 mm

153. If 6 mm A.C. sheets are used for roofing, maximum spacing is
(a) 1.4 m
(b) 1.6 m
(c) 1.8 m
(d) 2.0 m

154. If 7 mm thick A.C. sheets are used maximum spacing of J bolts is
(a) 1.4 m
(b) 1.6 m
(c) 1.8 m
(d) 2.0 m

155. Unit weight of G.I. sheets is
(a) 65 N/m^2
(b) 85 N/m^2
(c) 105 N/m^2
(d) 125 N/m^2

156. The roof covering weight including A.C. sheets, laps, connector etc. may be taken as
(a) 100–125 N/m^2
(b) 125–150 N/m^2
(c) 150–170 N/m^2
(d) 170–200 N/m^2

157. To account for weight of electrical fixtures like lights and fans, on lower panel points of trusses additional occasional load to be considered is
(a) 5–10 kN
(b) 10–15 kN
(c) 15–20 kN
(d) 20–30 kN

II. Match List-I with List-II selecting the answer code given below each item No. 159–162

158.

	List I		**List II**
	Alloying with		**Effect on steel**
A.	Carbon	1.	Increases corrosion resistance
B.	Phosphorus	2.	Improves resistance to high temperature
C.	Chrome and nickel	3.	Increases brittleness
D.	Copper	4.	Increases tensile strength but reduces in ductility

Codes:

(a)	A – 1	B – 2	C – 3	D – 4
(b)	A – 2	B – 3	C – 4	D – 1
(c)	A – 4	B – 3	C – 2	D – 1
(d)	A – 4	B – 3	C – 1	D – 2

159.

	List I		List II
	Terminology in bolted connection		**Meaning of the terminology**
A.	Pitch	1.	Distance between two consecutive bolts measured at right angles to the direction of load.
B.	Gauge distance	2.	Nearest bolt hole distance from end of plate.
C.	Edge distance	3.	Nearest hole distance from adjacent edge of plate.
D.	End distance	4.	Centre-to-centre distance of the bolts along the direction of load.

Codes:

(a)	A – 1	B – 4	C – 2	D – 3
(b)	A – 4	B – 1	C – 2	D – 3
(c)	A – 1	B – 4	C – 3	D – 2
(d)	A – 4	B – 1	C – 3	D – 2

160.

	List I		List II
	Type of beam connection		**Connecting members used**
A.	Framed connection	1.	Flange cleats only
B.	Unstiffened seated connection	2.	Flange and web clips
C.	Stiffened seated connection	3.	Web cleat only
D.	Rigid connection	4.	Flanged cleats and stiffener angle

Codes:

(a)	A – 3	B – 2	C – 1	D – 4
(b)	A – 4	B – 1	C – 2	D – 4
(c)	A – 4	B – 3	C – 2	D – 1
(d)	A – 3	B – 1	C – 4	D – 2

161.

List I	List II
Member shown in Fig. Q. 161	**Nomenclature**

A.	1	1.	bottom chord
B.	2	2.	strut
C.	3	3.	sling
D.	4	4.	tie

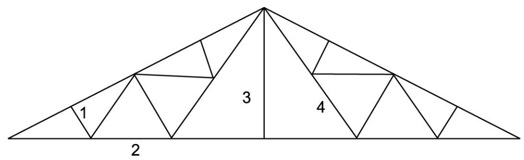


Fig. Q. 161

Codes:

(a)	A – 1	B – 2	C – 3	D – 4
(b)	A – 2	B – 1	C – 4	D – 3
(c)	A – 2	B – 1	C – 3	D – 4
(d)	A – 1	B – 2	C – 3	D – 4

III. Select your answer according to the coding system given for the Assertion (*A)* and Reason (*R)* given below:

(a) Both A and R are true and R is the correct explanation of A
(b) Both A and R are true but R is not correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

162. Assertion: Trusses comprise triangular figures.
Reason: A pin-jointed stable figure is a triangle
(a) Both A and R are true and R is the correct explanation of A
(b) Both A and R are true but R is not the correct explanation of A.
(c) A is true but R is false
(d) A is false but R is true

Answers to Multiple-Choice Questions

1. (d)	2. (b)	3. (d)	4. (c)	5. (d)
6. (b)	7. (b)	8. (b)	9. (a)	10. (d)
11. (c)	12. (d)	13. (c)	14. (d)	15. (a)
16. (a)	17. (d)	18. (c)	19. (b)	20. (b)
21. (d)	22. (d)	23. (c)	24. (c)	25. (c)
26. (d)	27. (c)	28. (d)	29. (c)	30. (a)
31. (c)	32. (c)	33. (b)	34. (c)	35. (a)
36. (d)	37. (c)	38. (d)	39. (b)	40. (a)
41. (a)	42. (a)	43. (c)	44. (b)	45. (a)
46. (b)	47. (c)	48. (b)	49. (c)	50. (c)
51. (a)	52. (d)	53. (b)	54. (a)	55. (a)
56. (d)	57. (d)	58. (d)	59. (c)	60. (a)

61. (b)	62. (a)	63. (a)	64. (c)	65. (a)
66. (b)	67. (d)	68. (a)	69. (d)	70. (b)
71. (c)	72. (c)	73. (d)	74. (a)	75. (c)
76. (d)	77. (d)	78. (c)	79. (b)	80. (c)
81. (d)	82. (d)	83. (d)	84. (b)	85. (d)
86. (d)	87. (b)	88. (b)	89. (d)	90. (a)
91. (c)	92. (a)	93. (c)	94. (c)	95. (b)
96. (a)	97. (b)	98. (c)	99. (c)	100. (b)
101. (c)	102. (a)	103. (b)	104. (a)	105. (c)
106. (d)	107. (c)	108. (b)	109. (b)	110. (d)
111. (b)	112. (a)	113. (b)	114. (a)	115. (c)
116. (d)	117. (d)	118. (a)	119. (b)	120. (a)
121. (c)	122. (d)	123. (d)	124. (d)	125. (b)
126. (b)	127. (c)	128. (c)	129. (d)	130. (a)
131. (a)	132. (b)	133. (c)	134. (b)	135. (c)
136. (b)	137. (c)	138. (d)	139. (a)	140. (a)
141. (d)	142. (a)	143. (b)	144. (d)	145. (a)
146. (c)	147. (b)	148. (b)	149. (a)	150. (a)
151. (b)	152. (b)	153. (a)	154. (b)	155. (b)
156. (d)	157. (a)	158. (c)	159. (d)	160. (d)
161. (b)	162. (a)			

9

Fluid Mechanics

9.1 INTRODUCTION

- Very strong intermolecular attractive forces exist in solids which give them the property of rigidity. These forces are weaker in liquids and very weak in gases. A solid has volume and shape, a liquid has volume but no shape and a gas has neither.
- A fluid is a substance which deforms continuously under the action of shear stress, regardless of its magnitude. Hence, both liquid and gas are fluids.
- In liquids the molecules are so closely spaced that strong molecular cohesive force compels the fluid to behave as a continuous mass.
- Density is mas per unit volume.

$$r = \lim_{v \to 0} \frac{\Delta m}{\Delta v} = \frac{dm}{dv}$$

- Specific gravity = $\frac{\text{Density of the substance}}{\text{Density of water}}$
- Specific weight = dg

The specific weight of water under normal condition = 9.81×10^3 N/m^3.

- Specific volume: It is the volume occupied by a unit mass of fluid. It is commonly applied to gases.

  Specific volume = $\frac{1}{\rho}$.
- Viscosity is the property by virtue of which a fluid offers resistance to the movement of one layer over another adjacent layer under the influence of a shear force.

Newton's law of viscosity is

$$t = m\,\frac{du}{dy}$$

where t = shear stress

m = coefficient of viscosity or absolute viscosity

$\frac{du}{dy}$ = rate of shear strain and is known as velocity gradient.

Thus, for a given shear stress acting on a fluid element, the rate at which the fluid deforms is inversely proportional to the viscosity.

- A fluid which obeys Newton's law of viscosity is known as a Newtonian fluid. Air, water light oils and gasolines are Newtonian fluids.
- Non-Newtonian fluids are those in which shear stress is not linearly dependent upon the velocity gradient. Examples of such fluids are: human blood, lubricating oils, printers ink, molten rubber, and sewage sludge. They have the relation of the form

$$t = A\left(\frac{du}{dy}\right)^n + B.$$

If $n > 1$, Dilatant = e_a: printing ink, butter, quick sand

$n = 1$, Bingham plastic = e_x: Sewage sludge

$n < 1$, Pseudoplastic = e_u: Paper pulp, suspension paints, polymeric solutions

- Some fluids are time dependent and some are time independent. In time dependent fluids the rate of deformation and the viscosity depend upon both the shear stress and the duration of its application.
- Ideal fluid is non-viscous (frictionless) and incompressible (inelastic). It is a creation of mathematicians, just to simplify the analysis.
- The dimension of dynamic viscocity is $ML^{-1}\,T^{-1}$.
- The ratio of the dynamic viscosity and mass density is called the kinematic viscosity. It can be defined by only length and time dimension ($L^2\,T^{-1}$). Its unit in S.I. system is stoke which is equal to $1\,\frac{\text{cm}^2}{\text{sec}} = 10^{-4}\,\text{m}^2/\text{s}$.
- With increase in temperature, the intermolecular cohesive force decreases rapidly, resulting in the decrease of viscocity.

Kinematic viscocity of water

$$= \frac{0.0179}{1 + 0.0337\,T + 0.00022\,T^2}$$

is the equation given by Poiseuille.

- In case of gases, the viscocity is mainly due to transfer of molecular momentum in the transverse direction brought about by the molecular agitation. As the molecular agitation increases with the rise of temperature, the viscocity of the gases also increases with temperature. Thus, the viscocity of fluid is due to:
  1. intermolecular cohesion, and
  2. transfer of molecular momentum.

Surface Tension

- Surface tension is a force which exists on the surface of a liquid when it is in contact with another fluid or a solid boundary. It acts normal to a line of unit length drawn imaginarily on the surface. It is a line force. Its unit in SI system is N/m. It depends directly upon intermolecular cohesion.

Capillary Action

- Most of the liquids completely wet the surface of solids because the molecules of a solid surface attract liquid molecules with a greater force than that exists between the liquid molecules. Mercury is exception to it.
- If the adhesive force is greater than that of cohesive force, liquid tends to spread out and wets the surface. But in case of mercury cohesive force is more and hence it does not wet the surface of solids. Hence, when a glass tube is dipped in water, the level increases in the tube while if it is dipped in mercury, the level of mercury in the tube is lower.
- The phenomenon of rise or fall of liquid level in the tube is said to be due to capillary action.
- If q is the angle for contact between the liquid and solid surfaces, water in the glass tube will

continue to rise until the vertical component of the surface tension is equal to the weight of the water column.

- For pure water and clean glass q is zero. But for ordinary water, Gibson found q = 25°.32¢. For mercury q = 128°52¢.

Vapour Pressure

- Liquid molecules escaping from the free surface to air is known as vaporisation.
- After some time when air contains enough liquid molecules, it starts exerting pressure on liquid molecules and forces them to rejoin the liquid surface. When equilibrium is established, vaporisation stops. The pressure exerted by saturated air or liquid is called vapour pressure.
- Liquid starts boiling when the pressure on it is slightly below vapour pressure. Hence, boiling can be achieved by either raising the temperature or by lowering the pressure of overlaying air below the vapour pressure.
- Vapour pressure increases with temperature. For water, vapour pressure at 0°C is 0.063 m while its value is 10.790 m when temperature is 100°C.
- At 20°C water has vapour pressure of 2.345×10^3 N/m^2, i.e., 2.345×10^3 Pascal i.e., 0.239 m while mercury has 0.160 N/m^2 only.

Incompressible and Compressible Fluids

- The compressibility is the measure of change of volume when a substance is subjected to pressure.
- The reciprocal of coefficient of compressibility is known as bulk modulus of elasticity.
- The compressibility of liquid is so small that, to simplify analysis it is many times assumed incompressible.
- The values of bulk modulus E_v for water at standard atmospheric conditions is $E_v = 2.11\ 10^3$ N/m^2.
- The ratio of the velocity of flow V to the velocity of sound in the fluid medium is known as Mach number and denoted as M.

This is a measure of compressibility. If:

$M < 1$, compressibility effect is negligible

$M > 1$, compressibility of fluid is to be considered

- The flow is,

subsonic if $M < 1$

supersonic if $M > 1$

hypersonic if $M > 5$.

Fluid Statics

- In static fluid velocity gradient $\frac{du}{dy} = 0$
- Hence, viscosity of a fluid has no effect.
- If the distance h is measured from the free surface, pressure p is given by

$p = g\,h$ where g = is unit weight of fluid.

- The atmospheric pressure p at a height h from sea level is

$$p = p_o - g_a h \text{ where } p_o = \text{pressure at mean sea level.}$$

and g_a = specific weight of air.

- The atmospheric pressure at sea level is 760 mm of mercury.
- Absolute pressure is the pressure measured above complete vacuum (i.e., the absolute zero).
- Gauge pressure is the difference between its absolute value and the local atmospheric pressure. Thus

Gauge pressure = Absolute pressure – Local atmospheric pressure.

- If gauge pressure is negative, then vacuum or negative pressure

= Local atmospheric pressure – Absolute pressure.

- Mechanical pressure gauges like Bourdon gauge, measure gauge pressure.
- Local atmospheric is measured by a mercury barometer or by an aneroid barometer.
- The height of liquid that rises in a piezometer tube above the point is absolute pressure at that point. The piezometers when employed for pressure measurements are called manometers. Types of manometers are:
  1. Simple manometer
  2. Differential manometer
  3. Micro-manometer.
- Simple manometer can only be used for measuring small and moderate pressures because as the pressure gets higher, the length of the piezometer becomes larger.
- Simple manometer may be used of measuring negative pressure also by providing U-shaped turn to the tube.
- Differential manometer is used to measure the difference in pressures at two points.
- Use of mercury is advantageous where the pressure difference is large.
- The micro-manometers are used for measuring small difference of pressure.
- Inclined manometer is used for precise measurement of small pressure in low velocity gas flow. In this amplification of h is l/h where l is inclined length measured. Thus, amplification = $\frac{l}{h} = \frac{1}{\sin\theta}$, if q is the inclination of inclined manometer.
- The pressure on horizontal surface h below the free surface is $g\,h$ and on vertical surface it varies from zero at free surface to maximum of $g\,h$ at bottom of vertical surface, linearly.
- When a body is submerged in liquid, it is subjected to vertical force by liquid and this is known as buoyancy. The Archimedes' principle states that a submerged body is subjected to a buoyancy equal to the weight of the fluid displaced by it.
- The point through which the buoyancy force acts is known as the centre of buoyancy (CB) and is at the centre of gravity of the displaced fluid.
- In gravity dam, the overturning moment due to hydrostatic pressure is resisted by stabilizing moment

by weight of the dam and weight of the wedge-shaped water body supported by upstream side face.

- In arch dams the overturning moment by hydrostatic pressure is resisted by end thrust.
- Pipes subjected to internal pressure p are subjected to hoop tension $s = \frac{pr}{t} = \frac{pd}{2t}$.
- If B is the centre of buoyancy and G is the centre of gravity of a submarine, the submerged body is in:

  1. Neutral equilibrium when B and G coincide and B lies above G.
  2. Stable equilibrium, if slight rotational displacement generates the forces which oppose the change of position and tend to bring the body to its original position.
  3. Unstable equilibrium if G lies above B.

- The intersection of line of action of buoyancy force with the axis of symmetry of floating body is known as metacentre.
- If meracentre lies between centre of gravity G and centre of buoyancy B tilting of vessel progresses.
- The distance between centre f gravity G and metacentre M is called metacentric height. If metacentric height is positive (M above G) it is the condition of stable equilibrium.
- The initial metacentric height for a passenger steamer varies from 300 to 600 mm while for naval vessel it varies from 900 to 1200 mm.
- For a floating cylinder metacentre is zero.
- A vessel with sides diverging upwards has better stability.

9.2 KINEMATICS OF FLUID MOTION

- Study of motion of fluid particles with respect to coordinates fixed at a point is called Eulerian method of study.
- Study of motion of fluid particles w.r.t. coordinates fixed on a moving boat is known as Lagrangian method of study.
- In Eulerian method

$$v = f(x, y, z, t)$$
$$p = f(x, y, z, t)$$
$$r = f(x, y, z, t).$$

- In case of steady flow velocity, pressure, acceleration and density, etc., do not change with time.
- In case of unsteady flow above variable at a point may change with time.
- If the velocity vector at all points in the flow is same at any instant of time, the flow is known as uniform. The flow is known as non-uniform if the velocity vector varies from point to point at any instant of time.
- Depending upon the existence of flow characters the flow may be classified as one, two-and three-dimensional flow.
- In laminar flow, the fluid particles move along, regular paths which can be predicted well in advance. It is also known as streamline flow.

- In turbulent flow, the fluid particles are characterized by random and erratic movement resulting into formation of eddies.

- A streamline is an imaginary line drawn in a flow field such that a tangent drawn at any point on this line represents the direction of velocity vector.
- A pathline is the locus of a fluid particle as it moves along.
- A streakline connects all particles passing through a given point. It can be traced by injecting a dye in the liquid.
- The position of a streamline at a given instant of time is known as instantaneous streamline. In case of time-dependent flow, it may keep on changing.
- For incompressible fluid, the continuity equation is

$$Q = A_1 V_1 = A_2 V_2$$

- For compressible fluid, the continuity equation is

$$Q = r_1 A_1 V_1 = r_2 A_2 V_2$$

- The continuity equation for three-dimensional steady flow of incompressible fluid is

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0$$

$$\text{i.e., } \frac{\partial^2 \phi}{\partial x^2} + \frac{\partial^2 \phi}{\partial y^2} + \frac{\partial^2 \phi}{\partial z^2} = 0$$

where f is the velocity potential.

- The flownet is graphical representation of two-dimensional irrotational flow and consists of a family of streamlines intersecting orthogonally a family of equipotential lines.
- Uses of flownet are

1. For a given boundary of flow, the velocity and pressure distribution can be determined, if velocity distribution and pressure at any reference section are known.
2. Uplift pressure on the underside of the dam can be calculated.
3. Outlets can be designed for their streamlining.
4. Loss of flow due to seepage in earth dams and unlined canals can be evaluated.

- Fluid motion in which the streamlines are concentric circles is known as the vortex.
- It there is no-rotation of fluid particles about their respective mass centre, the vortex is irrotational or free vortex. If the fluid particles undergo rotation about their mass centres, the resulting vortex is known as the forced vortex.

9.3 DYNAMICS OF FLUIDS

- The science that considers the forces causing flow also is known as dynamics of fluids/kinetics of fluids.
- The fundamental transport phenomena associated with the motion of fluid are:

1. mass transport
2. heat transport
3. momentum transport.

Mass Transport

- All fluid motions satisfy the principles of conservation of matter.
- A homogeneous fluid is the one which exists throughout the region of interest as a single species.
- Non-homogeneous fluids are characterized by variation in the amount of one substance relative to another from point to point. A canal carrying sediment laden water is an example of non-homogeneous, two-phase flow. In case of non-homogeneous fluid, the principle of conservation of matter must be satisfied for each component.

Heat Transport

- It deals with transport of heat by fluid.
- In this principle of conservation of energy (known as the first law of thermodynamics) is the basic principle.

Momentum Transport

Momentum transport phenomena are of interest in fluid mechanics since they deal with mechanics of fluid resistance, shear stresses and propulsion and forces on immersed bodies. Newton's second law of motion provides the fundamental relation between resultant of forces and time rate of change of its momentum.

9.4 LAWS OF MECHANICS

Newton's Laws of Motion

First law Every body remains in its state of either rest or of uniform motion unless its state is changed by external forces impressed upon it.

$$\text{S}F = 0, \text{S}M = 0.$$

Second law The rate of change of momentum is proportional to the impressed force and takes place in the direction of that force.

$$F = \frac{d}{dt}(mv) = m\frac{dv}{dt} = m.a.$$

The momentum may be linear or angular.

Third law To every action there is always an equal and opposite reaction.

Laws of Thermodynamics

First law The change in total energy DE of a system is equal to the amount of heat dQ added to the system to the system minus the work dW done by the system.

$$\text{D}E = dQ - dW$$

Second law The change of entropy equals or exceeds the heat exchange divided by absolute temperature.

$$\text{D}s \geq \frac{\delta Q}{T}$$

Equations of Motion

In a fluid flow the following type of forces may be present.

1. Gravity force, F_g. 2. Pressure force, F_p.

3. Force due to viscocity, F_u. 4. Force due to turbulence, F_t.

5. Force due to compressibility, F_c.

• Thus, from Newton's second law

$$ma_x = (F_g)_x + (F_p)_x + (F_v)_x + (F_t)_x$$

when a small force due to compressibility is neglected.

• When expressions involved in the above equation and other similar equations are substituted, the resulting equations are known as Reynolds equations.

• For flow at low Reynolds number, the force due to turbulence is neglected. Hence,

$$ma_x = (F_g)_x + (F_p)_x + (F_v)_x$$

This equations is known as *Navier–Stokes equation*.

• If the flow is assumed to be ideal, i.e., possesses no viscocity, equation is known as *Euler's equation* for motion. In this case

$$ma_x = (F_g)_x + (F_p)_x$$

• Bernoulli equation is obtained by integrating the Euler's equation of motion. It states that for a steady, ideal flow of an incompressible fluid, the total energy at any point of the fluid is constant. Thus

$$\frac{p_1}{\rho g} + \frac{V_1^2}{2g} + Z_1 = \frac{p_2}{\rho g} + \frac{v_2^2}{2g} + Z_2.$$

• Actually slight energy is lost in overcoming resistance to flow due to viscocity and surface roughness and turbulance. This energy lost is given by

$$h_i = \frac{u_2 - u_1 - q}{g}$$

• Bernoulli equation finds its applications in

1. Pitot tube
2. Venturimeter
3. Orifice meter.

Pitot tube The pitot tube is used to measure velocity of flow in pipes. In using it, a piezometer is also required. A piezometer installed on the pipe boundary gives static pressure. The pitot tube having a 90° bend of shorter length is directed upstream. On account of stagnation pressure so caused, the liquid rises in the vertical limb. It h is the difference between piezometer and vertical limb of pitot tube,

$$v = \sqrt{2gh}$$

Venturimeter A venturimeter is a device for measuring rate of flow in a pipeline.

It consists of:

1. a converging enterance cone of angle about 20°.
2. a cylindrical portion of short length, known as throat.
3. a diverging part, known as diffuser, of cone angle 5° to 7°.

The discharge through venturimeter is given by

$$Q = C_d \frac{A_1 A_2}{\sqrt{A_1^2 - A_2^2}} \times \sqrt{2gh}$$

- To get uniform flow, free from turbulence, venturimeter should be preceded by straight pipe (from valve, bend, etc.) for a length of not less than 50 times its diameter.
- coefficient of discharge C_d depends upon:
  1. inside roughness and Reynolds number of pipe
  2. diameter ratio d_2/d_1
  3. placement of pipe fittings

Orifice flow Orifice is the opening through which reservoir water flows. The reservoir is very large compared to the size of opening. Hence, the velocities of all points in the reservoir are negligibly small. Therefore the velocity of flow in the jet is

$$V = \sqrt{2gh}$$

This equation is known as Torricelli's theorem.

- Trajectory of Free-Jet: If nozzle is directed at angle q to the horizontal, the water particles move in the from of projectiles.
  1. The path traced is parabolic
  2. $h_{\max} = \frac{(V_1)_z^2}{2g}$
- In Navier–Stokes equation the normal stresses and shear stresses in all the three directions are considered (s_x, s_y, s_z, t_{xy}, t_{yz}, t_{zx}).
- Since shearing stresses are considered, Navier-Stoles equation is applicable to viscous- fluids also.
- Owing to the mathematical complication of Navier-Stokes equation, the general solution of these equations are not possible. Only a few limiting cases have been analysed.

Boundary Layer Flow

- Viscous fluid satisfies no-slip boundary condition at the solid boundary. If the boundary is at rest like in case of a pipe, the velocity of fluid must reduce to zero at the boundary surface. As a result velocity gradient is developed.
- The region within which the effect of viscocity are confined is the boundary layer.
- The motion of fluid with very little friction (at very large Reynolds number) Prandtl made the following observations:

1. Viscous effects are confined to a very thin layer, called boundary layer.
2. The flow outside the boundary layer can be considered frictionless or ideal.

- The boundary layer nominal thickness is defined as the distance of the boundary where velocity of fluid particle is very close to free stream velocity (0.99 × free stream velocity).
- The displacement thickness *d** may be defined as 'the distance, measured perpendicular to the boundary, by which the free stream is displaced on accent of formation of boundary layer'.

or

It is an additional 'wall thickness' that would have to be added to compensate for the reduction in flow rate on account of boundary layer formation.

- The momentum thickness (*q*) is the ratio of actual moment transport to momentum transport through the free-stream velocity.
- The ratio of displacement thickness to momentum thickness is called the shape factor.

$$H = \frac{\delta^*}{\theta}.$$

- The energy thickness (*de*) is the thickness of fluid moving with a free velocity that represents the loss of energy transport rate of actual fluid.

Laminar Flow

- The laminar motion of fluid is characterised by the motion in layers (i.e., laminar), parallel to the boundary surface.
- The conditions favourable for laminar flow are:
  1. High viscocity (*m*)
  2. Low mass density (*r*)
  3. Low mean velocity (*V*)
  4. Small flow passage (*L*)
- Hence, dimensionless parameter $\frac{\rho VL}{\mu}$ provides a criterion for ascertaining the type of flow. This term $\frac{\rho VL}{\mu}$ is known as Reynolds number.
- A laminar flow becomes unstable and tends to change over to turbulent as the Reynolds number increases.
- If Reynolds number is less than about 2000, the flow is laminar. For higher values the flow becomes turbulent.
- The characteristic length is usually taken as:
  1. Diameter *d* in case of circular pipes
  2. Spacing *b* of plates in case of flow through parallel plates
  3. Depth of flow *y* in case of flow in wide open channels
  4. Diameter of spheres in case of flow about a sphere.
- The devices which are used for viscocity measurement are based on the principle of existence of fully established laminar flow.

• The devices used for the measurement of viscocity are known as 'viscometers' or 'viscometer'

Types of viscometers:

1. Capillary tube viscometer
2. Concentric cylinder viscometer
3. Falling cylinder viscometer
4. Ostwald viscometer.
5. Sayholf viscometer.

• Flow through porous media is a case of laminar flow through small irregular passages.

• Porous media flow is characterized by low velocity, high pressure drops and very small pore diameters and hence it is laminar flow.

• For flow through porous media Darcy's law may be used.

9.5 TURBULENT FLOW IN PIPES

In case of turbulent flow Reynolds found that the loss in pressure head is proportional to V^n where V is mean velocity and n varies from 1.75 to 20. Transition from laminar to turbulent flow depend upon pipe diameter and the physical properties of the fluid also.

• The factors which affect the transition from laminar to turbulent flow are:

1. Turbulence prevailing in the incoming fluid.
2. The pressure gradient: For accelerated flow $\left(\frac{dp}{dx}<0\right)$ critical Reynolds number increases whereas for retarded flow $\left(\frac{dp}{dx}>0\right)$, critical Reynolds number decreases.
3. The roughness of boundary decrease the critical Reynolds number.

• Below a critical Reynolds number all disturbances are suppressed by viscous damping while above the critical Reynolds number certain frequencies will be amplified and others damped.

• According to Darcy-Weisbach equation, the loss of head due to friction in the pipe is given by

$$h_f = \frac{4fLV^2}{2gd}$$

where f = Friction factor

L = Length of pipe

V = Mean velocity of liquid

D = Diameter of pipe

• Major loss of head is due to friction.

• Minor losses of head included the following cases.

1. Loss of head due to sudden enlargement

$$h_e = \frac{(V_1 - V_2)^2}{2g} = \frac{V_2^2}{2g}\left(\frac{A_2}{A_1} - 1\right)^2$$

Since from the continuity equation $V_1A_1 = V_2A_2$.

2. Loss due to sudden contraction $h_c = \frac{V_2^2}{2g}\left[\frac{1}{C_c} - 1\right]$

where C_c = Coefficient contraction = $\frac{A_c}{A}$.

3. Loss of head at the inlet (entry loss):

$$h_i = 0.5\ \frac{V_2^2}{2g}$$

4. Loss of head at the outlet of pipe (exit loss)

$$h_o = \frac{V^2}{2g}$$

5. Loss of head in pipe fittings

$$h_L = K_L \frac{V^2}{2g}$$

where K_L is loss coefficient.

- The line representing the sum of pressure head and datum head w.r.t. some reference line is called hydraulic gradient line (H.G.L).
- The line representing the sum of pressure head, datum head and velocity head w.r.t. some reference line is known as total energy line (T.E.L).
- The losses in pipe fittings are expressed is terms of an equivalent length which is a length of an unobstructed straight pipe in which an equal loss of energy due to friction would occur for the same discharge.

$$L_{eq} = K_L \frac{d}{f}$$

- A pipe of length L_1, diameter d_1 and friction factor f_1 is equivalent to a pipe of length L_2, diameter d_2 and friction factor f_2, if $\frac{f_1 L_1}{d_1^5} = \frac{f_2 L_2}{d_2^5}$.
- The equivalent size of the pipes connected in series is given by

$$\frac{L}{d^5} = \frac{L_1}{d_1^5} + \frac{L_2}{d_2^5} + \frac{L^3}{d_3^5} + \cdots$$

where $L = L_1 + L_2 + L_3 \ldots$ = Equivalent length

d = Equivalent size

$d_1, d_2, d_3 \ldots$ = Diameters of pipes connected

- The rate of discharge in the main pipe is equal to the sum of discharges in each of the parallel pipes.

$$Q = Q_1 + Q_2 + \ldots$$

and the loss of head in each pipe is same $h_{f1} = h_{f2}$ i.e. $\frac{4 f_1 L_1 V_1^2}{2gd_1} = \frac{4 f L_2 V_2^2}{2gd_2}$

• A syphon is a long bent pipe which carries liquid from higher level to a lower level through an intermediate high obstruction.

Water Hammer

• When the valve at the end of the pipe is suddenly closed a pressure wave of high intensity is produced in the fluid which has the effect of hammering action on the walls of the pipe. This phenomenon is known as water hammer.

• The magnitude of the water hammer depends upon:

1. The length of the pipe
2. The elastic properties of pipe material
3. The elastic properties of the liquid flowing
4. The speed at which valve is closed.

Thus,

$p_i = \frac{\delta LV}{t}$, if valve is closed gradually

$= V\sqrt{K\rho}$, if valve is closed suddenly

$= V\sqrt{\frac{\rho}{1/k + D/Et}}$, if valve is closed suddenly and pipe is elastic.

where L = Length of pipe

V = Velocity of flow

K = Bulk modulus of fluid

E = Modulus of elasticity of pipe material

D = Diameter of pipe

T = Time for closing valve.

• The valve closure is said to be gradual

If, $t > \frac{2L}{C}$

where C = velocity of pressure wave produced due to water hammer = $\sqrt{K/\rho}$.

Flow through Open Channels

• The flow in an open channel is characterized by the existence of a free surface and interfaces being subjected to a constant pressure throughout its length and breadth.

• A sewer under ordinary condition of flow behaves as an open channel and a channel under pressure when sewer runs full at times of heavy rains.

• The flow in open channels is at the expense of potential energy and the flow is caused by gravity force provided by the sloping bottom.

• The open channels may have various shapes, like triangular, rectangular, trapezoidal circular or any irregular.

- The surface roughness in open channels varies over wide limits.
- The piezometric head in open flow is $Z + y$ where y is depth of flow and Z is datum head where as in pipe flow it is $Z + \frac{p}{r}$.
- If Froude number in channel flow is
  1. less than 1, the flow is said to be subcritical
  2. equal to 1, the flow is known as critical
  3. more than 1, the flow is called supercritical
- Manning's formula used in open channel flow is

$$V = \frac{1}{n} R^{2/3} S^{1/2}$$

where, V = Mean velocity in m/sec

R = Hydraulic radius in metre

S = Channel slope

n = Pugosity coefficient

- A relation between the Chezy's C and Mannings n is

$$C = \frac{1}{n} R^{1/6}$$

- Most economical section of channel is the one which
  1. Gives maximum discharge for a given cross-sectional area and bed slope.
  2. Has minimum wetted perimeter.
  3. Involves lesser excavation for the designed amount of discharge.
- For a trapezoidal channel to be most efficient hydraulic radius R is equal to half the depth of flow.
- In an efficient rectangular channel the flow depth is half the bed width B and hydraulic radius R is half of flow depth.
- The optimum inclination of the sides of a channel is 60° to horizontal for a given area and flow depth.
- A semicircular channel is theoretically the most efficient channel for getting maximum discharge for a given cross-sectional area and bed slope.

Non-Uniform Flow

- The specific energy is the energy per unit weight of flowing fluid measured above the channel bottom and is equal to the depth of flow plus the velocity head.

$$E = y + \frac{V^2}{2g}$$

- The depth of water in a channel corresponding to the minimum specific energy is known as critical depth.
- At the critical state of flow, the specific energy in a rectangular channel is equal to 1.5 times the depth of flow.

- In case of a rectangular channel with discharge q per unit width, critical depth is $\left(\frac{q^2}{g}\right)^{3/2}$.
- When the flow is critical, the discharge per unit width is maximum for a given specific energy.
- A venturiflume is essentially an artificial construction in a channel which by producing a change in velocity and depth, facilitates the measurement of flow rate. A venturiflume in its conventional from consists of a bell mouthed entry, parallel throat and a diverging portion in the downstream.
- The coefficient of venturiflume, generally lies between 0.91 and 0.99.
- At the critical depth, both specific energy and specific force attain minimum values.

Flow Measurements

- For pipeline flow measurement, any of the following devices can be used:
  1. Venturimeter
  2. Nozzle meter
  3. Orificemeter
  4. Bend meter
- For measurement of flow in open channels is generally by means of weirs and gates.
- In large open channels and rivers the flow is estimated by dividing the flow section into a number of smaller sections and determining the average velocity for each by means of current meter.
- In venturimeter if A_1 and A_2 are inlet and outlet sectional areas, h is the difference in the piezometric head,

$$Q = \frac{C_d A_1 A_2}{\sqrt{A_1^2 - A_2^2}} \sqrt{2gh}$$

$$= K\sqrt{h}$$

where k is venturimeter constant for a particular meter.

- Nozzle meter is simply a construction with well rounded entrance placed in the pipeline. It is simpler than a venturimeter.
- In its simplest and most familiar form, the orifice is a circular hole in a flat plate which is fixed between the flanges at a joint in the pipeline with its plane at right angles to the axis of the pipe and the hole concentric with the pipe . If plate is thicker, on the outlet side edge the hole is champered. Measuring pressure on both sides of the gauge help in determining the flow.
- The bend meter utilizes the fact that in a curved flow pressure increases with radius and hence a pressure difference exists between the outer and inner wall of the bend.
- A short pipe equal to the size of the orifice connected to orifice is known as mouthpiece. It usually extends downstream by not more than 2.5 times the diameter of orifice. It may be cylindrical, converging or diverging type.
  1. For cylindrical mouthpiece, rounding the entrance greatly reduces the losses.
  2. For converging and diverging type of mouthpieces coefficient of discharge depends upon the angle of convergence/divergence.

3. For maximum discharge to pass through a diverging mouthpiece, its length should be equal to 9 times its diameter and the angle of divergence be equal to 5°.

- Weir is an obstruction in the channel which causes the liquid to rise behind it and then allows to flow over it. By measuring the height of upstream liquid surface, the flow rate can be determined.
- The jet of liquid over the weir, so formed is known as 'nappe'.
- If nappe springs freely leaves the upstream face, the weir is known as strap-crested weir.
- The broad crested weirs are those which support the falling nappe over their crest.
- The weirs may be rectangular, triangular, trapezoidal, etc.
- When the liquid level downstream of weir is above its crest level, the weir is said to be a submerged weir.
- According to Francis formula, the discharge over a rectangular weir is

$$Q = \frac{2}{3} C_d (B - 0.1\, n\mathrm{H}) \sqrt{2g}\, H^{3/2}$$

where n = Number of contractions

B = Length of weir

- In case of a triangular notch discharge varies as $H^{5/2}$, i.e., $Q = KH^{2.5}$.
- Cipoletti weir is a trapezoidal weir in which the sides have a slope of 1 horizontal to 4 vertical. Advantage of Cipoletti weir is that the decrease in discharge due to end contraction is balanced by the discharge through the triangular portion and hence rectangular weir formula can be used to find out discharge.

MULTIPLE-CHOICE QUESTIONS

I. *Select correct options from the list given below each item.*

1. Mass per unit volume is known as
   (a) density
   (b) specific gravity
   (c) specific weight
   (d) specific volume.

2. The reciprocal of the density is known as
   (a) specific gravity
   (b) specific weight
   (c) specific volume
   (d) none of these

3. The most important property which influences the fluid motion to a great extent is
   (a) density
   (b) specific weight
   (c) specific volume
   (d) viscocity

4. The rate of shear strain of fluid is known as

(a) shear modulus
(b) hydraulic gradient
(c) velocity gradient
(d) all the above

5. Newton's law of viscocity states that shear stress is directly proportional to
(a) velocity
(b) shear strain
(c) velocity gradient
(d) viscocity

6. A Newtonian fluid is defined as the fluid which
(a) is highly viscous
(b) is compressible and non-viscous
(c) is incompressible and viscous
(d) obeys Newton's law of viscocity

7. A general relationship between shear stress and velocity gradient for non-Newtonian fluid may be written as

$$t = A\left(\frac{du}{dy}\right)^n + B$$

If in the above relation, $n > 1$, the fluid is classified as
(a) dilatant
(b) Bingham plastic
(c) pseudoplastic
(d) none of these.

8. An ideal fluid is defined as the fluid which is
(a) compressible
(b) incompressible
(c) compressible and viscous
(d) incompressible and non-viscous

9. Kinematic viscocity is equal to
(a) dynamic viscocity × density
(b) dynamic viscocity × pressure
(c) dynamic viscocity/density
(d) dynamic viscocity/pressure

10. Dimension of dynamic viscocity is
(a) MLT^{-1}
(b) $ML^{-1}T^{-1}$
(c) MLT^{-2}
(d) ML^2T^{-1}

11. The viscocity of a fluid is considered to be composed of
(a) intermolecular cohesion

(b) transfer of molecular momentum
(c) both (a) and (b)
(d) none of (a) and (b)

12. The viscocity of gases
(a) changes with temperature but is practically unaffected by pressure.
(b) practically unaffected by temperature but very much affected by pressure.
(c) affected considerably by temperature and pressure.
(d) unaffected by temperature and pressure.

13. Stoke is the unit of
(a) dynamic viscocity
(b) kinematic viscocity
(c) specific volume
(d) specific weight

14. 1 stoke is equal to
(a) 1 m^2/sec
(b) 1×10^{-2} m^2/sec
(c) 1×10^{-3} m^2/sec
(d) 1×10^{-4} m^2/sec

15. Which one of the following is the wrong statement about capillarity?
Magnitude depends upon
(a) the diameter of tube
(b) the specific weight of the liquid
(c) its surface tension
(d) its viscocity.

16. Surface tension is a
(a) line force
(b) force per unit surface area
(c) force per unit volume
(d) all the above

17. The unit of surface tension is
(a) N
(b) N/m
(c) N/m^2
(d) N/m^3.

18. The property of water to wet a solid surface when it comes in contact is known as
(a) surface tension
(b) viscocity
(c) capillary action
(d) vapour pressure.

19. The angle of contact q between water and solid surfaces is equal to

(a) 0°

(b) 30°
(c) 60°
(d) 90°

20. The angle of contact between mercury and solid surface is
(a) 0°
(b) 45°
(c) 90°
(d) more than 90°

21. Boiling of liquid can be achieved by either
(a) raising the temperature
(b) lowering the pressure of overlaying air below the vapour pressure
(c) either (a) or (b)
(d) none of the above.

22. 1 pascal pressure is equal to
(a) 1 m water pressure
(b) 10.01 m water pressure
(c) 0.0001 m water pressure
(d) None of the above

23. The reciprocal of coefficient of compressibility is known as
(a) viscocity
(b) capillary action
(c) vapour pressure
(d) bulk modulus of elasticity

24. Falling drops of water become spherical due to
(a) surface tension
(b) capillary action of water
(c) compressibility of water
(d) viscocity of water

25. The intensity of pressure at any point in a liquid is
(a) w
(b) wh
(c) $\frac{w}{h}$
(d) h/w

where w = specific weight
h = depth of liquid from the surface.

26. The ratio of the velocity of flow V to the velocity of sound in the fluid medium is known as
(a) Fraude number
(b) Mach number
(c) Newton number

(d) coefficient of viscocity

27. The atmospheric pressure at sea level is
   (a) 360 mm of mercury
   (b) 600 mm of mercury
   (c) 760 mm of mercury
   (d) 960 mm of mercury.

28. Gauge pressure is
   (a) pressure measured above complete vacuum
   (b) absolute pressure + local atmospheric pressure
   (c) absolute pressure – local atmospheric pressure
   (d) none of the above.

29. For measuring small difference of pressure
   (a) simple manometer is preferred
   (b) differential manometer is advantageous
   (c) micromanometer is used
   (d) mercury manometers are used

30. Inclined manometer is used for precise measurement of small pressure in
   (a) low velocity gas flow
   (b) in high velocity gas flow
   (c) in high velocity water flow
   (d) in low velocity water flow

31. If l is inclined length of pressure difference and h is vertical depth of pressure difference the amplification is
   (a) $\frac{l}{h}$
   (b) h/l
   (c) $\tan^{-1} l/h$
   (d) $\tan^{-1} \frac{h}{l}$.

32. A submerged body is subjected to a buoyancy equal to the weight of the fluid displaced by it. This principle is known as
   (a) Newton's principle
   (b) Archimedes' principle
   (c) Bourden's principle
   (d) none of the above

33. The gravity dam of height h is subjected to a overturning moment of _______ per metre length.
   (a) $\frac{1}{6}gh^3$
   (b) $\frac{1}{3}gh^2$
   (c) $\frac{1}{6}gh^2$

(d) $\frac{1}{2}gh^2$

34. Pipes subjected to internal pressure p are subjected to hoop tension ______ where t is the thickness and r is radius of pipe.

(a) $\frac{pr}{2t}$

(b) $\frac{pr}{t}$

(c) $\frac{pr^2}{2t}$

(d) $\frac{pr^2}{t}$

35. The intersection of line of action of buoyancy force with the axis of symmetry of floating body is known as

(a) centre of buoyancy
(b) centre of gravity
(c) metacentre
(d) all the above

36. If centre of gravity G lies above the centre of buoyancy B, the submarine is in

(a) neutral equilibrium
(b) stable equilibrium
(c) unstable equilibrium
(d) dynamic equilibrium

37. For a floating cylinder metacentre is

(a) –ve
(b) zero
(c) +ve
(d) both (a) or (b) depending upon diameter.

38. A floating vessel has better stability if its sides.

(a) diverge upward
(b) straighten upward
(c) convert upward
(d) both (b) and (c).

39. In case of steady flow ______ change with time

(a) displacement
(b) velocity
(c) pressure
(d) all the above

40. The flow is known as uniform if ______ is same at any instant.

(a) pressure
(b) velocity

(c) velocity gradient
(d) acceleration

41. Unsteady flow occurs when
(a) the velocity change from place to place.
(b) the velocity at a given point changes from time to time
(c) the flow fluctuates but the average values of flow parameters remain same.
(d) none of the above.

42. If the velocity vector varies from point to point at any instant of time the flow is known as
(a) unsteady flow
(b) non-uniform flow
(c) turbulent flow
(d) all of these

43. A flow in which the quantity of liquid flowing per second is constant is called
(a) steady flow
(b) streamline flow
(c) unsteady flow
(d) turbulent flow

44. A flow in which each liquid particle has a definite path and the paths of individual particles do not cross each other is called
(a) steady flow
(b) uniform flow
(c) streamline flow
(d) all the above

45. A flow in which streamline is represented by a straight line is called ______ dimensional flow.
(a) one
(b) two
(c) three
(d) multi

46. The line that connects all particles passing through a point is known as
(a) streamline
(b) pathline
(c) streakline
(d) all the above.

47. ______ can be traced by injecting a dye in the flowing liquid.
(a) Streamline
(b) Pathline
(c) Streakline
(d) all the above

48. If f is velocity potential, and u is the velocity in x direction, then
(a) $u = f$

(b) $u = \frac{\partial \phi}{\partial x}$

(c) $u = \frac{\partial^2 \phi}{\partial x^2}$

(d) $f = \frac{\partial u}{\partial x}$

49. Equipotential lines intersect streamlines at
(a) acute angles
(b) 90°
(c) obtuse angles
(d) any of the above

50. Using flownets
(a) uplift pressure on dam can be found.
(b) outlets can be designed for their streamlining.
(c) loss of flow due to seepage in earth dam can be evaluated.
(d) all the above.

51. In irrotational flow
(a) the fluid does not rotate as it moves along.
(b) the net rotation of fluid particles about their mass centre remains zero.
(c) the streamlines are curved and closely spaced.
(d) none of the above

52. The science that considers the forces causing flow of fluids is known as
(a) statics of fluid
(b) kinematics of fluid
(c) dynamics of fluid
(d) none of these

53. The fundamental transport phenomenon associated with the motion of fluid
(a) is mass transport
(b) is heat transport
(c) momentum transport
(d) all the above

54. In Reynolds equation
(a) no force is neglected.
(b) only force of compressibility is neglected.
(c) both force of compressibility and force of turbulence are neglected.
(d) forces of compressibility, turbulence and velocity are neglected.

55. In Navier–Stroke equation
(a) no force is neglected.
(b) only force of compressibility is neglected.
(c) both force of compressibility and force of turbulence are neglected.
(d) forces of compressibility, turbulence and velocity are neglected

56. In Euler's equations
(a) no force is neglected.
(b) only force of compressibility is neglected.
(c) both force of compressibility and force of turbulence are neglected.
(d) forces of compressibility, turbulence and velocity are neglected.

57. The term $\frac{v^2}{2g}$ is known as

(a) kinematic energy
(b) kinetic energy
(c) kinetic energy per unit weight
(d) none of the above

58. The term $\frac{p}{\rho g}$ is known as

(a) potential energy
(b) pressure energy
(c) pressure energy per unit weight
(d) none of the above

59. The term z in total energy expression

$\frac{p}{\rho g}+\frac{v^2}{2g}+z$ is

(a) potential energy
(b) pressure energy
(c) potential energy per unit weight
(d) none of the above

60. Head lost between two points 1 and 2 in fluid flow is given by

(a) $\frac{u_2-u_1-q}{g}$
(b) $\frac{u_2-u_1+q}{g}$
(c) u_2-u_1-q
(d) u_2-u_1+q

where u_2, u_1 are velocities of flow, q is heat transfer

61. Bernoulli equation finds its application in
(a) pitot tube
(b) venturimeter
(c) orifice meter
(d) all the above

62. If h is the difference between piezometer and vertical limb of pitot tube, velocity is

(a) $2gh$
(b) $\sqrt{2gh}$

(c) $\frac{h^2}{g}$

(d) $\frac{h^2}{2g}$

63. In a venturimeter, entrance cone is having
(a) converging angle of 20°
(b) converging angle of 5° to 7°
(c) diverging angle of 20°
(d) diverging angle of 5° to 7°

64. A venturimeter is having a exit cone of
(a) diverging angle 20°
(b) diverging angle of 5° to 7°
(c) converging angle of 20°
(d) converging angle of 5° to 7°

65. Venturimeter is a device based on
(a) Euler's equation
(b) Reynolds equation
(c) Navier–Stokes equation
(d) Bernauli's principle

66. The discharge through venturimeter is given by

(a) $Q = C_d \frac{A_1 A_2}{A_1^2 - A_2^2} \sqrt{2gh}$

(b) $Q = C_d \frac{A_1 A_2}{\sqrt{A_1^2 - A_2^2}} \sqrt{2gh}$

(c) $Q = C_d \frac{\sqrt{A_1 A_2}}{A_1^2 - A_2^2} \sqrt{2gh}$

(d) $\sqrt{\frac{A_1 A_2}{A_1^2 - A_2^2}} \sqrt{2gh}$

67. Venturimeter should be preceded by a straight portion of the pipe of length ______ times the diameter
(a) 25
(b) 50
(c) 75
(d) 100

68. The coefficient of discharge in a venturimeter depends upon
(a) roughness of inner portion of pipe
(b) diameter ratio d_2/d_1
(c) nearness of placement of fittings
(d) all the above

69. The velocity of flow in a orifice is $V = \sqrt{2gh}$. This equation is known as

(a) Euler's equation
(b) Bernoulli equation
(c) Navier–Stokes equation
(d) Torricelli's equation

70. Trajectory of a free jet is
(a) circular curve
(b) parabola
(c) catenery
(d) elliptic curve

71. The maximum height reached by a free jet with initial vertical velocity $(V_1)_z$ is
(a) $\frac{(V_1)_z}{g}$
(b) $\frac{(V_1)_z^2}{g}$
(c) $\frac{(V_1)_z}{2g}$
(d) $\frac{(V_1)_z^2}{2g}$

72. The dynamics of fluid in which normal stresses and shear stresses in all the three mutually perpendicular directions is considered is known as
(a) Navier-Stokes theory
(b) Reynolds theory
(c) Bernoulli's theory
(d) Euler's theory

73. The region within which the effect of viscocity is confined is known as
(a) cavitation
(b) stagnation layer
(c) boundary layer
(d) free layer

74. The nominal thickness of boundary layer may be considered the distance between the solid boundary and the layer where the velocity of fluid particles is _______ of free stream velocity.
(a) 90%
(b) 95%
(c) 99%
(d) 100%

75. The ratio of displacement thickness to momentum thickness is called
(a) viscocity factor
(b) shape factor
(c) factor of safety
(d) none of the above.

76. The conditions favourable for laminar flow are
(a) high viscocity

(b) low mass density

(c) low mean velocity

(d) all the above

77. If viscocity is *m*, mass density is *r*, mean velocity is *V* and characteristic length is *L*. Reynolds number is

(a) $\frac{\mu\rho V}{L}$

(b) $\frac{\mu\rho L}{V}$

(c) $\frac{\rho VL}{\mu}$

(d) $\frac{\mu VL}{\rho}$

78. The flow is laminar if Reynolds number is less than

(a) 1000

(b) 1500

(c) 2000

(d) 3000

79. In finding Reynolds number, the characteristic length of circular pipe is taken as

(a) d

(b) $2d$

(c) $5d$

(d) $10d$

where d is the diameter of pipe.

80. If b is the spacing of two parallel plates the characteristic length is usually taken as

(a) $0.1b$

(b) $0.5b$

(c) $0.75b$

(d) b

81. In case of flow about a sphere, the characteristic length is taken as

(a) $\frac{D}{L}$

(b) D

(c) $2D$

(d) $5D$

where D is the diameter of sphere

82. In case of flow in wide open channels, for finding Reynolds number, characteristic length taken is

(a) $0.5y$

(b) y

(c) $2y$

(d) $5y$

where y is the depth of flow.

83. The viscometer of _______ type may be used for measuring viscocity of fluids.

(a) capillary tube
(b) concentric cylinder
(c) falling cylinder
(d) any of the above

84. Industrial viscometers are

(a) Ostwald viscometer
(b) Saybolt viscometer
(c) Bernaulli's viscometer
(d) both (a) and (b).

85. Porous media flow is characterized by

(a) low velocity
(b) high pressure drops
(c) very small pore diameters
(d) all the above

86. In case of turbulent flow, the loss of pressure head is proportional to V^n where V is mean velocity and n is from

(a) 1.0 to 1.5
(b) 1.75 to 2.0
(c) 2.25 to 2.5
(d) 2.75 to 3.0

87. The factors which affect the transition from laminar to turbulent flow are

(a) turbulence in the incoming fluid
(b) the pressure gradient
(c) the roughness of the boundary
(d) all the above.

88. According to Darcy-Weihach, the loss of head due to friction in the pipe is given by

(a) $h_f = \frac{4fLV^2}{2gd}$

(b) $\frac{4fLd^2}{2gV}$

(c) $h_f = \frac{4fLV^2}{gd}$

(d) $\frac{4fLd^2}{gV}$

where f = Friction factor L = Length of pipe

V = Mean velocity d = Diameter of pipe

89. Maximum loss of head in flow through pipe is due to

(a) sudden enlargement
(b) sudden contraction
(c) at outlet

(d) friction

90. If K_L is loss coefficient, V is velocity of flow and g is gravitational acceleration, loss of head in pipe fittings is

(a) $\frac{K_L V^2}{g}$

(b) $K_L \frac{V^2}{2g}$

(c) $\frac{K_L V}{g}$

(d) $K_L \frac{V}{2g}$.

91. A pipe of length L_1, diameter d_1 and friction factor f_1 is equivalent to a pipe of length L_2, diameter d_2 and friction factor f_2, if

(a) $\frac{f_1 L_1}{d_1^2} = \frac{f_2 L_2}{d_2^2}$

(b) $\frac{f_1 L_1}{d_1^3} = \frac{f_2 L_2}{d_2^3}$

(c) $\frac{f_1 L_1}{d_1^4} = \frac{f_2 L_2}{d_2^4}$

(d) $\frac{f_1 L_1}{d_1^5} = \frac{f_2 L_2}{d_2^5}$

92. If three pipes are connected in series,

(a) $\frac{L}{d^5} = \frac{L_1}{d_1^5} + \frac{L_2}{d^5} + \frac{L_3}{d^5}$

(b) $\frac{L}{d_1^4} = \frac{L_1}{d_1^4} + \frac{L_2}{d_2^4} + \frac{L_3}{d_2^4}$

(c) $\frac{L}{d^2} = \frac{L_1}{d_1^3} + \frac{L_2}{d_2^3} + \frac{L_3}{d_3^3}$

(d) $\frac{L}{d^2} = \frac{L_1}{d_1^2} + \frac{L_2}{d_2^2} + \frac{L_3}{d_3^2}$

where L and d are equivalent length and diameter while L_1, L_2, L_3 and d_1, d_2, and d_3 are length and diameter of connected pipes.

93. If a valve is closed gradually, the pressure built-in a pipe is

(a) $\frac{\rho L t}{V}$

(b) $\frac{\rho t V}{L}$

(c) $\frac{\rho L V}{t}$

(d) $\frac{L V t}{\rho}$

where r = unit weight of liquid, L = the length of pipe

V = velocity of flow t = time for closing value.

94. If a valve is closed suddenly, the pressure built in the pipe behind the valve is

(a) $p_i = V\sqrt{\frac{\rho}{\frac{1}{K} + D/Et}}$

(b) $p_i = V\sqrt{\frac{\rho}{K + EtD}}$

(c) $p_i = V\frac{\rho}{\frac{1}{K} + \frac{D}{Et}}$

(d) $p_i = V\frac{\rho}{(K + EtD)}$

where V = velocity of flow K = bulk modulus of fluid
D = diameter of pipe E = Young's modulus of material of pipe
t = time for closing valve.

95. The piezometric head in open channel is
(a) $z - y$
(b) $z + y$
(c) $z - y/2$
(d) $z + y/2$

96. If the Froude number in open channel flow is less than 1.0, the flow is known as
(a) subcritical
(b) critical
(c) supercritical
(d) none of the above

97. If the Froude number in open channel is 1.0, this flow is known as
(a) subcritical
(b) critical
(c) supercritical
(d) none of the above

98. If the Froude number in open channel is more than 1.0, the flow is known as
(a) subcritical
(b) critical
(c) supercritical
(d) none of the above

99. The Manning's formula used in open channel flow is

(a) $V = \frac{1}{n}R^{1/3}s^{2/3}$

(b) $V = \frac{1}{n}\sqrt{RS}$

(c) $V = \frac{1}{n}R^{2/3}s^{1/2}$

(d) $V = \frac{1}{n}RS$

where V = Mean velocity in m/sec

S = Channel slope

R = Hydraulic radius in m

n = Rugosity coefficient

100. A relation between Chezy's C and Mannings n is

(a) $C = \frac{1}{n} R^{1/2}$

(b) $C = \frac{1}{n} R^{1/3}$

(b) $C = \frac{1}{n} R^{1/5}$

(d) $C = \frac{1}{n} R^{1/6}$

101. The most economical section of a channel is the one which

(a) gives minimum discharge for a given cross-sectional area and bed slope.

(b) has minimum wetted perimeter.

(c) involves lesser excavation for the designed amount of discharge.

(d) all the above

102. A trapezoidal channel is most efficient if hydraulic radius is equal to ______ times the depth of flow

(a) $\frac{1}{3}$

(b) $\frac{1}{2}$

(c) $\frac{2}{3}$

(d) 1

103. In an efficient rectangular channel the flow depth y is ______ the bed width

(a) $\frac{1}{3}$

(b) $\frac{1}{2}$

(c) $\frac{2}{3}$

(d) equal to

104. In an efficient rectangular channel hydraulic radius R is ______ flow depth

(a) $\frac{1}{3}$

(b) $\frac{1}{2}$

(c) $\frac{2}{3}$

(d) equal to

105. For a given area and flow, optimum inclination of a channel is ______ to horizontal

(a) 90°
(b) 60°
(c) 45°
(d) 30°

106. The most efficient theoretical section to get maximum discharge for a given cross section is
(a) triangular
(b) rectangular
(c) trapezoidal
(d) circular

107. The discharge through a circular channel takes place when depth of flow is equal to ______ times the diameter
(a) 0.95
(b) 0.81
(c) 0.6
(d) 0.5

108. The maximum velocity through a circular channel takes place when depth of flow is equal to ______ times the diameter
(a) 0.95
(b) 0.81
(c) 0.6
(d) 10.5

109. The specific energy of the flow in a channel is equal to

(a) $y + \frac{V^2}{2g}$

(b) $\frac{y}{2} + \frac{V^2}{g}$

(c) $y - \frac{V^2}{2g}$

(d) $\frac{y}{2} - \frac{V^2}{g}$

where y = Depth of flow V = Velocity of flow

110. The depth of flow of water in a channel corresponding to the minimum specific energy is known as
(a) hydraulic radius
(b) critical depth
(c) hydraulic gradient line
(d) none of the above

111. At the critical state of flow, the specific energy in a rectangular channel is equal to ______ times the depth of flow.
(a) 1.0
(b) 1.5

(c) 2.0

(d) 2.5

112. In case of a rectangular channel with discharge q per unit width, critical depth is equal to

(a) $\frac{q^2}{g}$

(b) $\left(\frac{q^2}{g}\right)^{1.5}$

(c) $\left(\frac{q^2}{g}\right)^{2}$

(d) $\left(\frac{q^2}{g}\right)^{2.5}$

113. Which one of the following is not used for measuring flow in a pipe

(a) nozzle meter

(b) orificemeter

(c) bend meter

(d) venturiflume

114. Which one of the following is not used for measuring flow through open channel.

(a) gates

(b) weir

(c) orificemeter

(d) venturiflume

115. In an venturimeter, if A_1 and A_2 are inlet and outlet sectional areas, h is difference in the piezometric head, the discharge is given by

(a) $\frac{C_d A_1 A_2}{\sqrt{A_1^2 - A_L^2}} \sqrt{2gh}$

(b) $\frac{C_d A_1 A_2}{\sqrt{A_1^2 - A_2}} \sqrt{h}$

(c) $\frac{C_d}{\sqrt{A_1^2 - A_2^2}} \sqrt{2gh}$

(d) $\frac{C_d}{\sqrt{A_1^2 - A_2^2}} \sqrt{h}$

116. For maximum discharge to pass through a divergent mouthpiece, its length should be ______ times its diameter and the angle of divergence should be ______

(a) 4, 5°

(b) 9, 5°

(c) 4, 10°

(d) 9, 10°

117. According to Francis formula, the discharge over a rectangular weir is

(a) $Q = \frac{2}{3} C_d (B - 0.1\ nH) \sqrt{2g}\ H^{3/2}$

(b) $Q = \frac{1}{3} C_d (B - 0.1\ nH) \sqrt{2g}\ H^{5/2}$

(c) $Q = \frac{2}{3} C_d (B - 0.1\ nH) \sqrt{2g}\ H^{5/2}$

(d) $Q = \frac{1}{3} C_d (B - 0.1\ nH)\ H^{3/2}$

where n = Number of contractions
B = Length of weir

118. In case of a triangular notch,
(a) $Q = KH^{1.5}$
(b) $Q = KH^2$
(c) $Q = KH^{2.5}$
(d) $Q = KH^3$

119. Cipoletti weir is a type of trapezoidal weir in which the sides have a slope of
(a) 1 horizontal to 2 vertical
(b) 1 horizontal to 3 vertical
(c) 1 horizontal to 4 vertical
(d) 60° slope

II. *Match List I with List II, selecting the answer code given below each item No. 120–122*

120.

List I List II

A. Subsonic flow through a converging duct	1. Velocity increases and pressure decreases.
B. Supersonic flow through a converging duct.	2. Velocity increases and density decreases
C. Subsonic flow through a diverging duct	3. Velocity decreases and pressure, density and temperature increase
D. Supersonic flow through a diverging duct	4. Density increases and velocity decreases.

Codes:

(a)	A–4	B–2	C–1	D–3
(b)	A–2	B–4	C–3	D–1
(c)	A–3	B–2	C–4	D–1
(d)	A–4	B–3	C–1	D–2

121.

List I	List II
A. Vortex flow	1. A fluid motion in concentric circles.
B. Free vortex flow	2. The fluid particles moving in concentric circle, may not be rotating about their mass centre.
C. Forced vortex flow	3. Flow near a curved solid boundary.

D. Rotational flow 4. The fluid particles moving in concentric circle, may rotate.

Codes:

(a)	A–1	B–3	C–2	D–4
(b)	A–2	B–3	C–1	D–4
(c)	A–1	B–2	C–4	D–3
(d)	A–2	B–1	C–3	D–4

122.

List I	List II
A. Stream lines	1. Tracing of motion of any one fluid particle.
B. Streak lines	2. Identification of location number of fluid particle.
C. Path lines	3. Tracing of motion of different fluid particles.
D. Equipotential lines	4. Location of equal piezometric heads.

Codes:

(a)	A–3	B–2	C–1	D–4
(b)	A–2	B–3	C–1	D–4
(c)	A–3	B–4	C–1	D–2
(d)	A–4	B–3	C–2	D–1

III. *Select your answer according to the coding system given for the Assertion (A) and Reason (R) given below in the item Nos. 123 to 134.*

(a) Both A and R are true and R is the correct explanation of A.
(b) Both A and R are true but R is not the correct explanation of A.
(c) A is true but R is false.
(d) A is false but R is true.

123. Assertion: Surface tension decreases with the rise in temperature.
Reason: Surface tension depends directly upon the intermolecular cohesion.

124. Assertion: Most of the liquids completely wet the surface of a solid when they come in contact with solids.
Reason: The molecules of a solid surface attract liquid molecules with a greater force than that exists between the liquid molecules.

125. Assertion: Mercury does not wet the surface of solids with which it comes in contact.
Reason: Mercury has greater cohesion.

126. Assertion: Water tends to spread out and wet the surface of solids, when it comes in contact with them.
Reason: Adhesive force of water is greater than its cohesive force.

127. Assertion: Visocity of a fluid should be considered in analysis of static fluid.
Reason: In static fluid velocity gradient = 0.

128. Assertion: Simple monometers can be used for measuring small and moderate pressures only.
Reason: As the pressure gets higher, the length of piezometer becomes longer.

129. Assertion: Velocities of all points in a reservoir are considered zero for finding velocity of jet in orifice.
Reason: The reservoir is very large compared to the size of orifice.

130. Assertion: Novier–Stokes equations are not applicable to viscous fluids.
Reason: Navier–Stokes theory considers shearing stresses as well as normal stresses.

131. Assertion: These is velocity gradient in flow through pipe.
Reason: No-slip boundary condition exists at the boundary with pipe.

132. Assertion: In open channel flow is caused by gravity force provided by the sloping bottom.
Reason: In open channels the flow is at the expense of potential energy.

133. Assertion: Bend meters can be used for measuring flow through pipes.
Reason: In curved flow pressure increases with radius.

134. Assertion: Rectangular weir formula cannot be used to find out discharge in Cipolletti weir.
Reason: In Cipolletti weir decrease in discharge due to end contraction is balanced by the discharge through the triangular portion.

IV. *State whether the following statements are True or False (item No. 135 to 196)*

135. A fluid is a substance which deforms continuously under the action of shear stress.

136. The property by virtue of which a fluid offers resistance to the movement of one layer over another layer under the influence of a shear force is shear modulus of the fluid.

137. A general relationship between shear stress and velocity gradient for non-Newtonian fluid is

$$t = A\left(\frac{du}{dy}\right)^n + B$$

138. The viscocity of gases changes with temperature but is practically unaffected by pressure.

139. With the increase of temperature, the cohesive force decreases rapidly resulting in the increase of viscocity of the liquid.

140. The property of a liquid by virtue of which it resists tensile stress is called its surface tension.

141. When a tube of smaller diameter is dipped in water, the water rises in the tube due to viscocity.

142. When a tube of smaller diameter is dipped in water, the water rises in the tube with an upward concave surface.

143. When air contains enough liquid molecules, it starts exerting pressure in liquid modecules to rejoin the liquid surface.

144. Liquid starts boiling when the pressure on it is slightly above vapour pressure.

145. Vapour pressure of water is less than that of mercury.

146. Vapour pressure of water increases with temperature.

147. If Mach number is more than 6, the flow is supersonic.

148. If Mach number is less than 1, compressibility of fluid should be considered.

149. The atmospheric pressure p at a height h from sea level is

$$P = p_o + g_{ah}$$

where p_o = pressure at mean sea level and

v_a = specific weight of air.

150. If gauge pressure is negative, then

vacuum pressure = Local atmospheric pressure – Absolute pressure.

151. Aneroid barometer measures gauge pressure.

152. Local atmospheric pressure is measured by a mercury barometer.

153. Monometer employs piezometers for pressure measurement.

154. Simple manometers may be used for measuring negative pressure also.

155. Use of mercury in pressure gauges is advantages, where pressure difference is low.

156. On vertical surface pressure of fluid varies linearly from zero at free surface to a maximum of gh at bottom of vertical surface.

157. If metacentric height is positive it is the condition of stable equilibrium.

158. Study of motion of fluid particles w.r.t. coordinates fixed at a point is called Eulerian method of study.

159. Study of motion of particles w.r.t. coordinates fixed on a moving boat is known as Lagrangian method of study.

160. Laminar flow is same as streamline flow.

161. In case of laminar flow, fluid particles move can be predicted.

162. Formation of eddies takes place in laminar flow.

163. In case of time dependent flow the instantanceus streamline may change.

164. For compressible fluid, the continuity equation is

$$Q = A_1V_1 = A_2V_2$$

165. The continuity equation for three-dimensional flow is

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0$$

$$\text{i.e., } \frac{\partial^2 Q}{\partial x^2} + \frac{\partial^2 Q}{\partial y^2} + \frac{\partial^2 Q}{\partial z^2} = 0$$

166. The flownet consists of a family of streamlines intersecting orthogonally a family of equipotentially lines.

167. Fluid motion in which the streamlines are circles is known as vortex.

168. If the fluid particles undergo rotation about their mass centre, it is known as free vortex.

169. All fluid motions satisfy the principles of conservation of motion.
170. A canal carrying sediment laden water is an example of two-phase flow.
171. Newton's laws of mechanics are not applicable to fluid flow.
172. In fluid dynamics the force of compressibility is negligible compared to the other forces.
173. Euler's equation considers only force of gravity and force of velocity.
174. Bernoulli equation is obtained by differentiating Euler's equation.
175. Pitot tube is always used with piezometer.
176. Viscous fluid satisfies no-slip boundary condition at solid boundary.
177. The flow outside the boundary layer may be considered ideal.
178. The displacement thickness is an additional wall thickness that would have to be added to compensate for the reduction in flow rate on account of boundary layer formation.
179. The energy thickness (d_e) is the thickness of the fluid moving with a free velocity that represents the loss of energy transport of ideal fluid.
180. Large flow passage length is favourable for laminar flow.
181. As the Reynolds number decreases a laminar flow becomes turbulent.
182. The devices which are used for measuring viscocity are based on the principle of existence of absolute laminar flow.
183. Flow through porous media is a case of laminar flow through small irregular passages.
184. For accelerated flow critical Reynolds number decreases.
185. In a pipe loss of head at the inlet is more than that at the exit.
186. A siphon is a long bent pipe which carries liquid from higher level to a lower level through an intermediate high obstruction.
187. If a valve is closed gradually pressure built behind the valve is more if the diameter of the pipe is more.
188. The valve closure is said to be gradual if time taken is more than $\frac{2L}{C}$, where C is velocity of pressure wave produced.
189. A sewer under ordinary condition of flow behaves as an open channel.
190. The specific energy is the energy per unit weight of fluid measured above any datum line.
191. When the flow is critical, the discharge per unit width is maximum for a given specific energy.
192. At the critical depth, both specific energy and specific force attain minimum values.
193. In an orifice meter, if thicker plates are used, on the inlet side the edge of the hole is champered.
194. For cylindrical mouthpiece, rounding the entrance greatly reduces the losses.
195. A weir is an obstruction in the channel which causes the liquid to rise behind it.
196. The broad crested weirs support the falling nappe over their crest.

Answers to Multiple-Choice Questions

1. (a)	2. (c)	3. (d)	4. (c)	5. (c)
6. (d)	7. (a)	8. (d)	9. (c)	10. (b)
11. (c)	12. (a)	13. (b)	14. (d)	15. (d)
16. (a)	17. (b)	18. (c)	19. (a)	20. (d)
21. (c)	22. (c)	23. (d)	24. (c)	25. (b)
26. (b)	27. (c)	28. (c)	29. (c)	30. (a)
31. (a)	32. (b)	33. (a)	34. (b)	35. (c)
36. (c)	37. (b)	38. (a)	39. (a)	40. (b)
41. (b)	42. (b)	43. (b)	44. (c)	45. (a)
46. (c)	47. (c)	48. (b)	49. (b)	50. (d)
51. (b)	52. (c)	53. (d)	54. (b)	55. (c)
56. (d)	57. (c)	58. (c)	59. (c)	60. (a)
61. (d)	62. (b)	63. (a)	64. (b)	65. (d)
66. (b)	67. (b)	68. (d)	69. (d)	70. (b)
71. (d)	72. (a)	73. (c)	74. (c)	75. (b)
76. (d)	77. (c)	78. (c)	79. (a)	80. (d)
81. (b)	82. (b)	83. (d)	84. (d)	85. (d)
86. (b)	87. (d)	88. (a)	89. (d)	90. (b)
91. (d)	92. (a)	93. (c)	94. (c)	95. (b)
96. (a)	97. (b)	98. (c)	99. (c)	100. (d)
101. (d)	102. (b)	103. (b)	104. (b)	105. (b)
106. (d)	107. (a)	108. (b)	109. (a)	110. (b)
111. (b)	112. (b)	113. (d)	114. (c)	115. (a)
116. (b)	117. (a)	118. (c)	119. (c)	120. (b)
121. (c)	122. (a)	123. (a)	124. (a)	125. (a)
126. (a)	127. (d)	128. (a)	129. (a)	130. (d)
131. (a)	132. (a)	133. (a)	134. (d)	135. True
136. False	137. True	138. True	139. False	140. False
141. False	142. True	143. True	144. False	145. False
146. True	147. False	148. False	149. False	150. True
151. False	152. True	153. True	154. True	155. False
156. True	157. False	158. True	159. True	160. True
161. True	162. False	163. True	164. False	165. True
166. True	167. True	168. False	169. True	170. True
171. False	172. True	173. False	174. False	175. True
176. True	177. True	178. True	179. False	180. False
181. False	182. True	183. True	184. False	185. False
186. True	187. False	188. True	189. True	190. False
191. True	192. True	193. False	194. True	195. True
196. True				

10

Hydraulic Machines

10.1 TURBINE

* The hydraulic turbines convert the energy of water into the mechanical energy of the rotating shaft.
* The water from the reservoir is allowed to flow through a pressure pipe, known as penstock and made to strike the rotating part of the turbine. It changes moment of momentum into mechanical energy to rotate the turbine shaft. Since the turbine shaft is coupled to the generator shaft, the generator shaft rotates in the magnetic field producing electricity.
* The principle on which a pump works is exactly opposite to that of turbine. Pump utilizes electric energy, converts it to mechanical energy and then to hydraulic energy.
* Compressor is a pump used to increase the pressure of air considerably while blower is a pump primarily used to cause movement of air. Fan is a blower. In this case the change in pressure is quite small and hence the variation of density is neglible. Therefore, the fluid (air) may be regarded as incompressible.
* Force exerted by a jet of velocity V on a plate inclined at q to its direction and rotating at a velocity u, is

$$F = rA(V - u)^2 \sin^2 q$$

* Force exerted by a jet of velocity V on a surface curved at q and moving at velocity u is

$$F = rA(V - u)^2 (1 + \cos \text{q}).$$

* Efficiency of a series of flat plates mounted on a wheel where the number and location of plates is so arranged that no portion of jet goes without doing work is

$$n = \frac{2(V - u)u}{V^2}$$

\ Maximum efficiency is when $u = V/2$ and its value is 50%.

* In case of curved vanes, efficiently mounted on the periphery of a wheel moving at a velocity u, efficiency is given by

$$n = \frac{2u(V - u)(1 + \cos\theta)}{V^2}$$

\ The efficiency is maximum when $u = v/2$ and its value is $\frac{1}{2}(1 + q) \times 100\%$. For a semicircular vane, $q = 0°$, hence if $u = \frac{v}{2}$

\ $h_{\max} = 100\%$

Pelton turbine works on a similar principle.

10.2 TYPES OF HYDRAULIC TURBINES

1. Impulsive turbines
2. Reaction turbines

* ***Impulsive Turbine*** In an impulse turbine the total energy at the inlet is only kinetic energy. The pressure of water both at entering and leaving the vanes is atmospheric only. Pelton wheel is an impulsive turbine. In impulsive turbine:

1. All the available hydraulic energy is converted into kinetic energy by a nozzle to produce a jet which strikes the runner blades.
2. The velocity of jet changes, the pressure throughout remaining atmospheric.
3. Casing is provided to prevent splashing and guide water to the tailrace. It does not serve any hydraulic function.
4. There may be one or more number of jets striking equal number of buckets simultaneously.
5. The turbine is installed above the tailrace and there is no draft tube used.
6. The flow regulation is done by means of a needle valve fitted into the nozzle.
7. The hydraulic efficiency is maximum when the velocity of the wheel is half the velocity of the jet water at inlet.
8. The maximum efficiency is given by $h_{\max} = \frac{1+\cos\phi}{2}$,

   where f = Angle of blade tip at outlet.
9. The width of the bucket for a Pelton wheel is generally five times the diameter of the jet.
10. The depth of the bucket is generally 1.2 times the diameter of jet.
11. The number of buckets on the periphery of a Pelton wheel = $\frac{D}{2d} + 15$

    where D = Pitch diameter of the wheel and
    d = Diameter of the jet
12. The maximum number of jets generally employed are six.

• ***Reaction Turbines*** If at the inlet of a turbine, the total energy is kinetic as well as pressure energy, the turbine is called reaction turbine.

* Francis and Kaplan turbines are reaction turbines.

**** In reaction turbines***

1. Only a fraction of the hydraulic energy is converted into kinetic energy before the fluid enters the runner.
2. Both pressure and velocity change as the fluid passes through the runner.
3. The runners are enclosed within a watertight casing.
4. Water fills the passage between the blades and casings and does the work on the blades when it flows through.
5. The turbine is connected to the tailrace through a draft tube which is a gradually expanding passage.

6. A Kaplan turbine is an axial flow reaction turbine. The number of blades are generally 4 to 8 in it.
7. A Francis turbine is an outward flow reaction turbine. The number of blades are generally 16 to 24 in it.

* ***Draft tube*** It is a pipe of gradually increasing area used for discharging water from the exit of a reaction turbine.

• ***Specific speed*** It is the speed at which a turbine when working under unit head develops unit power

$$N_s = \frac{N\sqrt{P}}{H^{5/4}}$$

where P = Power H = Net head on turbine
N = Rotation speed

Unit speed It is the speed of a turbine, when the head on the turbine, is 1 metre.

$$N_u = \frac{N}{\sqrt{H}}$$

where N = Rotation speed H = Net head on turbine

Unit discharge It is a discharge through a turbine when the head on the turbine is unity.

$$Q_u = \frac{Q}{\sqrt{H}}$$

Unit power It is the power developed by a turbine when the head on the turbine is unity

$$P_u = \frac{P}{H^{3/2}}$$

Performance curves The turbines are designed for particular values of

H–head, Q-discharge, P–power, N–speed, h–efficiency

N, Q and H are the physical independent variables. To study the variation of all other quantities with respect to variation of any one of the independent quantities test resulting are plotted between unit quantities and the resulting curves, known as the performance curves.

Constant head characteristics For constant head the curves are plotted between unit discharge-unit speed, unit power-unit speed and efficiency-unit speed

Constant speed characteristics In this study speed is constant and curves are plotted between the efficiency and the percentage of full load.

Constant efficiency From these curves, for a given head and power, the speed and the gate opening can be determined for the best performance.

Cavitation

Cavitation is the formation, growth and collapse of vapour filled cavities or bubbles in a flowing liquid due to local fall in fluid pressure.

• ***Effects of cavitation***

1. It causes vibration of various parts of turbines and creates noise

2. It makes surface rough
3. It reduces the discharge
4. It causes sudden drop in power output.

*** Methods of reducing formation of cavity**

1. Install the turbine below the tailrace level
2. Use stainless steel runner
3. Use highly polished blades
4. Run the turbine runners at the designed speed.

10.3 PUMPS

According to the direction of flow through them pumps are classified as

1. Radial flow (or centrifugal)
2. Axial flow (propeller type)
3. Mixed flow

Centrifugal Pumps

* The principal parts of a centrifugal pump are the impeller with its shaft and casing which surround it.
* The liquid is admitted to the impeller in an axial direction, through a central opening. The rotating impeller energy is imparted to the liquid which results in increase in both pressure and kinetic energies. The high pressure near the outlet forces the liquid to rise in delivery pipe.

*** Types of centrifugal pumps**:

1. Volute Pumps In this type of pumps, the impeller is surrounded by a spiral casing, the outlet boundary of which is a curve, called volute. Since cross-sectional area of the passage of fluid gradually increases, part of its kinetic energy gets converted into the pressure energy.

2. Diffuser or Turbine Pumps In this type of pump, the impeller is surrounded by a series of stationary guidevanes mounted on a diffuser ring. The guidevanes provide gradually enlarging passages so as to result in gradual reduction in velocity. Due to gradual reduction in velocity, less energy is wasted in eddies and hence, increase in efficiency.

* A well designed diffuser is capable of converting as much as 75% of kinetic energy at the propeller outlet into pressure energy.
* The efficiency of a pump is generally less than of a turbine, since the possibility of flow separation and formation of eddies is more in a diverging flow.
* *Single suction and Double suction pumps*: classification is based on whether the impeller receives water on one side or on both sides. Impeller of a double suction pump, may be treated as equivalent of two single-section impellers placed back to back. The advantage of using double suction pump is that the thrusts on each side are hydraulically balanced.
* *Single- and Multistage pumps*: At the higher head, liquid which has passed through the impeller may flow in limited quantity back to the suction side, thereby decreasing the efficiency of the pump. This is known as leakage loss. The practical limiting head against which a single impeller

may be used is about 38 metres.

* For high heads two or more impellers nay be used in series. In this arrangement, water discharged with increased pressure from one impeller flows to the suction opening of the second and so on. Thus, several impellers and their connecting passages are contained in a single casing, it is known as multistage pump. Such pumps are used to obtain a high head.
* Pumps using up to ten stages have been used, but it is better to limit it to five stages to avoid mechanical construction difficulties.
* To discharge a large quantity of liquid, the impellers are connected in parallel.

Definitions

Static Head It is the difference between the liquid levels in sump and high level reservoir. It consists of suction head and delivery head.

$$h = h_s + h_d.$$

Total Head It includes static head, head loss and velocity head in the delivery pipe.

$$H = h + h_{fs} + h_{fd} + \frac{V_d^2}{2g} = h + h_f + \frac{V_d^2}{2g}$$

where h_{fs} = head loss in the suction and h_{fd} head loss in delivery pipes.

Manometric head The difference in the piezometric head between a point on the discharge side and a point on the suction side of the impeller, both as close to the pump as possible is known as manometric head. The difference of head is as shown by the manometers connected between the inlet and outlet flanges of the pump.

Manometric efficiency It is the ratio of the manometric head to the head delivered to the liquid by the impeller.

$$h_{\text{mano}} = \frac{g\,H_m}{u_2\,Vu_2}$$

where

$$u_2 = \text{velocity of impeller at outer diameter}$$

$$Vu_2 = \text{velocity of fluid at exit.}$$

* Discharge of a centrifugal pump is

$$Q = pD\,bV_f$$

$$D = \text{diameter of impeller at inlet}$$

$$b = \text{width of impeller at inlet}$$

$$V_f = \text{velocity of flow at inlet}$$

* *Specific speed of a centrifugal pump*: It is the speed of an imaginary pumps identical with the given

pump, which will discharge unit volume of water, being raised through a unit head.

$$N_s = \frac{N\sqrt{Q}}{H_m^{3/4}}$$

• *Net Positive Suction Head (NPSH)*: It is defined as the difference between the net inlet head and the head corresponding to the vapour pressure of the liquid.

$$\text{NPSH} = \frac{p_s}{\gamma} - \frac{p_v}{\gamma} + \frac{V_s^2}{2g}$$

where $\frac{p_s}{\gamma}$ = Absolute pressure head at inlet

$\frac{p_v}{\gamma}$ = Vapour pressure head of liquid

$\frac{V_s^2}{2g}$ = Velocity head in the suction pipe

Characteristic Curves for Centrifugal Pumps

Performance curves are obtained from the actual tests conducted in the laboratory in which the pump is run at the design speed and variation of manometric head, input power and efficiency h_o are studied as the discharge is varied. These curves are plotted in non-dimensionalised form like $\frac{\eta_o}{\eta_{oo}}$, $\frac{p}{p_o}$, and $\frac{H_m}{H_{md}}$. Typical curves are as shown is Fig. 10.1 in which,

A – is for head B – for efficiency C – is for power.

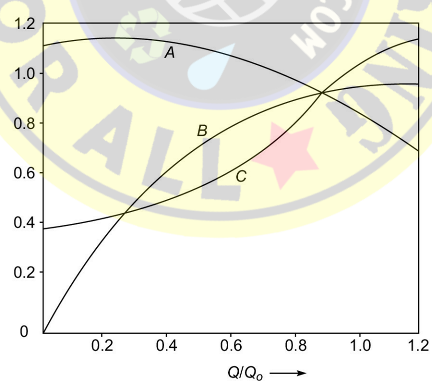


Fig. 10.1 Head, efficiency and power curves in non-dimensionalized form

Reciprocating Pump

* It is a pump in which a piston executes a reciprocating motion in a closely fitted cylinder. The self-acting lift valves are provided on the suction and delivery sides to allow fluid motion only in the forward direction.

* The reciprocating action of the piston expels the air from its working chamber, creating vacuum within the pump. The pressure of the atmosphere on the surface of water in the sump pushes the water up in the evacuated chamber.

* Reciprocating pumps have nowadays become absolute due to the following advantages offered:

1. Flow is non-pulsating

2. Light weight
3. Compact
4. Easy installation and
5. Low initial cost.

* Reciprocating pumps are suited for less discharge and higher heads.

* Theoretical discharge through a reciprocating pump

$$Q = LA\frac{N}{60} \text{ m}^3\text{/sec in single acting}$$

$$= 2LA\frac{N}{60} \text{ m}^3\text{/sec in double acting}$$

* On account of leakage through valves and plunger and due to lag in the closure of valve, the actual discharge Q_A is less than Q. The difference between the theoretical discharge and actual discharge is called the slip of the pump. Thus,

$$\text{Slip} = \frac{Q - Q_a}{Q} \times 100\%$$

* For pumps maintained in good condition, the slip is of the order of 2%.

* Power required to drive a reciprocating pump

$$= wQ(H_S + H_A) \text{ watts in single acting pump.}$$

$$= 2wQ(H_S + H_A) \text{ watts in double acting pump.}$$

where w = unit weight of the liquid in N/m^3

H_s = suction head in metres

H_d = delivery head in metres

Air Vessels

An air vessel is a closed chamber provided in reciprocating pump at suction or delivery side at position as close to pump as possible. The advantages of providing air vessels at the suction and delivery heads are:

1. almost constant discharge is maintained in suction and delivery pipes.
2. friction losses and accelerations are reduced considerably as they now correspond to the mean velocity in the suction and delivery pipes.

* Work done by a pump with air vessels is

$= wQ(H_{ts} + H_{td})$ by a single acting pump.

where $H_{ts} = H_s + H_{Ls} + \frac{V_s^2}{2g}$

and $H_{td} = H_d + H_{Ld} + \frac{V_d^2}{2g}$

H_{Ls} and H_{Ld} being friction losses and V_s and V_d are mean velocities in suction and delivery pipes.

Miscellaneous Hydraulic Devices

The following are the miscellaneous hydraulic devices:

1. Hydraulic press
2. Hydraulic crane
3. Hydraulic lift
4. Hydraulic ram
5. Hydraulic accumulator
6. Hydraulic intensifier
7. Hydraulic coupling

* ***Hydraulic press*** It is a simple device by which larger loads can be lifted by applying smaller forces. The efficiency of a hydraulic press is given by

$$h = \frac{W}{P} \times \frac{a}{A}$$

where W = Weight lifted; P = Force applied
A = Area of ram; a = Area of plunger

* ***Hydraulic crane*** It is a device used to lift heavy loads. It is widely used in warehouse, foundries, heavy industries and in docks.

* ***Hydraulic lift*** It is a device used to carry persons and loads from one floor to another in multistorey buildings. It consists of a cage which is secured to the top of a vertical ram sliding in fixed vertical cylinder. Water from delivery pipe enters the bottom of the cylinder and works underside of cylinder. As a result of it lift moves upwards.

* ***Hydraulic ram*** It is a device used to lift small quantity of water to a greater height when a large quantity is available at smaller height. It does not need any external power like electricity. It works on the principle of water hammer.

* ***Hydraulic accumulator*** Hydraulic accumulator consists of a fixed vertical plunger with a central vertical hole. The fixed plunger is surrounded by a brass sleeve which is further surrounded by an inverted movable cylinder. The water pumped moves up the vertical tube and exerts an upward pressure on the annular area of the loaded cylinder. The pressure energy so stored may be supplied to a machine later on.

* ***Hydraulic intensifier*** It increases the intensity of pressure of a given liquid with the help of low pressure liquid of large quantity.

* ***Hydraulic coupling*** It is a device in which power is transmitted from driving shaft to driven shaft without any change of torque.

MULTIPLE-CHOICE QUESTIONS

I. *Select correct options from the list given below each question.*

1. Turbine converts

(a) mechanical energy into hydraulic energy.
(b) hydraulic energy into mechanical energy.
(c) mechanical energy into electrical energy.
(d) electrical energy into heat energy.

2. A pump is a device which converts

(a) mechanical energy into hydraulic energy.
(b) hydraulic energy into mechanical energy.
(c) mechanical energy into electrical energy.
(d) none of the above.

3. The force exerted by a jet of velocity V on a stationary vertical plate in the direction of jet is

(a) rAV
(b) rAV^2
(c) $\frac{\rho AV^2}{g}$
(d) $\frac{\rho AV^2}{2g}$

4. Force exerted by a jet of velocity on a plate inclined at q to its direction is

(a) $rAV^2 \sin^2 q$
(b) $rAV^2 \sin q$
(c) $\frac{\rho AV^2 \sin^2 \theta}{2g}$
(d) $\frac{\rho AV^2 \sin \theta}{g}$

5. Force exerted by a jet of velocity V on a plate inclined to its direction at q and rotating at a velocity u is

(a) $rA(V^2 - u^2) \sin^2 q$
(b) $rA(V - u)^2 \sin^2 q$
(c) $\frac{\rho A(V^2 - u^2) \sin^2 \theta}{2g}$
(d) $\frac{\rho A(V - u)^2 \sin^2 \theta}{2g}$

6. Force exerted by a jet of velocity V on a surface curved at q and moving at velocity u is

(a) $rA(V^2 - u^2)(1 + \cos q)$
(b) $rA(V^2 - u^2) \sin^2 q$
(c) $rA(V - u)^2 (1 + \cos q)$
(d) $rA(V - u)^2 \sin^2 q$

7. Efficiency of the jet of water having velocity V and striking a series of vertical plates moving with a velocity u if plates are so arranged that no portion of jet goes without doing work is

(a) $\frac{2(V-u)V}{u^2}$

(b) $\frac{2(V-u)u}{V^2}$

(c) $\frac{2(V-u)V^2}{u}$

(d) $\frac{2(V-u)^2 u}{V^2}$

8. In case of curved vanes, efficiently mounted on the periphery of a wheel moving at a velocity u, efficiency is

(a) $\frac{u(V-u)\sin^2\theta}{V^2}$

(b) $\frac{2u(V-u)\sin^2\theta}{V^2}$

(c) $\frac{2u(V-u)(1-\cos\theta)}{V^2}$

(d) $\frac{2u(V-u)(1+\cos\theta)}{V^2}$

9. If V is the velocity of jet and u is the velocity of vanes, efficiency is maximum when

(a) $u = V$
(b) $u = 1.5\ V$
(c) $u = \frac{V}{2}$
(d) none of the above

10. For a semicircular vane when its velocity is half the jet velocity, efficiency is

(a) 50%
(b) 60%
(c) 75%
(d) 100%

11. In impulsive turbine, the total energy at inlet is

(a) kinetic energy only
(b) pressure energy only
(c) both kinetic and potential energy
(d) none of the above

12. Which one of the following is a impulsive turbine

(a) Francis turbine
(b) Kaplan turbine
(c) Pelton wheel
(d) none of the above

13. In Pelton wheel

(a) the velocity of jet changes, the pressure throughout remain at atmospheric
(b) the velocity of jet remains same, the pressure changes
(c) both velocity and pressure change

(d) both velocity and pressure do not change

14. In impulsive turbines casing is provided to
   (a) prevent splashing of water
   (b) guide water to the tailrace
   (c) to maintain higher pressure
   (d) both (a) and (b)
15. The width of the bucket in a Pelton wheel is generally ______ times the diameter of the jet
   (a) two
   (b) three
   (c) four
   (d) five
16. The depth of the bucket in a Pelton wheel is generally ______ times the diameter of jet
   (a) 1.0
   (b) 1.2
   (c) 1.5
   (d) 2.0
17. If D is pitch diameter of a Pelton wheel and d is the diameter of the jet, the number of buckets is
   (a) $\frac{D}{2d} + 15$
   (b) $\frac{D}{d} + 15$
   (c) $\frac{D}{2d} + 10$
   (d) $\frac{D}{d} + 10$
18. In a Pelton wheel the maximum number of jets generally employed are
   (a) 4
   (b) 6
   (c) 8
   (d) 12
19. In reaction turbines, total inlet energy is
   (a) kinetic energy only
   (b) pressure energy only
   (c) both (a) & (b)
   (d) none of the above
20. In reaction turbines ______ changes as fluid passes through the runner.
   (a) pressure
   (b) velocity
   (c) both pressure and velocity
   (d) none of the above
21. A Pelton wheel is a ______ impulse turbine

(a) tangential flow

(b) axial flow
(c) inward flow
(d) outward flow

22. A Kaplan turbine is an ______ flow reaction turbine
(a) tangential
(b) axial
(c) inward
(d) outward

23. A Francis turbine is an ______ flow reaction turbine
(a) tangential
(b) axial
(c) inward
(d) outward

24. In Kaplan turbine, the number of blades are generally
(a) 4 to 8
(b) 8 to 12
(c) 12 to 16
(d) 16 to 20

25. Draft tube is a pipe of gradually ______ area used at ______ of a reaction turbine
(a) increasing, exit
(b) decreasing, exit
(c) increasing, inlet
(d) decreasing, inlet

26. If P is power, H is head and N is the rotation speed of a turbine, the specific speed is given by

(a) $N_s = \frac{NP}{H^{3/4}}$

(b) $N_s = \frac{N\sqrt{P}}{H^{5/4}}$

(c) $N_s = \frac{N\sqrt{P}}{H^{3/2}}$

(d) $N_s = \frac{NP}{H^{5/4}}$

27. Unit speed is the speed of the turbine when it is working
(a) under unit head
(b) under unit head and discharging one cubic metre of water
(c) under unit head and developing unit power
(d) none of the above

28. If N is rotation speed and H is net head on turbine, unit speed is

(a) $N_u = \frac{N}{H}$

(b) $N_u = \frac{N}{\sqrt{H}}$

(c) $N_u = \frac{N}{H^{3/2}}$

(d) $N_u = \frac{N}{H^{5/2}}$

29. Unit discharge is a discharge through a turbine when it is working under
(a) unit head
(b) unit head and discharging one cubic metre of water
(c) unit head and developing unit power
(d) none of the above

30. Unit discharge of a turbine is given by

(a) $Q_u = \frac{Q}{H}$

(b) $Q_u = \frac{Q}{\sqrt{H}}$

(c) $Q_u = \frac{Q}{H^{3/2}}$

(d) $Q_u = \frac{Q}{H^{5/2}}$

31. Unit power is the power developed by turbine when it is working under
(a) unit head
(b) unit head and discharging one cubic metre of water
(c) unit head and developing unit power
(d) none of the above

32. Unit power is given by the expression

(a) $P_u = \frac{P}{H}$

(b) $P_u = \frac{P}{\sqrt{H}}$

(c) $P_u = \frac{P}{H^{3/2}}$

(d) $P_u = \frac{P}{H^{5/2}}$

33. If H is the head of water under which a turbine is working, the power developed is
(a) directly proportional to $H^{3/2}$
(b) inversely proportional to $H^{3/2}$
(c) directly proportional to $\sqrt{H}$
(d) inversely proportional to $\sqrt{H}$

34. The cavitation in a turbine is mainly due to
(a) low velocity

(b) high velocity
(c) low pressure
(d) high pressure

35. Cavitation
(a) causes vibration of various parts of turbine and creates noise
(b) reduces discharge
(c) causes sudden drop in power output
(d) all the above

36. Cavitation in a reaction turbine is avoided to a great extent by
(a) installing the turbine below the tailrace level
(b) using stainless steel runners
(c) running the turbine at the designed speed
(d) all the above

37. Centrifugal pump is a ______ type of pump.
(a) radial flow
(b) axial flow
(c) mixed flow
(d) none of the above

38. Involute type centrifugal pump, the passage of fluid ______.
(a) gradually decreases
(b) remains same throughout
(c) gradually increases
(d) both (a) and (b)

39. In case of diffuser type centrifugal pumps, the vanes mounted on diffuser ring provide ______ passage to fluid.
(a) gradually decreasing
(b) uniform
(c) gradually increasing
(d) both (a) and (b)

40. With a well designed diffuser of centrifugal pump, it is possible to convert as much as ______ if kinetic energy at the propeller outlet into pressure energy.
(a) 45%
(b) 60%
(c) 75%
(d) 90%

41. At higher heads, the liquid which has passed through the impeller of the centrifugal pump may flow in limited quantity back to the suction side. This is known as
(a) friction loss
(b) leakage loss
(c) suction head loss

(d) delivery head loss.

42. Practical limiting head against which a single impeller may be used is about
(a) 8 m
(b) 18 m
(c) 28 m
(d) 38 m

43. It is better to limit number of multistage pumps to ______ to reduced mechanical construction difficulties
(a) 3
(b) 5
(c) 7
(d) 10

44. The difference of head as shown by manometers connected between the inlet and outlet flanges of the pump is known as
(a) manometric head
(b) static head
(c) dynamic head
(d) total head

45. In case of a centrifugal pump, manometric head is equal to
(a) pressure head at outlet of pump–pressure head at inlet
(b) velocity head at outlet–total head at outlet
(c) total head at inlet–total head a outlet
(d) total head at outlet–total head at inlet

46. The manometric efficiency of a centrifugal pump is given by

(a) $\frac{g H_m}{u_2 Vu_2}$

(b) $\frac{H_m}{g u_2 V_{u_2}}$

(c) $\frac{g u_2 Vu_2}{H_m}$

(d) $\frac{u_2 Vu_2}{g H_m}$

where u_2 = Velocity of impeller at outer diameter

Vu_2 = Velocity of fluid at exit.

47. Discharge of a centrifugal pump is given by

(a) pDV_f

(b) $pD\, bV_f$

(c) $\frac{\pi D^2}{4} V_f$

(d) $\frac{\pi D^2}{4} bV_f$

where D = Diameter of impeller at inlet

b = Width of impeller at inlet

V_f = Velocity of flow at inlet

48. Specific speed of a centrifugal pump is the speed at which a pump runs when
   (a) head and discharge are unity
   (b) head and shaft power are unity
   (c) discharge and shaft power are unity
   (d) none of the above
49. The specific speed of a pump is given by

   (a) $N_s = \frac{N\sqrt{P}}{H^{3/4}}$

   (b) $N_s = \frac{N\sqrt{Q}}{H^{3/4}}$

   (c) $N_s = \frac{N\sqrt{P}}{H^{5/4}}$

   (d) $N_s = \frac{N\sqrt{Q}}{H^{5/4}}$
50. Net positive suction is given by

   (a) $\frac{p_s}{\gamma} + \frac{p_v}{\gamma} + \frac{V_s^2}{2g}$

   (b) $\frac{p_s}{\gamma} - \frac{p_v}{\gamma} + \frac{V_s^2}{2g}$

   (c) $\frac{p_s}{\gamma} + \frac{p_v}{\gamma} - \frac{V_s^2}{2g}$

   (d) $\frac{p_s}{\gamma} - \frac{p_v}{\gamma} + \frac{V_s^2}{2g}$

   where $\frac{p_s}{\gamma}$ = Absolute pressure head at inlet

   $\frac{p_v}{\gamma}$ = Vapour pressure head of liquid

   $\frac{V_s^2}{2g}$ = Velocity head in the section pipe.
51. Cavitation takes place if the pressure of the fluid flowing at any point is
   (a) less than vapour pressure of the fluid
   (b) equal to vapour pressure of the fluid
   (c) more than vapour pressure of the fluid
   (d) both (b) and (c)
52. The operating characteristic curves of a centrifugal pumps are shown in Fig. Q. 52 curve A is for

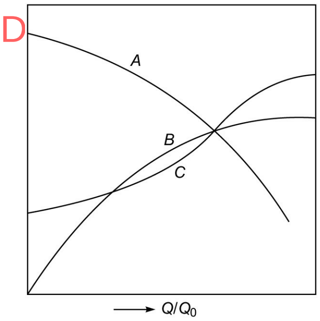


Fig. Q. 52

(a) power
(b) efficiency
(c) head
(d) none of the above

53. In Fig. Q. 52, Curve *B* is for
(a) power
(b) efficiency
(c) head
(d) none of the above

54. In Fig. Q. 52, Curve *C* is for
(a) power
(b) efficiency
(c) head
(d) none of the above

55. Reciprocating pumps have nowadays become absolute due to the advantage offered by reciprocating pump
(a) non-pulsating flow
(b) compactness
(c) easy installation
(d) all the above

56. Reciprocating pump is suited for
(a) high discharge and high head
(b) high discharge and low head
(c) low discharge and low head
(d) low discharge and high head

57. Theoretical discharge through a single acting reciprocating pump is

(a) $LA \frac{N}{60}$ m^3/sec

(b) $\frac{LN}{60A}$ m^3/sec

(c) $\frac{AN}{60L}$ m^3/sec
(d) none of the above

where A = C.S. area of cylinder in m^2

L = Length of cylinder in m

N = speed of crank in rpm

58. For well maintained reciprocal pumps, slip is of the order
(a) 2%
(b) 5%
(c) 10%
(d) 15%

59. Power required to drive a single acting reciprocating pump is
(a) $W(H_s + H_d)$
(b) $WQ(H_s + H_d)$
(c) $\frac{Q(H_s + H_d)}{W}$
(d) none of the above

where W = Unit weight of fluid

Q = Discharge

H_s and H_d = suction and delivery heads respectively.

60. Air vessel is provided to reciprocating pump near its
(a) suction pipe
(b) delivery pipe
(c) both at suction and delivery pipes
(d) neither at suction nor at delivery pipes

61. Work done by a reciprocating pump with air vessels is
(a) $WQ(H_s + H_d)$
(b) $WQ(H_s + H_d) + \frac{V_s^2}{2g}$
(c) $WQ(H_s + H_d) + \frac{V_d^2}{2g}$
(d) $WQ(H_s + H_d + H_{Ls} + H_{Ld}) + \frac{V_s^2}{2g} + \frac{V_d^2}{2g}$

where H_s, H_d = Suction and delivery heads

H_L, H_{Ld} = Friction losses in suction and delivery pipes

V_s, V_d = Velocities in suction and delivery pipes

62. Hydraulic press is a device used to
(a) lift small quantity of water to greater height
(b) lift larger loads by applying smaller force
(c) increase the pressure of a liquid
(d) all of the above

63. Efficiency of a hydraulic press is given by

(a) $\frac{W}{p} \times \frac{a}{A}$

(b) $\frac{W}{p} \times \frac{A}{a}$

(c) $\frac{p}{W} \times \frac{a}{A}$

(d) $\frac{p}{W} \times \frac{A}{a}$

where W = Weight lifted

P = Force applied

A = Area of ram

a = Area of plunger

64. Hydraulic ram is a device used to

(a) lift small quantity of water to greater heights

(b) lift larger loads by applying smaller force

(c) increase the pressure of a liquid

(d) none of the above

65. Hydraulic accumulator is a device used to store ______ energy which may be supplied to a machine later on.

(a) kinetic

(b) pressure

(c) strain

(d) none of the above

66. A hydraulic coupling belongs to

(a) energy generating machine

(b) power developing machine

(c) energy transfer machine

(d) none of the above.

II. *Match List I with List II, selecting the answer code given below Q. No. 67.*

67.

	List I		List II
	Hydraulic device		**Function of the device**
A.	Hydraulic press	1.	Pressure energy stored to supply to a machine later.
B.	Hydraulic ram	2.	Used to transfer power.
C.	Hydraulic accumulator	3.	Used to lift small quantity of water to a great height when large quantity is available of smaller height.
D.	Hydraulic coupling	4.	Larger loads can be lifted by applying smaller force.

Codes:

(a)	A – 3	B – 2	C – 4	D – 1
(b)	A – 2	B – 3	C – 1	D – 4
(c)	A – 1	B – 2	C – 4	D – 3
(d)	A – 4	B – 3	C – 1	D – 2

III. *Select your answer according to the coding system given for the Assertion (A) and Reason (R) given below in the Question nos. 68 to 71.*

(a) Both A and R true and R is the correct explanation of A.
(b) Both A and R are true but R is not the correct explanation of A.
(c) A is true but R is false.
(d) A is false but R is true.

68. Assertion: Air blown by a blower is regarded as incompressible
Reason: Blowers are used to move air and in this case the change in pressure is very small.
69. Assertion: In volute pumps part of its pressure energy gets converted to kinetic energy.
Reason: In volute pumps the cross-sectional area of the passage of fluid gradually increases.
70. Assertion: The efficiency of diffuser type of centrifugal pumps efficiency is more.
Reason: The guidevanes provide gradually enlarging passage to the fluid.
71. Assertion: Acceleration and friction losses are reduced in reciprocating pumps by providing air vessels.
Reason: Friction losses and acceleration corresponding to mean velocity in the suction and delivery pipes.

IV. *State whether the following statements are true or false in Question no. 72 to 94.*

72. Compressor is a pump used to increase the pressure of air considerably.
73. In an impulsive turbine all the available hydraulic energy is converted into kinetic energy by a nozzle.
74. In impulsive turbines there is only one jet striking the buckets.
75. In impulsive turbines draft tube should always be provided.
76. Francis turbine is a reaction turbine.
77. In reaction turbines only a fraction of hydraulic energy is converted into kinetic energy partially before the fluid enters the runner.
78. In reaction turbines runners are enclosed in a watertight casing.
79. The speed at which a turbine when working under unit head developing unit power is known as specific speed.
80. By installing the turbine below the tailrace level formation of cavity in reaction turbine can be reduced to a great extent.
81. In volute type of centrifugal pumps, the impeller is surrounded by a spiral casing.
82. The efficiency of a diffuser (i.e., turbine) type pump is generally more than that of a turbine.

83. The possibility of flow separation and formation of eddies is less in a diverging flow compared to converging flow.

84. The classification centrifugal pumps as single-suction and double-suction is based on whether the propeller receives water on one side or both sides.

85. Impeller of a double-suction pump may be considered equivalent to two single-suction impellers placed back to back.

86. The advantage of using double-suction pump is that the thrust on each side are hydraulically balanced.

87. In multistage pumps water discharged from one impeller flows to the suction opening of second impeller.

88. To discharge a large quantity of liquid impellers are connected in series.

89. To obtain high head, pumps are connected in parallel.

90. Manometric head is the actual of water against which a centrifugal pumps has to work.

91. Reciprocating pumps give non-pulsating flow.

92. In reciprocating pumps the difference between theoretical discharge and actual discharge is called slip.

93. By providing air vessels to reciprocating pumps almost constant discharge is maintained in suction and delivery pipes.

94. Hydraulic intensifier increases the intensity of pressure of a given liquid with the help of low pressure liquid of large quantity.

Answers to Multiple-Choice Questions

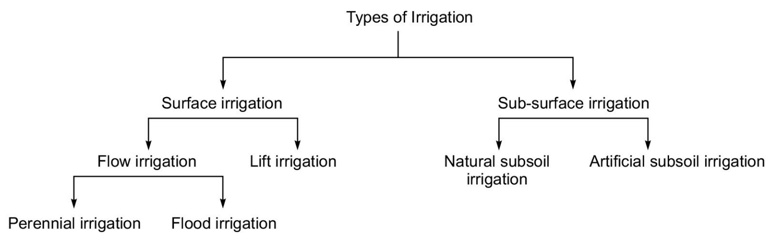
1. (b)	2. (a)	3. (b)	4. (a)	5. (b)
6. (c)	7. (b)	8. (d)	9. (c)	10. (d)
11. (a)	12. (c)	13. (a)	14. (d)	15. (d)
16. (b)	17. (a)	18. (b)	19. (c)	20. (c)
21. (a)	22. (b)	23. (d)	24. (a)	25. (a)
26. (b)	27. (a)	28. (b)	29. (a)	30. (b)
31. (a)	32. (c)	33. (b)	34. (c)	35. (d)
36. (d)	37. (a)	38. (c)	39. (c)	40. (c)
41. (b)	42. (d)	43. (b)	44. (a)	45. (d)
46. (a)	47. (b)	48. (a)	49. (b)	50. (b)
51. (a)	52. (c)	53. (b)	54. (a)	55. (d)
56. (d)	57. (a)	58. (a)	59. (b)	60. (c)
61. (d)	62. (b)	63. (a)	64. (a)	65. (b)
66. (c)	67. (d)	68. (a)	69. (d)	70. (a)
71. (a)	72. True	73. True	74. False	75. False
76. True	77. True	78. True	79. True	80. True
81. True	82. False	83. False	84. True	85. True
86. True	87. True	88. False	89. False	90. True

91. False 92. True 93. True 94. False

11

Irrigation Engineering

Science of artificial application of water to the land, in accordance with crop requirements is known as irrigation.



Techniques of water distribution in the field

1. Free flooding
2. Border flooding
3. Check flooding
4. Basin flooding
5. Furrow irrigation
6. Sprinkler irrigation
7. Drip irrigation

11.1 QUALITY OF IRRIGATION WATER

Sediment When fine sand from water is deposited on sandy soils, the fertility is improved. If the sediment has been derived from eroded areas, it may reduce the fertility.

Soluble Salts The critical self-concentration in the irrigation water depends upon many factors.

However, amount in excess of 700 ppm is harmful to some plants and more than 2000 ppm is injurious to all crops.

Low salinity (C_1) – 100 to 250 micro mhos/cm at 25°C

Medium salinity (C_2) – 250 to 750 micro mhos/cm at 25°C

High salinity (C_3) – 750 to 2250 micro mhos/cm at 25°C

Very high salinity (C_4) – more than 2250 micro mhos/cm at 25°C

Sodium Ions to other Cations (Sodium Absorption Ratio)

Low sodium water (S_1) → SAR = 0 to 10

Medium sodium water (S_2) → SAR = 10 to 18

High sodium water (S_3) → SAR = 18 to 26

Very high sodium water (S_4) → SAR > 26

S_1 – Can be used for irrigation on all soils.

S_2 – Not suitable for fine textured soil.

S_3 – May be used with good drainage, high leaching, gypsum addition, etc.

S_4 – Not suitable.

Concentration of Toxic Elements

The wastewater containing soap, etc., should be used with great care.
Boron concentration.

Above 0.3 ppm – toxic to certain plants
Above 0.5 ppm – dangerous to nuts and deciduous fruits
– cotton is moderately tolerant
– dates, asparagus tolerant
Above 4 ppm – no plant can tolerate.

Bacterial Contamination

Harmful, only if the crop is eaten without being cooked. Contaminated wastewater can be used for crops like cotton which are processed after harvesting.

Water Requirement of Crops

Water requirement of a crop means the total quantity and the way in which a crop requires water, from time to time it is sown to the time it is harvested.

Some Definitions

Crop period It is the time period elapsed from the instant of sowing to the instant of harvesting.

Base period It is the time between the first watering of a crop at the time of sowing to its last watering before harvesting.

Frequently of irrigation/rotation period It is the time interval between two consecutive watering to a crop.

Delta Total depth of water (in mm) required by a crop to come to maturity is called its delta. It may be expressed in hectare-metre also.

Duty of water It is the number of hectares of land irrigated for full growth of a given crop by supply of 1 m^3/sec of water continuously during the entire base period of the crop.

Relation between Delta (D) and Duty (D)

If B is the base period in days the volume of water applied to the crop during its base period

$$V = 1 >\times 60 \times 60 \times 24 \times B \text{ m}^3.$$
$$= 864000\, B \text{ m}^3.$$

By definition of duty, one cubic metre supplied for B days matures D hectares of land. One hectares = 100 >× 100 m^2.

$$\backslash\, D = \frac{86400\, B}{100 \times 100 \times D} = 8.64\, \frac{B}{D} \text{ metres.}$$
$$= 8640\, B/D \text{ mm.}$$

Shows approximate values of delta and duty for various crops in India

Table 11.1 Approximate value of delta and duty for various crops

Crop	*Delta*	*Duty*
Sugar cane	1200 mm	730 hectare/cu mec
Rice	1200 mm	775 hectare/cu mec
Cotton	500 mm	1400 hectare/cu mec
Wheat	400 mm	1800 hectare/cu mec
Fodder	225 mm	2000 hectare/cu mec

11.2 CANAL IRRIGATION SYSTEM

* Canal system consists of main canals, branch canals, distributaries and minors.
* The soil which is formed by transportation and deposition of silt through the agency of water, over a course of time, is called alluvial soil.
* Irrigation canals may be aligned in any of the following three ways:
  1. as watershed canal or ridge canal
  2. as contour canal
  3. as side-slope canal
* A canal aligned on the watershed saves the cost of construction of cross-drainage works.
* A contour canal irrigates only on one side because of the area on the other side is higher.
* Since a side-slope canal runs parallel to the natural drainage flow, usually it does not intercept drainage channels and hence avoids construction of cross-drainage works.
* In storage schemes main canal need not always take off from the reservoir, it may take off from a pickup weir or a barrage.
* Discharge in a minor canal is generally less than 2.5 cu mec.
* The main canals, branch canals, distributaries and minors are government canals while water courses belong to the cultivators.

11.3 SEDIMENTATION TRANSPORT AND DESIGN OF CHANNELS

* In a channel bed made of fine sand, when the velocity is gradually increased, the sequence of bed formation is—saw-tooth ripples-dunes with ripples-dunes-flat surface sand waves and anti-dunes.
* When a few particles on the bed just start moving, the condition is known as critical condition.
* A regime channel or a stable channel is one in which neither silting nor scouring takes place.
* Critical velocity in a channel is the mean velocity which will just keep the channel free from silting or scouring.
* Kennedy formula for critical velocity is

$$V_o = 0.55\, m\, y^{0.64}.$$

where y = depth of flow

m = critical velocity ratio.

Recommended values of critical value ratio (m) are shown in the Table 11.2.

Table 11.2 Values of critical values ratio

S.No.	*Type of silt*	*CVR (m)*
1.	Silt of Indus river	0.7
2.	Light sandy silt of north Indian river	1.0
3.	Light sandy silt, a little coarser	1.1
4.	Sandy, loam silt	1.2
5.	Debris of hard soil	1.3

* Lacy differentiated between true regime, initial regime and final regime.
* According to Lacy
  1. Natural silt transporting channels have a tendency to assume a semi-elliptic section.
  2. The coarser the silt, the flatter is the semi-ellipse.
  3. Silt factor f is given by

$$f = \frac{5}{2}\frac{V^2}{R}$$

  where V is in m/sec and R hydraulic mean depth in m.
  4. Wetted perimeter

$$P = 4.75\sqrt{Q}$$

  where Q is discharge in m^3/sec and P is in m.
  5. The sediment is kept in suspension by vertical components of the eddies which are generated on the channel bed as well as on the sides of the channel.
  6. Score depth $R¢$ is given by

$$R¢ = 0.473\ (Q/f)^{1/3}$$

11.4 CROSS SECTION OF CANAL

* A typical and most desirable section of a canal is partly in cutting and partly in filling and aims at balancing the quantity of earthwork.
* Berm is a narrow strip of land at the ground level between the inner toe and top edge of the cutting.
* Counter berm (or back berm) is provided on the outside of the canal bank to contain the hydraulic gradient line within the bank.
* Minimum free board required in any canal is 0.5 m. With increase in discharge, minimum free board specified is increased for a canal with discharge more than 30 cumec free board of 0.90 m is enough.

Lining of Canal

* Advantages of lining a canal are
  1. Seepage is controlled

2. Waterlogging can be prevented
3. Channel capacity is increased
4. Command area is increased
5. Maintenance cost is reduced
6. Danger of flood is eliminated.

* Maximum permissible velocities in different types of lining are:
  1. Cement concrete lining – 2.0 to 2.5 m/sec
  2. Burnt clay tile lining – 1.8 m/sec
  3. Boulder lining – 1.5 m/sec
* As per IS : 10300 – 1982, free board for lined canal are
  1. Main and branch canal 0.75 m
  2. Branch and distributaries
     (a) Q = 5 to 10 cumecs 0.6 m
     (b) Q = 1 to 5 cumecs 0.5 m
  3. Water courses 0.1 to 0.15 m
* Types of Lining
  1. Hard surface lining:
     (a) Cast in situ cement concrete lining
     (b) Shotcrete or plaster lining
     (c) Cement concrete tile lining or brick lining
     (d) Asphaltic concrete lining
     (e) Boulder lining
  2. Earth type lining
     (a) Compacted earth lining
     (b) Solid cement lining
* For lining a canal in black cotton soil a layer of cohesive non-swelling soil (CNS) like murram is required.
* Safety ladders are to be provided on both banks of canal alternatively at 300 m staggered distance.

11.5 WATERLOGGING AND SALINITY OF SOIL

* An agricultural land is said to be waterlogged, when its productivity gets affected by the high water table.
* Wherever there is waterlogging, there will be salinity of soil also.
* If water table is more than 3 m, there is no danger of waterlogging.
* For reclaiming waterlogged area leaching followed by growing salt resistant crops like fodder, berseem, bajra for one or two seasons is necessary.
* To remove excess rainwater or excess irrigation water drains are constructed. Types of drains are:
  1. Surface drains
     (a) Shallow surface drains

(b) Deep surface drains

2. Sub-surface drains or tile drainage.

* Suitable inlet and outlet arrangement are necessary for drains.

Rivers Training

The river training works serve the following objectives:

1. To prevent the river from changing its course
2. To prevent flooding of the surrounding
3. To protect river banks
4. To ensure effective disposal of sediment
5. To provide minimum water depth for navigation.

* River training works may be classified as
  1. Training for discharge
  2. Training for depth
  3. Training for sediment
* Methods of river training, including bank protection are:
  1. Marginal embankment or levees.
  2. Guide banks
  3. Groynes or spurs
  4. Artificial cut-offs
  5. Pitching of banks
  6. Pitched islands

11.6 DIVERSION HEAD WORKS

The works, which are constructed at the head of the canal, in order to divest the river water into the canal are known as diversion head works.

* If the major part or entire ponding of water is achieved by a raised crest, the barrier is known as a weir. On the other hand, if most of ponding is by gates, then the barrier is known as a barrage.
* Type of weir are:
  1. Masonry weirs with vertical drop
  2. Rock-fill weirs with sloping aprons
  3. Concrete weirs with sloping glacis
* A structure which enables the fish to pass upstream of weir is known as fish ladder.
* A canal head regulator is provided at the head of the off-taking canal, which serves the following functions:
  1. It regulates the supply of water entering the canal.
  2. It controls the entry of silt in the canal
  3. It prevents the river floods from entering the canal.

11.7 HYDRAULIC JUMP

* Hydraulic jump is the jump of water that takes place when a supercritical flow changes into a subcritical flow.

* Froude number $F = \frac{V}{\sqrt{gy}}$

where v = velocity of flow
y = depth of flow
g = gravitational attraction

* If incoming Froude No. F_1 is
  $F_1 = 1$, no hydraulic jump
  $F_1 = 1$ to 1.7, undulates jump is observed
  $F_1 = 2.5$ to 4.5, oscillating jump is observed
  $F_1 = 4.5$ to 9.0, steady jump is observed
  $F_1 \geq 9.0$, strong jump.

* The loss of head in hydraulic jump is given by $H_L = \frac{(y_2 - y_1)^3}{4y_1y_2}$

where y_1 = depth of water on upstream
y_2 = depth of water on upstream

11.8 THEORIES OF SEEPAGE

* Whenever a hydraulic structure is founded on a pervious foundation, it is subjected to seepage of water beneath the structure, which may cause the failure either by
  1. piping
  2. direct uplift

* According to Bligh's Theory
  (i) The percolating water follows the outline of the base of the foundation of the hydraulic structure.
  (ii) Safety against piping can be ensured by providing sufficient creep length.
  (iii) The water standing on upstream floor counterbalances the uplift caused by the same water, and hence, only a nominal floor thickness is required on the upstream side.

* Lane's weighted creep theory stipulated that the horizontal creep is less effective in reducing uplift than the vertical creep.
  He suggested a weightage factor of 1/3 for the horizontal creep as against 1 for vertical creep. However, since it is only empirical formula without any rational basis, it is generally not adopted in any rotational basis, it is generally not adopted in any design.

* According to Khosla:
  1. Seeping water moves along a set of streamlines.
  2. The first streamline follows the bottom contour of the structure.
  3. The remaining streamlines follow smooth curves, transmitting slowly from outline of foundation to a semi-ellipse.

* The exit gradient is said to be critical, when the upward distributing force on the grain is just equal to the submerged weight of the grain at the exit.
* Owing to the simplicity, Bligh's theory is still used for design of small works, but it should never be used, as it may lead to expensive and unsafe designs.

11.9 CANAL FALLS

* Whenever the available natural ground slope is steeper than the designed bed slope of the channel, the difference is adjusted by constructing vertical 'falls' or 'drops'.
* Types of falls
  1. *Ogee falls:* Water is gradually led down by providing convex and concave curves.
  2. *Rapids:* Long slopes of 1 : 15 to 1 : 20 with boulder facings are known as rapids. They are quite satisfactory but very expensive and hence became obsolete.
  3. *Trapezoidal Notch Falls:* It consists of a number of trapezoidal notches across the channel with a smooth entrance and a flat circular lip projecting downstream from each notch. There will be neither drawdown nor heading up of water, as the channel approaches the fall. Now these are obsolete since simpler, economical and better modern falls are developed.
* *Well type/cylinder/syphon well falls:* This type consists of two wells, one for inlet and another for outlet connected by a pipe. The down stream well is necessary in the case of falls greater than 1.8 m and for discharge greater than 0.29 cumecs. This type of falls are very effective for larger drops with smaller discharges.
* Simple vertical drop (Sarda type fall):
  1. It is a raised crest fall with a vertical impact
  2. It is simple and economical
  3. In it canal drops into a water cushion.
* *Straight Glacis Falls*:
  1. In this type, a straight glacis, sloping generally at 2 : 1, is provided after a raised crest.
  2. It is suitable up to 60 cumecs discharge and 1.5 m drop.
* *Montague Type Fall:* In this type the straight glacis is replaced by a parabolic glacis to improve energy dissipation.
* *Inglis fall or Baffle fall:* For as straight glacis type fall a baffle platform and a baffle wall are added.
* Vertical drops – suitable up to 15 cumecs and upto 1.5 m fall.
  Straight glacis – suitable for discharge up to 60 cumecs and 1.5 m fall.
  Baffle fall – suitable for all discharge and more 1.5 m fall.
  Well type – suitable for high drops and low discharge
* A fall to be used as a meter must be provided with a broad crest.

11.10 MISCELLANEOUS CANAL STRUCTURES

* Canal falls, head regulators, canal escapes, metering flumes, canal outlets and modules are canal structures.

* The best alignment of off-taking channel is when it makes zero angle with the parent channel initially and then separates out in transition.
* The main function of a head regulator is
  1. To control the supplies entering the off-take channel
  2. To control silt entry into off-take channel
  3. To serve as a meter for measuring discharge
* The main functions of a cross regulator are:
  1. Control canal irrigation system.
  2. When the water level in the main canal is low, it helps in heading up water.
  3. It helps in absorbing fluctuations in various sections of the canal system.
  4. It is often combined with a road bridge and a fall, if required.

Canal Escapes

* A canal escape is a side channel constructed to remove surplus water from an irrigation channel.
* The importance of such an escape is realised more, in case, a breach occurs in a channel.
* Weir type and sluice type (regulator type) canal escapes are in use.

Canal Outlet or Module

* It is a small structure built at the head of the water course so as to connect it with a minor or a distributary channel.
* The control and maintenance of canal network upto the module is under the jurisdiction of the state government and beyond the module it is the responsibility of cultivators.
* Types of outlets (modules)
  1. *Non-modular:* Open sluice and drowned pipe outlets.
  2. *Semi-modules or flexible-modules:* Pipe outlets venture flume and orifice semi-module
  3. *Rigid-module or modular outlets:* Cribbs module.
* Performance of modules is judged from:
  1. *Flexibility:* It is the ratio of the rate of change of discharge of the outlet to the rate of change of discharge of the distributary channel.
  2. *Proportionality:* The outlet is said to be proportional when the rate of change of outlet discharge equals the rate of change of channel discharge. ($F = 1$).
  If $F > 1$, hyper proportionality, If $F < 1$, sub-proportionality
  3. *Setting:* The ratio of the depth of the sill level of the outlet below the FSL of the distributary, to the full supply depth of the distributary, is known as setting.
  4. *Sensitivity:* It is defined as the ratio of the rate of change of discharge through the outlet to the rate of change of water level of the distributary, referred to the normal depth of the channel. For rigid modules the sensitivity is zero, since discharge is fixed.
* Types of non-modular outlets are
  1. Open sluice 2. Pipe outlet

* Types of semi-modules or flexible outlets are:
  1. Pipe outlet discharging freely into the air.
  2. Venturiflume or Kennedy gauge outlet.
  3. Open flume outlet
  4. Adjustable orifice semi-module.

Cattle crossings In remote village areas where no major movement is involved arrangements are made so that cattle, bullock carts, etc., can cross the canal. Such crossings are called cattle crossings.

1. If water depth is of the order of 0.75 m, ramps are provided for the entry and exist.
2. If water depth is greater than 1.2 m the cattle have to swim certain distance across the canal.

Bed bars Bed bars are masonry or concrete toe wall like structure constructed along unlined canal, so as to serve as permanent reference marks, and thus to indicate the correct alignment and theoretical bed levels of the canal.

Cross-Drainage Works

* A cross-drainage work is a structure, constructed at the crossing of a canal and a natural drain, so as to dispose of drainage water without interrupting the continuous canal supplies.
* Types of cross-drainage works:
  1. By passing canal over the drainage
     – aqueduct
     – syphon aqueduct
  2. By passing the canal below the drainage
     – super passage
     – canal syphon
  3. By passing the drain through the canal
     – level crossing
     – inlets and outlets.

11.11 TANK IRRIGATION

* Tanks are small reservoirs created by building earthern bunds across small streams. When the depth of the tank exceeds 12 m, it is known as a reservoir. Usually, depth of a tank is less than 4.5 m.
* In tanks, surplus escape arrangement is in the form of a surplus escape weir, provided in the body of the tank bund. Occasionally, syphon spillway is provided as is done in the case of earth dam project.
* Tanks may be in groups or isolated.
* Provision of breaching sections is necessary if tanks are in groups as a precaution against their failure.
* The capacity of an irrigation tank is sometimes increased by installing dam stones.
* The discharge through the sluice of a small irrigation tank is usually controlled by plug.

MULTIPLE-CHOICE QUESTIONS

I. *Select correct options from the questions 1 to 105*

1. Which of the following methods of applying water may be used on land with irregular topography?
   (a) Free flooding
   (b) Border flooding
   (c) Check flooding
   (d) Furrow irrigation method
2. In which of the following methods of applying water to land, ditches are excavated in the field?
   (a) Free flooding
   (b) Border flooding
   (c) Check flooding
   (d) Furrow irrigation method
3. In border flooding type of water distribution in the forms, the supply ditch is in the form of
   (a) earthern channel
   (b) lined channel
   (c) underground concrete pipe having risers at intervals
   (d) any one of the above
4. In check flooding levees are generally constructed along the contours, having vertical interval of about
   (a) 50 to 100 mm
   (b) 100 to 250 mm
   (c) 300 to 600 mm
   (d) 600 to 1000 mm
5. The best technique of water distribution in the field that can be used for all types of soils and for widely different topographies and slopes is
   (a) free flooding
   (b) border flooding
   (c) sprinkler irrigation method
   (d) furrow irrigation method
6. Which one of the following is the wrong statement about sprinkler irrigation?
   The conditions favouring the adoption of sprinkler irrigation method are
   (a) land topography is irregular
   (b) land soil is excessively permeable
   (c) when water table is low
   (d) when water is available with difficulty
7. Sprinkler system is
   (a) permanent system
   (b) semi-permanent system
   (c) portable system
   (d) any one of the above

8. Which one of the following is the wrong statement about sprinkler system of irrigation?
The advantages of sprinkler irrigation are:
(a) there is no seepage loss.
(b) land leveling is not required.
(c) it leaches down salt and prevents waterlogging.
(d) it is ideally suited for paddy field.

9. The best irrigation method that suits area where scarcity of irrigation water is
(a) sprinkler irrigation
(b) drip irrigation
(c) furrow irrigation
(d) check flooding

10. In drip irrigation, laterals are usually ______ dia and ______ long.
(a) 25 to 30 mm and 50 m
(b) 25 to 30 mm and 100 m
(c) 10 to 12.5 mm and 20 m
(d) 10 to 12.5 and 50 m

11. More than ______ critical salt concentration is injurious to all crops.
(a) 500 ppm
(b) 1000 ppm
(c) 1500 ppm
(d) 2000 ppm

12. When electrical conductivity of irrigation water is up to ______ micro mhos/cm, it is called low conductivity water
(a) 125
(b) 250
(c) 375
(d) 500

13. When Sodium-Absorption Ratio (SAR) is 30, it is called
(a) low sodium water
(b) medium sodium water
(c) high sodium water
(d) very high sodium water

14. Even for the most tolerant crop, the boron concentration should not exceed
(a) 4 ppm
(b) 8 ppm
(c) 12 ppm
(d) 16 ppm

15. If wheat requires about 75 mm of water after every 28 days, and the base period for wheat is 140 days, the value of delta for wheat is
(a) 2100 mm
(b) 375 mm

(c) 52.3 mm
(d) none of the above

16. Among the following, which crop has the highest value to delta?
   (a) wheat
   (b) vegetables
   (c) rice
   (d) cotton

17. The canal that finally feeds field is known as
   (a) minor canal
   (b) field channel
   (c) distributary
   (d) branch canal

18. In a canal system the order in which water flows is
   (a) branch canal–distributary–minor–field channels
   (b) branch canal minor–distributary–field channels
   (c) branch canal–minor–field channel–distributary
   (d) branch canal–field canal–distributary–minor

19. In a channel bed made of fine sand, when the velocity is gradually increased the sequence of bed formation is:
   (a) flat surface dunes–saw tooth ripples–antidunes
   (b) saw tooth ripples–dunes–flat surface–antidunes
   (c) flat surface–dunes–antidunes saw tooth ripples
   (d) saw tooth ripples–flat surface–antidunes–dunes

20. Kennedy gave a relation between
   (a) area and velocity
   (b) critical velocity and depth of flowing water
   (c) velocity and hydraulic mean depth
   (d) rainfall and runoff

21. The relation between critical velocity V_o and depth of flowing water y given by Kennedy is
   (a) $V_o = 0.55\, m\, y^{0.64}$
   (b) $0.64\, m\, y^{0.55}$
   (c) $V_o = 0.7\, m\, y^{0.55}$
   (d) $V_o = 0.55\, y\, m^{0.7}$

where m = critical velocity ratio in m

22. For sands greater than the standard, the critical velocity ratio is ______ one.
   (a) less than
   (b) equal
   (c) more than
   (d) equal or more than

23. A channel is said to be in regime when
(a) silt grade and silt charge are constant
(b) discharge is constant
(c) is flowing in unlimited incoherent alluvium of the same character as that transported
(d) all the above

24. According to Lacey
(a) natural silt transporting channels have a tendency to assume a semi-elliptic section
(b) finer the silt, channel closely approximates a semi-circle.
(c) silt is kept in suspension due to the force of vertical eddies
(d) all of these

25. The Lacey's silt factor f is equal to

(a) $\frac{3}{2}\frac{V^2}{R}$

(b) $\frac{5}{2}\frac{V^2}{R}$

(c) $\frac{7V^2}{2R}$

(d) $\frac{9}{2}\frac{V^2}{R}$

where V = mean regime velocity, R = hydraulic mean depth.

26. According to Lacey's silt theory, perimeter P of a channel is proportional to
(a) $Q^{2/5}$
(b) $Q^{1/2}$
(c) $Q^{0.8}$
(d) Q

where Q is discharge

27. Lacey gave a relation between
(a) area and velocity
(b) velocity and hydraulic mean
(c) both (a) and (b)
(d) none of these

28. Lacey assumed that silt is kept in suspension because of the normal components of eddies generated from
(a) sides only
(b) bed only
(c) whole perimeter
(d) none of these

29. Lacey's general regime equation is

(a) $V = 10.8\ R^{1/3}\ S^{2/3}$
(b) $V = 10.8\ R^{1/2}\ S^{1/3}$

(c) $V = 10.8\ R^{2/3}\ S^{1/3}$

(d) $V = 10.8\ R^{1/2}\ S^{2/3}$

where V = mean regime velocity

R = hydraulic mean depth

S = slope of water surface

30. According to Lacey's equation normal regime scour depth $R¢$ is

(a) $0.473\ (Q/f)^{1/2}$

(b) $0.473\ (Q/f)^{1/3}$

(c) $0.473\ (Q/f)^{1/4}$

(d) $0.473\ (Q/f)^{1/5}$

31. A typical and most desirable section of a canal is

(a) in cutting

(b) in filling

(c) partly in cutting and partly in filling

(d) none of the above

32. The berms in canal serve

(a) as a good lining for reducing losses

(b) help to attain regime conditions

(c) provide a scope for future widening of the canal

(d) all of them

33. Assumed value of saturation gradient (H : V) in clay is

(a) 1 : 3

(b) 1 : 4

(c) 1 : 6

(d) 1 : 8

34. By adopting lining canals in new projects

(a) earthwork can be reduced

(b) number of canal structures can be reduced

(c) storage and diversion capacity may be reduced

(d) all the above

35. The corners of trapezoidal canal sections are rounded

(a) to increase A/P ratio

(b) depth is limited

(c) both (a) and (b)

(d) none of the above

36. If cement concrete lining is provided to canal, maximum permissible velocity is

(a) 1.5 to 1.8 m/sec

(b) 2 to 2.5 m/sec

(c) 3.0 to 3.5 m/sec

(d) 4.0 to 5.0 m/sec

37. As per I.S. code requirement of free board for main canal is
(a) 0.75 m
(b) 1.0 m
(c) 1.25 m
(d) 1.5 m

38. As per I.S. recommendations, for a canal with discharge of more than 30 cumecs minimum width of inspection bank is
(a) 5.0 m
(b) 6.0 m
(c) 8.0 m
(d) 10.0 m

39. Which one of the following is wrong about cement concrete tile lining of canals?
(a) Rigid quality control is required.
(b) Expansion joints are not required.
(c) Rounded sections can be easily laid.
(d) Damaged portion can be repaired easily.

40. Which one of the following is wrong statement about boulder lining of canals?
(a) It helps in retaining the shape of canal section.
(b) It prevents seepage of canal water.
(c) Rounded or sub-angular river cobbles are preferred for such works.
(d) Blasted rock pieces with sufficient base area are ideal for such works.

41. Thickness of stone lining to be adopted for a canal of capacity less than 50 cumecs is
(a) 80 mm
(b) 120 mm
(c) 150 mm
(d) 200 mm

42. Generally, pressure relief valves open out, as soon as the differential pressure become
(a) 100 mm
(b) 200 mm
(c) 300 mm
(d) 500 mm

43. The diameter of pressure relief valves used in the bed and sides of canal are ______respectively.
(a) 50 mm and 150 mm
(b) 100 mm and 200 mm
(c) 150 mm and 50 mm
(d) 200 mm and 100 mm

44. To safeguard the lining material of canals in black cotton soil a thickness of ______ of non-cohesive soil is required if the swelling pressure is upto 350 to 500 kN/m^2.
(a) 750 to 850 mm

(b) 900 to 1000 mm
(c) 1050 to 1250 mm
(d) 1400 – 1500 mm

45. In a canal safety ladders are provided on both banks, alternately at about ______ staggered distance, in straight reaches
(a) 150 m
(b) 300 m
(c) 450 m
(d) 600 m

46. A land is said to be waterlogged when
(a) it is submerged in flood
(b) the air circulation is stopped in the root zone due to rise in water table
(c) the soil pores within a depth of 300 mm are saturated
(d) all of these

47. The infertility of the soil in waterlogged area is due to
(a) death of bacteria causing nutrification
(b) increase in salinity
(c) growth of weeds
(d) all of the above

48. Waterlogging is due to
(a) overirrigation
(b) impervious obstruction
(c) inadequate drainage
(d) all of these

49. To avoid formation of saline soil, water table should be kept at least ______ below root zone.
(a) 1 m
(b) 2 m
(c) 3 m
(d) 5 m

50. Tile drains increase crop yield by
(a) removing the free gravity water that is not directly available to the plants
(b) increasing air circulation
(c) reducing and removing toxic substances such as sodium and other soluble salts
(d) all the above

51. Drainage coefficient depends upon
(a) rain fall
(b) type of soil
(c) type of crop
(d) all the above

52. The recommended value of drainage coefficient is ______ per cent of the average rainfall to be

removed per day.

(a) 0.5 %
(b) 1.0 %
(c) 2 %
(d) 2.5 %

53. Which one of the following is not layout of tile drains?
(a) French drain system
(b) Grid iron system
(c) Herring bone system
(d) Intercepting drain system

54. In tube well irrigation system the best method of pricing is
(a) flat rate pricing
(b) crop rate system
(c) volumetric method
(d) any of the above

55. The basic factor which controls the process of meandering is
(a) discharge
(b) bed and side resistance
(c) valley slope
(d) all of these

56. A diversion head work is to
(a) reduce fluctuations in the supply level of the water
(b) raise water level of the head of the canal
(c) to regulate the intake of water into the canal
(d) all of these

57. A weir is generally aligned at right angles to the direction of river flow, because
(a) it is economical
(b) it needs less length of weir
(c) it gives better discharge capacity
(d) all the above

58. A solid construction across a river to raise its water level and divert the water into the canal is known as
(a) bund
(b) barrage
(c) weir
(d) dam

59. Okhla weir on Yamuna river, in Delhi, is an example of
(a) masonry weir
(b) rock fill weir
(c) concrete weir

(d) none of the above

60. Normally difference between the crest level of the under-sluices and the crest level of the weir is
(a) 1 to 1.5 m
(b) 2 to 3.0 m
(c) 3 to 4.0 m
(d) more than 5 m

61. The function of a scouring sluice is to
(a) control the silt entry into the canal
(b) pass the low floods without dropping the shutters of the main weir
(c) to scour the silt
(d) all the above

62. A fish ladder is
(a) a ladder provided in the canal for the maintenance of canal
(b) a ladder to climb up dam
(c) a structure which enables the fish to pass upstream
(d) none of the above

63. The canal head regulator
(a) regulates the supply of water entering the canal
(b) controls the entry of silt in the canal
(c) prevents the river floods from entering the canal
(d) all the above

64. If V_1 is the velocity of flow and y_1 is the depth of horizontal bed, the incoming Froude number is

(a) $\frac{V_1}{2gy_1}$

(b) $\frac{V_1}{gy_1}$

(c) $\frac{V_1}{\sqrt{2gy_1}}$

(d) $\frac{V_1}{\sqrt{gy_1}}$

65. A hydraulic jump is formed when
(a) the two flows of supercritical velocities meet each other
(b) the two flows of subcritical velocities meet each other
(c) a supercritical flow strikes against a subcritical flow
(d) a subcritical flow strikes against a supercritical flow

66. The loss of head in hydraulic jump is given by

(a) $\frac{y_2 - y_1}{4 y_1 y_2}$

(b) $\frac{(y_2 - y_1)^2}{4 y_1 y_2}$

(c) $\frac{(y_2 - y_1)^3}{4 y_1 y_2}$

(d) $\frac{(y_2 - y_1)^4}{4 y_1 y_2}$

where y_1 = depth of water on upstream

y_2 = depth of water on downstream

67. According to Bligh's creep theory, the percolating water follows:

(a) the outline of the base of the foundation

(b) in a straight line path under the floor

(c) in a straight path under the foundation work

(d) none of the above

68. Which one of the following is the wrong statement about Bligh's creep theory?

(a) Percolating water follows the outline of the base of foundation.

(b) It makes no distinction between horizontal and vertical creeps.

(c) Safety against piping can be ensured by providing sufficient creep length.

(d) On upstream side floor thickness should be designed carefully.

69. The suggested weightage factor for horizontal to vertical creep by lane is

(a) 1/2

(b) 1/3

(c) 2

(d) 3

70. The loss of head per unit length of creep is called

(a) coefficient of creep

(b) Bligh's coefficient

(c) Lane's coefficient

(d) percolation coefficient

71. According to Khosla's theory, the undermining of the floor starts from

(a) starting end

(b) intermediate point

(c) foundation bed

(d) tail end

72. According to Khosla's theory, the first streamline follows bottom contour of the structure and the remaining streamlines follow smooth curves, transmitting slowly from the outline of foundation to a _______.

(a) circular curve

(b) catenary curve

(c) semi-elliptic

(d) parabolic curve

73. A parabolic glacis type of fall is known as

(a) Sarda fall

(b) Inglis fall

(c) Montague fall
(d) Ogee fall

74. The type of fall which consists of an inlet well with a pipe at its bottom to carry water to a downstream well is known as
(a) cylindrical fall
(b) pipe fall
(c) vertical drop type fall
(d) straight glacis fall

75. The fall consisting of convex and concave curves is known as
(a) Moutague type fall
(b) Inglis fall
(c) straight glacis fall
(d) Ogee fall

76. The fall that is suitable for high drops with low discharge is
(a) baffle type
(b) straight glacis
(c) well type
(d) vertical drop type

77. ______ fall can be used for all discharges when drop is more than 1.5 m.
(a) Baffle type
(b) Straight glacis
(c) Well type
(d) Vertical drop type

78. The canal fall which is quite satisfactory but becomes obsolete due to high cost is
(a) Ogee fall
(b) rapids
(c) trapezoidal notch fall
(d) well type fall

79. Which of the following statement is wrong?
(a) Ogee fall consists of convex and concave curves.
(b) Rapids worked out quite satisfactory but were expensive.
(c) By introduction of trapezoidal notch fall, the depth-discharge relationship of the channel remains practically unaffected.
(d) Simple vertical drop type falls are known as well type falls.

80. Which one of the following is the wrong statement about a head regulator?
(a) When the water level in main channel is low, it helps in heading up water.
(b) Controls the supplies entering the off-take channel.
(c) Controls entry of silt into off-take channel.
(d) Serves as a meter for measuring discharge.

81. Hand operated gates of cross regulators can have spans of

(a) 2 – 3 m
(b) 4 – 5 m
(c) 6 – 8 m
(d) 9 – 12 m

82. The crest level of the distributary head is generally kept at ______ higher than the bed level of the parent channel.
(a) 0.3 to 1.0 m
(b) 1.2 – 1.8 m
(c) 2.0 to 2.5 m
(d) more than 2.5 m

83. The minimum capacity of the escape channel is kept as ______ of the channel capacity.
(a) 1/4
(b) 1/3
(c) 1/2
(d) 2/3

84. The outlet through which the discharge depends upon the difference of head between the distributary and the water-course, is known as
(a) non-modular outlet
(b) modular outlet
(c) semi-modular outlet
(d) rigid module

85. In a flexible module, the discharge depends upon
(a) water level of the water-course
(b) water level of the distributary
(c) difference of water levels of water-course and distributary
(d) none of the above

86. In Gib's module, the discharge
(a) depends upon water level of the water-course only
(b) depends upon water level of the distributary only
(c) depends upon both (a) and (b)
(d) is independent of all above

87. The ratio of the rate of change of discharge of the outlet to the rate of change of discharge of the distributary channel is known as
(a) flexibility
(b) proportionality
(c) sensitivity
(d) setting

88. An outlet is said to be proportional when the ratio of the rate of change of outlet discharge to the rate of channel discharge is
(a) less than unity
(b) equal to unity

(c) more than unity

(d) any constant

89. For rigid modules sensitivity is

(a) zero

(b) less than unity

(c) unity

(d) more than unity

90. A pipe or orifice type outlet is proportional, if the outlet is fixed at ______ times the depth below the water surface.

(a) 0.3

(b) 0.4

(c) 0.5

(d) 0.6

91. For the weir type outlet to be proportional, the outlet should be set at ______ times the depth below the water surface.

(a) 0.3

(b) 0.5

(c) 0.7

(d) 0.9

92. The ratio of the rate of change of discharge through the outlet to the rate of change of water level of the distributary, referred to the normal depth of the channel, is known as

(a) setting

(b) sensitivity

(c) flexibility

(d) drowning ratio

93. The ratio of the depth of water level over crest on the downstream of the module to the depth of water level over crest on the upstream of module is known as

(a) setting

(b) sensitivity

(c) flexibility

(d) drowning ratio

94. Which of the following is a non-modular outlet?

(a) Pipe outlet

(b) Submerged pipe outlet

(c) Venturiflume

(d) Open flume

95. Which of the following is a type of semi-module outlet?

(a) Submerged pipe outlet.

(b) Open sluice.

(c) Open flume.

(d) Gibb’s module.

96. Which one of the following statements is about a syphon aqueduct?

(a) The drain bed is depressed and provided with pucca floor.
(b) The drainage bed is joined to pucca floor by a vertical drop.
(c) The downstream rising slope should not be steeper than 5 : 1.
(d) HFL of the drain is sufficiently below the bottom of the canal.

97. The cross drainage work in which the drain is taken over the canal such that the canal water runs below the drain freely is known as
(a) aqueduct
(b) syphon aqueduct
(c) super-passage
(d) canal syphon

98. Which one of the following statement is wrong?
(a) An inlet is a structure constructed in order to allow the drainage water to enter canal.
(b) Inlets are constructed when the drainage discharge is small and the drain crosses the canal with its bed level is equal to or slightly higher.
(c) Outlets are located a little downstream along the canal.
(d) The number of inlets and outlets should always be same.

99. By greater fluming the canal
1. width of aqueduct is reduced.
2. the length of transition wings is increased
(a) both 1 and 2 are correct
(b) 1 is correct but 2 is wrong
(c) 1 is wrong but 2 is correct
(d) both 1 and 2 are wrong

100. The depth of water stored in an irrigation tank, rarely exceeds
(a) 4 m
(b) 8 m
(c) 12 m
(d) 16 m

101. The storage created by construction of low earthern bunds, is known as
(a) a reservoir
(b) a lake
(c) a tank
(d) none of these

102. The provision of suitable breaching sections becomes more important in irrigation tanks, which are
(a) in groups
(b) isolated
(c) both (a) and (b)
(d) none of them

103. The capacity of an irrigation tank is sometimes increased by installing

(a) dam stones

(b) breast well
(c) divide wall
(d) saddle

104. A minor irrigation scheme involves command area equal to or less than
(a) 500 hectares
(b) 1000 hectares
(c) 2000 hectares
(d) 3000 hectares

105. The discharge through the sluice of a small irrigation tank is usually controlled by
(a) dam stone
(b) shutter gate
(c) plug
(d) all of these

II. *Match List I with List II selecting the answer code given below question no. 106-109.*

106.

List I	**List II**
Techniques of water distribution in the forms	
A. Free flooding	1. Levees are constructed along the contours.
B. Border flooding	2. Ditches are excavated in the field.
C. Check flooding	3. The land is divided into a number of strips separated by low levees.
D. Basin flooding	4. Suitable for orchard trees.

Codes:

(a)	A – 3	B – 2	C – 1	D – 4
(b)	A – 2	B – 1	C – 3	D – 4
(c)	A – 2	B – 3	C – 1	D – 4
(d)	A – 1	B – 3	C – 4	D – 1

107.

List I	**List II**
Type of soil	**Saturation gradient (H : V)**
A. Sand	1. 1 : 4
B. Loamy sand	2. 1 : 8
C. Clay	3. 1 : 10

D. Loan 4. 1 : 15

Codes:

(a)	A – 4	B – 3	C – 1	D – 2
(b)	A – 4	B – 2	C – 3	D – 1
(c)	A – 3	B – 1	C – 2	D – 4
(d)	A – 3	B – 2	C – 1	D – 4

108.

List I	**List II**
Type of soil	**Maximum permissible velocity in m/sec in unlined canal**
A. Murram	1. 0.3 to 0.6
B. Black cotton soil	2. 0.6 to 0.9
C. Gravel	3. 1.0 to 1.1
D. Average sandy soil	4. 1.5

Codes:

(a)	A – 3	B – 1	C – 2	D – 4
(b)	A – 2	B – 3	C – 4	D – 1
(c)	A – 3	B – 2	C – 4	D – 1
(d)	A – 2	B – 3	C – 1	D – 4

109.

List I	**List II**
Type of canal fall	**Suitable for**
A. Vertical drop	1. Discharge any, fall more than 1–5 m.
B. Straight glacis	2. Discharge low and high drops.
C. English fall	3. Discharge up to 15 cumecs and drop up to 1.5 m.
D. Well type	4. Discharge up to 60 cumecs and drop up to 1.5 m.

Answer Code:

(a)	A – 3	B – 4	C – 2	D – 1
(b)	A – 3	B – 4	C – 1	D – 2
(c)	A – 4	B – 3	C – 1	D – 2

(d)	A – 4	B – 3	C – 2	D – 1

III. *Select your answer according to the coding system given for the Assertion (A) and Reason (R) given in the question nos 110 to 116 coding system:*

(a) Both A and R are true and R is the correct explanation of A.
(b) Both A and R are true but R is not the correct explanation of A.
(c) A is true but R is false.
(d) A is false but R is true.

110. Assertion: Salts of calcium, magnesium, sodium and potassium, present in the irrigation water may prove injurious to plants.
Reason: When present in excessive quantities they prevent adequate aeration.

111. Assertion: In saline soil plants die due to lack of water.
Reason: Pure water from within the roots starts flowing out of the roots by osmosis.

112. Assertion: Hydraulic jump is generally accompanied by a large-scale turbulence.
Reason: It is due to dissipation of kinetic energy of supercritical flow.

113. Assertion: Lane's theory of creep is generally adapted in any design.
Reason: Lane's theory is purely empirical.

114. Assertion: Glacis type fall is a suitable as a metering device.
Reason: A broad crest gives a constant coefficient of discharge with varying head.

115. Assertion: The canals are generally aligned along the ridge line.
Reason: If canals are aligned along ridge line cross-drainage works are generally not required.

116. Assertion: As far as possible cross-drainage works should be avoided.
Reason: Cross-drainage work is generally a costly construction.

IV. *State whether the following statements are True or False (Q. No. 117 to 154).*

117. In general, groundwater or surface water from reservoirs does not have sufficient sediment to cause any serious problems in irrigation.

118. The salt concentration in irrigation water is generally measured by determining the electrical conductivity of water.

119. The total depth of water required by a crop to come to maturity is called its delta.

120. The duty of water is the relationship between the volume of water and the area of the crop it matures.

121. Duty at the head of a minor will be less than that at the head of distributary.

122. The outlet discharge factor is nothing but duty at the head of water-course.

123. Paleo irrigation means applying water to soil just before sowing crop.

124. The first watering which is given to a crop, when the crop is a few centimetres high is called Kor-watering.

125. Cash crop means the crop which gives more profit.

126. 10 cumec of water is delivered to a 16 hectare field for 2 hours. Soil probing indicated that 0.3 metres of water has been stored in the root zone. Then water application efficiently is 66.67 per cent.

127. In the study of mechanics of sediment transport, it is assumed that the soil is coherent.

128. When the velocity in the canal is less than critical velocity, the canal is said to be in silting.

129. When a channel is constructed with defective slope, to attain the final regime, the channel forms its section first before the final slope.

130. Kennedy has not given any importance to bed width and depth ratio.

131. In irrigation canals a comparatively steeper slope is provided in cutting rather than filling.

132. Berm is the horizontal distance left at ground level between the toe of the bank and the top edge of the cutting.

133. In canals pressure relief valves are provided to safeguard lining.

134. The crops do not come up in waterlogged area due to growth of bacteria.

135. Land affected by efflorescence is called saline soil.

136. Drainage coefficient is a dimensionless quantity

137. If most of the pending is done by a gate, then the barrier is known as weir.

138. Sometimes weir may be aligned at an oblique angle to the direction of river flow to get safe and better foundation.

139. Under sluices are also called scouring sluices.

140. Hydraulic jump is the jump of water that takes place when a subcritical flow changes into a supercritical flow.

141. Depth before the hydraulic jump is always more than the depth after the jump.

142. There is no hydraulic jump, if incoming Froude No. $F_1 = 1$.

143. Bligh's creep theory for seepage flow assumes that the loss of head is proportional to the length of the creep.

144. Bligh's makes distinction between horizontal and vertical creep.

145. According to Khosla, it is absolutely essential to have a reasonably deep vertical cut-off at the downstream end to prevent undermining.

146. The ideal alignment is when branch channel makes zero angle with the parent channel initially.

147. Canal escapes are built to remove surplus water from an irrigation channel into a natural drain.

148. A metering flame is an artificially widened section of the channel, which can be utilised for calculating the discharge in the channel.

149. An outlet is known as sub-proportional outlet if its flexibility is less than unity.

150. Bed bars are constructed along an unlined canal to indicate the correct alignment and theoretical bed levels.

151. When the HFL of the drain is sufficiently below the bottom of the canal, so that the drainage of the water flows freely under the gravity, the cross drainage work required is an aqueduct.

152. A level crossing is generally provided when a large canal and a small stream approach each other practically at the same level.

153. Inlets and outlets are used when high flood drainage discharge is small.

154. The contraction in watering of the canal is known as fluming.

Answers to Multiple-Choice Questions

1. (a)	2. (a)	3. (d)	4. (a)	5. (c)
6. (c)	7. (d)	8. (d)	9. (b)	10. (d)
11. (d)	12. (b)	13. (d)	14. (a)	15. (b)
16. (c)	17. (b)	18. (a)	19. (b)	20. (b)
21. (a)	22. (d)	23. (d)	24. (d)	25. (b)
26. (b)	27. (c)	28. (c)	29. (c)	30. (b)
31. (c)	32. (d)	33. (b)	34. (d)	35. (c)
36. (d)	37. (a)	38. (c)	39. (a)	40. (b)
41. (c)	42. (a)	43. (c)	44. (c)	45. (b)
46. (b)	47. (d)	48. (d)	49. (c)	50. (d)
51. (d)	52. (b)	53. (a)	54. (c)	55. (d)
56. (d)	57. (d)	58. (c)	59. (b)	60. (a)
61. (d)	62. (c)	63. (d)	64. (d)	65. (c)
66. (c)	67. (a)	68. (d)	69. (b)	70. (d)
71. (d)	72. (c)	73. (c)	74. (a)	75. (d)
76. (c)	77. (a)	78. (b)	79. (d)	80. (a)
81. (c)	82. (a)	83. (c)	84. (a)	85. (b)
86. (d)	87. (a)	88. (b)	89. (a)	90. (a)
91. (d)	92. (b)	93. (d)	94. (b)	95. (c)
96. (d)	97. (c)	98. (d)	99. (a)	100. (c)
101. (c)	102. (a)	103. (a)	104. (c)	105. (c)
106. (c)	107. (a)	108. (c)	109. (b)	110. (a)
111. (a)	112. (a)	113. (d)	114. (a)	115. (a)
116. (a)	117. True	118. True	119. True	120. True
121. False	122. True	123. True	124. True	125. False
126. True	127. False	128. True	129. True	130. True
131. True	132. True	133. True	134. False	135. True
136. False	137. False	138. True	139. True	140. False
141. False	142. True	143. True	144. False	145. True
146. True	147. True	148. False	149. True	150. True
151. True	152. False	153. True	154. False	

12

Soil Mechanics and Foundation Engineering

12.1 INTRODUCTION

* Karl Terzagi is known as the father of soil mechanics. He defined *soil mechanics* as the application of the laws of mechanics and hydraulics to engineering problems dealing with sediments and other unconsolidated accumulations of solid particles produced by the mechanical and chemical disintegration of rocks regardless of whether or not they contain any admixture of organic constituents.

Now the term soil mechanics is generally means the discipline of engineering which deals with the properties and behaviour of soil as a structural material.

* *Residual soil* means the soil resulting from disintegration of rock and staying at the place of their formation.

* Transported soil is the soil that is carried away from its place of formation by natural forces.

Classification of transported soil

1. Talus: The soil transported by gravity.
2. Aeoline deposits (loess): Soil deposits formed by wind.
3. Alluvial deposits: Soil transported by streams and rivers.
4. Glacial Soils (or till): Soil transported by glaciers.
5. Lacustrine deposits: Soil deposited in lake bed.
6. Marine deposit: Soil deposits formed by seawater.

Soils of India

1. Red soil It is formed by decomposition of granite, gneiss, quartzite and feldspar rocks rich in iron and magnesium bearing minerals. It does not contain soluble and calcareous materials.

2. Moorum It is a powdered rock which includes all kinds of disintegrated rock.

3. Desert soil It is mainly sand covering an irregular rocky floor. In most of the area, the sand is piled up into dunes.

4. Alluvial soil Alluvial soil is formed due to sediment deposits by stream and rivers. Indo-Ganges plain is the biggest alluvial soil deposit. The older alluvial is generally darker in colour. They contain impure calcium carbonate. They are loamy soils possessing high degree of fertility.

5. Lateritic soil It is a product of tropical alteration suffered by alkali rocks and sedimentary rocks. The soil is rich in iron and aluminium content. When fresh it can be easily cut but after weathering it turns into a hard stone.

6. Saline and alkaline soils These soils contain high salt concentration. They are often found in areas of poor drainage with high evaporation.

7. Black cotton soil The name is due to its colour and its immense fertility for growing cotton. It covers about 20% of total area of India. It is an expansive soil. The thickness of this soil deposit varies from 0.3 m to 15 m. It usually contains high alumina, lime and magnesia.

8. Clay It is an aggregate of mineral particles of very fine particles (microscopic). It may be organic or inorganic.

9. Loam It is a mixture of sand, silt and clay.

10. Shale This is a material in the stage of transformation from clay to slate.

11. Kaolin It is a pure form of white clay. It is known as china clay. It is used in ceramic industry.

12. Peaty and marshy soils This type of soil is formed in the waterlogged area. They are rich in organic materials.

Structure of Soils

* Structure of soil may be defined as the physical constitution of a soil material as expressed by the size, shape and the arrangement of solid particles.

* Size of soil particles:

1. The soil particles coarser than 0.075 mm are visible to the naked eye or may be examined by means of a hand lense.
2. It is possible to distinguish the grains lying between 0.075 mm to 2*m* [*m* = micron = 1×10^{-6} m = 0.001 mm].
3. Grains of size 2*m* to 0.1 *m* can be observed under a microscope but their shapes cannot be made out. The shape of these particles may be determined by means of an electron microscope.

* Specific surface is defined as the total area of the surface of grains expressed in square centimetres per gram or cubic centimetre. A sphere has least specific surface whereas a plate exhibits the maximum.

* Soil mass structure: Bulk soil is random assembly of soil particles with air and water occupying the voids amongst the particles. Thus, soil mass is a three-phase system consisting of solid particles, water and air as shown in Fig. 12.1.

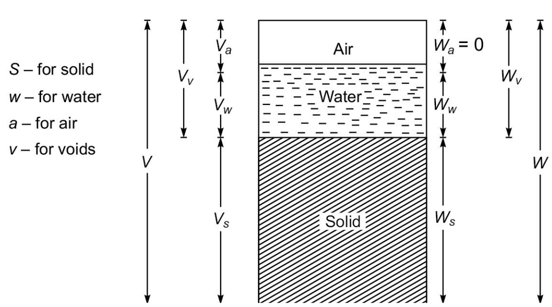


Fig. 12.1

Basic Terms

* Volume related:

1. Void ratio $e = \frac{\text{Volume of voids}}{\text{Volume of soil solids}} = \frac{V_v}{V_s}$. This value may range from 0.5 to 1.5.

2. Porosity $n = \frac{\text{Volume of voids}}{\text{Total volume}} \times 100 = \frac{V_v}{V} \times 100$. Its range is between 0 and 100.

3. Degree of saturation, $S = \frac{\text{Volume of water}}{\text{Volume of voids}} \times 100 = \frac{V_w}{V_v} \times 100$

$S = 0$, dry soil

$S = 100$, saturated soil

0 £ S £ 100, partially saturated soil.

* Weight related terms

1. Water content, $w = \frac{\text{Weight of water}}{\text{Weight of soil solids}} \times 100 = \frac{W_w}{W_s} \times 100$.

It can be zero to as high as 400%

2. Unit weight of water $g_w = \frac{W_w}{V_w}$

3. Unit weight of soil solids $g_s = \frac{W_s}{V_s}$

4. Bulk weight of soil $g = \frac{W}{V}$

5. Dry unit weight of soil $g_d = \frac{W_s}{V}$

6. Saturated unit weight of soil $g_{sat} = \frac{W_{sat}}{V}$

7. Submerged unit weight of soil $g_{sub} = g_{sat} - g_w$

* Density related terms

1. Bulk density, $r = \frac{\text{Total mass}}{\text{Total volume}} = \frac{M}{V}$

2. Dry density, $r_d = \frac{\text{Mass of solids}}{\text{Total volume}} = \frac{M_s}{V}$

3. Density of solids, $r_s = \frac{\text{Mass of solids}}{\text{Volume of solids}} = \frac{M_s}{V_s}$

4. Saturated density, $r_{sat} = \frac{\text{Mass of fully saturated soil}}{\text{Total volume}} = \frac{M_{sat}}{V}$

5. Submerged density, $r_{sub} = \frac{(M_s)_{sub}}{V} = r_{sat} - r_w$

* Specific gravity related terms

1. Specific gravity: The specific gravity of a substance is the ratio of its mass in air to the mass of an equal volume of water at 4°C.

Specific gravity of soil solids, $G = \frac{\rho_s}{\rho_\omega}$. Generally, G varies between 2 and 3.

2. Mass specific gravity.

$$G_m = \frac{\text{Mass density of soil}}{\text{Density of water}} = \frac{\rho}{\rho_w}$$

3. Absolute specific gravity. The absolute volume of soil is the volume of soil minus the volume of permeable and impermeable voids. Hence, absolute specific gravity

$$G_a = \frac{(\rho_s)a}{\rho_w} = \frac{\text{Mass density of absolute solids}}{\text{Density of water}}$$

It is also known as 'grain specific gravity' or 'specific gravity of solids'.

4. Density Index: It is the ratio of the difference between the voids ratio of the soil in its loosest ($e_{\max}$) and its natural void ratio (e) to the difference between the void ratio in the loosest and denset state ($e_{\min}$)

$$I_D = \frac{e_{\max} - e}{e_{\max} - e_{\min}}$$

Important Relations

The following relationships among soil parameters can be easily derived.

1. $e = \frac{n}{1-n}$
2. $n = \frac{e}{1+e}$
3. $w = \frac{1}{G} \times s \times e$
4. $g_d = \frac{\gamma}{1+w} = G\, g_w\,(1-n)$
5. $g_{\text{sat}} = G\, g_w\,(1-n) + n\, g_w$
6. $g_{\text{sub}} = \frac{\gamma_w}{1+e}(G-1)$

Determination of Specific Gravity

Constant volume or pycnometer method is commonly used for determining specific gravity of soil. Pycnometer is a bottle of volume 500 cc. Distilled water and soil sample of about 200 cc are required for this test. Figure 12.2 shows diagrammatically the materials to be weighed.

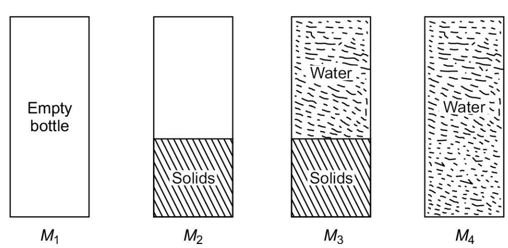


Fig. 12.2 Determination of specific gravity

$$G = \frac{\text{Mass of dry soil}}{\text{Mass of an equal vol. of water}} = \frac{M_2 - M_1}{(M_4 - M_1) - (M_3 - M_2)}$$

Determination of Water Content

1. Over dry method Find the mass of clean container with lid, M_1. Fill the container with about 300 grams of sample and find the mass, M_2. Oven dry the sample and fill the container and find the mass, M_3. Then

$$\text{Water content } w = \frac{\text{Mass of water}}{\text{Mass of solid}} \times 100$$

$$= \frac{M_2 - M_3}{M_3 - M_1} \times 100$$

Note Oven temperature should be 110°C. Clay takes 10 to 15 hours to dry. Sandy soil takes 4 hours to dry.

2. Pycnometer method In this method pycnometer of 1 litre capacity with conical cap is used.

(a) Find mass of clean pycnometer, M_1

(b) Find mas of pycnometer + wet sample, M_2

(c) Find mass of pycnometer + sample + water, M_3

(d) Find mass of pycnometer + water, M_4

$$w = \frac{M_\omega}{M_s} \times 100 = \left(\frac{M_2 - M_1}{M_3 - M_4} \times \frac{G-1}{G} - 1\right) \times 100$$

12.2 PROPERTIES OF SOILS

1. Shape of Grains

Particles coarser than 0.075 mm can be observed by naked eye to get some qualitative idea about the behaviour of soil. Coarser fraction comprising angular grains have higher bearing capacity. They can be compacted to a dense mass by vibration.

2. Size of Grains

The properties of cohesionless soil depend upon the grain size distribution to a great extent whereas the properties of cohesive soil depend upon the grain size distribution to some extent.
Based on the size of grain the soil is classified as shown in Table below.

Fine grained		Coarse grained						
Clay	Silt	Sand			Gravel		Cobble	Boulder
		Fine	Medium	Coarse	Fine	Coarse		

0.002 0.075 0.475 2.0 4.75 20 80 300 mm

Determining the percentage of particles of different sizes in a soil is known as 'grain size distribution' or 'mechanical analysis' of soil. Mechanical analysis may be divided into:

1. Sieve analysis
2. Sedimentation analysis/wet mechanical analysis.

Sieve Analysis It is carried out by sieving about 500 gm of dry soil sample through a set of standard gives arranged one over the other is ascending order of their sizes. The percentage of sample retained on each sieve is determined by weight and the percentage finer than the sieve size found. The result is plotted in the form of a graph on a semi-log paper with the percentage finer on arithmetic scale and the particle size on logarithmic scale. A smooth curve is drawn through the points to see grain size distribution as shown in Fig. 12.3.

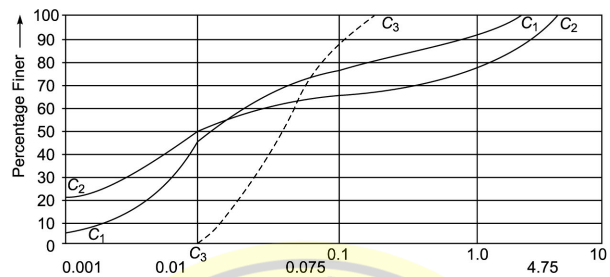


Fig. 12.3 Grain size distribution curve

C_1C_1 – Well graded, since it ranges over a large range of particle sizes.

C_2C_2 – Gap graded, since some of the particle sizes missing.

C_3C_3 – Poorly graded or uniformly graded, since it is confined to a narrow range of particles.

* The sizes corresponding to 30% finer is designated as D_{30}, 60% finer as D_{60} and so on.

* Size D_{10} is known as effective diameter.

* Uniformity coefficient, $Cu = \frac{D_{60}}{D_{10}}$

$$Cu < 5, \text{ uniform size}$$

$$Cu = 5 \text{ to } 10, \text{ medium graded soil}$$

$$Cu > 15, \text{ well graded soil.}$$

* Coefficient of curvature

$$C_C = \frac{D_{30}^2}{D_{10} \times D_{60}}$$

The soil is said to be well graded if C_C lies between 1 and 3.

Sedimentation Analysis The particle size distribution of soil fraction less than 75m is determined by sedimentation analysis, which is based on Stokes' law. According to this law, fine particles settle in liquid at different rates according to their size. Coarser size particles settle quickly.

Stokes' law states

$$V = \frac{g(G-1)D^2}{18\eta}$$

where V = Velocity of settling particle in still water

D = Equivalent diameter of particle

g = Gravitational acceleration

G = Specific gravity of particle

h = Viscocity of water

Limitations of Stokes' law

1. It is true for spherical particles only.
2. It cannot be applied to particles of size smaller than 0.002 mm (0.2 m).
3. The upper limit of particle size to which this law holds good is 0.2 mm^3. The limitation is because the liquid develops a turbulent motion at the boundaries of the particles.
4. All particles may not have same specific gravity.
5. Side walls of the container also affect the fall of particle.

* It may be noted that if a soil suspension contains less than 50 gm of solids per litre, the influence of the particles on each other is not appreciable.

* Note that if organic matter and calcium compounds are present they bind aggregates of particles. Hence, they should be removed by pretreatment. Pretreatment consists of:

1. Prepare soil hydrogen peroxide mixture at about 60°C and stir gently to remove organic matter.
2. Then boil the mixture to decompose hydrogen peroxide.
3. After cooling the mixture treat it with about 0.2 N hydrochloric acid.
4. When the reaction with calcium compound is complete, filter the mixture and wash with distilled water until acid free.
5. Then dry it to constant weight.

* Another method of pretreatment: Use dispersing agent hexametaphosphate (trade name Colgon). The dispersing agent solution is prepared by dissolving 38 gm of Colgon and 12 gm of sodium carbonate in distilled water to make 1 litre solution. Soil soaked with the dispersing agent solution is kept for test.

* The hydrometer method of test is preferred for finding grain size distribution of finer soils.

* Effect of temperature on velocity of fall:

1. Density of water varies with temperature. However, it is not much hence, its effect on the velocity of sedimentation may be neglected.
2. Variation in viscocity should be considered.
3. Viscocity of water decreases with temperature.

* Viscocity is measured in the unit 'poise'.

1 poise = 10^{-4} kN sec/m^2.

* Hydrometers are normally calibrated at 27°C. Hence, temperature corrections are required to hydrometer readings if soil sample is at different temperature while testing.

* The corrections are required for:

1. correction for meniscus (always +ve)

2. correction for dispersing agent (always –ve)

Density Index of Cohesionless Soils

* In the loosest form spherical shaped particles can have void ratio = 0.90.
* If such grains are packed, void ratio can be about 0.35.
* In the soil, grains are not uniform, hence smaller grains fill the space between the bigger ones and the void ratio can get reduced to as low as 0.25 in the densest state.
* Sandy soils can be classified as
  1. Very loose, if density index is 0–15
  2. Loose, if density index is 15–50
  3. Medium dense, if density index is 50–70
  4. Dense, if density index is 70–85
  5. Very dense, if density index is 85–100

Consistency of Cohesive Soil

* Consistency is a term used to indicate the degree of firmness of cohesive soils. This is expressed qualitatively as soft, stiff, very stiff and hard.
* A gradual increase water content changes a fine grained soil from solid state to semi-solid state, plastic state and liquid state.
* Curve showing transition stages from the liquid to solid state is as shown in Fig. 12.4.
* The water contents corresponding to transition from one state to the next state are known as the liquid limit (W_L), plastic limit (W_P), and shrinkage limit.

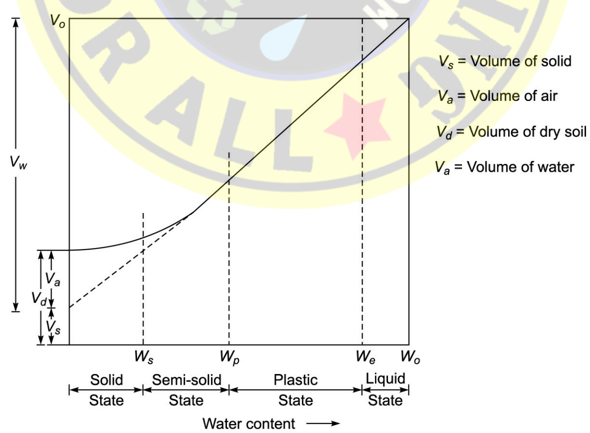


Fig. 12.4 Transition stages of cohesive soil

Liquid Limit (W_L) It is the minimum water content at which a pat of soil cut by a groove of standard dimensions, flow together a distance of 13 mm under the impact of 25 blows in a standard liquid limit apparatus. It is the water content at which the soil shows shearing resistance as the water content is reduced.

Plastic Limit (W_P) It is the limit of water content that represents the boundary between plastic and semi-solid states of soil. It is determined as the minimum water content at which the soil can be rolled into a thread approximately 3 mm in diameter without breaking.

Shrinkage Limit (W_S) It is the lowest water content at which a soil can still be completely saturated.

It represents the boundary between semi-solid and solid states of soil.

In the laboratory, shrinkage limit is determined by completely drying out a lump of soil and measuring its volume and mass.

$$W_S = \frac{(W_i - W_d) - (V_i - V_d)\gamma_\omega}{W_d} \times 100$$

where W_i = Initial wet weight of soil

W_d = Final dry weight of soil

V_i = Initial volume of soil

V_d = Dry volume of soil

Plasticity index It is the range of water content in which the soil behaves like plastic material.

$$I_p = \text{Liquid limit} - \text{Plastic limit.}$$

Consistency index It is defined as the ratio of liquid limit minus the natural water content to the plasticity index.

$$I_c = \frac{W_L - w}{I_p}$$

where w is natural water content

$I_c = 0$ means soil is at its liquid limit

$I_c = 1$ means soil is at its plastic limit

I_c is negative, soil behaves just like liquid

$I_c > 1$, the soil is in a semi-solid state, i.e., it is stiff.

Liquidity index

$$I_L = \frac{w - w_p}{I_P}$$

Shrinkage ratio It is given by

$$\text{SR} = \frac{(V_1 - V_2)/V_d}{w_1 - w_2} \times 100$$

where V_1 = Volume of soil mass at water content, w_1

V_2 = Volume of soil (mass at water content, w_2)

V_d = Volume of dry soil mass

Thus, it may be defined as the ratio of given volume change, expressed as a percentage of the dry volume, to the corresponding change in the water content above the shrinkage limit.

12.3 PERMEABILITY OF SOIL

* Permeability of soil is the property that permits the seepage of water through its interconnected voids. The gravels are highly permeable while clay is least permeable.

* *Darcy's Law*: Darcy (1856) experimentally demonstrated that for laminar flow conditions the rate of flow (i.e., discharge) per unit time, through a saturated soil, is proportional to the hydraulic gradient. Thus,

$$q = k\,i\,A$$

where A = Total cross-sectional area of soil mass normal to the direction of flow.

i = Hydraulic gradient

k = Darcy's coefficient of permeability.

The above equation may be written as

$$v = \frac{q}{A} = ki$$

where v is the velocity of flow or discharge velocity. From this relation the coefficient of permeability may be defined as the velocity of flow which occurs through the total cross-sectional area of soil under a unit hydraulic gradient.

Seepage velocity Flow can occur through voids only, i.e., it cannot occur through solids. Hence, the velocity inside the soil pores is different form velocity of flow. The actual velocity through the pores is known as seepage velocity. If A_v is cross-sectional area of the voids, then

$$q = A \times v = A_v \times V_s.$$

$$\text{or } V_s = \frac{A}{A_v} v = \frac{V}{n} \text{ where } n \text{ is porosity.}$$

$$\text{or } v = n\,V_s = \frac{e}{1+e} v_s$$

$$\text{Thus, } V_s = \frac{v}{n} = \frac{k\,i}{n} = K_p\,i$$

where K_p is **coefficient of percolation.**

Thus, $k_p = \frac{k}{n}$

The coefficient of permeability k is expressed in terms of cm/sec.

* Table 12.1 gives the coefficient of permeability of some soils.

Table 12.1 Coefficient of permeability of some soils

Soil	*k in cm/sec*
Gravel	10^2 to 1
Sand	1 to 10^{-3}
Silt	10^{-3} to 10^{-6}
Clay	Less than 10^{-6}

* The permeability of soil sample may be determined by:

1. Constant water level method
2. Falling water level method
3. Rising water level method

* Factors affecting permeability

1. *Size and shape of particles* The angular sands of greater specific surface will be less permeable at a given porosity than rounded sands.
2. *Properties of water*: Permeability varies directly with the density and inversely with the visocity of water. It may be noted that viscocity of water varies considerably with temperature.
3. *Voids ratio*: For coarse-grained soils, the following relations are almost correct.

$$k \times e^2$$

$$\text{or } k \times \frac{e^2}{1+e}$$

even for fine grained soil it has been found that a semi-logarithmic plot of void ratio versus permeability is approximately a straight line.

4. *Structure of soil*: Stratified soil masses have different permeabilities in the direction parallel and perpendicular to stratification. The permeability is greatly affected by shrinkage cracks, fissures, joints, and warping of layers.
5. *Degree of saturation*: Tiny air bubbles entrapped and foreign matter present in water may plug the soil pores and reduce the permeability considerably.
6. *Adsorbed water*: The adsorbed water surrounding the fine soil particles reduces the flow of water.

12.4 SEEPAGE

* Seepage is the movement of water through the soil under hydraulic gradient.
* The pressure that is exerted on the soil due to the seepage of water is called the seepage force or seepage pressure.
* The problems posed by seepage are:

1. Loss of stored water by an earth dam
2. Settlement of water retaining structures resting on soil due to consolidation of soil underneath.
3. Uplift pressure on hydraulic structures exerted by percolating water.
4. Instability of soil bunds.

* If flow occurs in the downward direction, the effective pressure is increased. If flow occurs in the upward direction effective pressure is decreased.
* If the seepage pressure becomes equal to the submerged weight of the soil, the effective pressure reduces to zero. At this stage, the cohesionless soil losses its shear strength completely and its particles have tendency to move up in the direction of flow. This phenomenon is known as *quick condition* or *quick sand*.

  The hydraulic gradient at which quick condition occurs is called critical hydraulic condition (i_c). Mathematically

$$i_c = \frac{G-1}{1+e}$$

where G = sp.gr of soil particles and e = Void ratio

Laplace Equation

The two-dimensional flow of water through soil is governed by Laplace equation

$$\frac{\partial v_x}{\partial x} + \frac{\partial v_z}{\partial z} = 0$$

where x is horizontal direction and z is vertical direction.

According to Darcy's law,

$$v_x = k\frac{\partial h}{\partial x} \quad v_z = k\frac{\partial h}{\partial z}$$

\ Laplace equation reduces to

$$\frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial z^2} = 0$$

$$\text{or } \frac{\partial^2 \phi}{\partial x^2} + \frac{\partial^2 \phi}{\partial z^2} = 0$$

where *f* is hydraulic potential.

Flow Net

The graphical representation is given by two sets of curves intersecting at right angles. One set is the flow lines which represents the path followed by percolating water through a saturated soil under laminar conditions. Another set, known as equipotential lines represent lines connecting points of equal potential. The head lost between two equipotential lines is known as *potential drop* D*h*.

* The portion of a flow net bounded by two adjacent flow lines is known as *flow channel*.

* The properties of flow nets are:

1. Flow lines and equipotential lines meet each other at right angles.
2. No two flow lines cross each other.
3. No two flow or equipotential lines start from the same point.
4. Flow and equipotential lines are smooth curves.

Applications of Flow Nets

1. Determination of seepage: It is given by the expression.

$$q = kh_1 \frac{N_f}{N_d}$$

where k = coefficient of permeability

h_1 = Total hydraulic head causing the flow

N_f = Total number of flow channels

N_d = Total number of potential drops in a flow net

$\frac{N_f}{N_d}$ is known as shape factor

2. Determination of uplift pressure

$$\text{Uplift pressure} = h_w\, g_w$$

3. Seepage pressure: Seepage pressure = $(h_1 - N_d \, \text{D}h)\, g_w$.

4. Exit gradient: It is given by

$$i_e = \frac{\Delta h}{L}$$

where Dh is the potential drop between two successive potential lines and L the average length of the seepage.

Piping

When the uplift forces due to seepage on the downstream side of a hydraulic structure exceed the submerged weight of the soil, the soil grains are dislodged and eroded. Gradually, it results into a pipe shaped discharge channel and ultimately it may lead to a failure of the structure. This is called piping failure.

Piping failure may be prevented by:

1. increasing the stress due to weight of the structure
2. increasing the creep length of flow of water
3. diverting the seepage water into filter wells.

12.5 COMPRESSIBILITY AND CONSOLIDATION

* The property of soil by virtue of which its volume changes under compressive stress is known as compressibility. It is expressed as decrease in volume per unit increase of pressure.
* When compressive load acts on a saturated soil mass, the change in volume takes place due to explosion of water from pores and rearrangement of soil skeleton. This gradual process of compression resulting into reduction of volume is known as consolidation.
* The total compression is the sum of:

(i) Elastic or immediate compression

(ii) Primary consolidation

(iii) Secondary compression

The settlement of soil which occurs immediately on application of compressive force under undrained condition is called immediate consolidation. This is calculated by assuming the soil mass to behave as an elastic material.

The application of compressive load on soil mass creates hydrostatic pressure in saturated soils resulting into gradual expulsion of water through the voids. The volume change due to this process is known as primary consolidation.

Primary consolidation ends when pore water pressure approaches zero and secondary compression starts by compressing the clay layers. This phenomenon is very slow. No satisfactory theory is so far developed to estimate this settlement.

Coefficient of volume compressibility The change in volume of soil per unit initial volume due to a given increase in the pressure is called the coefficient of volume compressibility

$$m_v = \frac{a_v}{1+e_o}$$

where a_v = change in volume

e_o = initial void ratio

Coefficient of consolidation It is used to indicate the combined effects of permeability and compressibility of a soil on the rate of volume change. It is given mathematically as

$$C_v = \frac{k(1+e_o)}{a_v \gamma_\omega}$$

where k = Coefficient of permeability

e_o = Initial void ratio

g_w = Unit weight of water

Degree of consolidation It is the ratio of settlement of clay at a particular time to the final settlement when the process of consolidation is complete. It depends upon:

1. Thickness of clay layer
2. Coefficient of permeability
3. Coefficient of consolidation
4. Magnitude and distribution of consolidating pressure.

Time Factor It is a dimensionless constant and is defined by the equation

$$T_v = \frac{C_v t}{d^2}$$

where C_v = coefficient of consolidation

t = time

d = drainage path

Note The time factor T_v is given by

$$T_v = \frac{\pi}{4}\left(\frac{U}{100}\right)^2 \text{ when } U \text{ £ } 60\%$$

$$= -\,0.9332 \log\left(1-\frac{U}{100}\right) - 0.0851 \text{ when } U > 60°$$

where U is the degree of consolidation.

Compaction It is the process by which the soil particles are forced to move together due to the expulsion of air from the voids.

At the end of compaction and consolidation

1. Soil grains are packed closer
2. Shear strength increases
3. Compressibility and permeability decreases.

Table 12.2 Differences between compaction and consolidation

Compaction	*Consolidation*
1. It is instantaneous	It is time dependent
2. It is due to reduction of air voids	It is due to expulsion of pore water from voids
3. It is in case of unsaturated soil	It is in case of saturated soil
4. For a specified compaction energy, the compaction takes place only upto a certain limiting water content.	No limiting value of moisture content for the consolidation.

Water content-density curve Figure 12.5 shows water content and density curve for cohesive and moderately cohesive soils. Figure 12.6 shows such curve for cohesionless sandy.

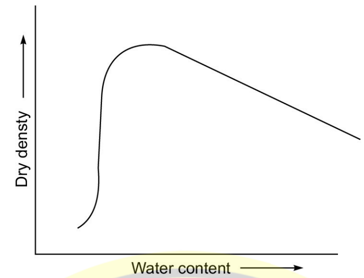


Fig. 12.5 For cohesive soil

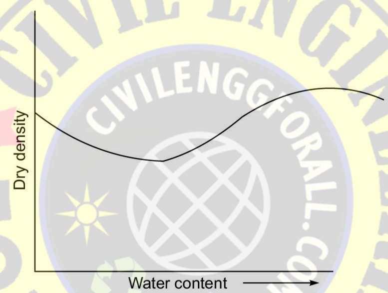


Fig. 12.6 For cohesionless soil

In case of sandy soil initially, there is decrease in density due to bulking of sand. Then the density reaches the maximum when it is fully saturated. The trend reverses when sufficient quantity of water is available. Thus, the maximum density is reached when the soil is either dry or saturated.

12.6 SHEAR STRENGTH

* Shear strength of soil is its ability to resist sliding along internal surface within mass. The force causing this type of sliding is called shear force and the resistance offered just before failure per unit area is termed shear strength.

* Natural slopes of hillsides, slopes of earth dam, slopes of a cut and bearing capacity of soil depend upon the shearing strength.

* Shear strength is mainly due to
  1. Internal friction due to interlocking of particles and friction between individual particles of their contact surfaces.
  2. Cohesion, which is due to interparticle forces which tend to hold the particles in soil mass.

* Coulomb's equation for shear strength is

$$t = c + s \tan f$$

where s = Normal stress on the failure plane

c = Cohesion

f = Angle of internal friction

* Angle of internal friction depends upon
  1. Shape of particles
  2. Surface roughness
  3. Type of interlocking
  4. Lateral pressure
  5. State of packing

The angle of internal friction is 25° to 30° for loose sand and 32° to 37° for dense sand.

Coulomb gave the above equation on the basis of total stress *s* which is the total load per unit area.

* Terzaghi modified Coulomb's equation on the basis of effective stress. The effective stress is given as the difference between the total stress and the pore water pressure. Thus

$$s¢ = s - u$$

where *u* is pore water pressure. The equation suggested is

$$T = c¢ + s¢ \tan f¢$$

where *c¢* = Effective cohesion

f¢ = Effective angle of friction

* In case of stresses in two-dimensional problems, principal planes (planes on which there is no shear stress) can be found by the equations derived in strength of materials or by drawing Mohr's circle of stress.

* In case of three-dimensional problems, the equations suggested for two-dimensional problems may be used, noting that,

s_1 = maximum principal stress

s_2 = minimum principal stress, normally referred as s_3.

Thus, Fig. 12.7 shows the Mohr's circle of stress.

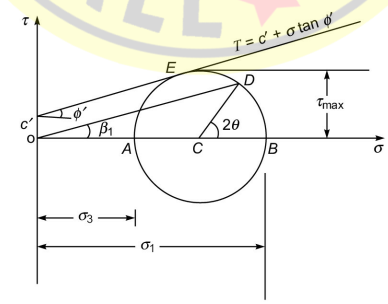


Fig. 12.7 Mohr's circle of stress

Note

s_1 = Maximum principal stress

s_3 = Minimum principal stress

Radius of Mohr's circle = $\frac{\sigma_1 - \sigma_3}{2}$

Centre of Mohr's circle = $\frac{\sigma_1 + \sigma_3}{2}$

Any point *D* on the Mohr's circle indicates the state of stress on a plane at *q* to maximum principal plane.

$$\text{Maximum stress} = t_{\max} = \frac{\sigma_1 - \sigma_3}{2}$$

Angle of obliquity with the normal of the plane $b = \tan^{-1}\left(\frac{\tau}{\sigma}\right)$

$$\backslash \sin b_{\max} = \frac{\frac{(\sigma_1 - \sigma_3)}{2}}{\frac{(\sigma_1 + \sigma_3)}{2}} = \frac{\sigma_1 - \sigma_3}{\sigma_1 + \sigma_2}$$

* The shear stress on the plane of maximum obliquity is less than the maximum shear stress.

* *Drainage Conditions*: Three types of shear tests have been developed based on drainage conditions:

1. Undrained test: Drainage is not permitted during the test, i.e., no dissipation of pore pressure is permitted.
2. Consolidated undrained test: Drainage is permitted initially till full primary consolidation takes place. Later no drainage is permitted during subsequent application of either normal or shear stresses.
3. Drained test: Drainage is permitted throughout the test so that full consolidation occurs and no excess pore pressure is set up.

* The following types of tests are used to find the shear strength of soils:

Laboratory Tests

1. Direct shear test
2. Triaxial compression test
3. Unconfined compression test
4. Laboratory shear test

Field test: Vane shear test

Note the following:

1. Box shear test (direct shear stress) is suitable for clay samples. However, drained tests on sand may be carried out.
2. In triaxial text vertical stress is the major principal stress (s_1). The other two stresses (s_2 and s_3) are both equal to the confining fluid pressure. In case of unconfined compression test cylindrical specimen is failed under uniaxial stress only. In this case the cross-sectional area A at any stage of loading may be computed on the assumption that the total volume of the sample remains the same:

$$A_o h_o = Ah$$

where A_o and h_o are initial cross-sectional area and height of the sample respectively.

* The triaxial apparatus is well suited for carrying out all the three types of shear tests.

* Undrained shear strength of soft cohesive soil can be made by direct measurement by a shear vane test. This test can be performed on a soil sample in a laboratory or on a undisturbed soil in situ at the bottom of a bore hole.

* *Effect of rate of strain*: The shear strength of cohesive soil is affected by the rate of strain. Lower the rate of strain, the lower is the shear strength.

1. Undrained strength of saturated cohesive soil for a test duration of 30 days is 40 to 80 per cent of the strength of one minute test.
2. According to Skempton, if the variation of rate of strain is ± 5 times the normal rate of strain makes hardly 5 to 10 per cent difference in the undrained strength.
3. If the shear strengths are compared on the effective stress basis, the changes in straining rate is considerably less.

* Shear strength of cohesionless soils: Typical stress-strain curves for loose sand and dense sand are as shown in Fig. 12.8.

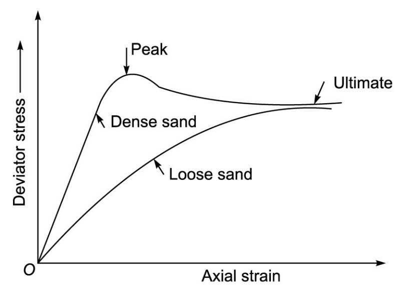


Fig. 12.8 Axial strain

From the curve it may be noted that

1. Dense sand shows a relatively high initial tangent modulus and reaches peak value. Then stress drops but strain increases.
2. Loose sand shows a relatively slower rate of increase of stress with strain.
3. The ultimate stress in both the cases is more or less the same.

* *Sensitivity of clays*: It is defined as the ratio of the shear strength of undisturbed clay to the shear strength of remoulded clay in its undrained condition.

$$S_t = \frac{(\tau_f)_{\text{undisturbed}}}{(\tau_f)_{\text{remoulded}}}$$

Table 12.3 shows classification of clay according to its sensitivity.

Table 12.3 Classification of clay according to sensitivity

Classification	*Sensitivity*
Insensitive	< 2
Medium sensitive	2–4
Sensitive	4–8
Extra-sensitive	8–16
Medium quick sensitive	16–32
Quick sensitive	32–64
Extra-quick sensitive	> 64

12.7 EARTH PRESSURE AND RETAINING STRUCTURE

* A retaining structure is a wall used to maintain the ground surface at different elevation on either

side of it. The following terms are used:

1. Back fill: The material retained by the wall is called back fill.
2. Surcharge: The weight of back fill above the elevation of top of the wall and any other load (may be due to building, etc.) is called surcharge.
3. Back face and face: The side of wall in contact with back fill is back face and other side face.
4. The slope of back fill above the horizontal is known as surcharge angle.
5. Angle of inclination of the back is the angle made by back face with vertical.

* *Earth Pressure as per Rankine's Theory*: The lateral pressure exerted by the soil when the retaining wall has no movement relative to the back fill is called *lateral earth pressure at rest*. The lateral earth pressure when the retaining wall tends to move away from the back fill is called *active earth pressure*. This is the minimum earth pressure exerted by the soil when the retaining wall moves towards the back fill due to any natural cause is known as *passive earth pressure*.

* Coefficient of earth pressure at rest: It is the ratio of lateral pressure to vertical pressure.

$$k_o = \frac{\sigma_h}{\sigma_v}$$

Since s_v at depth z form top surface of earth fill is g_z,

$$s_h = K_o g_z$$

By equating lateral strain to zero, it can be shown that

$$K_o = \frac{\mu}{1-\mu}$$

where m is Poisson's ratio.

Horizontal earth pressure varies linearly from zero at top to maximum value of vertical height H. Hence, horizontal force per unit length of retaining structure

$$P_o = \frac{1}{2} K_o \gamma H^2$$

Table 12.4 Coefficient of earth pressure at rest

Type of soil	K_o
Loose sand, saturated	0.46
Dense sand, saturated	0.36
Loose sand, dry	0.64
Dense sand, dry	0.49
Compacted clay	0.42 to 0.60

Coefficient of active earth pressure for cohesionless soil K_a is given by

$$K_a = \frac{1-\sin\phi}{1+\sin\phi}$$

Coefficient of passive earth pressure for cohesion soil K_p is given by

$$K_p = \frac{1+\sin\phi}{1-\sin\phi}$$

Coefficient of active earth pressure of dry cohesionless soil with top surface inclined at B is given by

$$K_a = \cos b\ \frac{\cos\beta - \sqrt{\cos^2\beta - \cos^2\phi}}{\cos\beta + \sqrt{\cos^2\beta + \cos^2\phi}}$$

$$\text{and } K_p = \cos b\ \frac{\cos\beta + \sqrt{\cos^2\beta - \cos^2\phi}}{\cos\beta - \sqrt{\cos^2\beta - \cos^2\phi}}$$

In case of cohesive soil:

Active earth pressure at top

$$P_a = -2c \cot a$$

and at depth z is

$$P_a = g_z \cot^2 a - 2c \cot a$$

where g = Dry weight of soil

c = Cohesion

$a = 45° + f/2$

The variation of pressure is as shown is Fig. 12.9.

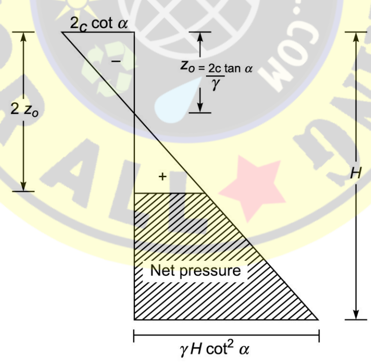


Fig. 12.9 Variation of P_a in cohesive soil

* Coulomb's earth pressure theory for sand.

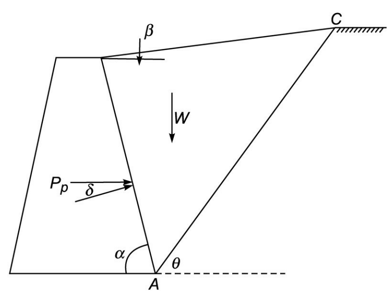


Fig. 12.10 Earth pressure theory for sand

It is for finding passive earth pressure P_p.

$$P_p = \frac{1}{2}\gamma K_p H^2$$

where $K_p = \dfrac{\sin^2(\alpha - \phi)}{\sin^2\alpha \sin(\alpha + \delta)\left[1 - \sqrt{\dfrac{\sin(\phi + \delta)\sin(\phi + \beta)}{\sin(\alpha + \delta)\sin(\alpha + \beta)}}\right]}$

when wall is smooth ($d = 0$) and vertical ($d = 90°$)

$$K_p = \frac{1 + \sin\phi}{1 - \sin\phi}, \text{ same as Rankine's expression}$$

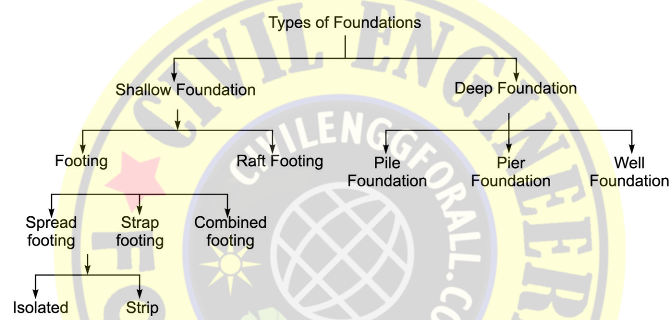
* The value of angle of friction for concrete walls is generally taken as $\frac{2}{3}\phi$.

* Use Rankine's formula for R.C.C. retaining walls, i.e., cantilever or counterfort type Use Coulomb's formula for masonry gravity walls.

12.8 FOUNDATIONS

* Foundation is the lower part of a structure, which transmits the load from the structure to soil.

* Footing is the portion of foundation which transmits load directly to the soil.



The above terms have been explained in the Chapter on "Building Construction".

Bearing Capacity of Soil

1. ***Ultimate bearing capacity*** It is the maximum gross pressure on soil at the base of footing at which soil fails in shear.

2. ***Net bearing capacity*** It is the maximum net pressure at which soil fails in shear and is equal to ultimate bearing capacity minus overburden pressure

$$q_{\text{net ult}} = q_{\text{ult}} - gD$$

where D is the depth of the foundation.

3. ***Net safe bearing capacity***

$$= \frac{q_{\text{net ult}}}{\text{Factor of safety}}$$

4. ***Gross safe bearing capacity***

$$= \frac{q_{\text{net ult}}}{\text{Factor of safety}} + \gamma D$$

5. ***Safe settlement pressure*** It is the net pressure which the soil can carry safely without exceeding the allowable settlement.

6. ***Allowable bearing pressure*** It is the maximum allowable net bearing pressure from the consideration of shear failure and settlement failure. It is also known as *allowable bearing capacity of soil*.

* Minimum depth of foundation: Rankine's theory is used to determine minimum depth of foundation. According to it,

$$D_{\min} = \frac{q}{\gamma} \times \left(\frac{1-\sin\phi}{1+\sin\phi}\right)^2, \text{ where } q = \text{Intensity of loading}$$

According to I.S. specifications in any case it should not be less than 800 mm and 900 mm in sand and clay respectively.

* Terzaghi developed the following equation of ultimate shearing capacity of soil for strip footing by analysing the forces acting on the wedge of the soil mass.

$$q_{\text{ult}} = CN_c + gD_f N_q + \tfrac{1}{2} g\, B\, N_f$$

where C = Unit cohesion

g = Effective unit weight of soil

D_f = Depth of foundation

N_c, N_q and N_g are the bearing capacity factors, which depend upon the angle of friction, f as given in Table 12.5.

Table 12.5 Bearing capacity factors of Terzaghi

f	N_c	N_q	N_g
0	5.7	1.0	0.0
5	7.3	1.6	0.5
10	9.6	2.7	1.2
15	12.9	4.4	2.5
20	17.7	7.4	5.0
25	25.1	12.7	9.7
30	37.2	22.5	19.7
35	57.8	41.5	42.4
40	95.7	81.3	100.4
45	172.3	173.3	297.5
50	347.5	415.1	1153.0

* *Effect of water Table:* If foundation is in contact with the water table, bearing capacity is reduced due to:

1. Reduction in cohesion
2. Reduction in effective unit weight of soil

Note that reduction in the effective angle of shearing resistance is not much in the above case.

To account for effect of water table Terzaghi's equation for ultimate bearing capacity may be modified as

$$q_{\text{ult}} = CN_c + gD_f N_q R_{w1} + \tfrac{1}{2} g B N_g R_{w2}$$

where R_{w1} = reduction factor for water given in Table 12.5 above the base level of foundation

R_{w2} = reduction factor for water table below the base level of the foundation

The reduction factors can be as high as 50% in granular soil.

When the water table is under the base of the footing at a depth equal to the width of footing the bearing capacity is reduced to three-fourths.

* The bearing capacity equations given above are derived for a strip footing of infinite length, which is a plain strain case. For a square or circular footing which are three-dimensional case Terzaghi gave the following approximate equations for bearing capacity per unit area:

1. For square footing

$$q_{\text{ult}} = 1.3\ CN_c + g\ D_f N_q + 0.4\ g\ B\ N_{\text{g}}$$

2. For circular footing

$$q_{\text{ult}} = 1.3\ CN_c + g\ DN_q + 0.3\ g\ BN_g$$

Settlements of Foundation

Total settlement of a foundation consists of:

1. Immediate settlement
2. Consolidation settlement
3. Secondary consolidation settlement

The immediate settlement is also known as elastic settlement. It can be found by elastic theory as,

$$S_e = q_n\ B\ \frac{1-\mu^2}{E_s} I_f$$

where q_n = Net foundation pressure B = Width of foundation

m = Poisson's ratio E_s = Modulus of elasticity

q_n = Influence factor which depends upon $\frac{L}{B}$ ratio of the foundation and the thickness of compressible layer

Consolidation settlement may be found by

$$S_c = H \frac{C_c}{1+e_o} \log \frac{p_o + \Delta p}{p_o}$$

where H = Thickness of compressible layer

C_c = Compression index

e_o = Initial void ratio

P_o = Initial overburden pressure

D_p = Increase in the pressure due to load

Secondary consolidation settlement is small and takes place over a long period.

Plate Load Test

By loading a rigid square plate in a pit with reaction frame this test is conducted to measure the settlement. The following points may be noted:

1. The minimum size of plate 300 mm. Commonly used plate sizes are 300 mm, 450 mm and 600 mm.
2. It is preferable to use 600 mm square plate for fissured clays and relatively loose sands and silts.
3. Width of the test pit should be at least 5 times the plate side.
4. The plate should be at the level of actual foundation proposed.
5. IS code recommends a preliminary seating load of 70 gm/cm^2 before the main test.
6. Apply the load in increments and measure the settlement with dial gauge. The maximum load corresponds to $1\frac{1}{2}$ times the estimated ultimate load.
7. In cohesionless soil each incremented load is maintained for at least one hour before the settlement. On clayey soil the load is maintained until about 75% of probable settlement has reached or for 24 hours.
8. Load settlement curve is plotted and ultimate bearing capacity is found as the load corresponding to the settlement after which settlement rate is fast. If load-settlement curve does not indicate a marked breaking point, a settlement equal to $\frac{1}{5}$th of the width of the test plate is considered the failure point.

* According to IS code the permissible values of settlements in clays and sands are 40 mm and 25 mm respectively.

12.9 SOIL STABILIZATION

* Soil stabilization is a technique of increasing or maintaining stability of soil mass.

* Methods of soil stabilization:

1. Mechanical stabilization: It is by suitable grading or by compaction. Mechanical stabilized construction needs retention of a certain amount of moisture. It is achieved by mixing calcium chloride and sodium chloride.
2. Cement stabilization: Depending upon the type of soil 5 to 14 per cent cement is mixed to stabilize the soil.
3. Lime stabilization: It is mainly used to stabilize subgrades of roads. In this process:
   (a) Clay particles get flocculated into larger size.
   (b) Shrinkage limit increases, Resistance to water absorption, capillary size and volume change increases.
   (c) Strength and durability increase.
4. Bitumen stabilization: Bitumen binds soil and reduces water absorption. Hence, it stabilizes soil.
5. Miscellaneous chemicals: Molasses, waterproofers up to 0.1 to 1 per cent help in stabilization.
6. Thermal stabilization: Heating a plastic soil to a temperature of 400° to 600°C makes the soil

less plastic and less sensitive to water.

7. Electrical stabilization: It is a process of draining fine grained soils by passing a direct current through them.

* Thermal stabilization and electrical stabilization are relatively costly methods.

12.10 TYPES OF FOUNDATIONS

Refer the Chapter 2 on "Building Construction".

MULTIPLE-CHOICE QUESTIONS

I. *Select correct options from the list given in questions 1–180*

1. The term Soil Mechanics was coined by
   (a) Rankine
   (b) Newton
   (c) Terzaghi
   (d) Newmark

2. In engineering, soil is defined as
   (a) a disintegrated rock
   (b) the top surface of the earth which is good for growth of plant
   (c) natural aggregates of mineral grains, loose or moderately cohesive, inorganic or organic in nature
   (d) all of the above.

3. Talus is the soil transported by
   (a) gravity
   (b) wind
   (c) rivers
   (d) glaciers

4. Aeoline deposit is a soil transport by
   (a) gravity
   (b) wind
   (c) streams
   (d) glaciers

5. Alluvial deposits is the soil transported by
   (a) gravity
   (b) wind
   (c) streams and rivers
   (d) glaciers

6. Till is the soil transported by
   (a) wind
   (b) streams
   (c) glaciers

(d) gravity

7. Soil deposited in lake bed is known as
   (a) aeoline deposit
   (b) alluvial deposit
   (c) Till
   (d) lacustrine deposit
8. Red soil is rich in
   (a) iron
   (b) magnesium
   (c) calcium carbonate
   (d) both (a) and (b)
9. The powdered rock which includes all kinds of disintegrated rock is known as
   (a) alluvial soil
   (b) red soil
   (c) murram
   (d) shale
10. Which one of the following is not a correct statement about alluvial soil?
   (a) It is formed due to sediment transported by streams and rivers.
   (b) It is darker in colour.
   (c) They contain mainly iron and magnesium.
   (d) They are loamy soils.
11. The soil often found in areas of poor drainage with high evaporation is
   (a) clay
   (b) peaty
   (c) kaoline
   (d) alkaline
12. Which one of the following is wrong statement about black cotton soil?
   (a) It covers about 20% of total area of India.
   (b) It usually contains calcium carbonate.
   (c) Thickness of this soil varies from 0.3 m to 15 m.
   (d) It is an expansive soil.
13. The soil particles coarser than ______ can be examined by means of hand lense
   (a) 0.75 mm
   (b) 0.15 mm
   (c) 0.075 mm
   (d) 0.015 mm
14. The minimum size of soil particles which can be distinguished under microscope is
   (a) 10 m
   (b) 5 m
   (c) 2 m

(d) 3 m

15. Soil is considered a
   (a) single-phase system
   (b) two-phase system
   (c) three-phase system
   (d) none of the above
16. Void ratio is the ratio of volume of voids to
   (a) volume of solids
   (b) total volume of soil
   (c) unit weight of soil
   (d) none of the above
17. Degree of saturation is
   (a) $\frac{V_v}{V} \times 100$
   (b) $\frac{V_w}{V} \times 100$
   (c) $\frac{V_w}{V_s} \times 100$
   (d) $\frac{V_w}{V_v} \times 100$

   where V = Total volume V_V = Volume of void
   V_w = Volume of water V_s = Volume of solids
18. Water content is
   (a) $\frac{\text{Volume of water}}{\text{Total volume}} \times 100$
   (b) $\frac{\text{Volume of water}}{\text{Volume of voids}} \times 100$
   (c) $\frac{\text{Weight of water}}{\text{Weight of soil}} \times 100$
   (d) $\frac{\text{Weight of water}}{\text{Weight of soil solids}} \times 100$
19. The ratio of voids to total volume of soil mass is called
   (a) void ratio
   (b) porosity
   (c) degree of saturation
   (d) water content ratio
20. Water content can be
   (a) zero to 50%
   (b) zero to 100%
   (c) zero to 200%
   (d) zero to 400%

21. Bulk weight of soil is the ratio of
(a) weight of soil mass to its total volume
(b) weight of soil solid to its volume of solids
(c) weight of soil solid to its total volume
(d) weight of soil solid to volume of solids

22. Density of soil in SI units is expressed as
(a) kg/m^2
(b) kg/m^3
(c) N/m^2
(d) N/m^3

23. If the volume of voids is equal to the volume of soil solids, then the porosity and void ratio are respectively
(a) 0 and 1
(b) 1 and 0
(c) 0.5 and 1
(d) 1 and 0.5

24. Submerged unit weight of soil is equal to
(a) $g_{sat} + g_w$
(b) $g_w - g_{sat}$
(c) $g_{sat} + g_w$
(d) $\frac{1}{\gamma_\omega} + \frac{1}{\gamma_{sat}}$

25. Specific gravity of a substance is the ratio of its mass in air to the mass of equal volume of water at
(a) 4°
(b) 15°C
(c) 27°C
(d) 40°C

26. Generally, specific gravity of soil solid varies between
(a) 1.5 to 2
(b) 2 to 3
(c) 3 to 3.5
(d) more than 3.5

27. If e is void ratio and n is porosity then
(a) $e = \frac{1-n}{n}$
(b) $e = \frac{n}{1-n}$
(c) $e = \frac{1+n}{n}$

(d) $e = \frac{n}{1+n}$

28. If e is void ratio and n is porosity then

(a) $n = \frac{e}{1+e}$

(b) $n = \frac{e}{1-e}$

(c) $n = \frac{1+e}{e}$

(d) $n = \frac{1-e}{e}$

29. If w is water content, e is porosity, S is saturation degree and G is specific gravity then

(a) $w = G \times s \times e$

(b) $w = \frac{GS}{e}$

(c) $w = \frac{Ge}{s}$

(d) $\frac{Se}{G}$

30. Dry unit weight of soil is given by

(a) $\frac{\gamma}{1+w}$

(b) $\frac{\gamma}{1-w}$

(c) $g + w$

(d) $g - w$

where g = Bulk weight, w = water content

31. Dry unit weight of soil is given by

(a) $G\, g_w\, n$

(b) $G\, g_w\, (1 - n)$

(c) $\frac{1}{G}\, g_w\, n$

(d) $\frac{1}{G}\, g_w\, (1 - n)$

where G = specific gravity W = water content

g_w = unit weight of water and n = porosity

32. Submerged unit weight of soil is equal to

(a) $\frac{\gamma_w}{1-e}(G+1)$

(b) $\frac{\gamma_w}{1+e}(G+1)$

(c) $\frac{\gamma_w(G-1)}{1-e}$

(d) $\frac{\gamma_w(G-1)}{1+e}$

where g_w = unit weight of water, G = specific gravity

e = void ratio

33. The soil particles of size below ______ are considered fine grained
   (a) 0.002 mm
   (b) 0.075 mm
   (c) 0.475 mm
   (d) 2.0 mm

34. Particle size of sand is between
   (a) 0.002 to 0.075 mm
   (b) 0.075 to 2.0 mm
   (c) 0.075 to 4.75 mm
   (d) 0.002 to 2.0 mm

35. Size of gravel is between
   (a) 0.475 to 4.75 mm
   (b) 0.475 to 2.0 mm
   (c) 2.0 to 20 mm
   (d) 4.75 to 80 mm

36. Size of cobble vary from
   (a) 20 to 80 mm
   (b) 80 to 100 mm
   (c) 80 to 200 mm
   (d) 80 to 300 mm

37. Size of boulders varies from
   (a) 20 to 80 mm
   (b) 80 to 200 mm
   (c) 80 to 300 mm
   (d) more than 300 mm

38. Figure Q. 39 shows grain size distribution of soils. Curve C_1C_1 corresponds to
   (a) well graded soil
   (b) gap graded soil
   (c) poorly graded soil
   (d) none of the above

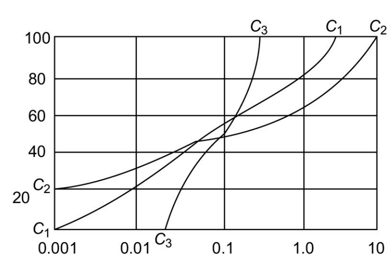


Fig. Q. 39

39. In Fig. Q. 39, the curve $C_2 - C_2$ represents
   (a) well graded soil
   (b) gap graded soil
   (c) poorly graded soil
   (d) none of the above
40. In Fig. Q. 39, the curve $C_3 - C_3$ represents
   (a) well graded soil
   (b) gap graded soil
   (c) poorly graded soil
   (d) none of the above
41. Effective size of the soil is
   (a) D_{10}
   (b) D_{30}
   (c) D_{50}
   (d) D_{60}
42. The uniformity coefficient of soil is defined as
   (a) $\frac{D_{30}}{D_{10}}$
   (b) $\frac{D_{60}}{D_{10}}$
   (c) $\frac{D_{40}}{D_{10}}$
   (d) $\frac{D_{50}}{D_{10}}$
43. A soil is said to be of uniform size if the uniformity coefficient C_u is
   (a) less than 3
   (b) less than 5
   (c) between 5 to 10
   (d) more than 15
44. A soil is said to be of medium size, if the uniformity coefficient is
   (a) less than 5
   (b) between 5 and 10
   (c) between 10–15
   (d) between 15 and 20
45. A soil is said to well graded, if the uniformity coefficient is
   (a) less than 5
   (b) between 5 and 10
   (c) between 10 and 15
   (d) more than 15
46. Coefficient of curvature of soil is

(a) $\frac{D_{60}^2}{D_{30} \times D_{10}}$

(b) $\frac{D_{30}^2}{D_{10} \times D_{60}}$

(c) $\frac{D_{10}^2}{D_{30} \times D_{60}}$

(d) $\frac{D_{60}}{D_{10}}$

47. A soil is said to be well graded if coefficient of curvature lies between
   (a) 1 and 3
   (b) 3 and 5
   (c) 5 and 7
   (d) more than 7

48. The particle size distribution of soil fraction less than ______ is determined by sedimentation analysis.
   (a) 2 mm
   (b) 0.475 mm
   (c) 75 *m*
   (d) 2 *m*

49. With usual notations, Stokes' law for velocity of setting of soil on still water is

   (a) $v = \frac{g(G-1)D^2}{10\eta}$

   (b) $\frac{(G-1)D^2}{18\eta g}$

   (c) $v = \frac{g(G+1)D^2}{18\eta}$

   (d) $\frac{(G+1)D^2}{18\eta g}$

50. Limitation of Stokes' law
   (a) It is true for spherical particles only.
   (b) It cannot be applied to particles of size smaller than 0.2 *m*.
   (c) All particles should have same specific gravity.
   (d) All the above.

51. Stokes' law is applicable to soil particles of size between
   (a) 0.3 mm to 0.2 *m*
   (b) 0.2 mm to 0.2 *m*
   (c) 0.3 mm to 3 *m*
   (d) 0.2 mm to 2 *m*

52. To minimize the influence of one particle over the other particle, the mass of soil in sedimentation analysis is limited to ______ in the sedimentation jar of 1 litre
   (a) 20 gm
   (b) 50 gm

(c) 75 gm

(d) 100 gm

53. To remove organic matter from the soil sample to be used in sedimentation analysis, it is mixed with hydrogen peroxide at
(a) 20°C
(b) 27°C
(c) 60°C
(d) 80°C

54. In pretreatment of soil sample, after boiling and cooling the mixture of soil and hydrogen peroxide, it is treated with about ______ hydrochloric acid for removing calcium compound.
(a) 0.1 N
(b) 0.2 N
(c) 0.5 N
(d) 0.75 N

55. For pretreatment of a soil sample in sedimentation analysis 1 litre of dispersing agent solution is prepared by dissolving Colgon and sodium carbonate
(a) 38 gm and 12 gm respectively
(b) 50 gm and 25 gm respectively
(c) 80 gm and 40 gm respectively
(d) 100 gm and 50 gm respectively

56. Effect of temperature on velocity of fall due to change in density may be ______ but due to change in viscosity should be ______
(a) neglected, considered
(b) considered, neglected
(c) neglected, neglected
(d) considered, considered

57. Viscocity is measured in the unit 'poise', where 1 poise is equal to
(a) 10^{-1} kN-sec/m^2
(b) 10^{-2} kN-sec/m^2
(c) 10^{-3} kN-sec/m^2
(b) 10^{-4} kN-sec/m^2

58. Hydrometers are normally calibrated at
(a) 0°C
(b) 20°C
(c) 27°C
(d) 35°C

59. The correction to hydrometer readings due to meniscus and dispersing agents are
(a) both positive
(b) both negative
(c) –ve and +ve respectively

(d) +ve and –ve respectively

60. In the loosest form spherical shaped particles have void ratio upto
(a) 0.7
(b) 0.80
(c) 0.90
(d) 0.95

61. By compaction void ratio of uniform sized spherical particles can be reduced upto
(a) 0.25
(b) 0.35
(c) 0.45
(d) 0.55

62. In the densest state void ratio of soil can be as low as
(a) 0.3
(b) 0.25
(c) 0.2
(d) 0.15

63. Sandy soil can be classified as very loose, if density index is
(a) 0 – 15
(b) 15 – 30
(c) 30 – 50
(d) 50 – 70

64. Sandy soil can be classified as dense if its density index is
(a) 50 – 60
(b) 60 – 70
(c) 70 – 85
(d) 85 – 95

65. Plastic limit of a soil is defined as
(a) the limit of water content that represents the boundary between plastic and semi-solid state.
(b) the lowest water content at which soil can still be completely saturated.
(c) the water content at which the soil shows shearing resistance as the water content is reduced.
(d) none of the above.

66. Plastic limit is defined as ______
(a) the limit of water content that represents the boundary between plastic and semi-solid state.
(b) the lowest water content at which soil can still be completely saturated.
(c) the water content at which the soil shows shearing resistance as the water content is reduced.
(d) none of the above.

67. Shrinkage limit is defined as ______
(a) the limit of water content that represents the boundary between plastic and semi-solid state.
(b) the lowest water content at which soil can still be completely saturated.
(c) the water content at which the soil shows shearing resistance as the water content is reduced.

(d) none of the above.

68. Difference between liquid limit and plastic limit is known as
(a) plasticity index
(b) consistency index
(c) liquidity index
(d) none of the above

69. If W is natural water content, W_L is liquid limit and W_p is plastic limit, consistency index is given by
(a) $\frac{W_L - W_p}{W_L - W}$
(b) $\frac{W - W_L}{W_L - W_P}$
(c) $\frac{W_L - W}{W_L - W_p}$
(d) $\frac{W_L - W}{W_p - W_L}$

70. If consistency index is zero, it means that the soil
(a) is at plastic limit
(b) is at liquid limit
(c) behaves like liquid
(d) is tiff

71. If W is natural water content, W_L is liquid limit, W_p is plastic limit, liquidity index is
(a) $\frac{W - W_p}{W_L - W_p}$
(b) $\frac{W_p - W}{W_L - W_p}$
(c) $\frac{W_L - W_p}{W - W_L}$
(d) $\frac{W_p - W_L}{W - W_L}$

72. A sample of soil has liquid limit 50%, plastic limit 25%, shrinkage limit 20% and moisture content 35%. The consistency index is
(a) $\frac{30}{25}$
(b) $\frac{15}{25}$
(c) $\frac{10}{25}$
(d) $\frac{5}{25}$

73. The moisture content of a clayey soil is gradually reduced from a large value. The correct sequence of the occurrence of the limit are

(a) plastic limit, liquid limit and shrinkage limit.

(b) shrinkage limit, plastic limit and liquid limit.
(c) liquid limit, plastic limit and shrinkage limit.
(d) plastic limit, shrinkage limit and liquid limit.

74. Which of the following is highly permeable?
(a) Clay
(b) Fine sand
(c) Coarse sand
(d) Gravel

75. Least permeable soil is
(a) clay
(b) fine sand
(c) coarse sand
(d) gravel

76. The property of soil which permits the seepage of water is known as
(a) porosity
(b) capillarity
(c) permeability
(d) viscocity

77. Darcy's law is based on the assumption that
(a) there is laminar flow condition
(b) soil is saturated
(c) soil is homogeneous and isotropic
(d) all the above

78. Seepage velocity V_s and flow velocity v are related as

(a) $V_s = \frac{v}{\eta}$
(b) $V_s = vn$

(c) $V_s = \frac{v}{e}$
(d) $V_s = ve$

where h = porocity and e = void ratio

79. Flow velocity v and seepage velocity v_s are related as

(a) $v = \frac{n}{1+n} v_s$

(b) $v = \frac{n}{1-n} v_s$

(c) $v = \frac{e}{1+e} v_s$

(d) $v = \frac{e}{1-e} v_s$

where h = porosity and e is void ratio

80. Coefficient of percolation and coefficient of permeability are related as

(a) $k_p = \frac{k}{n}$

(b) $k_p = \frac{k}{e}$

(c) $k_p = n_k$

(d) $k_p = ek$

where n = porocity and e = void ratio

81. The coefficient of permeability of gravel is
(a) between 1 and 100 cm/sec
(b) between 0.001 and 1 cm/sec
(c) between 1×10^{-6} and 1×10^{-3} cm/sec
(d) less than 10^{-6} cm/sec

82. The coefficient of permeability of clay is not more than
(a) 1 cm/sec
(b) 1×10^{-2} cm/sec
(c) 1×10^{-4} cm/sec
(d) 1×10^{-6} cm/sec

83. The permeability of a soil sample may be determined by _______ water level method.
(a) constant
(b) falling
(c) rising
(d) all the above

84. Which one of the following is not a factor influencing coefficient permeability.
(a) Size and shape of particle
(b) Viscocity of water
(c) Degree of saturation
(d) Hydraulic gradient

85. For coarse grained soil the coefficient of permeability k and void ratio e the following relation is generally true:

(a) $k \times e$
(b) $k \times e^2$

(c) $k \times \frac{1}{e}$

(d) $k \times \frac{1}{e^2}$

86. Permeability is greatly affected by
(a) direction of stratification
(b) cracks

(c) warping of layers

(d) all the above

87. If the direction of flow of water is parallel to the planes of stratification, the permeability is ______ times more than in a direction perpendicular to them.

(a) 2 to 10

(b) 2 to 20

(c) 2 to 30

(d) 2 to 40

88. The average velocity of flow that will take place through the total cross-sectional area of soil under unit hydraulic gradient is known as

(a) uniformity coefficient

(b) coefficient of permeability

(c) Stokes' coefficient

(d) Darcy's coefficient

89. Quick sand is

(a) a sand which can act as a quick filter

(b) a uniformly graded sand

(c) a condition when cohesionless soil loses its shear strength due to upward flow water

(d) the conditions focusing quick flow of water through the soil.

90. The critical hydraulic condition i_c is given by

(a) $\frac{G+1}{1+e}$

(b) $\frac{G-1}{1+e}$

(c) $\frac{G+1}{1-e}$

(d) $\frac{G-1}{1-e}$

where G = specific gravity of soil particles

e = void ratio

91. The Laplace equation with usual notations is

(a) $\frac{\partial v_x}{\partial x}+\frac{\partial v_z}{\partial z}=0$

(b) $\frac{\partial^2 h}{\partial x^2}+\frac{\partial^2 h}{\partial z^2}=0$

(c) $\frac{\partial^2 \phi}{\partial x^2}+\frac{\partial^2 \phi}{\partial z^2}=0$

(d) all the above

92. In a flow net, flow lines and equipotential lines

(a) are parallel to each other

(b) are perpendicular to each other

(c) intersect each other at 90°

(d) none of the above

93. In flow net
(a) no two flow lines cross each other
(b) flow and equipotential lines are smooth curves
(c) no two lines start from the same point
(d) all the above

94. Flow net is useful in determining
(a) seepage
(b) uplift pressure
(c) exit gradient
(d) all the above

95. Seepage pressure is given by
(a) $(h_1 - N_d \mathrm{D}h)\ g_w$
(b) $(h_1 + N_d \mathrm{D}h)\ g_w$
(c) $(h_1 + N_F \mathrm{D}h)\ g_w$
(d) $(h_1 - N_F \mathrm{D}h)\ g_w$

96. If h_1 is total hydraulic head, N_f is total number of flow channels and N_d is total number of potential drops in a flow net, then seepage flow rate is given by

(a) $q = Kh_1 \frac{N_f}{N_d}$
(b) $q = Kh_1 \frac{N_f}{N_d}$
(c) $\mathrm{q} = kh_1 N_f N_d$
(d) none of the above

97. The piping failure in a hydraulic structure can be prevented by
(a) increasing the stress due to weight of the structure
(b) increasing the creep length of flow of water
(c) diverting the seepage water into filter wells
(d) all the above

98. Settlement of soil under compressive load takes place due to
(a) expulsion of air
(b) expulsion of water from pores
(c) restructuring of soil mass
(d) all the above

99. Settlement of soil under compressive force due to expulsion of water from pores is known as
(a) elastic compression
(b) primary consolidation
(c) secondary compression

(d) none of the above

100. Coefficient of volume compressibility is given by

(a) $m_v = \frac{a_v}{1+e_o}$

(b) $a_v\,(1 + e_o)$

(c) $m_v = \frac{a_v}{1+e}$

(d) $a_v\,(1 + e)$

where a_v = change in volume

e_o = initial void ratio

e = final void ratio

101. Coefficient of consolidation is given by the expression

(a) $C_v = \frac{k\,(1+e)}{a_v\,\gamma_\omega}$

(b) $\frac{k\,(1+e_o)}{a_v\,\gamma_\omega}$

(c) $C_v = \frac{k\,(1-e)}{a_v\,\gamma_\omega}$

(d) $\frac{k\,(1-e)}{a_v\,\gamma_\omega}$

where k = coefficient of permeability, e_o = initial void ratio

e = void ratio, g_w = unit wt. of water, a_v = change in volume

102. The combined effect of permeability and compressibility of a soil on the rate of volume change is given by

(a) coefficient of volume compressibility

(b) coefficient of permeability

(c) coefficient of consolidation

(d) compaction factor

103. Degree of compaction depends upon

(a) thickness of clay layer

(b) coefficient of permeability

(c) coefficient of consolidation

(d) all the above

104. In consolidation, time factor is defined as

(a) $\frac{c_v\,t}{d^2}$

(b) $\frac{c_c\,t}{d^2}$

(c) $\frac{c_v\,t}{d}$

(d) $\frac{c_c t}{d}$

where c_v = coefficient of consolidation

c_c = coefficient of compaction

t = time

d = drainage path

105. Time factor T_v is given by

(a) $\frac{\pi}{4}U^2$

(b) $\frac{\pi}{8}U^2$

(c) $\frac{\pi}{8}\left(\frac{U}{100}\right)^2$

(d) $\frac{\pi}{4}\left(1-\frac{U}{100}\right)$

when U £ 60%

where U is the degree of consolidation.

106. If consolidation factor is more than 60% the time factor is given by

(a) –0.9332 log $\frac{U}{100} - 0.0851$

(b) –0.9332 log $\left(1+\frac{U}{100}\right) - 0.0851$

(c) –0.9332 log $\left(1-\frac{U}{100}\right) - 0.0851$

(d) –0.9332 log U^2 – 0.0851

where U is degree of consolidation.

107. Which one of the following is not a correct statement about compaction and consolidation?

(a) At the end, soil grains are packed closure.

(b) Compressibility increases.

(c) Shear strength increases.

(d) Permeability decreases.

108. Compaction is due to

(a) reduction of air voids

(b) expulsion of pore water

(c) both (a) and (b)

(d) none of (a) and (b)

109. In sandy soil maximum density can reach when the soil is

(a) dry

(b) saturated

(c) either (a) or (b)

(d) none of the above

110. Time required for 50% consolidation of a remoulded sample of clay with single drainage is t. Hence, to consolidate same clay to the same degree of consolidation but with 3 times drainage is

(a) $\frac{t}{3}$

(b) $\frac{t}{9}$

(c) $3t$

(d) $9t$

111. Natural slope of hill sides depends upon ______ strength of soil.

(a) compressive

(b) tensile

(c) shear

(d) compressive and shear

112. Shear strength of soil does not depend upon

(a) internal friction due to interlocking of particles.

(b) friction between individual particles at their contact surfaces.

(c) cohesion.

(d) compressive strength.

113. Shear strength of soil increases with increase in

(a) cohesion of soil

(b) angle of internal friction

(c) normal stress on soil

(d) all the above

114. Effective stress is

(a) $s - u$

(b) $s + u$

(c) $s \tan f - u$

(d) $s \tan f + u$

where s = Normal stress on the failure plane

u = Pore water pressure

f = Angle of internal friction

115. If s_1 is maximum principal stress, s_2 is intermediate stress and s_3 is minimum principal stress, the radius of Mohr's circle for stress is

(a) $\frac{\sigma_1 + \sigma_2}{2}$

(b) $\frac{\sigma_1 - \sigma_2}{2}$

(c) $\frac{\sigma_1 + \sigma_3}{2}$

(d) $\frac{\sigma_1 - \sigma_3}{2}$

116. The centre of Mohr's circle is at

(a) $\frac{\sigma_1 + \sigma_2}{2}$

(b) $\frac{\sigma_1 - \sigma_2}{2}$

(c) $\frac{\sigma_1 + \sigma_3}{2}$

(d) $\frac{\sigma_1 - \sigma_3}{2}$

117. According to Coulomb's law, the shearing strength of soil is
   (a) $c - s \tan f$
   (b) $s - c \tan f$
   (c) $c + s \tan f$
   (d) $s + c \tan f$

   where c = cohesion, s = normal stress
   and f = Angle of internal friction

118. Angle of internal friction depends upon
   (a) shape of particle
   (b) lateral pressure
   (c) state of packing
   (d) all the above

119. Angle of internal friction for loose grained sand is about
   (a) 15° to 20°
   (b) 20° to 25°
   (c) 25° to 30°
   (d) 35° to 48°

120. Angle of internal friction of round grained dense sand is about
   (a) 2° to 7°
   (b) 12° to 17°
   (c) 22° to 27°
   (d) 32° to 37°

121. When a soil sample is subjected to purely hydrostatic pressure s the Mohr's circle is
   (a) a point at distance s from the origin
   (b) a circle of radius s at distance s from the origin
   (c) a circle of radius s at the origin
   (d) none of the above

122. In triaxial test
   (a) stress in all the three directions is the same
   (b) stress in all the three directions is different
   (c) stress in vertical direction is different from the stress in other two directions
   (d) none of the above

123. The apparatus that is suitable for conducting drained, undrained and consolidated drained shear test is

(a) box shear apparatus
(b) triaxial test apparatus
(c) shear vane test apparatus
(d) all the above

124. The test suitable for conducting in the laboratory as well as on site for finding shear strength of cohesive soil is
(a) direct shear test
(b) triaxial test
(c) shear vane test
(d) all the above

125. In a triaxial test when the drainage is allowed initially only and not during latter stage, the test is known as
(a) consolidated drained test
(b) consolidated underained test
(c) unconsolidated drained test
(d) unconsolidated undrained test

126. In unconfined compression test, height to diameter ratio of the specimen is
(a) 1.0
(b) 1.5
(c) 2.0
(d) 3.0

127. In unconfined compression test the cross-sectional area *A* at any stage of loading is
(a) constant
(b) decreases
(c) increases
(d) depends upon type of soil it may be constant or increase

128. Undrained strength of saturated cohesive soil for a test duration of 30 days is ______ per cent of one minute test.
(a) 0
(b) 20 to 25
(c) 30 to 40
(d) 40 to 80

129. According to Skempton, if the variation of rate of strain is ± 5 times the normal rate of strain, the undrained strength varies by
(a) 5 to 10%
(b) 10 to 20%
(c) 20 to 25%
(d) 30 to 40%

130. The state of stress on a plane at 45° to horizontal is represented by a point where

(a) normal stress = $\frac{\sigma_1 + \sigma_3}{2}$ and shear stress = $\frac{\sigma_1 - \sigma_3}{2}$

(b) normal stress = $\frac{\sigma_1 - \sigma_3}{2}$ and shear stress = $\frac{\sigma_1 + \sigma_3}{2}$

(c) normal stress = $\frac{\sigma_1 + \sigma_3}{2}$ and shear stress = 0

(d) normal stress = 0 and shear stress = $\frac{\sigma_1 + \sigma_3}{2}$

131. In case of dense sand initial tangent modules compared to loose sand is
(a) low
(b) same
(c) high
(d) (a) or (b)

132. The rate of increase of stress in loose sand compared to dense sand is
(a) slower
(b) same
(c) faster
(d) same or faster

133. A clay is classified as extra-sensitive if its sensitivity is
(a) 2 – 4
(b) 4 – 8
(c) 8 – 16
(d) more than 32

134. Rankine's theory of earth pressure assumes that the back of wall is
(a) vertical and smooth
(b) vertical and rough
(c) plane and smooth
(d) plane and rough

135. Coefficient of earth pressure at rest is given by

(a) $\frac{\mu}{1+\mu}$

(b) $\frac{\mu}{1-\mu}$

(c) $\frac{1+\mu}{\mu}$

(d) $\frac{1-\mu}{\mu}$

where m = Poisson's ratio

136. Horizontal force per unit length of retaining wall is

(a) $K_o\, gH^2$

(b) $K_o\, gH$

(c) $\frac{1}{2} K_o gH^2$

(d) $\frac{1}{2} K_o gH$

where H = height of retaining wall
g = unit weight of earth
K_o = coefficient of earth pressure at rest

137. Coefficient of earth pressure at rest of loose, saturated sand is about
(a) 0.36
(b) 0.46
(c) 0.54
(d) 0.64

138. Coefficient of earth pressure at rest of compacted clay varies from
(a) 0.24 to 0.32
(b) 0.36 to 0.46
(c) 0.42 to 0.60
(d) 0.64 to 0.72

139. Coefficient of earth pressure of cohesionless soil K_a is given by

(a) $\frac{1+\sin\phi}{1-\sin\phi}$

(b) $\frac{1-\sin\phi}{1+\sin\phi}$

(c) $\frac{1+\tan\phi}{1-\tan\phi}$

(d) $\frac{1-\tan\phi}{1+\tan\phi}$

140. Coefficient of active earth pressure of dry cohesionless soil with top surface inclined at b to horizontal is given by

(a) $\cos\beta \frac{\cos\beta - \sqrt{\cos^2\beta - \cos^2\phi}}{\cos\beta + \sqrt{\cos^2\beta - \cos^2\beta}}$

(b) $\cos\beta \frac{\cos\beta + \sqrt{\cos^2\beta - \cos^2\phi}}{\cos\beta - \sqrt{\cos^2\beta - \cos^2\phi}}$

(c) $\sin\beta \frac{\sin\beta - \sqrt{\sin^2\beta - \sin^2\phi}}{\sin\beta + \sqrt{\sin^2\beta - \sin^2\phi}}$

(d) $\sin\beta \frac{\sin\beta + \sqrt{\sin^2\beta - \sin^2\phi}}{\sin\beta + \sqrt{\sin^2\beta - \sin^2\phi}}$

141. The coefficient of active earth pressure for a dense sand is 1/3. Then coefficient of passive earth pressure is
(a) 1/3
(b) 1

(c) 3

(d) none of the above

142. In case of cohesive soil, active earth pressure at top is

(a) –2*c* cot *a*

(b) zero

(c) 2*c* cot *a*

(d) 2*c* $\cot^2$ *a*

where *C* = Cohesion and *a* = 45° + *f*/2

143. If *H* is the height of retaining wall, the active earth pressure at the base is

(a) *gH* $\cot^2 a$ + 2*c* cot *a*

(b) *gH* $\cot^2 a$ – 2*c* cot *a*

(c) *gH* cot *a* + 2*c* $\cot^2$ *a*

(d) *gH* cot *a* – 2*c* $\cot^2$ *a*

144. In case of cohesive soil, active earth pressure is zero, at a depth *z* given by

(a) $\frac{c}{\gamma}\tan\alpha$

(b) $\frac{2c}{\gamma}\tan\alpha$

(c) $\frac{c}{\gamma}\cot\alpha$

(d) $\frac{2c}{\gamma}\cot\alpha$

where *a* = 45° + *f*/2

145. The net earth pressure on a retaining wall exerted by a cohesive soil is zero at

(a) top

(b) $\frac{2c}{\gamma}\tan\alpha$

(c) $\frac{4c}{\gamma}\tan\alpha$

(d) $\frac{4c}{\gamma}\cot\alpha$

146. The maximum height of an unsupported vertical cut in a cohesive soil is given by

(a) $\frac{2c}{\gamma}\tan(45° - \phi/2)$

(b) $\frac{2c}{\gamma}\tan(45° - \phi/2)$

(c) $\frac{4c}{\gamma}\tan(45° - \phi/2)$

(d) $\frac{4c}{\gamma}\tan(45° + \phi/2)$

where *C* = cohesion, *f* = angle of internal friction

g = unit weight of soil

147. Cohesive soils are
(a) good for back fill since they exert low lateral pressure
(b) good for back fill because of their high shear strength
(c) poor for back fill because of large lateral pressure
(d) none of the above

148. The effect of cohesion on a soil is to
(a) reduce P_a and P_p
(b) reduce P_a and increase P_p
(c) increase P_a and P_p
(d) increase P_a and reduce P_p
where P_a = Active earth pressure
and P_p = Passive earth pressure

149. Earth pressure at rest is calculated using
(a) Rankine's theory
(b) Euler's theory
(c) Stokes' law
(d) Theory of elasticity

150. The coefficient of active earth pressure of a loose sand having an angle of internal friction 30° is,
(a) 1/3
(b) 1/2
(c) 1
(d) 3

151. Coulomb's earth pressure theory gives the same value as Rankine's theory when
(a) wall is smooth
(b) wall is vertical
(c) wall is smooth and vertical
(d) none of the above

152. Rankine's theory of earth pressure suits well for
(a) R.C.C. – Cantilever type retaining walls
(b) R.C.C. – Counterfort type retaining walls
(c) Masonry gravity walls
(d) Both (a) and (b)

153. The value of angle of wall friction for concrete retaining walls is generally taken as
(a) f
(b) $\frac{2}{3}\phi$
(c) $\frac{1}{2}\phi$

(d) $\frac{1}{3}\phi$

154. Ultimate bearing capacity of soil is the
   (a) maximum gross pressure at which soil fails in shear.
   (b) maximum net pressure at which soil fails in shear.
   (c) maximum pressure at which soil settles beyond the specified limit.
   (d) both (a) and (c).

155. According to Rankine's theory minimum depth of foundation is
   (a) $\frac{q}{\gamma}\left(\frac{1-\sin\phi}{1+\sin\phi}\right)^2$
   (b) $\frac{q}{\gamma}\left(\frac{1+\sin\phi}{1-\sin\phi}\right)^2$
   (c) $\frac{q}{\gamma}\frac{1-\sin\phi}{1+\sin\phi}$
   (d) $\frac{q}{\gamma}\frac{1+\sin\phi}{1-\sin\phi}$

   where q is intensity of loading.

156. According to IS specifications in any case depth of foundation in sand and clay should not be less than ______ respectively.
   (a) 600 mm and 800 mm
   (b) 800 mm and 900 mm
   (c) 900 mm and 1000 mm
   (d) 1000 mm and 1200 mm

157. Terzaghi's expression $CN_c + g\,D_f N_q + \frac{1}{2} g\,B\,N_g$ for bearing capacity gives
   (a) gross safe bearing capacity
   (b) net safe bearing capacity
   (c) ultimate bearing capacity
   (d) net ultimate bearing capacity

158. The ultimate bearing capacity of a soil for general shear failure in case of strip footing is
   (a) $CN_c + gD_f N_q + \frac{1}{2} g\,BN_g$
   (b) $g\,D_f N_q + 0.5\,g\,BN_g$
   (c) $1.3\,CN_c + g\,D_f N_q + 0.5\,g\,BN_g$
   (d) $1.3\,CN_c + g\,D_f N_q + 0.4\,g\,BN_g$

159. For square footing ultimate bearing capacity Terzaghi suggested the expression for finding ultimate hearing capacity from consideration of shear strength.
   (a) $CN_c + g\,D_f N_q + 0.5\,g\,BN_g$
   (b) $1.3\,CN_c + g\,D_f N_q + 0.5\,g\,BN_g$
   (c) $1.3\,CN_c + g\,D_f N_q + 0.4\,g\,BN_g$

(d) $1.3\ CN_c + g\ D_f N_q + 0.3\ g\ BN_g$

160. For circular footing Terzaghi suggested the following formula to get ultimate bearing capacity from the consideration of shear strength.

(a) $CN_c + g\ D_f N_q + 0.5\ g\ BN_g$

(b) $1.3\ CN_c + g\ D_f N_q + 0.5\ g\ BN_g$

(c) $1.3\ CN_c + g\ D_f N_q + 0.4\ g\ BN_g$

(d) $1.3\ CN_c + g\ D_f N_q + 0.3\ g\ BN_g$

161. If the footing is in contact with water table the reduction factor for bearing capacity may be as high as

(a) 25%

(b) 50%

(c) 65%

(d) 75%

162. Bearing capacity factor N_c can have maximum value of ______ for angle of internal friction 50°.

(a) 9.6

(b) 25.1

(c) 95.7

(d) 345.5

163. The bearing capacity factor N_q given by Terzaghi varies from ______ depending upon the angle of internal friction 0° to 50°.

(a) 0 to 12.5

(b) 0 to 81.3

(c) 1 to 173.3

(d) 1 to 451.1

164. Bearing capacity factor N_q for $f = 0°$ and $f = 50°$ are ______ respectively.

(a) 0 and 19.7

(b) 1.0 and 19.7

(c) 0 and 1153.0

(d) 1.0 and 1153.0

165. When the water table is under the base of the footing at a depth of half the width of footing, the hearing capacity is to be reduced to

(a) 1/4 th

(b) 1/2 th

(c) 2/3 th

(d) 3/4 th

166. The elastic settlement may be found by the formula

(a) $S_e = q_n B \frac{1-\mu}{E_s}$

(b) $S_e = q_n B \frac{1+\mu}{E_s}$

(c) $S_e = q_n B \frac{1-\mu^2}{E_s}$

(d) $S_e = q_n B \frac{1+\mu^2}{E_s}$

where q_n = Net foundation pressure B = Width of foundation

m = Poisson's ratio E_s = Modulus of elasticity

167. When width of foundation is 900 mm, the settlement is found to be 30 mm. Under the same condition, if width of footing is 600 mm, the settlement will be

(a) 30 mm
(b) 20 mm
(c) 10 mm
(d) none of the above

168. The consolidation settlement is given by the expression

(a) $S_c = H \frac{C_c}{1+e_o} \log \frac{p_o + \Delta p}{p_o}$

(b) $S_c = H C_c \log \frac{p_o + \Delta_p}{p_o}$

(c) $S_c = H \frac{C_c}{1+e_o} \log (p_o + \Delta_p)$

(d) $S_c = H C_c \log \left(\frac{p_0 + \Delta_p}{u}\right)$

169. In a plate load test minimum size of plate to be used is

(a) 250 mm × 250 mm
(b) 300 mm × 300 mm
(c) 400 mm × 400 mm
(d) 450 mm × 450 mm

170. For relatively loose sandy and silts, the recommended size of plate for load test is

(a) 300 mm × 300 mm
(b) 400 mm × 400 mm
(c) 450 mm × 450 mm
(d) 600 mm × 600 mm

171. In plate load test width of pit should be at least _______ times the plate.

(a) 3
(b) 4
(c) 5
(d) 6

172. In plate load test preloading recommended by IS code is

(a) 70 gm/cm^2

(b) 100 gm/cm^2
(c) 120 gm/cm^2
(d) 125 gm/cm^2

173. Plate load test is carried over upto ______ times expected ultimate load.
(a) 90%
(b) 100%
(c) 125%
(d) 150%

174. If load-settlement curve of plate load test does not show marked breaking point, settlement equal to ______ of the width of the test plate is considered as failure point.
(a) $\frac{1}{10}$th
(b) $\frac{1}{5}$th
(c) $\frac{1}{4}$th
(d) $\frac{1}{3}$rd

175. According to IS code, the permissible values of settlement in clays and sands are ______ respectively.
(a) 20 mm and 40 mm
(b) 40 mm and 20 mm
(c) 30 mm and 60 mm
(d) 60 mm and 30 mm

176. The value of factor of safety adopted in foundation design is
(a) 1.2 to 1.5
(b) 1.5 to 2.0
(c) 2 to 3
(d) 3 to 4

177. In stabilizing soil by mixing with cement, the amount of cement used is ______ of soil.
(a) 0.1 to 1%
(b) 1 to 5%
(c) 5 to 14%
(d) 15 to 20%

178. In the process of lime stabilization of clay
(a) clay particles get flocculated into large size.
(b) shrinkage limit increases.
(c) strength increases.
(d) all the above.

179. For soil stabilization waterproofers added is up to
(a) 0.1 to 1%
(b) 1 to 5%

(c) 5 to 14%

(d) 15 to 20%

180. During electrical stabilization of soil
(a) soil particles get flocculated to form large particles
(b) friction between particles increase
(c) fine grained soil is drained
(d) all the above

II. *Match List I with List II, selecting the answer code given below each in question nos. 181 to 185.*

181.

	List I		**List II**
A.	Talus	1.	Soil transported by wind
B.	Till	2.	Soil transported by gravity
C.	Loess	3.	Soil transported by glaciers
D.	Lacustrine deposit	4.	Soil deposited in lake bed

Codes:

(a)	A – 1	B – 3	C – 2	D – 4
(b)	A – 2	B – 3	C – 1	D – 4
(c)	A – 1	B – 2	C – 4	D – 1
(d)	A – 3	B – 2	C – 4	D – 1

182.

	List I		**List II**
A.	Unit weight of soil solid	1.	$\frac{W_s}{V}$
B.	Bulk weight of soil	2.	$\frac{W}{V}$
C.	Dry unit weight of soil	3.	$\frac{M}{V}$
D.	Bulk density	4.	$\frac{W_s}{V_s}$

where W = Weight of soil mass, V = Volume of soil (mass)
W_s = Dry weight of soil, V_s = Volume of soil (solids)
M = Total mass of soil.

Codes:

(a)	A – 3	B – 2	C – 1	D – 4
(b)	A – 2	B – 3	C – 1	D – 4
(c)	A – 1	B – 3	C – 4	D – 2
(d)	A – 4	B – 2	C – 1	D – 3

183.

	List I		List II
A.	Consistency index is –ve	1.	Soil is at plastic limit.
B.	Consistency index is zero	2.	Soil is at liquid limit.
C.	Consistency index = 1	3.	Soil is stiff.
D.	Consistency index > 1	4.	Soil behaves like liquid.

Codes:

(a)	A – 3	B – 2	C – 1	D – 4
(b)	A – 4	B – 2	C – 1	D – 3
(c)	A – 3	B – 1	C – 2	D – 4
(d)	A – 4	B – 2	C – 3	D – 1

184.

	List I		List II
A.	Lateral earth pressure at rest	1.	Wall moves away from earth fill.
B.	Active earth pressure	2.	Wall is at rest.
C.	Passive earth pressure	3.	Wall moves towards earth fill.

Codes:

(a)	A – 3	B – 1	C – 2
(b)	A – 2	B – 1	C – 3
(c)	A – 1	B – 2	C – 3
(d)	A – 3	B – 2	C – 1

185.

List I **List II**

Type of soil **Coefficient of earth pressure at rest (K_o)**

A. Loose sand, saturated	1.	0.36
B. Loose sand, dry	2.	0.46
C. Dense sand saturated	3.	0.49
D. Dense sand, dry	4.	0.64

Codes:

(a)	A – 1	B – 3	C – 2	D – 4
(b)	A – 3	B – 1	C – 4	D – 2
(c)	A – 2	B – 4	C – 1	D – 3
(d)	A – 4	B – 2	C – 3	D – 1

III. *Select your answer according to the coding system given for the Assertion (A) and Reason (R) given below in the questions No. 186 to 191.*

(a) Both A and R are true and R is the correct explanation of A.
(b) Both A and R are true but R is not the correct explanation of A.
(c) A is true but R is false.
(d) A is false but R is true.

186. Assertion: For sedimentation tests, it is desirable to have a fairly large container.
Reason: Sides of container affect the fall of particles near the wall.

187. Assertion: Mass of soil for sedimentation analysis should be small.
Reason: The velocity of fall of a particle is influenced by adjoining particle.

188. Assertion: Organic matter and calcium compounds, should be removed from soil sample before sedimentation analysis.
Reason: Organic compounds and calcium compounds increase the velocity of fall of particles, since they find particles.

189. Assertion: In the densest state, void ratio of soil cannot be less than 0.40.
Reason: In the soil grains are not uniform, hence smaller grains fill the space between the bigger ones.

190. Assertion: Permeability of soil varies with temperature.
Reason: Viscocity of water varies with temperature.

191. Assertion: Entrapped air and foreign matters reduce permeability considerably.
Reason: Entrapped air and foreign matters plug the soil pores.

IV. *State whether the following statements are true or false in question nos. 192 to 241*

192. The soil resulting from disintegration of rock and staying at the place of their formation is known as residual soil.

193. Loam is a mixture of sand, silt and clay.

194. Shale is a material in the stage of transformation from clay to slate.

195. Loam is formed in the waterlogged area.

196. The minimum size of soil which can be examined by means of a hand lense is 0.75 mm.

197. Grains of size 2 *m* to 0.1 *m* can be observed under a microscope but their shape cannot be made out.

198. The sphere has least specific surface.

199. The specific surface of plate is maximum.

200. If g is bulk weight of soil and r bulk density $r = gg$.

201. Mass specific gravity of soil is the ratio of mass density of soil and density of water at 4°C.

202. Absolute specific gravity is also known as specific gravity of solids.

203. Density index is given by $\frac{e}{e_{\max} - e_{\min}}$.

204. Coarser fraction of soil comprising spherical grains are having higher bearing capacity.

205. The properties of cohesionless soil depend upon the grain size distribution to a greater extent compared to cohesive soil.

206. Determination of the percentage of different sizes in a soil is termed mechanical analysis.

207. A particle is said to have an equivalent diameter D_e, if a sphere of diameter D having the same unit weight as the particle, has the same velocity of fall as the particle.

208. In pretreatment of soil sample, the mixture of soil and hydrogen peroxide sample is boiled to remove calcium compound.

209. The hydrometer of test is preferred for finding grain-size distribution of finer soils.

210. The viscocity of water increases with temperature.

211. According to Darcy's law, for laminar flow conditions the rate or flow per unit time, through a saturated soil, is proportional to void ratio.

212. Unit of coefficient of permeability is same as that of velocity.

213. Coefficient of percolation is expressed in terms of cm/sec.

214. Coefficient of percolation is always less than the coefficient of permeability.

215. For a fine grained soil, the semi-logarithmic plot of void ratio versus permeability is approximately a straight line.

216. The adsorbed water reduces the flow of water.

217. If flow occurs in the upward direction effective pressure is increased.

218. The hydraulic gradient at which quick condition occurs is called critical hydraulic condition.

219. The shape factor of flow net is termed as $\frac{N_d}{N_f}$, where N_d and N_f are total number of drops and flow channels in a flow net.

220. Exit gradient in a earthern bund is given by $i_c = \frac{\Delta h}{L}$, where Dh is the potential drop between two successive potential lines and L is the average length of the seepage.

221. The immediate compression is calculated by assuming the soil mass to behave as an elastic material.

222. Primary consolidation starts when pore water pressure is zero.

223. The change in volume of soil per unit initial volume due to a given increase in the pressure is called the coefficient of volume compressibility.

224. Compaction is instantaneous and consolidation is time dependent.

225. Compaction is in case of saturated soil and consolidation is in case of unsaturated soil.

226. The maximum shear stress is more than the shear stress on the plane of maximum obliquity.

227. In consolidated undrained test drainage is permitted initially.

228. Direct shear test is an ideal test for cohesionless soil.

229. Drained shear strength of soft cohesive soil can be made by shear vane test.

230. Shear strength of cohesive soil is affected by the rate of strain.

231. If the shear strength is compared on the basis of effective stress, the change due to straining rate is considerably less.

232. As strain is very large, the ultimate stress in case of loose and dense sand is more or less same.

233. Sensitivity of clay is defined as the ratio of shear strengths of remoulded clay in its undrained condition to that of undisturbed clay.

234. Sensitivity of clay can be as high as 30.

235. Active earth pressure is more than passive earth pressure.

236. Coefficient of earth pressure at rest is the ratio of horizontal pressure to vertical pressure.

237. Coulomb's formula of earth pressure suits well for masonry gravity walls.

238. For determining earth pressure Coulomb assumed wedge-shaped failure.

239. Bearing capacity factors suggested by Terzaghi decrease with angle of internal friction.

240. Bitumen stabilization is due to binding of soil particles and reduction in water absorption.

241. Thermal stabilization and electrical sterilization are the methods of soil stabilization.

Answers to Multiple-Choice Questions

1. (c)	2. (c)	3. (a)	4. (b)	5. (c)
6. (c)	7. (d)	8. (d)	9. (d)	10. (c)
11. (d)	12. (b)	13. (c)	14. (c)	15. (c)
16. (a)	17. (b)	18. (d)	19. (d)	20. (b)
21. (d)	22. (a)	23. (b)	24. (c)	25. (a)
26. (a)	27. (b)	28. (b)	29. (a)	30. (d)
31. (a)	32. (b)	33. (d)	34. (b)	35. (c)
36. (d)	37. (d)	38. (d)	39. (a)	40. (b)
41. (c)	42. (a)	43. (b)	44. (b)	45. (b)

46. (c)	47. (b)	48. (a)	49. (c)	50. (a)
51. (d)	52. (b)	53. (b)	54. (c)	55. (b)
56. (a)	57. (a)	58. (d)	59. (c)	60. (d)
61. (c)	62. (b)	63. (b)	64. (a)	65. (c)
66. (c)	67. (a)	68. (b)	69. (a)	70. (c)
71. (b)	72. (a)	73. (b)	74. (c)	75. (d)
76. (a)	77. (c)	78. (d)	79. (a)	80. (c)
81. (a)	82. (d)	83. (d)	84. (d)	85. (b)
86. (d)	87. (c)	88. (b)	89. (c)	90. (b)
91. (d)	92. (c)	93. (d)	94. (d)	95. (a)
96. (a)	97. (d)	98. (d)	99. (b)	100. (a)
101. (b)	102. (c)	103. (d)	104. (a)	105. (c)
106. (c)	107. (b)	108. (c)	109. (c)	110. (b)
111. (c)	112. (d)	113. (d)	114. (a)	115. (d)
116. (c)	117. (c)	118. (d)	119. (c)	120. (d)
121. (a)	122. (c)	123. (b)	124. (c)	125. (b)
126. (c)	127. (c)	128. (d)	129. (a)	130. (a)
131. (c)	132. (a)	133. (c)	134. (a)	135. (b)
136. (c)	137. (b)	138. (c)	139. (b)	140. (a)
141. (c)	142. (a)	143. (b)	144. (b)	145. (c)
146. (d)	147. (c)	148. (b)	149. (d)	150. (a)
151. (c)	152. (d)	153. (b)	154. (a)	155. (a)
156. (b)	157. (c)	158. (a)	159. (c)	160. (d)
161. (b)	162. (b)	163. (d)	164. (c)	165. (d)
166. (c)	167. (d)	168. (a)	169. (b)	170. (d)
171. (c)	172. (a)	173. (d)	174. (b)	175. (b)
176. (c)	177. (c)	178. (d)	179. (a)	180. (c)
181. (b)	182. (d)	183. (b)	184. (b)	185. (c)
186. (a)	187. (a)	188. (a)	189. (d)	190. (a)
191. (a)	192. True	193. True	194. True	195. False
196. False	197. True	198. True	199. True	200. False
201. True	202. True	203. False	204. False	205. True
206. True	207. True	208. False	209. True	210. False
211. False	212. True	213. True	214. False	215. True
216. True	217. False	218. True	219. False	220. True
221. True	222. False	223. True	224. True	225. False
226. True	227. True	228. False	229. False	230. True
231. True	232. True	233. False	234. True	235. False
236. True	237. True	238. True	239. False	240. True
241. True				

13

Environmental Engineering

13.1 SOURCES OF WATER

* Rainwater, surface water, groundwater and water from reclamation are the sources of water.
* Water is stored in small underground tanks or cisterns from roofs of buildings.
* Streams, rivers, ponds, lakes and impounded reservoirs are the surface waters.
* A portion of rainwater falling on earth infiltrates into the ground, travels down and when checked by impervious layer to travel, forms groundwater. The total groundwater potential is estimated to be one-third the capacity of oceans. Groundwater may be tapped from natural springs, wells, bore holes, infiltration galleries, and river side radial collector wells.
* Water is also obtained by reclamation and desalination and reuse of treated wastewater.
* Municipal water supply system consists of collection, transmission, purification and distribution.

Hydrology

* Hydrology is the science which deals with the occurrence, distribution and movement of water on the earth, including that in the atmosphere and below the surface of the earth.
* Transpiration is the process of water being lost from the leaves of the plants. Total evaporation includes transpiration as well as evaporation from water bodies.
* Precipitation is the fall of moisture from the atmosphere to the earth surface in any form like rainfall, snow, hail, sleet, freezing rain.
* Run-off is that portion of precipitation which is not evaporated. Run-off may be further classified as surface run-off, sub-surface runoff and groundwater flow.
* There are four types of precipitation, namely, cyclonic precipitation, convective precipitation, orographic precipitation and precipitation due to turbulent ascent. Cyclonic precipitation results from lifting of air masses converging into low pressure area or cyclone. Convective precipitation is caused by natural rising of warmer, lighter air in colder, denser surrounding. Orographic precipitation is due to lifting of moisture laden air due to topographic barrier, such as mountains. Air mass is raised due to greater friction of earth surface after it travels from ocean. Ultimately, it condenses and precipitates. Winter rainfall in Tamil Nadu is due to this process.
* The types of rain gauges used are non-automatic or automatic. Symon rain gauge is non-automatic rain gauge which is prescribed for use at all Government rain gauge stations in India. Automatic rain gauges are of three types, namely, (1) weighing bucket rain gauge (2) tipping bucket rain gauge and (3) float type.
* Average rainfall is calculated by arithmetic average method, thissen polygon method or by isohyetal method.
* Evaporation may be determined from empirical formulae or from field measurements.

  1. Mayer's formula:

$E = C\,(V - v)\left(1 + \frac{W}{k}\right)$

E = Evaporation loss in cm per month

V = Max. vapour pressure, expressed in cm of mercury

v = Actual vapour pressure, expressed in cm of mercury

C = Constant which is 1.1 for deep bodies and 1.5 for shallow bodies of water

K = Constant, the value may be taken as 16.

2. Rohwer's formula:

$$E = C¢\,(1.465 - 0.00732\,p_a)\,(0.44 + 0.0732\,W)\,(V - v)$$

where $C¢$ = constant approximately 0.75

p_a = Atmospheric pressure in cm of mercury

* Evaporation from field measurement is by constructing waterpans near water body or placing a waterpan on a float.

* The run-off of a catchment area in any specified period is the total quantity of water drained into a stream or into a reservoir.

* Run-off calculation by formulae and tables:

$$R = Kp$$

where R = run-off in cm, P = rainfall in cm and K = run-off coefficient

Area	K
Urban residential–single houses	0.3
– apartments	0.5
Commercial and industrial	0.9
Forest, depending upon soil	0.05 – 0.2
Parks, farmland, pasture	0.05 – 0.3
Asphalt and concrete roads	0.85

* Barlow gave his table for *k*-values after studying catchment in U.P. in terms of percentage. It varied from 10% to flat, cultivates and black cotton soil to 45% for hilly and steep areas.
* Strange gave tables and curves to find out daily run-off for dry, damp and wet areas.
* C.C. Inglis gave the formula as

$R = 0.85\, P - 30.5$ for the Ghat area

$R = \frac{P - 17.8}{24} \times P$ for the non-Ghat area in which R and P are in cm units.

* Lacey's formula is

$$R = \frac{P}{1 + \frac{304.8F}{PS}}$$

where S = catchment factor and

F = Mansoon duration. S value varies from 0.25 to 3.45 for different classes of catchment.

* Khosla's Formula:

$R = P - \frac{T - 32}{3.74}$ where T = mean temperature in °F.

* The estimation of peak flow or flood can be made by various methods.

1. *Physical indication of past flood*: It is based on flood marks and flood level observed in past 35 years and the cross section of stream.

The observations may be at various sections to check consistency of results.

2. Flood discharge formulae: They are of the form

$$Q = CA^n$$

where Q = flood discharge in cumecs, A = catchment area is sq km

n = flood index and C = flood coefficient

(a) Dicken's formula $Q = CA^{3/4}$

C values for north India = 11.4; Central India = 13.9 to 19.5 and for Western Ghats = 22.2 – 25

(b) Ryve's formula: For Tamil Nadu

$$Q = CA^{2/3}$$

C values vary from 6.75 to 10.1

(c) Inglis formula for Bombay Presidency

$$Q = \frac{123\,A}{\sqrt{A + 10.4}} = 123\ A^{1/2}$$

(d) Nawab Jung's formula for Hyderabad region

$$Q = CA^{\left(0.993 - \frac{1}{14}\log A\right)}$$

(e) Fanning's formula for American catchment

$$Q = CA^{5/6}$$

Surface Sources

* Dams are constructed across rivers and streams to create reservoirs. Purpose of creating a reservoir may be for (i) storage of water, (ii) flood protection (iii) generating electricity and others.

* Before constructing a dam engineering surveys, geological investigations and hydrological investigations are carried out.

* The site that gives deep reservoir is preferable, the reasons being: (i) Lower cost of submerged land, (ii) less evaporation losses and (iii) less likelihood of weed growth.

* Yield is the amount of water that can be supplied from the reservoir in a specified interval of time. The maximum quantity of water that can be guaranteed during a critical dry period is known as the

safe yield.

Secondary yield is the quantity of water available in excess of safe yield during periods of high flood.

* A dam is a hydraulic structure across a river to store water on upstream side. Dams are classified on various basis:
 1. According to use: Storage dam, diversion dam and detention dam.
 2. Based on hydraulic design: Overflow dam and non-overflow dams.
 3. Based on materials used: Rigid and non-rigid dams.

 Rigid dams may be further classified as solid masonry dams, concrete gravity dams arched dams, concrete buffers dam, steel dam and timer dam. Non-rigid dams are earth dams, rockfill dams and combined earth and rockfill dams.

* Intakes are the structures used for admitting water from the river, reservoir or lake and conveying it further. Types of intakes are
 1. Submerged intake and exposed intake
 2. Wet intake and dry intake
 3. River intake, reservoir intake, lake intake and canal intake.

Groundwater

* Groundwater hydrology is the science of occurrence, distribution and movement of water below the surface of the earth. The main source of groundwater is precipitation.
* Types of aquifers are unconfined aquifers and confined aquifer. Unconfined aquifers are known as water table aquifers also. In this type water table serves as the upper surface. Confined aquifer is the one in which groundwater is confined under pressure greater than atmospheric by overlaying inpermeable strata. When a well penetrates a confined aquifer, water rises in the well under local static pressure and it may flow over the surface of well. Such well is known as flowing well.
* The coefficient of permeability k is defined as the velocity of flow which will occur through the total cross-sectional area of the soil under a unit hydraulic gradient. For clean gravel it is 1.0 and greater while for clean sand it is 1.0–0.01. For clay it is the least, the value being in the range 0.000001 or less.
* Coefficient of transmissibility is defined as the rate of flow of water through a vertical strip of aquifer of unit width and extending the full saturation height under unit hydraulic gradient, at a temperature of 60°F.

 $T = Bk$ where B is the aquifer thickness.

* Darcy's law states that under laminar flow conditions in saturated soil, the rate of flow or the discharge per unit time is proportional to the hydraulic gradient. Thus,

$$Q = k\,i\,A \text{ or } v = \frac{\theta}{A} = ki$$

 where i = hydraulic gradient

 k = Darcy's coefficient of permeability.

* A water well is a hole or shaft excavated in the earth for bringing groundwater to the surface. It may

be open well (day well) or drilled well-known as tube well. Tube wells may be strainer well, cavity well or slotted well. For drilling bore well the methods adopted are

1. Wash boring
2. Cable tool method
3. Hydraulic rotary method
4. Reverse rotary method

* Economical feasible depth of an open well is limited to 30 m. In open well, the entry of water is from the bottom and not from the sides. Open wells may be classified as shallow wells and deep wells. A deep well is a well in which water is drawn from the pervious formation below the impervious layer. A shallow well penetrates the pervious strata only.
* Yield from an open well can be found by constant level pumping test or by recuperation test.
* Apart from wells, underground water may be tapped with springs, infiltration galleries and karez. Springs are of the type stratum springs, valley springs, fault springs, artesian springs and deep seated springs. Infiltration galleries are small tunnel in the form of pipes laid under the ground to tap underground flow at moderate depth. A karez is an underground tunnel driven into the hill side to tap water from the underground springs.

Water Demand

* For the design period the population and rate of demand is to be estimated. Normally, the design period selected is 20 to 40 years.
* Various methods used for population forecast are (1) arithmetic increase method, (2)geometric increase method, (3) incremental increase method, (4) decreased rate of growth method, (5) graphical method, (6) zoning method, (7) ratio and correlation method, and (8) growth composition analysis method.
* Factors affecting population growth are: (1) economic factors, (2) development programmes, (3) social facilities, (4) communication links, (5) tourism (6) community life and (7) unforeseen factors like floods, epidemics, earthquakes.
* Total water demand consists of residential use, institutional use, public use, industrial use and water system losses. For residential use 135 litres/day/capita is required. Domestic animals need water which may be taken as

Cow and buffalo – 40 to 60 litres/per animal/day

Horse – 40 to 50 litres/per animal/day

Dog – 8 to 12 litres/per animal/day

Sheep or goat – 5 to 10 litres/per animal/day

The requirement for institutional needs are

Hospitals – 340 to 450 litres/bed/day

Hotels – 180 litres per day per bed

Hostels – 135 litres per day per bed

Schools and colleges, offices, etc. – 45 litres day/head.

* The formulae for fire demand are

1. Kuichling formula : $Q = 3182 \sqrt{p}$
2. Buston's formula : $Q = 5663 \sqrt{p}$
3. Freeman's formula : $Q = 1136 \left(\frac{p}{5} + 10\right)$
4. National Board of Fire Underwriters formula

$$Q = 4637 \sqrt{p}(1 - 0.01\sqrt{p})$$

where p = population in thousands and F is the number of simultaneous fire streams.

* The quantity of water required depends upon the type of industry for a city with moderate factories, a provision of 20 to 25 per cent per capita consumer may be made.

* If fully metered, losses hardly exceed 20% if not losses may be upto 50%.

* There are variations in the rate of demand

1. Seasonal : 130%
2. Monthly : 140%
3. Daily : 180 %
4. Hourly : 150 %

Quality of Water

* For domestic use water should be potable. It should be colourless, free from solids, odours and disease producing bacteria.

* Common impurities in water are suspended, dissolved and colloidal impurities.

* Impounding of water in the reservoir has both beneficial and detrimental effects. The beneficial effects are—reduction in turbidity, reduction in hardness, organic oxidation, reduction in B.O.D. reduction in coliform density and colour. The detrimental effects are lower atmospheric reaeration, increased algal bloom, thermal stratification, etc.

* Water analysis is carried out to determine impunities present in water:

1. Physical examination: Colour test, taste and odour test, temperature test and turbidity test. The permissible turbidity of domestic water may be between 5 to 10 ppm. The common methods are by turbidity rod, Jackson's turbidometer, Baylis turbidometer and by Nephelo meters.
2. Chemical examination: Chemical tests are carried out to determine: total solids, chlorides, hardness, pH value, metals and other chemical substances, nitrogen, and dissolved gases. There are three methods of determining total hardness of water, namely, Clark's method, Hehner method and Versenate method. The hydrogen ion concentration (pH value) is determined by colourimetric method and electrometric method.

* Bacteria are single-celled microorganisms with rigid cell walls. They may be classified on various basis:

1. According to shape: (a) round, ovoid or spherical bacteria called cocci (b) straight rod like cells with square or rounded ends, called bacilli, (c) curved rods comma shaped or helical or spiral shaped, called spirilla. They vary in diameter from 0.5 to 1.5 *m* and are less than 10 *m* long.
2. According to type: (a) Saprophytic bacteria (beneficial to man), (b) parasitic bacteria (c) pathogenic bacteria and (d) non-pathogenic bacteria.
3. According to oxygen need: (a) aerobic bacteria, (b) anaerobic bacteria, and (c) facultative bacteria.
4. According to temperature at which they flourish:
   (a) Psychrophilic bacteria (10 to 20°C)
   (b) Mesophilic bacteria (20° to 40°C)
   (c) Thermophilic bacteria (40° to 65°C)
5. According to the origin of occurrence: (a) natural water bacteria, (b) bacteria from soil, (c) bacteria from sewage.

* The bacteria from sewage may be further classified as (i) Coli-aerogenes group. A negative test for gas for mass indicates that the water is safe, (ii) clostridium welchii, and (iii) Faecal streptococci.
* The most probable number of coliform or *E coli* is defined as that bacterial density, which if it had been actually present in the sample, would more frequently than any other, have given the observed result.
* There are some types of bacteria which when present may cause pitting and tuberculations in pipes. Iron bacteria, sulphur bacteria, gelatine liquefying bacteria and slime forming bacteria are the nuisance bacteria.
* Common water-borne diseases are:
  1. Bacterial diseases like typhoid fever, paratyphoid fever, cholera and bacillary dysentery.
  2. Protozoal diseases like amaebiasis and amoebic dysentery.
  3. Virus diseases like polio viruses, coxsakie viruses, ECHO viruses
  4. Helminthic (worm) disease
* Ministry of Urban Development, India has recommended physical and chemical standards for water supply.

Water Treatment

For surface water, the following are generally adopted processes: Screening, aeration, sedimentation with or without coagulants, filtration, disinfection, water softening, desalination, removal of iron, manganese, etc.

* Screening and aeration: Two types of screens are used, namely, coarse screens and fine screens. Coarse screens are in the form of bass, 25 mm dia. At 75 to 100 mm spacing. They are placed at 1 horizontal to 3 to 6 vertical. They prevent floating materials. Fine screens are used at surface intakes. It needs some devices to keep it clean. Its openings are holes of about 6 mm diameter usually a pair of straining fabric is submerged in water to be submerged. Microstrainess of stain steel wires of 23 *m* to 35 *m* are also used.
* Aeration of water is necessary to remove taste, hydrogen sulphide and hence odour, to kill bacteria to some extent and to increase dissolved oxygen. Types of aerators used are cascade aerators, inclined appron aeration, slat tray aerators, gravel bed aerators, spray aerators and air diffusers.

The thickness of gravel bed may be from 1 to 1.5 m. Spray aerator needs considerable head but it reduces carbon dioxide by 70 to 90%. Removal of odour is upto 50 per cent. It is economical only in warmer months.

* Sedimentation is removal of suspended particles by gravitational settling. The technique used is to reduce the velocity of flow so as to permit suspended particles settle. Settling velocity may be found by Newton's formula or Stoke's formula.

Newton's Formula: $v = \sqrt{\frac{4}{3}\frac{g}{C_D}\frac{(\rho_s-\rho)d}{\rho}}$

$= \sqrt{\frac{4}{3}\frac{g}{C_d}(S_s-1)d}$

where C_D = drag coefficient = $\frac{\pi}{4}d^2$

r_s = Mass density of particle

r = Mass density of fluid

d = Diameter of spherical particle

S_s = Specific gravity of the particle.

Stokes Law: $V_s = \frac{1}{18}\frac{g}{v}(S_s-1)d^2$.

where v = kinematic viscosity of water in centistoke (1 centistoke = 0.01 mm^2/second)

Effect of shape: At low values of Reynolds numbers, the settling velocity of rod-like and disk-like spheroidal particles are respectively 78% and 73% of the velocity of an equal volume sphere.

* Sedimentation tanks may be fill and draw type or continuous flow type.
* The inlet and outlet arrangements should be such that minimum disturbance is caused due to influent and effluent streams. To achieve it each inlet and outlet should face a baffle. Uniform velocity may be achieved by passing the water through a perforated wall with holes or slots.
* Particles settled in the basin (sludge) can be removed either manually or mechanically.
* Plain sedimentation tanks may be rectangular with horizontal flow, circular with radial or spiral flow or hopper bottom with vertical flow.
* Coagulants are used to remove fine suspended particles. The coagulants neutralize the negative charge on the colloidal particles and allow them to coagulate. Common coagulants used are aluminium sulphate (alum), chlorinated coppers, ferrous sulphate and lime, magnasium carbonate, polyelectrolytes and sodium aluminate.
* Method of feeding may be dry feeding or wet feeding. The following mixing devices are used: (1) centrifugal pump (2) compressed air agitation (3) narrow mixing channel and fume (4) mixing basins with baffle walls and (5) mixing basins with mechanical devices.
* Flocculation is essentially an operation designed to force agitation in the fluid and induce coagulation. It is normally regarded as a preliminary to settlement. After flocculation, water enters the settling tank which is known as clarifier. The detention period required is $2\frac{1}{2}$ to 3 hours.

Filtration

* In filtration, water is passed through a filter media to remove the turbidity and non-settleable

colloidal matter. Colour and chemical characteristics improve and bacterial content of water is reduced.

* Filters are classified as slow sand filters and rapid sand filters. Rapid sand filter may be of gravity type or pressure type.

* The normal rate of flow in slow sand filters may be between 100 to 200 litres per hour per m^2 of the filter area. They remove 98 to 99% of bacteria but they are not effective in removing colloidal turbidity over 50 ppm. It removes only 20 to 25% of colour. If the colour is higher than 25 to 30 Hazen units slow sand filters should not be used. They are not effective in removing any high concentration of manganese. They are good at removing algae.

* Rapid sand filters are preceded by sedimentation with coagulants. Rapid sound filter may be of gravity type or pressure type. Gravity type filter media uses coarser sand than that used in slow sand filters. In the pressure type, water is allowed to filter under pressure through filter media. Filters are normally designed for a filtration rate of 3000 to 6000 litres per hour per m^2 area.

* A filter needs back washing when the loss of head through it has reached the maximum permissible. The pressure at which wash water applied is about 5 m head of water. The rate of application of wash water may be 600 litres/m^2 of filter surface. Through repeated back washing the finer sand tends to stratify at top. It needs surface wash which is applied by jets of water through nozzles at a rate of 200 to 400 litres per minute per m^2 of area under a pressure of 0.7 to 1.0 kg/cm^2.

* Due to poor design or poor operations, the following filter troubles may occur: (1) cracking and clogging (2) formation of mud balls (3) air binding (4) sand incrustation (5) jetting and sand boils and (6) sand leakage.

* The pressure filter is a type of rapid filter which is a closed container and through which the water passes under pressure. The pressure may very from 3 to 7 kg/cm^2. It may be of horizontal or vertical type. The diameter of vertical filter varies from 2 to 2.5 m and length 2.5 to 8.0 m.

Disinfection

* Disinfection of filtered water is necessary to kill pathogenic bacteria. This disinfection either destroys or inactivates the micro-organisms by damaging their cell wall, changing the colloidal nature of the cell protoplasm and inactivating critical enzyme systems.

* Methods of disinfections are boiling, excess lime treatment, silver treatment, ultraviolet ray treatment, potassium manganate treatment and chlorination. Generally, most waters are satisfactorily disinfected, if the free available residual chlorine is about 0.2 mg/litre at the end of 10 minutes contact period.

* Chlorine gas may be fed directly to the point of application to the water or the gas may be first dissolved in a semi-flow of the solution and then fed to the point.

Water Softening

* Water is said to be ‘hard’ when it contains relatively large amount of bicarbonate, carbonate, sulphates and chlorides. Such water needs large amount of soap.

* Hardness is of two types: temporary and permanent. Temporary hardness can be removed by

boiling. It is usually carbonate hardness. To remove permanent hardness the methods used are: lime soda process, zeolite process and de-ionization process.

* The other methods of treatment are: Deflouridation, desalination, distillation, reverse osmosis, freezing and solar evaporation methods.

Pumps and Pumping

* In a water supply scheme pumping is necessary to lift water from the source or to lift the treated water to overhead tanks or reservoirs. Pumps may be required to supply water at reasonable pressure also.
* Pumps may be classified on various basis:
  1. Based on mechanical principles of operation:
     (a) Displacement pumps—reciprocating and rotary
     (b) Centrifugal pumps—volute or turbine pumps
     (c) Air lift pumps
     (d) Hand pumps.
* Economical diameter of pump may be found by empirical formula given by Lea.

$$D = a\sqrt{Q}: a = \text{constant } 0.97 \text{ to } 1.22$$

Conveyance of Water

* Open channels, tunnels and pipes are used to convey water. Open channels and tunnels are usually to convey raw water from the source.
* Pipes may be made of cast iron, steel, galvanized iron, cement concrete, asbestos cement, plastic, lead, copper, etc.
* The following accessories are required in piping: sluice valve, air valves, reflux valve, relief valves, altitude valves and scour valves.

Distribution System

* Water is distributed by gravity system, pumping system and combination of the above two. The pressures required in distribution are:
  (a) Residential area:
  Upto 3 — storeys 2 kg/cm^2, 3 to 6 storeys — 2 to 4 kg/cm^2, 6 to 10 storeys – 4 to 5.5 kg/cm^2 and above 10 storeys – 5.5. to 7 kg/cm^2.
  (b) In commercial system – 5 kg/cm^2
* A minimum velocity of 0.6 m/sec should be maintained.
* The minimum pipe sizes required are:
  (a) Towns with population up to 50,000, 100 mm dia.
  (b) Towns with population above 50,000, 150 mm dia.
* Water may be supplied continuously or intermittently. Continuous water system is the best system but many times intermittent water supply system is unavoidable. The drawbacks of intermittent systems are:

1. Fire demand is not met immediately.
2. Domestic storage is necessary.
3. Pollution in supply is possible.
4. Size of pipes required will be larger.
5. Wastage is more.
6. Needs more staff since valves to be operated is large.

* Methods of laying out distribution system are:
  1. Dead end or tree system.
  2. Grid iron or reticulation system
  3. Ring system
  4. Radial system.

Water Supply for Buildings

* G.I. pipes or PVC pipes are generally used. The domestic service connection includes:
  1. Brass or bronze ferrule
  2. Goose neck
  3. Stop cock
  4. Main service pipe and water meter
* Meters used may be velocity meter or displacement meters. Commonly used valves are globe valve and gate valve.

13.2 SANITARY ENGINEERING

* Sanitary engineering deals with collection, conveyance, treatment and disposal of sewage. The term refuse is used to indicate the material left as worthless. Garbage refers to dry refuse. Sullage indicates wastewater from bathrooms, kitchen sinks, washbasins and washing places. Sewage is the liquid waste. It includes sullage, discharge from W.C Night soil indicates the human and animal excreta. Sewer is underground drain through which sewage is carried. Storm water sewer carries only rainwater. House sewer carries sewage from houses to street sewer. Sewerage is the process of removing sewage.

Collection and Conveyance of Refuse

* Solid waste and liquid waste are to be collected and conveyed rapidly and safely to disposal sites. For this conservancy system or water carriage systems are employed. In conservancy system night soil, garbage, sullage and storm water are collected separately and transported. In water carriage system night soil and sullage are carried through sewage. Storm water may be carried in open channels while garbage is collected separately. In water carriage system 5 to 10 litres of water is used to flush water closets after its use by every person.
* Separate system, combined system or partially separate systems may be used for carrying domestic and industrial sewage. For collection of liquid waste fan pattern, interceptor pattern, perpendicular pattern, radial pattern or zonal pattern may be adopted.

Quantity of Sewage

* The quantity of dry weather flow depends on rate of water supply, population growth, type of area and infiltration and exfiltration. For calculating peak rate of domestic sewage the following two formulae are available:

1. Babbit's formula

$\frac{Q_{max}}{Q_{av}} = \frac{5}{P^{0.2}}$ where P is population in thousands.

2. Harmon's formula:

$$\frac{Q_{max}}{Q_{av}} = 1 + \frac{14}{4 + P^{0.5}}$$

* To avoid silting, longitudinal gradient of sewer should be based on minimum sewage of $\frac{1}{2}$ to $\frac{1}{3}$ of the average rate of flow.

* Groundwater infiltration may be assumed as follows:

	Minimum	Maximum
Litres/day/hectare	5000	50,000
Litres/day/km	500	5000
Litres/day/manhole	250	500

* For estimating storm water flow rational method or empirical formulae may be used.
Rational method: $Q = CIA$ where C is run-off coefficient, I is intensity of rainfall and A is drainage area

* Percentage of imperviousness may be found from the records or may be assumed as shown in Table 13.1.

Table 13.1 Percentage of imperviousness

Type of area	*% Imperviousness*
Commercial and industrial residential area	70 to 90
(a) High density	60 to 75
(b) Low density	35 to 60
Parks and underdeveloped area	10 to 20

* Empirical formula:

1. Burkli-Ziegler formula:

$$Q = 0.0173\ CAI \left(\frac{S}{A}\right)^{1/4}$$

where C = 50 to 90, depending upon nature of ground
S = Slope of ground in m per 1000 m

2. McMah formula:

$$Q = 2.30\ CAI \left(\frac{S}{A}\right)^{1/5},\ C \text{ varies from } 0.3 \text{ to } 0.9$$

3. Metcalf and Eddy formula

$$Q = 215.67\ (A)^{0.73}$$

4. Fanning's formula

$$Q = 3125\ A^{5/8}$$

5. Dicken's formula

$$Q = CA^{3/4}$$

6. Ryve's formula = $Q = CA^{2/3}$

7. Ingli's formula $Q = \frac{124\,A}{\sqrt{A+10.4}} = 124\ A^{1/2}$

Hydraulic Design of Sewers

* Sewers are generally designed as open channels. The velocity of flow may be estimated with the following formula:

1. Chezy formula: $V = C\sqrt{RS}$

where R = Hydraulic mean depth, C = Chezy's coefficient and S = slope of sewer.

The hydraulic mean depth is green by $R = \frac{A}{P}$ where A is the area of flow and P is wetted perimeter. For finding C, Bazin's formula or Ganguillet-Kutters formula may be used.

2. Mannin'g formula: $V = \frac{1}{n} R^{2/3} S^{1/2}$, where n depends upon type of finishing material for sewage.
3. Crimp and Bruge's formula:

$$V = 83.47\ R^{2/3}\ S^{1/2}$$

4. Hazen-Williams formula

$$V = 0.849\ C_H\ R^{0.63}\ S^{0.54}$$

* Self-cleansing velocity may be defined as the minimum velocity of flow at which the solid particles present in the sewage will be held in suspension. Minimum velocity required for self-cleansing depends upon the type of material and its specific gravity. Badwin Latham found that it depends upon the diameter of sewer also.

* Maximum velocity also should be restricted so that no erosion of the inner surface of the sewer takes place. For different surfaces this velocity is as shown in Table 13.2.

Table 13.2 Minimum velocity for different surface of sewers

Sewer material	*Max./f. Velocity permitted*
Vitrified tiles and glazed bricks	4.5 to 5.5 m/sec
Cast ion sewers	3.5 to 4.5 m/sec

Stoneware sewers	3.0 to 4.0 m/sec
Cement concrete swears	2.5 to 3.0 m/sec
Ordinary brick-lined	1.5 to 2.5 m/sec
Earthen channels	0.6 to 1.2 m/sec

* Cross-sectional shapes of channels used are circular, egg-shaped, horseshoe, rectangular, parabolic, semi-elliptic and U-shaped.

Construction of Sewers

* Materials used are brick, cement concrete, asbestos cement, stoneware, cast iron, steel, plastic, FRP, etc.
* Various types of joints used are socket and spigot, flanged, cement collar, mechanical coupling, simplex, flexible and expansion joints.
* To avoid clogging of sewers routine maintenance as well as emergency maintenance are required. Cleaning of large sewers may be manually done while for small sewers portable pump set, Manila rope and cloth ball, sectional sewer rods, sewer cleaning buckets, scrapes, hydraulically propelled devices are used.
* For ventilation of sewers the following methods are employed: Manholes with gratings, ventilation shafts, mechanical devices, manholes with chemicals.
* It is necessary to use the following safety equipment during maintenance: Gas mask, portable lights, breathing apparatus, non-sparking tools, safety belts, inhalers, diver's suit.

Sewer Appurtenances

* Sewer appurtenances are the structures constructed on sewer line at regular intervals to assist inefficient operation and maintenance. The sewer appurtenances are: inlets, catch basins, clean-outs, manholes, lamp holes, flushing devices, grease and oil traps, inverted siphons and storm water outflow devices.

Sewage Pumping

* For low lying areas sewage pumping is necessary. The types of pumps used may be centrifugal, reciprocating or air pressure type.

Characteristics of Sewage

Sewage is made of about 99.9% of water and 0.1% of solids in suspension and dissolved state. Physical characteristics are colour, odour, temperature. Chemical characteristics are about organic, inorganic materials and gases present in it. Biological constituents of sewage are about creatures, plants, bacteria, etc. The organic matter which can be decomposed by bacteria under biological action is called biodegradable organic matter. The biological degradation may be of aerobic or anaerobic decomposition. Biochemical oxygen demand (BOD) shows approximate quantity of oxygen that will be required to biologically stabilize the organic matter present in sewage. BOD is related to the amount of decomposable organic matter present in sewage.

Sewage Disposal

* Sewage may be disposed of in water or on land. Disposal in water is also known as disposal by dilution. In this system sewage is left in stream, river or in sea after partial treatment. The limit on sewage to be disposed of depends upon the quality of raw sewage as well as on purification capacity of the water body. Disposal on land is accomplished in the following three ways: irrigation or sewage forming, overland flow and rapid infiltration. In irrigation method of disposal sewage is applied by the following three methods:
  1. Sprinkler irrigation
  2. Sub-surface irrigation
  3. Surface irrigation.

Surface irrigation may be further classified as basin method and furrow method.

Sewage Treatment

Sewage treatments are classified as preliminary treatment, primary treatment, secondary treatment and tertiary treatment.

1. Preliminary treatment This is to remove floating materials, settlable inorganic solids, fats, oils and grease. Various units used in this process are:

(a) Screens – for removing floating materials

(b) Grit chambers – for grinding coarse sand

(c) Comminutors – for grinding coarse solids

(d) Skimming tanks – for removing false, oils and grease

(e) Floating units – for removing fine solids

2. Primary treatment It is to remove large suspended organic matter. Primary sedimentation tanks or primary settling tanks or primary clarifiers used for this treatment.

3. Secondary treatment This is to remove organic matter and the residual suspended material by biological unit processes.

4. Tertiary treatment This is to remove dissolved and suspended materials such as inorganic compounds of nitrogen and phosphorous residual organic matter, etc.

Sedimentation

Septic tanks, Imhoff tanks and clarigester are the units in which sedimentation and digestion of settlable solids are combined. Types of settling may be discrete settling, flocculant settling, hindered or zone settling and compression settling. On the basis of method of operation settling tanks are classified as fill and draw type and continuous flow type. On the basis of location they may be classified as preliminary settling tanks, primary settling tanks and secondary settling tanks. The settling tanks may be of horizontal flow type or vertical flow type.

Sludge can be removed manually, hydrostatically or mechanically from settling tanks.

Sewage Filters

Sewage filters that are commonly employed are:

1. Intermittent sand filters
2. Contact beds
3. Tricking filters. High rate trickling filters are sometimes used. The depth of such filters is 0.9 to 2.5 m only and filter media is coarse.

Disposal of Sludge

* The quantity of sludge produced from a primary settling tank is about 20 m^3 per million litres of sewage. Similarly, the chemical-precipitation sludge may be another 20 m^3/ million litres of sewage. Quantity of activated sludge is 35 to 50 m^3.
* Before disposing of sludge thickening is achieved by gravity thickening, floatation thickening or by centrifugation.
* Sludge digestion process is used to decompose micro-organisms and to stabilize sludge.
* Sludge dewatering is made to reduce the moisture content of sludge. For this purpose sludge drying beds are used.
* Final disposal of sludge is by the following methods:
  1. Spreading on farmland
  2. Dumping
  3. Landfill
  4. Sludge lagooning
  5. Disposal in water or sea.

MULTIPLE-CHOICE QUESTIONS

I. *Select correct option from the questions 1 to 233.*

1. Which one of the following is not surface water?
   (a) From river diversion.
   (b) From reservoir storage.
   (c) From natural lakes.
   (d) From natural spring.
2. Which one of the following is not groundwater?
   (a) Rooftop water stored in underground tank.
   (b) Water from natural springs.
   (c) From infiltration gallaries.
   (d) From river side radial collector wells.
3. Water supply system means
   (a) scheme of collection and disposal of used water
   (b) system of collecting, purifying and bringing water to user point
   (c) distribution of water to sinks, toilets and kitchens in the building

(d) construction of canals

4. Transpiration is the transport of water to air from
   (a) river surface
   (b) river and ocean surface
   (c) plants and leaves
   (d) any water body
5. Precipitation is
   (a) evaporation of water from water body to atmosphere.
   (b) evaporation from plants and leaves.
   (c) rainfall.
   (d) rain and snowfall.
6. Run-off is that portion of moisture collected on the surface of the earth which
   (a) runs to the ocean through surface
   (b) runs through subsurface
   (c) is not evaporated and transpirated
   (d) all the above
7. Winter rainfall in Tamil Nadu is mainly due to
   (a) cyclonic precipitation
   (b) convective precipitation
   (c) orographic precipitation
   (d) precipitation due to turbulent ascent
8. In Himalayan region precipitation is of the type
   (a) cyclonic
   (b) convective
   (c) orographic
   (d) turbulent ascent
9. Forms of precipitation
   (a) drizzle
   (b) hail
   (c) snow
   (d) all the above
10. Which one of the following is not an automatic rain gauge?
   (a) Symon's
   (b) weighing bucket type
   (c) tipping bucket type
   (d) float type
11. In India _______ rain gauge is used in all government rain gauge stations.
   (a) Symon's
   (b) weighing bucket type
   (c) tipping bucket type

(d) float type

12. Self-recording rain gauges are used to determine rainfall over
(a) one year
(b) rainy season
(c) month
(d) short period

13. Which one of the following is not a method for computing average rainfall over a region?
(a) arithmetic average
(b) geometric mean
(c) thissen polygon
(d) isohyetal

14. Evapo-transpiration of water by crop is ______ of water consumed by evaporation and transpiration during crop growth
(a) depth
(b) volume
(c) depth/month
(d) volume/month

15. Evaporation from water surfaces depends upon
(a) vapour pressure of water and air in contact
(b) wind velocity
(c) quality of water
(d) all the above

16. At the temperature of natural waters, the vapour pressure is almost ______ times for every rise of 10°C.
(a) 1.5
(b) 2.0
(c) 3.0
(d) 4.0

17. Meyer's and Rohwer's formula are used to determine
(a) precipitation
(b) transpiration
(c) evaporation
(d) average rainfall over a basin

18. Run-off can be expressed as
(i) mm of water over a catchment
(ii) cubic metre of for a catchment area.
The correct statement is
(a) (i) only
(b) (ii) only
(c) both (i) and (ii)

(d) none

19. In a dam project geological investigations are to get information about
(a) water-tightness of the reservoir basin
(b) type and depth of overburden
(c) structural features of rock such as folds, faults, fissures
(d) all the above

20. For reservoir planning the important investigation is
(a) engineering survey
(b) geological investigation
(c) hydrological investigation
(d) all the above

21. A dam built to raise water level slightly in the river and thus providing head for carrying water into canal is known as
(a) storage dam
(b) diversion dam
(c) detention dam
(d) overflow dam

22. A dam constructed to store water during floods and release it gradually later is known as
(a) storage dam
(b) diversion dam
(c) detention dam
(d) rigid dam

23. A timber dam is a
(a) rigid dam
(b) non-rigid dam
(c) detention dam
(d) non-overflow dam

24. _______ are suited across gorges with very steep slopes.
(a) gravity dams
(b) arch dams
(c) buttress dams
(d) steel dams

25. _______ may have a drainage/inspection gallery.
(a) gravity dam
(b) earthen dam
(c) arch dam
(d) buttress dam

26. All major and important gravity dams are nowadays constructed with
(a) brick masonry
(b) stone masonry

(c) earth and rock fill
(d) concrete

27. Water load on an arch dam is transferred to
(i) abutments
(ii) foundation by cantilever action
(iii) foundation by gravity force
(a) Only (i) is true
(b) Partly by (i) and partly by (ii)
(c) Partly by (i) and partly by (iii)
(d) all the three.

28. If the space to be dammed is divided into a number of piers connected by arches, it is known as
(a) multiple arch dam
(b) arch dam
(c) buttress dam
(d) all the above

29. A jack well is a ______ intake.
(a) submerged
(b) exposed
(c) wet
(d) dry

30. Groundwater hydrology is the science of ______ of water below the surface of earth.
(a) occurrence
(b) distribution
(c) movement
(d) all the above three

31. Total groundwater potential is estimated to be ______ of the capacity of oceans.
(a) $\frac{1}{5}$
(b) $\frac{1}{4}$
(c) $\frac{1}{3}$
(d) $\frac{1}{2}$

32. Water obtained from ______ is generally known as sub-surface water.
(a) rains
(b) rivers
(c) reservoirs
(d) artesian wells

33. Vertical wells provided along the banks of a riverbed to draw ground water in dry season are known as
(a) infiltration wells

(b) tubewells

(c) artesian wells
(d) open wells

34. A pipe sunk into the well to tap underground water is called
(a) infiltration well
(b) tube well
(c) artesian well
(d) open well

35. In a well, if the water level is below the ground level but is above the local water table, it is known as
(a) infiltration well
(b) tubewell
(c) artesian well
(d) open well

36. An artesian spring is formed
(a) due to fault in a rock through which water comes out under pressure
(b) when a porous strata gets enclosed between two impervious strata
(c) when an aquifier gets exposed in a valley against a vertical cut
(d) all the above

37. In most of the confirmed aquifiers, the value of storage coefficient ranges between
(a) 0.00005 – 0.005
(b) 0.005 – 0.004
(c) 0.004 – 0.003
(d) 0.003 – 0.002

38. Coefficient of permeability is highest in
(a) clean gravel
(b) sand
(c) silt
(d) clay

39. Coefficient of permeability is least in
(a) sand
(b) clay
(c) silty sand
(d) silt

40. Layers which do not allow water to pass through them are known as
(a) aquifers
(b) aquiclude
(c) aquifuge
(d) all the above

41. The water bearing strata is known as

(a) aquifer
(b) aquiclude
(c) aquifuge
(d) all the above

42. The portion of soil through which lateral movement of water takes place is called
(a) aquiclude
(b) water table
(c) zone of saturation
(d) none of the above

43. Unit of coefficient of permeability is
(a) dimensionless
(b) m^3
(c) m^3/day
(d) m^3/day/m^2

44. Which one of the following is not a type of tube well?
(a) strainer well
(b) cavity well
(c) gravity well
(d) slotted well

45. Well development is
(i) scheme of digging wells in a specified area
(ii) process of removing fine material from the aquifer formation surrounding the stainer pipe of tube well
(a) (i) is true and (ii) is false
(b) (ii) is true and (i) is false
(c) both (i) and (ii) are true
(d) both (i) and (ii) are false

46. Method of well development is by
(a) pumping
(b) surging
(c) dry ice
(d) all the above

47. Economically feasible depth of an open well is limited to
(a) 15 m
(b) 30 m
(c) 45 m
(d) 60 m

48. Normally design period for a water supply scheme is
(a) upto 20 years
(b) 20 – 40 years

(c) 40 – 60 years

(d) 60 – 80 years

49. The population of a town in three consecutive decades are 50,000; 70,000; 84,000 respectively. The population of the town in 4th consecutive decade according to geometric increase method is
(a) 96,000
(b) 10,4000
(c) 1,09,200
(d) 1,14,200

50. Suitable method for forecasting population of a large city, which has reached its saturation population is
(a) arithmetic increase method
(b) geometric increase method
(c) incremental increase method
(d) graphical method

51. Suitable method of forecasting population for a young and rapidly increasing city is
(a) arithmetic increase method
(b) geometric increase method
(c) incremental increase method
(d) graphical method

52. According to Indian Standards for domestic use water requirement per capita per day is
(a) 100 litres
(b) 120 litres
(c) 135 litres
(d) 150 litres

53. Consumption of water for cow and buffalo per day may be
(a) 20 litres
(b) 20 – 40 litres
(c) 40 – 60 litres
(d) 60 – 80 litres

54. According to Indian Standards, water requirement per head per day in an office building is
(a) 15 litres
(b) 30 litres
(c) 45 litres
(d) 60 litres

55. In hospitals with number of beds exceeding 100, water requirement per bed should be
(a) 135 litres/day
(b) 180 litres/day
(c) 360 litres/day
(d) 450 litres/day

56. Which of the following is used for computing the quantity of water for fire demand?

(a) Kuching's formula

(b) Buston's formula

(c) Freeman's formula

(d) all of these

57. In Kuching's formula $Q = 3182\sqrt{P}$ for estimating water demand for fire

(a) Q is in litres per day and P is population

(b) Q is in litres/minute and P is in population in thousands

(c) Q is in litres/minute and P is population

(d) Q is in litres/day and P is population in thousands

58. For Indian conditions a provision of ______ per head per day is sufficient quantity of water for firefighting

(a) 0.5 litres

(b) 0.75 litres

(c) 1.0 litres

(d) 1.5 litres

59. For a city with moderate factories, a provision of ______ percent of per capita consumption may be made for industrial use

(a) 10 – 15

(b) 20 – 25

(c) 30 – 35

(d) 40 – 45

60. In case of a well maintained and fully metered water distribution system, water system loss is approximately

(a) 5 %

(b) 10 %

(c) 15 %

(d) 20 %

61. Which of the following influence rate of water demand?

(a) Standard of living

(b) Quality of water

(c) Metering

(d) All of these

62. Maximum monthly consumption of water varies ______ percentage of annual average daily rate of demand

(a) 125

(b) 140

(c) 160

(d) 180

63. Maximum daily consumption of water varies ______ percentage of annual average daily rate of demand.

(a) 125

(b) 140

(c) 160
(d) 180

64. Filter units and pumping units are designed for ______ times average daily demand.
(a) 1.2
(b) 1.5
(c) 2.0
(d) 2.7

65. In a water supply system water mains are designed for ______ times maximum hourly demand of the maximum day.
(a) 1.4
(b) 1.6
(c) 1.8
(d) 2.0

66. Sedimentation tanks and clean water reservoir are designed for the n times rate of consumption, where n is
(a) 1.0
(b) 1.2
(c) 1.25
(d) 1.4

67. Suspended impurities in water is
(a) bacteria
(b) algae
(c) silts
(d) all of these

68. Which one of the following is not a dissolved impurity in water
(a) bacteria
(b) calcium carbonate
(c) iron oxide
(d) carbon dioxide

69. Which one is not the effect of presence of iron oxide in water
(a) causes red color
(b) increases corrosiveness
(c) increases hardness
(d) causes toxic effect

70. When lead is present in water, it
(a) changes colour
(b) causes turbidity
(c) causes alkalinity
(d) none of these

71. Presence of hydrogen sulphide in water causes

(a) alkalinity
(b) acidity
(c) bad taste
(d) softening

72. Presence of ______ causes red color to water.
(a) manganese
(b) iron
(c) fluoride
(d) calcium carbonate

73. Which one of the following causes cumulative poisoning by water?
(a) Manganese
(b) Iron
(c) Barium
(d) Lead

74. Which one of the following is the effect of impounding on water quality?
(a) Beneficial
(b) Detrimental
(c) Some beneficial and some detrimental
(d) No effect

75. Thermal stratification of impounded water is in the order
(a) epilimnion–mesolimnion–hypolimnion
(b) epilimnion–hypolimnion–mesolimnion
(c) hypolimnion–epilimnion–mesoilimnion
(d) mesolimnion–hypolimnion–epilimnion

76. Temperature of water more than ______ is considered objectionable
(a) 10°C
(b) 15°C
(b) 20°C
(d) 25°C

77. Colour of water is expressed in number of a
(a) pO value
(b) silica scale
(c) platinum cobalt scale
(d) none of these

78. The maximum pO value used for scaling odour in water is
(a) 6
(b) 8
(c) 10
(d) 12

79. The pO value of water is 3 means

(a) very faint odour
(b) distinct odour
(c) strong odour
(d) extremely strong odour

80. Maximum permissible colour of water for domestic supply on cobalt scale is
(a) 5 to 10 ppm
(b) 10 to 20 ppm
(c) 20 to 30 ppm
(d) 30 to 40 ppm

81. Odour and taste of water are due to presence of
(a) mineral salt
(b) microscopic organisms
(c) chemical compounds
(d) all the above

82. Permissible turbidity of domestic water supply is between
(a) 5 to 10 ppm
(b) 15 to 20 ppm
(c) 25 to 30 ppm
(d) 35 – 40 ppm

83. Which one of the following is not turbidity test on water?
(a) Jackson's
(b) Baylis
(c) Nephelometer
(d) Hehner's method

84. High turbidity of water can be determined by
(a) turbidity rod
(b) Jackson's turbidometer
(c) Baylis turbidometer
(d) Nephelometers

85. Low turbidity of water can be determined by
(a) Turbidity rod
(b) Jackson's turbidometer
(c) Baylis turbidometer
(d) Hellipe turbidometer

86. Maximum permissible total solid content in water for domestic purposes should not exceed
(a) 400 ppm
(b) 500 ppm
(c) 600 ppm
(d) 800 ppm

87. Permissible turbidity in water supply for domestic purpose is

(a) 5 ppm
(b) 10 ppm
(c) 15 ppm
(d) 20 ppm

88. Maximum permissible chloride in water for domestic purpose should not exceed
(a) 250 mg/l
(b) 500 mg/l
(c) 750 mg/l
(d) 1000 mg/l

89. Temporary hardness of water is due to the presence of
(a) chloride
(b) carbonates
(c) sulphates
(d) nitrates

90. pH value of water supplied to residential areas should not be more than
(a) 5
(b) 8.5
(c) 12
(d) 15

91. If hardness is 101 – 200 ppm water is classified as
(a) salt
(b) slightly hard
(c) moderately hard
(d) very hard

92. Which one of the following is not a method of determining hardness of water?
(a) Clark's
(b) Bayli's
(c) Hehner's method
(d) Versenate method

93. pH value of water indicates
(a) hardness
(b) chloride content
(c) acidity of alkalinity
(d) turbidity

94. When pH value is ______ water is considered neutral
(a) zero
(b) 7
(c) 14
(d) 20

95. For water with maximum acidity pH value is ______

(a) zero
(b) 5
(c) 7
(d) 14

96. Water with maximum alkalinity pH value is ______.
(a) zero
(b) 5
(c) 7
(d) 14

97. Colorimetric method of testing water is to determine
(a) turbidity
(b) hardness
(c) chlorides
(d) pH value

98. Product of H^+ ions and OH^- ions in water is equal to
(a) zero
(b) 10^{-3}
(c) 10^{-7}
(d) 10^{-14}

99. Pick up the correct statement about fungi
(a) non-photosynthetic plants
(b) grow in low-moisture
(c) flourish over a 4–10 pH range
(d) all the above

100. Width of fungi varies from
(a) 5 – 10 microns
(b) 50 – 100 microns
(c) 200 – 300 microns
(d) 400 – 500 microns

101. Which one of the following is not bacteria from sewage and animal excrement?
(a) cocci
(b) coli-aerogenes group
(c) *Clostridium welchii*
(d) faecal streptococci

102. Sphere-shaped bacteria are called
(a) spirilla
(b) bacilli
(c) cocci
(d) trichobacteria

103. *B. coli* or *E. coli* are harmless organisms but their presence in water indicates the

(a) presence of pathogenic bacteria

(b) presence of non-pathogenic bacteria

(c) absence of pathogenic bacteria

(d) absence of non-pathogenic bacteria

104. Bacteria that need oxygen to live are known as

(a) aerobic bacteria

(b) anaerobic bacteria

(c) facultative bacteria

(d) pathogenic bacteria

105. Bacteria that survive in the absence of oxygen are known as

(a) aerobic bacteria

(b) anaerobic bacteria

(c) facultative bacteria

(d) pathogenic bacteria

106. Bacteria that can live and multiply with or without oxygen are called

(a) aerobic bacteria

(b) anaerobic bacteria

(c) facultative bacteria

(d) pathogenic bacteria

107. Bacteria that can survive between 40°C to 65°C are known as

(a) psychrophilic bacteria

(b) masophilic bacteria

(c) thermophilic bacteria

(d) facultative bacteria

108. Aeration is carried out to

(a) remove gases from water

(b) add oxygen to water

(c) both to remove gas and add oxygen

(d) none of the above

109. Ion transfer takes place by means of

(a) chemical coagulation

(b) chemical precipitation

(c) adsorption

(d) all the above

110. Floatation is a method of water purification by

(a) gas transfer

(b) ion transfer

(c) solute stabilization

(d) solid transfer

111. _______ is one of the most important operations of solids transfer which combines a number of

solids transfer techniques.

(a) Straining
(b) Sedimentation
(c) Floatation
(d) Filtration

112. Shape factor for finding head loss through rocks and screens is highest in case of
(a) rectangular bars
(b) circular bars
(c) bars with semicircular upstream face
(d) same for all

113. In the process of screening, the screens should be inclined to horizontal at
(a) 10° to 20°
(b) 25° to 35°
(c) 40° to 60°
(d) 75° to 90°

114. Plain sedimentation is the process of removal of suspended particles by the action of
(a) sunrays
(b) gravity
(c) velocity of particles
(d) none of these

115. In fill and draw type of sedimentation tanks the time required for one cycle is
(a) 6 to 12 hours
(b) 18 to 24 hours
(c) 30 to 36 hours
(d) 42 to 48 hours

116. In continuous flow type tanks for sedimentation maximum permissible horizontal velocity of water is
(a) 0.3 m/sec
(b) 0.6 m/sec
(c) 0.9 m/sec
(d) 1.2 m/sec

117. Efficiency of sedimentation tank for a given discharge can be increased by
(a) decreasing the depth of tank
(b) increasing the depth of tank
(c) increasing the surface area of the tank
(d) decreasing the surface area of the tank

118. The most common and universal coagulant used in water works is
(a) aluminium sulphate
(b) chlorine
(c) magnesium sulphate

(d) calcium sulphate

119. Which one of the following is not a coagulating agent?
(a) aluminum sulphate
(b) chlorinated coppers
(c) sodium aluminate
(d) copper sulphate

120. The dose of alum to be used per litre of water is
(a) 10 to 30 mg
(b) 40 to 60 mg
(c) 80 – 100 mg
(d) 120 – 130 mg

121. Alum is found to be effective when pH of water ranges between
(a) 2.5 to 4.5
(b) 4.5 to 6.5
(c) 6.5 to 8.5
(d) 8.5 to 10.5

122. The process of purifying water by passing it through a bed of fine granular material is known as
(a) screening
(b) sedimentation
(c) filtration
(d) coagulation

123. When water is filtered through the bed of filter, usually consisting of clean sand, the actions taking place is
(a) sedimentation
(b) biological action
(c) electrolytic action
(d) all the above

124. The layer on the top of a filtering medium formed by organic impurities is known as
(a) filtering layer
(b) permeable layer
(c) tube settler
(d) dirty skin

125. Effective size of sand particles for slow sand filters shall be
(a) 0.2 to 0.3 mm
(b) 0.4 to 0.5 mm
(c) 0.6 to 0.7 mm
(d) 0.8 to 0.9 mm

126. Uniformity coefficient of sand is given by

(a) $\frac{D_{60}}{D_{10}}$

(b) $\frac{D_{50}}{D_{10}}$

(c) $\frac{D_{40}}{D_{10}}$

(d) $\frac{D_{30}}{D_{10}}$

127. Uniformity coefficient of sand for rapid sand filters shall be
(a) 1 to 1.2
(b) 1.3 to 1.7
(c) 2 to 3
(d) 4 to 5

128. Uniformity coefficient of sand for slow sand filters shall be
(a) 1 to 3
(b) 3 to 5
(c) 5 to 7
(d) 7 to 10

129. In slow sand filters rate of filtration varies between
(a) 50 and 100 litres/m^2/ hour
(b) 100 and 200 litres/m^2/hour
(c) 200 and 300 litres/m^2/hour
(d) 300 and 500 litres/m^2/hour

130. The depth of slow filtration tank varies between
(a) 1 and 2 m
(b) 2.5 and 4.0 m
(c) 4 and 6 m
(d) 6 and 8 m

131. In slow filters, the thickness of sand layer is _______ thick.
(a) 400 to 500 mm
(b) 600 to 700 mm
(c) 800 to 900 mm
(d) 900 to 1100 mm

132. Slow sand filter is efficient to remove the bacteria from water to an extent
(a) 60 %
(b) 70 %
(c) 85 %
(d) 99 %

133. Slow sand filter is more efficient for the removal of
(a) turbidity
(b) odour
(c) bacteria
(d) all of these

134. Slow sand filters need cleaning after ______ days.
(a) 6 to 8 days
(b) 10 – 12 days
(c) 20 to 40 days
(d) 2 to 3 months

135. In a rapid sand filter
(a) raw water from the source is supplied
(b) water from sedimentation tank is supplied
(c) water from coagulation tank is supplied
(d) any one of the above

136. The yield of a rapid sand filter is ______ times that of slow sand filter.
(a) 10
(b) 15
(c) 20
(d) 30

137. Back washing is necessary in
(a) slow sand filter
(b) rapid sand filter
(c) sedimentation tanks
(d) all of these

138. In a rapid gravity sand filter, the permissible head loss is
(a) 1 to 1.5 m
(b) 2 to 2.5 m
(c) 2.3 to 3.5 m
(d) 3.5 to 4.5 m

139. Under normal conditions, the frequency of filter is
(a) 2 to 4 days
(b) 2 to 3 weeks
(c) 30 to 40 days
(d) 2 to 3 months

140. In rapid sand filters, filter trouble is
(a) formation of mud balls
(b) air binding
(c) sand leakage
(d) all of these

141. If the influent water does not have turbidity of more than 35 to 40 ppm, the rapid sand filter can reduce the turbidity to less than
(a) 1 ppm
(b) 4 ppm
(c) 7 ppm
(d) 10 ppm

142. In treating swimming pool water the filtration system to be used is
(a) slow sand filters
(b) rapid sand filters
(c) pressure filters
(d) any of the above

143. Process of killing pathogenic bacteria from water is known as
(a) filtration
(b) sedimentation
(c) disinfection
(d) coagulation

144. Which one of the following is the correct statement? A disinfectant
(a) damages cell wall of micro-organisms
(b) alterates cell permeability
(c) changes the colloidal nature of cell protoplasm
(d) removes microorganisms

145. Which one of the following is universally practised for disinfection of water?
(a) Boiling
(b) Excess lime treatment
(c) Ultraviolet ray treatment
(d) Chlorination

146. Generally, water is satisfactorily disinfected if the free available residual chlorine is about ______ mg/litre at the end of 10 minutes contact periods.
(a) 0.2
(b) 0.5
(c) 1.0
(d) 2.0

147. Tests usually employed to determine chlorine residuals in water
(i) orthotolidine test
(ii) starch-iodide test
(a) (i)
(b) (ii)
(c) both (i) and (ii)
(d) none of (i) and (ii)

148. In orthotolodine test, safe residual for drinking water is indicated by
(a) yellow colour
(b) green colour
(c) blue colour
(d) pink colour

149. Temporary hardness in water is due to the presence of
(a) nitrates
(b) carbonates

(c) sulphates
(d) chlorides

150. Permanent hardness in water is caused due to the presence of
(a) nitrates
(b) sulphates
(c) chlorides
(d) all of these

151. Temporary hardness of water may be removed by
(a) boiling
(b) lime soda process
(c) zeolite process
(d) de-ionization method

152. Permanent hardness of water can be removed by
(a) boiling
(b) adding alum
(c) adding chlorine
(d) lime-soda process

153. Natural zeolites are mainly processed from
(a) green sand
(b) river sand
(c) sea sand
(d) quicksand

154. Zeolite is regenerated by passing a solution of
(a) salt
(b) chlorine
(c) carbonate
(d) all these

155. Activated carbon treatment has the function
(a) aids coagulation
(b) removes colour
(c) removes odours due to excess chlorine, hydrogen sulphide, phenol and other elements
(d) all these

156. The dose of copper sulphate in water treatment varies from
(a) 0.3 to 0.6 ppm
(b) 1 to 1.5 ppm
(c) 2 to 2.5 ppm
(d) 3 to 4 ppm

157. The dose of copper sulphate in water treatment
(a) removes colour
(b) removes odour and taste
(c) controls growth of algae

(d) all these

158. A fluoride concentration of ______ in water is beneficial for the prevention of dental caries in children.

(a) 0.1 to 0.6 ppm

(b) 0.7 to 1.2 ppm

(c) 1.4 to 2.0 ppm

(d) 2.5 to 3.0 ppm

159. Which one of the following is not a method of desalination?

(a) Reverse osmosis

(b) Electrodialysis

(c) Zeolite process

(d) Freezing

160. Lea formula for finding pipe diameter corresponding to the least cost is

$$D = a\sqrt{Q}$$

where D = diameter of pipe in m

Q = discharge to be pumped m^3/sec

and a is

(a) 0.6 to 0.75

(b) 0.75 to 0.95

(c) 0.97 to 1.22

(d) 1.25 to 1.43

161. Plain ends of cast iron pipes are joined by

(a) spigot and socket joint

(b) flanged joint

(c) coupled joint

(d) expansion joint

162. To serve as mains laid on bridges, ideally suited pipes are

(a) cast iron pipes

(b) wrought iron pipes

(c) steel pipes

(d) cement concrete pipes

163. Plain cement concrete pipes are used for a maximum head of

(a) 7 m

(b) 14 m

(c) 21 m

(d) 28 m

164. In order to prevent water flowing back to pumps, when pumps are stopped, we use

(a) scour valve

(b) air valve

(c) gate valve

(d) reflux valve

165. Which one of the following is not a formula to find head loss due to friction in flow through pipes?
(a) Darcy-Weisback formula
(b) Hazen-William's formula
(c) Lea formula
(d) Manning's formula

166. Distribution system in water supply should not ordinarily be designed for residual pressure exceeding
(a) 7 m
(b) 12 m
(c) 17 m
(d) 22 m

167. The manual on water supply recommends that for population above 50,000 minimum pipe size should be
(a) 100 mm
(b) 150 mm
(c) 200 mm
(d) 300 mm

168. A garden developed over top of surface water tank is known as
(a) water tank garden
(b) municipal garden
(c) hanging garden
(d) none of these

169. Reason for laying pipes in parallel is to
(a) increase the capacity of line
(b) facilitate repairs without complete closing down water supply
(c) use smaller diameter pipes
(d) all of these

170. For an area developed in haphazard way, the type of layout of water distribution system preferred is
(a) dead end system
(b) grid-iron system
(c) ring system
(d) radial system

171. Suitable layout of water distribution system for a well planned city is
(a) dead end system
(b) grid-iron system
(c) ring system
(d) radial system

172. Which one of the following layout of water distribution system is known as interlaced system?

(a) Dead end system
(b) Grid-iron system
(c) Ring system
(d) Radial system

173. Sluice valve (gate valve), in water supply system is used to
(a) control the flow of water through pipes
(b) protect pipe against negative pressure
(c) protect pumps against negative pressure
(d) all these

174. Checks valves (reflux valves) in water distribution is used to
(a) control the flow of water through pipes
(b) protect pipe against negative pressure
(c) protect pumps against negative pressure
(d) prevent flow of water in reverse direction

175. Reflux valve is also known as
(a) sluice valve
(b) air valve
(c) check valve
(d) drain valve

176. Drain valves/scour valves, in a water distribution system are provided at
(a) high end points
(b) low end points
(c) at regular intervals in a pipeline
(d) all the above

177. Hydrants are used for tapping water from mains for
(a) fire extinguishing
(b) street cleaning
(c) flushing sewer lines
(d) all of these

178. Hydrants are provided at all junctions of roads and at _______ a port along the road.
(a) 100 – 130 m
(b) 200 – 300 m
(c) 300 – 400 m
(d) 400 – 500 m

179. Hydrants should be of the following type
(a) flush hydrant
(b) post hydrant
(c) either flush or post
(d) none of the these

180. Which one of the following is not a correct statement? Water meters can be
(a) displacement type
(b) velocity type
(c) acceleration type
(d) venturi type

181. Water from kitchen, bathrooms and washbasin is called
(a) sewage
(b) combined sewage
(c) sullage
(d) none of these

182. Rainwater of the locality which flows in sewer is called
(a) storm water
(b) subsoil water
(c) sullage
(d) combined sewage

183. Sewerage means
(a) discharge from latrine
(b) discharge from bathrooms
(c) industrial waste
(d) science of carrying wastes through sewers

184. Solid wastes like broken furniture, pottery, waste building materials are termed as
(a) refuse
(b) garbage
(c) rubbish
(d) all the above

185. Sanitary work is
(a) collection of waste
(b) treatment of waste
(c) disposal of waste
(d) all the above

186. The sewer which carries domestic sewage and storm water is known as
(a) common sewer
(b) sub-main sewer
(c) combined sewer
(d) lateral sewer

187. The sewer which obtains its discharge from two or more sewers is known as
(a) depressed sewer
(b) trunk sewer
(c) outfall sewer
(d) common sewer

188. The length of trunk sewer between the connection of last branch and final disposal is known as

(a) outfall sewer
(b) relief sewer
(c) common sewer
(d) main sewer

189. The method in which various types of refuse are collected, conveyed and disposed of separately is called
(a) conservancy system
(b) dry system
(c) water carriage method
(d) either (a) or (b)

190. Which of the following statement is wrong about the combined system of sewerage?
(a) in the cities with less intensity of rainfall this system is more suitable
(b) in this system cost of pumping is high
(c) less degree of sanitation is achieved in this system
(d) it is more suitable in narrow streets

191. Combined sewerage is preferred
(a) in the cities with more intensity of rainfall
(b) if streets are narrow
(c) if due to topographic feature the pumping is required
(d) if high degree of sanitation is not required

192. It is better to provide separate system of sewerage if
(a) rainfall is throughout the year and intensity is less
(b) streets are narrow
(c) topography of city is flat
(d) city is in rocky area

193. If a portion of storm water is allowed to enter the sewers and the water remaining storm water flows in separate set of sewers, it is called
(a) separate system
(b) partially separate system
(c) combined system
(d) partially combined system

194. Which one of the following is not a pattern of collecting system of sewage?
(a) circular
(b) radial
(c) perpendicular
(d) fan type

195. Practically, the ratio of maximum to average flow of sewage is
(a) 1.0 to 1.2
(b) 1 to 1.5
(c) 1.5 to 1.8
(d) 2 to 2.2

196. The ratio of average to minimum sewage is between
(a) 1 to 1.2
(b) 1.2 to 1.5
(c) 1.5 to 1.8
(d) 2.0 to 2.2

197. According to Fanning's formula, the quality of storm water Q is directly proportional to
(a) $A^{3/4}$
(b) $A^{2/3}$
(c) $A^{5/8}$
(d) $A^{1/4}$
where A is drainage area in square km

198. Which one of the following is not a formula for determining quantity of storm water?
(a) Fuller's formula
(b) Fanning's formula
(c) Manning's formula
(d) Talbot's formula

199. According to Talbot's formula, the quantity of storm water Q is directly proportional to
(a) $A^{0.8}$
(b) $A^{2/3}$
(c) $A^{5/8}$
(d) $A^{1/4}$
where A is area of drainage in square km

200. Sewer lines are designed for a design period of
(a) 20 years
(b) 30 years
(c) 40 years
(d) 50 years

201. Which one of the following is not a formula for determining velocity of flow in sewers
(a) Fanning's formula
(b) Manning's formula
(c) Chezy's formula
(d) Hazen-William's formula

202. According to Hazen-William's formula, the velocity to flow in sewer is least in
(a) brick sewer
(b) vitrified clay sewer
(c) old cast iron sewer
(d) new cast iron sewer

203. Minimum size of public sewer prescribed is
(a) 150 mm
(b) 200 mm

(c) 225 mm
(d) 250 mm

204. The type of sewer which is most suited for the combined system is
(a) circular sewer
(b) semi-elliptic sewer
(c) egg-shaped sewer
(d) horseshoe type sewer

205. The most commonly used sewer under culvert is
(a) circular sewer
(b) semi-elliptic sewer
(c) egg-shaped sewer
(d) horseshoe type sewer

206. Which one of the following is not correct statement about egg-shaped sewers. It
(a) is suitable for combined system
(b) is suitable for separate system
(c) has good hydraulic properties
(d) is more stable than circular sections.

207. For domestic sanitary fitting most suitable sewer is
(a) stoneware sewer
(b) cement concrete pipes
(c) asbestos cement pipes
(d) cast iron pipes

208. An egg-shaped section of sewer
(a) is more stable than circular section
(b) provides self-cleansing velocity at low discharge
(c) is economical compared to circular sections
(d) is easy to construct

209. For cast iron pipes of all sizes the joint used is mainly
(a) bandage joint
(b) spigot and socket joint
(c) collar joint
(d) flush joint

210. Manholes are generally located at
(a) every change of alignments
(b) every change of gradients
(c) every change of diameter of sewer
(d) all the above

211. The minimum internal size of a chamber is
(a) 0.5 m
(b) 0.75 m

(c) 1.0 m

(d) 1.25 m

212. The minimum diameter of a manhole cover should be
(a) 0.5 m
(b) 0.75 m
(c) 1.0 m
(d) 1.25 m

213. For larger sewers, the maximum distance between two consecutive manholes is
(a) 100 m
(b) 150 m
(c) 200 m
(d) 300 m

214. For small diameter sewers the distance between any two consecutive manholes in a straight line should be not more than
(a) 50 m
(b) 75 m
(c) 150 m
(d) 200 m

215. Which soil can take maximum dose of sewage?
(a) Loam soil
(b) Clayey soil
(c) Sandy loam soil
(d) Sandy soil

216. Which one of the following is the wrong statement about land treatment of sewage disposal?
(a) The disposal of sewage is done without natural courses.
(b) The land is irrigated and receives high value fertilizing substance.
(c) Less area of land is required.
(d) The method is cheap.

217. Land treatment of sewage is suitable when
(a) overall rainfall is very low
(b) water table is much deep
(c) large area of land is sandy
(d) all the above

218. Sewage sickness can be prevented by
(a) giving primary treatment to sewage
(b) intermittent application of sewage on land and ploughing land during non-supply period
(c) providing under drainage system
(d) any of the above

219. Treatment plant is normally designed to meet the requirement over a ——— years period after its completion.
(a) 20

(b) 25

(c) 30

(d) 40

220. Purpose of screening sewage is

(a) to remove the floating solids

(b) to remove the solids from the sewage which will form ugly sludge banks at the site of disposal.

(c) to remove solids which will clog the trickling filters

(d) all the above.

221. Which one of the following is a wrong statement about chemical precipitation method?

(a) It is to be used when sewage flow has high seasonal variation.

(b) It is recommended when the suspended solids from industrial waste, are to be precipitated.

(c) It produces small volume of sludge.

(d) It is suitable when sludge conditioning for dewatering is required.

222. Which one of the following is a wrong statement about mechanical flocculators over horizontal flow rectangular baffle wall tanks?

(a) Requirement of chemical is reduced.

(b) Less capacity of tank is required.

(c) Very small loss in head of sewage.

(d) There are no dead spaces in corners.

223. Which one of the following is not a method of preventing fly nuisance at filter sites of sewage?

(a) Sprinkle alum

(b) Chlorinating the sewage

(c) Add insecticide in the sewage

(d) Sprinkle lime.

224. Sewage is treated by aerobic bacteria action in

(a) settling tank

(b) trickling filter

(c) oxidation pond

(d) all of the above

225. Sources of sludge in wastewater treatment system is

(a) primary settling tanks

(b) trickling filters

(c) chemical coagulation plants

(d) all these

226. The prioy pit should be located at least ______ away from the well or other groundwater supply

(a) 10 m

(b) 20 m

(c) 30 m

(d) 50 m

227. A septic tank is a

(a) sedimentation tank

(b) digestion tank

(c) aeration tank

(d) combination of sedimentation and digestion tanks

228. A single stock system without deaerators can be used upto ______ storeys.

(a) 3

(b) 5

(c) 7

(d) 9

229. Single stack system with deaerator can be used up to ______ storeys can.

(a) 5

(b) 10

(c) 15

(d) 20

230. Deaerators are provided at the ______ of stack to avoid excessive back pressure

(a) foot

(b) top

(c) every floor level

(d) every alternate floor level

231. In an office building one water closet should be provided for every ______ number of male personnel.

(a) 5

(d) 10

(c) 15

(d) 25

232. In an office building one water closet should be provided for every ______ number of female persons

(a) 5

(b) 10

(c) 15

(d) 25

233. In a office building one washbasin should be provided for every ______ number of persons.

(a) 5

(b) 10

(c) 15

(d) 25

II. *Match List I with List II selecting the answer code given below each Q. No. 234-244.*

234.

List I **List II**

Flood discharge formula		Regions to which applicable
A. Dicken's	1.	Old Madras Presidency
B. Ryve's	2.	Old Hyderabad state
C. Inglis	3.	North and Central India, Western Ghats
D. Nawab Jung Bahadur's Museum	4.	Old Bombay Presidency

Codes:

(a)	A – 2	B – 1	C – 2	D – 4
(b)	A – 3	B – 1	C – 4	D – 2
(c)	A – 4	B – 2	C – 3	D – 1
(d)	A – 1	B – 2	C – 4	D – 3

235.

List I		List II
Name of formula		**Formula for estimating water demand for fire**
A. Kuching's formula	1.	$Q = 4637\sqrt{p}\,(1 - 0.01\sqrt{P})$
B. Buston's formula	2.	$Q = 1136\ (P/5 + 10)$
C. Freeman's formula	3.	$Q = 3182\sqrt{P}$
D. National Board of Fire Underwriter's formula	4.	$Q = 5663\sqrt{P}$

where Q is quantity in litres/minute
P is population in thousands

Codes:

(a)	A – 4	B – 3	C – 1	D – 2
(b)	A – 4	B – 2	C – 3	D – 1
(c)	A – 3	B – 4	C – 1	D – 2
(d)	A – 3	B – 4	C – 2	D – 1

236.

List I		List II
Substance		**Permissible quantity for domestic purpose**
A. Copper	1.	0.1 ppm

B. Manganese 2. 200 ppm

C. Zinc 3. 1 ppm

D. Sulphate 4. 5 ppm

Codes:

(a)	A – 2	B – 3	C – 4	D – 1
(b)	A – 3	B – 1	C – 4	D – 2
(c)	A – 3	B – 2	C – 4	D – 1
(d)	A – 4	B – 2	C – 1	D – 3

237.

List I		List II
Types of bacteria		**Shape**
A. Micrococcus	1.	Curved rod comma shaped
B. Bacilli	2.	Spiral
C. Vibrio	3.	Straight
D. Spirilla	4.	Round or spherical

Codes:

(a)	A – 4	B – 3	C – 1	D – 2
(b)	A – 4	B – 2	C – 1	D – 3
(c)	A – 2	B – 3	C – 4	D – 1
(d)	A – 1	B – 3	C – 4	D – 1

238.

List I		List II
Types of bacteria		
A. Saprophytic	1.	Capable of causing diseases
B. Parasite	2.	Not capable of causing disease
C. Pathogenic	3.	Beneficial to man
D. Non-pathogenic	4.	Live and multiply on or within the body

Codes:

(a)	A – 4	B – 3	C – 2	D – 1
(b)	A – 1	B – 4	C – 2	D – 3
(c)	A – 4	B – 3	C – 2	D – 1
(d)	A – 3	B – 4	C – 1	D – 2

239.

	List I		List II
A.	Sewage	1.	Drains
B.	Sewer	2.	Waste water from bathrooms and kitchen
C.	Sewerage	3.	Discharge from latrines, urinals
D.	Sullage	4.	Science of carrying wastewater

Codes:

(a)	A – 1	B – 3	C – 4	D – 2
(b)	A – 1	B – 3	C – 2	D – 4
(c)	A – 3	B – 1	C – 2	D – 4
(d)	A – 3	B – 1	C – 4	D – 2

240.

	List I		List II
	Type of impurity		**Process used for removal**
A.	Bulky floating and suspended matter	1.	Floatation tanks
B.	Oil and grease	2.	Racks and screens
C.	Suspended solids	3.	Biological growth (slimes)
D.	Colloidal and dissolved organic matter	4.	Chemical flocculation

Codes:

(a)	A – 1	B – 2	C – 3	D – 4
(b)	A – 1	B – 2	C – 4	D – 3
(c)	A – 2	B – 3	C – 1	D – 4
(d)	A – 2	B – 1	C – 4	D – 3

241.

List I		List II	
	Type of sewer joints		**Suitable for**
A.	Bandage joint	1.	For pipes over 600 m diameter
B.	Spigot and socket joint	2.	Concrete pipes
C.	Collar joint	3.	Cast iron pipes of all sizes
D.	Filled and poured type	4.	For sewers passing below culverts

Codes:

(a)	A – 2	B – 3	C – 1	D – 4
(b)	A – 3	B – 2	C – 1	D – 4
(c)	A – 2	B – 3	C – 4	D – 1
(d)	A – 4	B – 2	C – 3	D – 1

242.

List I		List II	
	Chemicals used for precipitation		**Form in the market**
A.	Aluminium sulphate	1.	Anhydrous granular
B.	Ferric sulphate	2.	Anhydrous powder
C.	Ferrous sulphate	3.	Dirty grey solid in the form of lamps
D.	Ferric chloride	4.	Crystalline form

Codes:

(a)	A – 3	B – 1	C – 4	D – 2
(b)	A – 2	B – 1	C – 3	D – 4
(c)	A – 2	B – 3	C – 4	D – 1
(d)	A – 1	B – 2	C – 4	D – 3

III. *Select your answer according to the coding system given for the Assertion (A) and Reason (R) given in question nos 243 – 255 coding system:*

(a) Both A and R are true and R is the correct explanation of A.
(b) Both A and R are true but R is not the correct explanation of A.
(c) A is true but R is false.
(d) A is false but R is true.

243. Assertion: A masonry dam is known as a gravity dam also.
Reason: The resultant of all the forces acting on the dam should pass through the middle one-third of the base.

244. Assertion: Darcy's law is not applicable in the immediate vicinity of the well.
Reason: In the immediate vicinity of the wells hydraulic gradient is deep.

245. Assertion: Chemical coagulation is aimed at the removal of colloidal particles from water.
Reason: In chemical coagulation, organic cluster of different sizes, shapes and weights are formed.

246. Assertion: Spherical particles settle fast compared to rod-like particles.
Reason: Spherical particles possess less area per unit volume compared to rod-like particles.

247. Assertion: The zeolite process of water softening is unsuitable for acidic waters.
Reason: Acidic water attack the zeolite by dissolving alumina or silica from it.

248. Assertion: Calcined bones are used for fluoridation of water.
Reason: Bones have great affinity for fluorides.

249. Assertion: Cast iron pipes are used in great majority of water distribution mains.
Reason: Cast iron pipes are cheap.

250. Assertion: Steel pipes are more useful to serve as big mains laid on bridges.
Reason: Steel has high strength per unit mass.

251. Assertion: All the hydraulic formulae can be directly used in the design of sewage system and the treatment plants in water carriage system.
Reason: In water carriage system, water contains high percentage of solid matter.

252. Assertion: If rainfall is heavy and it is of short duration, it is better to provide separate sewerage system.
Reason: It is more expensive to lay one large sewer than two small sewers.

253. Assertion: Semicircular drains are not suitable for large discharges.
Reason: Semicircular drains occupy more space.

254. Assertion: Vitrified clay/stoneware pipes are manufactured in short length and diameter.
Reason: They are brittle.

255. Assertion: Cast iron sewers are not suitable for carrying sewage containing sulphates.
Reason: Cast iron has excellent resistance to corrosion.

VI. *State whether the following statement are True or False (Q. Nos. 256–289)*

256. A gravity dam should be always straight.

257. The load transferred by an arch dam to abutment depends upon the curvature of the dam.

258. The weight of the arch dam is not counted to assist materially in the resistance of external loads.

259. Entry ports provided in intake towers are known as penstock also.

260. If the depth of water near the banks is shallow, and greater depth is more only at its centre, a sub-merged intake is provided to draw water from lake.

261. Darcy's law for finding percolation of water through soil is valid for coarse grained soil only.

262. Darcy demonstrated that the rate of flow of water through saturated soil is proportional to hydraulic gradient.

263. If grain sizes of soil are small flow of water is laminar.

264. Darcy's law is not applicable in the immediate vicinity of wells.

265. Water becomes acidic when concentration of H ions is decreased.

266. Fungi are multicellular plants.

267. The bacteria which do not cause any disease are known as pathogenic bacteria.

268. By chlorination objectionable solutes in water are converted into unobjectionable forms without removal.

269. Particles settle down more rapidly in water at low temperature than at high temperature.

270. The rate of formation of floc is influenced more on temperature than on the amount of coagulant

271. Rapid sand filters are less efficient than slow sand filters.

272. The aim of lime-soda process is to make the calcium and magnesium content of hard water take their insoluble form.

273. By the base exchange method, water of zero degree hardness can be obtained.

274. Flow of water through zeolite should be always upward.

275. In lime-soda process pH value of water is increased.

276. In the lime-soda process of softening of water, a large quantity of sludge is formed.

277. To operate zeolite process of water softening, highly skilled labour is required.

278. In the zeolite process, softening of water is essentially a cation-exchange process.

279. Carbonaceous zeolites are used for deionization/demineralisation process.

280. The allowable level of fluoride in water supply is more when annual average of the maximum daily air temperature is higher.

281. The process of raising fluoride content of water is known as fluoridation.

282. For defluoridation calcined bones may be used.

283. Centrifugal pump is better suited to high heads.

284. Compared to centrifugal pumps, initial and maintenance cost of reciprocating pump is high.

285. A stand pipe is essentially a tall cylindrical storage water tank.

286. Smaller velocity assumed for pipes of smaller diameter and larger velocity for pipes of larger diameter.

287. Post-hydrant is connected to the main pipe, through a branch pipe and it can be operated by means of a gate value.

288. In separate sewerage system the domestic and industrial sewage are taken in separate set of sewers.

289. Semicircular drains are ideally suited for large discharges.

Answers to Multiple-Choice Questions

1. (d)	2. (a)	3. (b)	4. (c)	5. (d)
6. (c)	7. (d)	8. (c)	9. (d)	10. (a)
11. (a)	12. (d)	13. (b)	14. (a)	15. (d)
16. (b)	17. (c)	18. (c)	19. (d)	20. (d)
21. (b)	22. (c)	23. (a)	24. (a)	25. (a)
26. (d)	27. (b)	28. (c)	29. (c)	30. (d)
31. (c)	32. (d)	33. (a)	34. (b)	35. (c)
36. (b)	37. (a)	38. (a)	39. (b)	40. (b)
41. (a)	42. (c)	43. (d)	44. (c)	45. (b)
46. (d)	47. (b)	48. (b)	49. (c)	50. (a)
51. (b)	52. (c)	53. (c)	54. (c)	55. (d)
56. (d)	57. (b)	58. (c)	59. (b)	60. (d)
61. (d)	62. (b)	63. (d)	64. (b)	65. (c)
66. (a)	67. (d)	68. (a)	69. (d)	70. (d)
71. (b)	72. (b)	73. (d)	74. (c)	75. (a)
76. (d)	77. (c)	78. (a)	79. (b)	80. (b)
81. (d)	82. (a)	83. (d)	84. (a)	85. (c)
86. (b)	87. (a)	88. (a)	89. (b)	90. (b)
91. (c)	92. (b)	93. (c)	94. (b)	95. (a)
96. (d)	97. (d)	98. (d)	99. (d)	100. (a)
101. (a)	102. (c)	103. (a)	104. (a)	105. (b)
106. (c)	107. (c)	108. (c)	109. (d)	110. (d)
111. (d)	112. (a)	113. (c)	114. (b)	115. (c)
116. (a)	117. (c)	118. (a)	119. (d)	120. (a)
121. (c)	122. (c)	123. (d)	124. (d)	125. (a)
126. (a)	127. (b)	128. (b)	129. (b)	130. (b)
131. (d)	132. (d)	133. (c)	134. (c)	135. (c)
136. (d)	137. (b)	138. (c)	139. (a)	140. (d)
141. (a)	142. (c)	143. (c)	144. (d)	145. (d)
146. (a)	147. (c)	148. (a)	149. (b)	150. (d)
151. (a)	152. (d)	153. (a)	154. (a)	155. (d)
156. (a)	157. (d)	158. (b)	159. (c)	160. (c)
161. (c)	162. (c)	163. (a)	164. (d)	165. (c)
166. (d)	167. (b)	168. (c)	169. (d)	170. (a)
171. (c)	172. (b)	173. (a)	174. (d)	175. (c)
176. (b)	177. (a)	178. (a)	179. (c)	180. (c)
181. (c)	182. (a)	183. (d)	184. (c)	185. (d)
186. (c)	187. (b)	188. (a)	189. (d)	190. (c)
191. (b)	192. (d)	193. (d)	194. (a)	195. (b)
196. (a)	197. (c)	198. (c)	199. (d)	200. (b)
201. (a)	202. (c)	203. (a)	204. (c)	205. (a)
206. (d)	207. (c)	208. (b)	209. (b)	210. (d)
211. (b)	212. (a)	213. (d)	214. (b)	215. (d)
216. (c)	217. (d)	218. (d)	219. (c)	220. (d)
221. (c)	222. (d)	223. (a)	224. (c)	225. (d)
226. (c)	227. (d)	228. (b)	229. (c)	230. (a)
231. (d)	232. (c)	233. (d)	234. (b)	235. (d)
236. (b)	237. (a)	238. (d)	239. (d)	240. (d)
241. (a)	242. (a)	243. (b)	244. (a)	245. (a)
246. (a)	247. (a)	248. (a)	249. (b)	250. (a)
251. (c)	252. (b)	253. (a)	254. (a)	255. (d)
256. False	257. True	258. True	259. True	260. True
261. False	262. True	263. True	264. True	265. False

266. True	267. False	268. True	269. False	270. True
271. True	272. True	273. True	274. False	275. True
276. True	277. False	278. True	279. True	280. True
281. True	282. True	283. False	284. True	285. True
286. True	287. True	288. False	289. False	

Highway Engineering

14.1 ROLE OF TRANSPORTATION

Transportation facility plays an important role in the development of a nation. The benefits of transportation facility are as given below.

1. ***Economical growth*** Connecting producing centres to marketing centres avoids wastage of materials. By this both producer and consumer are benefitted. More industries will come up to cater to various needs of the public.
2. ***Social effects*** More frequent travels by people make them broadminded and reduce sectionalism. National and international integration improve. Antisocial activities come down.
3. ***Safety laws and order*** Efficient transportation of law enforcing forces bring safety to the public. The internal and external safety of the nation improve.
4. ***Disaster management*** If good transportation facility exists, in case of distress due to natural calamities, suffering of the affected people can be minimized by rushing aid.

Modes of Transportation

The following are the common modes of transportation:

1. Roadways
2. Railways
3. Airways
4. Waterways

Roadways and railways are jointly known as surface transportation. Apart from the above 4 types of transportation, the following types of transportations are required in special cases:

1. Conveyers
2. Pipelines
3. Ropeways

Historical Development of Roads

The first hard surface was constructed in 3500 BC in Mesopotamia. Almost at the same time good roads were built in Harappa and Mohenjo-Daro. In 600 BC metallic road of 6 to 7.5 m wide existed in Rajgiri near Patna. In about 300 BC, Kautilya got national highway built to connect the North-West Frontier province (now in Pakistan) and Patna. Shershah Suri got a highway constructed to connect Lahore and Kolkata (West Bengal). All the rulers who contributed to construction of roads are very well remembered even today.

Classification of Roads

I. ***Based on the usage of roads during any season*** They may be classified as (i) all weather road and (ii) fair weather roads. In case of fair weather roads overflowing of streams across the road is permitted during peak mansoon season.

II. Based on the type of pavement: The roads may be classified as

(i) surfaced roads and (ii) unsurfaced roads

Surfaced roads are provided with a finishing with bitumen or cement concrete while unsurfaced roads are mud roads or water bound macadam roads.

III. Based on width and quality: Roads road are classified as follows:

1. *Express Highways:* Wherever volume of traffic is very high these highways are built. They are provided with central separator and are fenced to keep animals away. For catering to local traffic separate feeder roads are provided adjoining express highways. They are designed for superior speed. Parking, loading and unloading of the goods and slow moving vehicles are not permitted on these roads. They have controlled entry points.
2. *National Highways:* These are important roads of a country connecting important cities, sea-ports, airports, tourist spots, etc. They even connect neighbouring countries also. They are at least 8 m wide with at least 2 m wide shoulders on each side. They are assigned members and are maintained by central government agencies like CPWD. or MES.
3. *State Highways:* These roads are built by state governments to connect important cities of the state with state capital or with highways of neighbouring states. These roads are maintained by state governments. These roads are also at least 8 m wide with 2 m wide shoulders on each side.
4. *Major District Roads (MDR):* These are the roads within a district connecting markets and production areas to state or national highways or railway stations. They have lower design speed and geometric design specification composed to highways.
5. *Minor or Other District Roads (ODR):* These roads connect rural areas of production to market centres, taluka centres or other main roads. These roads are maintained by district authorities with the help of state government departments. These roads have lower design specifications than MDR.
6. *Village Roads:* These roads connect a village or a group of villages to the roads of higher category. The local district boards are responsible for the construction and maintenance. These roads are usually unmetalled.
7. *City roads:* City roads are classified as:

   (a) *Arterial streets:* These are the roads within a city meant for thorough traffic, usually on a continuous route. The rods connecting city to highway also fall under this category.

   (b) *Sub-arterial streets:* The city roads which provide lower level of travel mobility than the arterial streets, are called sub-arterial streets.

   (c) *Collector streets:* These are located in residential, industrial and commercial areas. They connect the areas to sub-arterial streets. There are no parking or loading restrictions.

   (d) *Local streets:* The city roads which provide an access to residence, business and other buildings are called local streets.

Principles of Road Alignment

1. Straight alignment is shortest and hence the best.
2. Approaches to bridges, tunnels and road crossings should be straight.
3. Gradient should be easy.

4. It should aim at avoiding deep cuttings, fillings, steep grades, sharp curves, sensitive areas.

Surveys to be Conducted

1. *Economic survey:* Population, its distribution, trends of growth, revenue from taxation, etc.
2. *Traffic survey:* Traffic volume, flow pattern, etc.
3. *Engineering survey:* Topographic survey, reconnaissance survey, preliminary survey, soil survey, final alignment survey.

Preliminary survey It is carried out by aerial survey or by conventional survey. The main objectives of a the preliminary survey are:

1. To collect all the necessary physical information and details of topography, drainage and soil of alternative alignments proposed.
2. To compare the different proposals.
3. To estimate cost of alternate proposals
4. To finalise the best alignment.

In this survey the cross sections are taken generally at 100 to 200 m in plain terrain, 30 m in hilly terrain

Final Survey The final alignment selected in the office is translated on the ground and centre pegs are driven and location plans marked on the map. Centre line stakes are driven at about 50 m interval in plain and rolling terrain and at 20 m in hilly terrain.

Hydrological detail and soil sampling are collected and studies are made.

Drawings and Reports

The report giving details of the road project along with estimation and the following drawing are prepared in the office.

(i) Key plan
(ii) Index map
(iii) Preliminary survey plan
(iv) Detailed plan and longitudinal section
(v) Detailed cross sections
(vi) Land acquisition plan
(vii) Drawings of cross drainage and other retaining structures
(viii) Drawings of road intersection
(ix) Plans showing quarries, etc.

Components of a Divided Highway

The following technical terms are explained by taking cross section of a typical divided highway. Figure 14.1 shows the cross section and Fig. 14.2 shows the cross section of carriageway.

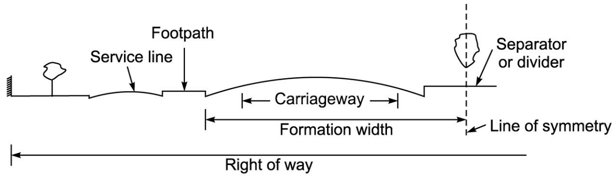


Fig. 14.1 Cross section of divided highway

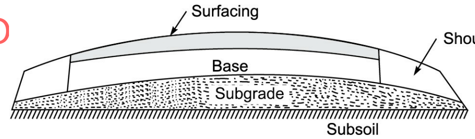


Fig. 14.2 Cross section of carriageway

1. *Right of way:* It is the width of land acquired for construction and future development.
2. *Formation width:* It is the width of road excluding side drains.
3. *Carriageway:* The portion of road surface exclusively meant for vehicular traffic.
4. *Separator or divider:* It is a continuous structure provided for dividing the two directions of the traffic flow.
5. *Kerbs:* Kerbs are the boundaries between carriageway and foot path/dividers.
6. *Shoulders:* The portion of the roadway between outer edges of carriageway and drains in case of cuttings or top edges of the top surface in case of embankment.
7. *Subsoil:* It is the natural or prepared soil which will take the load of the road. It is prepared by compacting the natural soil.
8. *Sub-grade:* It gives support to the road surface. It is made of gravel, sand, silt and clay. It should remain stable and dry throughout.
9. *Base:* The base may consist of two layers, top one is known as base bottom layer as sub-base. Sub-base is made with stabilized soil or selected granular soil, bricks or boulders. Base course is with broken stone aggregates.
10. *Surfacing:* It is the topmost layer of carriageway which takes loads from traffic directly. It provides a smooth but non-slippery and stable surface for vehicles. It is with cement concrete or with bitumen concrete. It should be impervious.
11. *Camber:* The rise of centre of carriageway over its outer edges is known as camber.

Width of formation (Road way) It is shown in Table 14.1.

Table 14.1 Width of formation for various classes

Road	*Road width in m at*	
	Plain rolling terrain	*Mountaineous and steep terrain*
National and state highways		
(a) Single lane	12.0	6.25
(b) Two lane	12.0	8.80
Major district roads	9.0	4.75
Other district roads	7.5	4.75
Village roads	7.5	4.0

Recommended right of way for different roads It is as shown in Table 14.2.

Table 14.2 Recommends right of way for different roads

Road	Plain and rolling terrain				Mountainous	
	Open areas		Built-up areas		Open areas	Built-up areas
	Normal	Range	Normal	Range	Normal	Normal
National and state highways	45	30–60	30	30–60	24	20
MDR	25	25–30	20	15–25	18	15
ODR	15	15–50	15	15–20	15	12
Village roads	12	12–18	10	10–15	9	9

Indian Road Congress recommendation of camber These are given in Table 14.3.

Table 14.3 IRC recommended cambers

Type of road surface	Range of counter	
	Heavy rainfall area	Light rainfall area
Earth	1 in 25 (4%)	1 in 33 (3%)
WBM	1 in 33 (3%)	1 in 40 (25%)
Bituminous	1 in 40 (25%)	1 in 50 (2%)
Concrete	1 in 50 (2%)	1 in 60 (1.7%)

Gradient

The slope of the road pavement in the longitudinal direction is called grade or gradient. This is required to drain the water in longitudinal direction. The normal ruling gradient, limiting gradient and exceptional gradient permitted are shown in Table 14.4.

Table 14.4 IRC recommended gradients

Terrain	*Ruling gradient*	*Limiting gradient*	*Exceptional gradient*
Plains	1 in 30	1 in 20	1 in 15
Hills	1 in 20	1 in 17	1 in 14
Steep terrain	1 in 17	1 in 14	1 in 12.5

Sight Distance

It is length of road visible to a driver clear of obstacles. It depends upon height of line of light of the driver above road surface. In the geometric design of roads this is taken as 1.2 m.

The following three sight distances are considered in the geometric design of highways.

1. ***Stopping sight distance*** It is the minimum distance required by a driver to stop his vehicle while running at design speed of the road when the obstruction on the road is sighted. For this height of line of sight of driver is taken as 1.2 m and height of obstruction 0.15 m above road surface. Its

value depends upon:
(i) total reaction time of driver
(ii) speed of vehicle
(iii) efficiency of brakes
(iv) frictional resistance between the road and the tyre of vehicle
(v) gradient of the road

The stopping sight distance for Indian highways is given by

$$\text{SD} = 0.278\ Vt + \frac{V^2}{254(f \pm i)}$$

where SD is in m
t = time of perception and reaction
V = speed in kmph
f = coefficient of friction
i = slope, +ve when upward and –ve when it is downward

IRC recommends the following coefficient of friction for design (Refer Table 14.5)

Table 14.5 IRC recommendations for coefficient of friction

Speed in kmph	20 to 30	40	50	60	65	80	100
f	0.40	0.38	0.37	0.36	0.36	0.35	0.35

2. *Overtaking sight distance (OSD)* The minimum distance/safe passing-sight distance required for a vehicle to overtake a vehicle without interfering with a vehicle coming in opposite direction at design speed of road is as shown in Table 14.6.

Table 14.6 OSD on two-lane highways

Speed in kmph	40	50	60	65	80	100
OSD in metres	165	235	300	340	470	640

3. *Sight distance at intersections* From safety considerations, the sight distance at uncontrolled intersections should satisfy the conditions given below:

1. Enable the approaching vehicle to change speed
2. Enable approaching vehicle to stop
3. Enable stopped vehicle to cross a main road

IRC recommended that this distance of each road is atleast equal to the safe stopping distance of the road. The minimum visibility distance of 15 m along the minor road and a distance of 220, 180, 145 and 110 m along the major road corresponding to design speeds 100, 80, 65 and 50 kmph respectively should be provided.

Classification of Terrain

It is as given in Table 14.7.

Table 14.7 Classification of terrain

Terrain	*Cross slope of the country*
Plain	0–10
Rolling	10–25
Mountainous	25–60
Steep	> 60

Horizontal Curves

When a vehicle traces a horizontal curves with uniform velocity v, a centrifugal force P acts on the vehicle

$P = \frac{W}{g}\frac{v^2}{R}$, in outward direction where R is the radius of horizontal curve

Vehicle will overturn when

$$\frac{W}{g}\frac{v^2}{R} \times h \geq \frac{Wb}{2}$$

where b = width of vehicle between outer and inner wheels

h = height of C.G. of vehicle from road surface

On a flat curve skidding of vehicle takes place when

$$\frac{W}{g}\frac{v^2}{R} \geq fW$$

Superelevation

To resist centrifugal force the outer edge of the road is raised above the inner edges in the horizontal curves. This is known as superelevation or cant or banking. It is expressed as the difference of heights of two edges of carriage to the carriageway. The rate of superelevation is given by

$$e + f = \frac{v^2}{gR}$$

If V is taken in terms of kmph,

$v = \frac{1000}{60 \times 60}$ where v is in m/sec

$= 0.278$ V

\ $e + f = \frac{V^2}{127R}$ since $g = 9.81$ m/sec^2

It is suggested that neglecting lateral friction developed, the superelevation should be provided to fully counter the centrifugal force due to 75% of design speed.

$$e = \frac{(0.75V)^2}{127R} = \frac{V^2}{225R}$$

* The minimum radius of the curve for ruling design speed V kmph is

$$R_{\text{ruling}} = \frac{V^2}{127(e+f)}$$

For design purpose f may be taken as 0.15.

* IRC recommends extra width of pavement in curves as given in Table 14.8.

Table 14.8 Extra width of pavement at horizontal curves

Radius of curves	*Upto 20 m*	*20–40 m*	*41–60 m*	*61 to 100 m*	*101–300 m*	*> 300 m*
Extra width for						
(i) Two lane	1.5	1.5	1.2	0.9	0.6	Nil
(ii) Single lane	0.9	0.6	0.6	Nil	Nil	Nil

Transition Curves

For the purpose of giving smooth change of direction transition curves are introduced between straight road and curved road. The radius of transition curve gradually changes from infinity at straight road to the radius of main curve at other end. The function of transition curve are:

1. To introduce the centrifugal force so that a sudden jerk on the wheels is avoided
2. To enable the driver to turn steering gradually
3. To enable gradual introduction of superelevation and road widening
4. It improves aesthetic appearance of the road

* Length of transition curve is decided on the basis of:
  1. Rate of superelevation
  2. Time rate
  3. Rule of change of radial acceleration

* Types of transition curves adopted are:
  1. Spiral (clothoid)
  2. Lemniscate
  3. Cubic parabola

Vertical Curves

These are required at the intersections of different grades. They may be classified as

(a) Summit curves

(b) Valley curves

(a) Length of summit curve

$$L = \frac{(i_1 - i_2) D_s^2}{\left(\sqrt{2H} + \sqrt{2h}\right)^2}$$

where i_1 and i_2 are slopes of grades in radians.

H = Height of drivers eye above the road (= 1.2 m)

h = Height of obstruction above the road (0.15 m)

with H = 1.2 m and h = 0.15 m,

$$L = \frac{(i_1 - i_2) D_s^2}{4.4}$$

D_s = Length of sight distance

(b) Length of valley curves

$$L = \frac{v^3}{CR}$$

where v = design speed in m/sec
C = Allowable rate of change of centrifugal acceleration
R = Radius of curve at common point

Flexible and Rigid Pavement

Waterbound mechadam road and pavement with bituminous material top are flexible pavements while concrete roads are rigid pavements. The cement grouted roads are known as semi-rigid roads. The differences between flexible road and rigid pavements are as given in Table 14.9.

Table 14.9 Flexible pavement vs. Rigid pavements

Flexible pavement	*Rigid pavement*
1. Flexible strength low	Flexural strength high
2. Load is transferred to lower layer grain to grain	Pavement bears the load itself
3. Deformations are recovered to great extent	Only elastic deformation is recovered
4. Structure capacity depends on the strength of sub-grade	Structural capacity does not depend upon strength of sub-grade
5. No temperature stresses	Temperature stresses cannot be neglected
6. Cost of construction is less	Cost of construction is high
7. Maintenance cost is high	Maintenance cost is less

Flexible Pavement Design

* Flexible pavements are built with number of layers
* Design has to ensure that under the application of load no layer is not over-stressed
* The stress intensity is maximum in top layer. Hence, superior pavement material should be used in upper layers.
* The following factors should be considered in the design:
  1. Properties of natural soil under pavement
  2. The moisture content under completed pavement
  3. Climatic conditions
  4. Volume and character of traffic
* The various design methods available are:
  (i) Group index method (ii) Triaxial test method

(iii) CBR method (iv) California R value method.
(v) Mchord method (vi) Burmister method

IRC has recommended CBR method

* California Bearing Ratio (CBR) method.

CBR test is a method for evaluating the stability of soil sub-grade and other flexible pavement material. Indian Road Congress (IRC) recommends CBR method as given below:

1. CBR tests should be performed on remoulded soil in the laboratory.
2. The soil sample should be compacted to the dry density expected to be achieved in the field.
3. The soil sample should have the most adverse moisture condition of the sub-grade.
4. The CBR of a soil which varies from 0 to 100 per cent should be determined. For an excellent base material CBR is 100 per cent
5. An estimate of traffic to be carried out for the end of life of pavement and its category A to G determined.
6. From CBR design chart recommended by IRC thickness of pavement should be found. The thickness so determined is excluding course and the courses containing aggregates of sizes 20 mm and above.

Design of Rigid Pavements

* A trial thickness is assumed.

* The warping stress at edge region is found and this value is subtracted from the allowable flexural stress in concrete.

* The load stress in edge region is found using stress charts or using the equation

$$s_z = p\left[1 - \frac{z^3}{(a^2 + z^2)^{3/2}}\right]$$

where s_z = vertical stress at depth z

P = surface pressure

a = radius of loaded area

* If factor of safety is less than 1, try higher thickness. If it is quite high try lower thickness. The factor of safety should be equal to or slightly more than 1.

Joints in Concrete Pavements

1. *Expansion joints/Transverse joints:* These joints are to be provided to limit temperature stresses. It is recommended that this gap should not be more than 25 mm in any case. IRC recommends maximum spacing between expansion joint should not exceed 140 m.

2. *Longitudinal joints:* Longitudinal joints are required if width of concrete pavement is more than 4.5 m. They reduce transverse warping due to difference in temperature at the centre and edge of the road. They take care of unequal settlement of subgrade. The joints may be of tongue and groove type, butt type or weakened plane type.

The maximum spacing of longitudinal joints may be kept 4.5 m in longitudinal slab. In case of reinforced slabs the spacing may be 13 m for 150 m thick slab and 14 m for 200 mm thick slab.

3. Warping joints are sometimes provided in the transverse direction. They are achieved by providing dowel bars. Actually, if longitudinal and transverse joints are properly provided, warping joints are not required. IRC recommends 25 mm diameter bars of length 500 mm to be spaced at 200 mm in case of 150 m thick slab and spaced at 300 mm in case of 200 mm thick slab.

* All the joints should be properly sealed with appropriate sealing materials so as to stop the possibility of moisture entering the subgrade.

14.2 HIGHWAY CONSTRUCTION

Types of highway construction

1. Earth road
2. Gravel roads
3. Water Bound Macadam (WBM) road
4. Bituminous or black top roads
5. Cement concrete roads

1. Earth road and gravel roads

Earth roads: Camber 1 in 20 to 1 in 12

Min. gradient 1 in 120 desirable

Min. width 8 for 2 lanes.

Soil property required is as shown in Table 14.10.

Table 14.10 Soil properly required for base material and wearing courses

	Base material	*Wearing course*
Clay content	< 5 %	10 to 18 %
Silt content	9 to 72 %	5 to 15 %
Sand content	60 to 80 %	65 to 80 %
Liquid limit	< 35 %	< 35 %
Plasticity index	< 6 %	4 to 10 %

2. Gravel road Camber 1 in 30 to 1 in 25.

Material : Hard variety of crushed stone or gravel of specified gradation.

3. WBM road In this case the pavement base course is made of broken aggregates mechanically interlocked by rolling and voids filled with screening and binding materials with the assistance of water. It may be used as sub-base, base course or surfacing course. It consists of a number of courses of thickness 75 mm to 100 mm. 120 to 180 mm broken stones are packed so that their pointed ends are upward. Hollow spaced of packed stones are filled with broken stones or gravel and rolled with 10 tonne rollers. Screenings are then spread and dry rolled. Then they are wet rolled. After a day 6 mm thick sandy clay is spread and rolled. Road is opened for traffic only after 10 days curing.

4. Bituminous pavements The following types of bituminous construction are practised:

(i) Surface dressing (BSD)
(ii) Grouted or penetration macadam
(iii) Built-up spray grout
(iv) Bituminous bund macadam
(v) Bituminous carpet
(vi) Bituminous concrete

Surface dressing is done on either existing bituminous payment or as a wearing course over a WBM rood. The steps involved are: preparation of existing surface-application of binder-application of stone chipping-rolling of first coat with 6 to 8 tonne roller-application of binder and stone chipping for second coat-rolling-finishing.

Construction Procedure for pre-mixed bituminous carpet involves the following steps:

* Preparation of the existing surface
* Application of tack coat
* Preparation and placing of premix
* Rolling and finishing
* Application of seal coat
* Surface finish

Construction procedure for bituminous concrete:

* Preparation of existing base course
* Application of tack coat
* Preparation and placing of premix
* Rolling
* Periodical checks for aggregate grading. Grade bitumen and temperature are to be carried out
* Finishing surface
* This is the highest quality construction in black top construction

Cement Concrete Roads

* Base prepared to given grade and camber
* Steel or wooden form provided
* Subgrade kept moist for at least one day
* Design mix of concrete prepared and placed in alternate bays or in long strips
* Surface compacted
* Before concrete develops initial setting, the edges of the slab are finished with tool
* Cured for 28 days
* Joints are filled with impervious elastic materials like soft wood or impregnated fibre board or cork bound with bitumen.

14.3 TRAFFIC ENGINEERING

Traffic engineering deals with the measures to be taken for safe, rapid and efficient flow of the traffic. For all this traffic survey should be carried out.

Traffic Survey

This is required to study the type and volume of present traffic and estimate future traffic. It helps in planning expansion or improving the road. The study involves:

1. Traffic volume
2. Speed
3. Origin and destination
4. Parking
5. Accident

Traffic volume study It is measured in terms of vehicles passing through a cross section of road during unit time. Thus, the volume is expressed as vehicles/second, vehicles/hour or vehicles/days etc.

In design not only number of vehicles but type of vehicle is also important. Hence, it is preferred to express the volume in terms of Equivalent Passenger Car Unit (EPCU) in unit time. The ministry of transport has given the following EPCU:

Car = 1 Truck, bus = 3

Cycle, motor cycles = 0.5 Horse driven vehicles = 4.0

Bullock cart = 6 to 8

Speed study Two types of speed studies are carried out (a) spot speed study (b) speed and delay study.

Spot speed study is measured on the time taken to travel a fixed distance. Earlier enoscopes were used to measure time taken to cross two fixed points, but now efficient electronic equipment are used. This study is used in geometric design and to control speed as per regulation.

Speed delay study is over a longer distance to study the causes of delay over a stretch of road. The best method for such study is to run a test car several times and each time record the time taken and the reasons for extra time taken.

Origin and destination of traffic These studies help in planning expansion of roads, bye passes, alternate routes, etc. These studies are carried out by observing number plates of vehicles or interviewing drivers or by conducting postcard surveys.

Parking studies Parking studies are carried out

(i) to obtain information for demand of parking spaces
(ii) for improving existing parking facility
(iii) for planning future parking facilities.

Accident studies Every minor and major accident should be studied for future improvements of roads and signal system or making a street one way.

Traffic Islands

Traffic islands are the raised constructions provided to channelise the traffic. Types of traffic islands are:

1. Divider islands to separate up and down traffic
2. Channelising islands to guide traffic into proper channels
3. Rotary islands around which traffic moves in clockwise direction at road junctions
4. Pedestrian loading islands provided at bus stops for the convenience of passengers.

Road Intersections

Two types of intersections :

1. Intersection at grades
2. Grade separated intersections

1. Intersections at grades:

- A basic requirement of it is the area of conflict should be small.
- Crossing angles should be preferably at 90° but not less than 60°.
- No blind corners. Any vehicle should safely travel for at least 8 seconds after sighting other vehicle.
- Adequate lighting is provided.
- Proper sign, guard rails and traffic islands should be provided.
- Speed should be reduced.

2. Grade separated intersections:

For important roads crossing, flyovers or over crossing may be provided. If major road is above the minor road, it is called over crossing. If minor road is above major road it is called flyover. For entry and exit from major road diamond junction, clover leaf junctions or rotary junctions are provided.

Traffic Controls

To regulate traffic the following measures are required:

1. Traffic signs
2. Traffic signals
3. Markings.

1. Traffic signs Traffic signs are provided in the form of symbols or inscriptions mounted on fixed or portable supports.

(i) Regulatory signs These signs are shown on a 600 mm disc installed at a height of 2.8 m above ground level. They may indicate:

- No turn
- No entry
- No parking
- Overtaking prohibited
- Sound horn prohibited, etc.

(ii) Warning signs These signs are shown on a rectangular board of size 450 × 400 mm mounted at a height of 2.8 m. They may indicate:

- Curve ahead

• Cross road ahead

• Level crossing
• School zones
• U-turns
• Narrow bridge ahead, etc.

(iii) Informatory signs These are the signs provided to guide drivers to their destination. They may indicate speed limit and name of road also.

2. Traffic signals These are provided at intersections of roads. They consist of three lights—red to indicate stop, amber to indicate clear and green to indicate 'go' signal. In some places the signal indicates how long the red signal will be there. To guide pedestrian the signals are provided at all these signal points.

3. Road markings Road markings are necessary to guide road users. Some of the markings are:

• Centre line of road
• Traffic lanes
• Edges of road
• Pedestrian crossing
• Parking space
• Bus stop markings
• Kerb marking, etc.

MULTIPLE-CHOICE QUESTIONS

I. *Select correct option from the following questions 1 to 114.*

1. Minimum of 8 m width and 2 m wide shoulders on the following roads are recommended
(a) EH and NH
(b) NH and SH
(c) EH, NH and SH
(d) MDR
where EH = Express highway NH = National highway
SH = State highway MDR = Major district road

2. In a national highway the minimum width of road and shoulder on each side are ______respectively.
(a) 10 m and 2.0 m
(b) 8 m and 2 m
(c) 10 m and 1.5 m
(d) 8 m to 1.5 m

3. The road connecting a district headquarters of one state to the district headquarters of a neighbouring state is called.
(a) Natural highway
(b) State highway
(c) Major district road

(d) Other district road

4. Major district roads connect market and production areas within a district to
   (a) state highways
   (b) national highways
   (c) railway stations
   (d) all the above
5. The road connecting a city to highway is called
   (a) arterial street
   (b) sub-arterial street
   (c) collector street
   (d) local street
6. The city roads providing an access to residence, business and other buildings are called
   (a) arterial street
   (b) sub-arterial street
   (c) collector street
   (d) local street
7. The longest road constructed during the time of Shershah Suri was from
   (a) Lahore to Kolkata
   (b) Lahore to Delhi
   (c) Lahore to Patna
   (d) Lahore to Agra
8. Which of the following statement is correct? According to the principle of road alignment
   (a) it should be straight
   (b) its gradient should be easy
   (c) it should aim avoiding deep cuttings and fillings
   (d) all the above
9. The sequence of survey in a road project is
   (a) topographic, reconnaissance, preliminary and detailed
   (b) reconnaissance, topographic, preliminary and detailed
   (c) preliminary, reconnaissance, topographic and detailed
   (d) topographic, preliminary, reconnaissance and detailed
10. The main object of a preliminary survey
   (a) to collect the necessary physical information and details of topography, drainage and soil properties.
   (b) to estimate cost of alternative alignment.
   (c) to finalise the best alignment.
   (d) all the above.
11. In the final survey the centre line stakes are driven at ______ interval in plain terrain.
   (a) 50 m
   (b) 100 m
   (c) 150 m

(d) 200 m

12. In the final survey the centre line stakes are driven at ______ interval in hilly terrain.
(a) 10 m
(b) 20 m
(b) 30 m
(d) 50 m

13. In preliminary survey of a road project, in hilly region cross sections are taken generally at ______.
(a) 20 m
(b) 30 m
(c) 50 m
(d) 100 m

14. The final report on road project should include
(a) land acquiescence plan
(b) cross-drainage details
(c) plans of quarries, etc.
(d) all the above

15. Ascending order according to width is
(a) right of way, formation width, carriageway
(b) formation width, carriageway, right of way
(c) right of way, carriageway, formation width
(d) carriageway, formation width, right of way

16. The portion of the roadway between outer edges of carriageway and drains in case of cuttings is known as
(a) kerb
(b) shoulder
(c) formation width
(d) right of way

17. The order in which a road is built is
(a) sub-soil, base, sub-grade, sub-base
(b) base, sub-soil, sub-grade, sub-base
(c) sub-base, base, sub-grade, sub-soil
(d) sub-soil, sub-grade, sub-base, base

18. Base course of a road is built with
(a) gravel, sand and silt
(b) stabilized soil or selected gralunar soil
(c) bricks or boulders
(d) broken stone aggregates.

19. Camber is provided in the road for
(a) counteracting the centrifugal force

(b) effective drainage
(c) getting better sighting distance
(d) getting least stopping distance

20. The factor influencing camber is
(a) topography of the area
(b) type of wearing coat provided
(c) amount of rainfall
(d) nature of subsoil

21. Maximum camber recommended by IRC is
(a) 1.7 %
(b) 2 %
(c) 3 %
(d) 4 %

22. For concrete road the camber recommended by IRC in heavy rainfall area is
(a) 1.7 %
(b) 2 %
(c) 3 %
(d) 4 %

23. For earthen roads in heavy rainfall area common camber is
(a) 1 in 25
(b) 1 in 33
(c) 1 in 50
(d) 1 in 60

24. For highways width of formation in plain area is
(a) 18 m
(b) 15 m
(c) 12 m
(d) 9 m

25. Width of formation for village roads in mountainous areas is
(a) 3.0 m
(b) 4.0 m
(c) 4.75 m
(d) 5.0 m

26. Minimum right of way required for a village road in open area is
(a) 9 m
(b) 10 m
(c) 12 m
(d) 15 m

27. Recommended right of way for highways in open areas is
(a) 50 m
(b) 45 m

(c) 40 m

(d) 30 m

28. In plains, exceptional gradient is limited to
(a) 1 in 25
(b) 1 in 20
(c) 1 in 15
(d) 1 in 12.5

29. In steep terrain ruling gradient is limited to
(a) 1 in 25
(b) 1 in 20
(c) 1 in 17
(d) 1 in 12.5

30. In geometric design of roads height of sight distance of a driven is taken as ______ above road surface
(a) 1.0 m
(b) 1.2 m
(c) 1.4 m
(d) 1.6 m

31. For finding stopping distance of a vehicle, the height of line of sight of driver and height of line of obstacle on road are taken as ______ respectively.
(a) 1.2 m and 0.15 m
(b) 1.5 m and 0.5 m
(c) 1.2 m and 0.5 m
(d) 1.5 m and 0.15 m

32. The stopping sight distance in metres for Indian highways for upward slope i is

(a) $0.278\,Vt + \frac{V^2}{254(f-i)}$

(b) $0.278\,Vt - \frac{V^2}{254(f-i)}$

(c) $0.278\,Vt + \frac{V^2}{254(f+i)}$

(d) $0.278\,Vt - \frac{V^2}{254(f+i)}$

where v = speed in kmph t = time of perception and response
f = coefficient of friction

33. If speed of vehicle is less than 30 kmph IRC recommended coefficient of friction is
(a) 0.40
(b) 0.35
(c) 0.30
(d) 0.25

34. If speed of vehicle is about 100 kmph IRC recommended value of coefficient of friction is

(a) 0.40
(b) 0.35
(c) 0.30
(d) 0.25

35. To overtake a vehicle going at 40 kmph on two-lane highway OSD is
(a) 150 m
(b) 165 m
(c) 200 m
(d) 250 m

36. To overtake a vehicle going at 80 kmph on a two-lane highway overtaking sight distance is
(a) 300 m
(b) 400 m
(c) 470 m
(d) 520 m

37. Sight distance at intersection should be equal to
(a) enabling the approaching vehicle to change speed
(b) enabling approaching vehicle to stop
(c) enabling the stopped vehicle to cross a main road
(d) highest the value of (a), (b) and (c)

38. Sight distance at intersection should be at least ______ along the minor road.
(a) 15 m
(b) 30 m
(c) 40 m
(d) 50 m

39. If design speed of a main road is 100 kmph, the sight distance at intersection should be at least
(a) 150 m
(b) 200 m
(c) 180 m
(d) 220 m

40. The length of vehicle controls the design of
(a) gradient
(b) camber
(c) overtaking distance
(d) all the above

41. If the cross slope of terrain is 15, it is classified as
(a) plain
(b) rolling
(c) mountainous
(d) steep

42. If the cross slope of a terrain in 35 it is classified as

(a) plain

(b) rolling
(c) mountainous
(d) steep

43. When a vehicle weighing W traces a horizontal curve of radius R with uniform v velocity, it is subjected to a centrifugal force

(a) $\frac{Wv}{R}$
(b) $\frac{W}{g}\frac{v}{R}$
(c) $\frac{Wv^2}{R}$
(d) $\frac{W}{g}\frac{v^2}{R}$

44. When a vehicle traces a horizontal curve, it is subjected to centrifugal force in ______direction.
(a) inward
(b) outward
(c) forward
(d) backward

45. A vehicle weighs 50 kN when empty. Its minimum velocity for skidding on a curve is v. If it is weighing 100 kN so that centroid remains at the same height when loaded, its minimum velocity for skidding on a curve is
(a) 0.5 v
(b) v
(c) $\sqrt{2v}$
(d) none of the above

46. If in the above case, if the centre of gravity moves up by 50 %, its minimum velocity for overturning will be

(a) $\frac{v}{\sqrt{1.5}}$
(b) $\frac{v}{\sqrt{3}}$
(c) $\frac{v}{1.5}$
(d) none of the above

47. A vehicle weighs 50 kN when empty. Its minimum velocity for skidding on a flat curve is v. When loaded it weighs 100 kN and its centre of gravity moves up by 50 %. The minimum velocity for skidding will be

(a) $\frac{v}{\sqrt{3}}$
(b) $\frac{v}{\sqrt{1.5}}$
(c) v

(d) $\frac{v}{1.5}$

48. On a flat curve a vehicle starts skidding when its velocity reaches

(a) $f\,g\,R$

(b) $\frac{fR}{g}$

(c) $\sqrt{fgR}$

(d) $\sqrt{\frac{fR}{g}}$

where f = coefficient of friction
R = radius of curve
and g = gravitational attraction

49. For designing highways, IRC recommends the coefficient of friction as
(a) 0.15
(b) 0.18
(c) 0.21
(d) 0.24

50. For a single-lane road there is need to provide extra width to pavements if radius of curve is
(a) 300 m
(b) 200 m
(c) 100 m
(d) 60 m

51. Extra width to be provided at curve in case of two lanes need not exceed
(a) 2.0 m
(b) 1.5 m
(c) 1.0 m
(d) 0.9 m

52. Transition curves are required to
(a) enable driver to turn steering gradually
(b) enable gradual introduction of superelevation
(c) improve aesthetic appearance of the road
(d) all the above

53. Length of the transition curve is decided on the basis of
(a) rate of superelevation
(b) time rate
(c) rate of change of radial acceleration
(d) higher of the above

54. Which one of the following is not a type of transition curve used?
(a) Clothoid
(b) Parabolic

(c) Lemniscate

(d) Cubic parabola

55. The maximum rate of superelevation is given by

(a) $\frac{V^2}{175R}$

(b) $\frac{V^2}{225R}$

(c) $\frac{V^2}{450R}$

(d) $\frac{V^2}{900R}$

where V = Speed of vehicle in kmph
R = Radius of curvature in metres

56. Length of summit curve is given by

(a) $\frac{(i_1+i_2)D_s^2}{\sqrt{2H}+\sqrt{2h}}$

(b) $\frac{(i_1-i_2)D_s^2}{\sqrt{2H}+\sqrt{2h}}$

(c) $\frac{(i_1+i_2)D_s^2}{\left(\sqrt{2H}+\sqrt{2h}\right)^2}$

(d) $\frac{(i_1-i_2)D_s^2}{\left(\sqrt{2H}+\sqrt{2h}\right)^2}$

where i_1, i_2 = Slopes of grades
H = Height of drivers eye, h = Height of obstruction
D_s = Length of sight distance.

57. Length of valley curve is given by

(a) $\frac{v^2}{CR}$

(b) $\frac{v^3}{CR}$

(b) $\frac{v^2 R}{C}$

(d) $\frac{v^2 R^3}{C}$

where v = Design speed in m/sec
R = Radius of curve at common point
C = Allowable rate of change of centrifugal acceleration

58. A pavement is classified as flexible or rigid based on its
(a) sub-grade
(b) sub-base
(c) base

(d) wearing course

59. Flexible pavement distributes the wheel load
   (a) through structural action
   (b) through a set of layers grain by grain
   (c) directly to sub-grade
   (d) none of the above
60. For the design of flexible pavement Indian Road Congress recommends
   (a) trained test method
   (b) Group Index method
   (c) CBR method
   (d) Burmister method
61. For an excellent base material CBR value is
   (a) 50 %
   (b) 65 %
   (c) 80 %
   (d) 100 %
62. For the purpose of designing flexible pavement IRC traffic is divided into ______ categories.
   (a) 3
   (b) 5
   (c) 7
   (d) 9
63. From CBR chart recommended by IRC thickness obtained is
   (a) including wearing coat and 20 mm aggregates courses
   (b) excluding wearing coat and 20 mm aggregate courses
   (c) excluding wearing coat but including 20 mm aggregate course
   (d) including wearing coat but excluding 20 mm aggregate coat
64. Expansion joints in rigid pavements should not be more than
   (a) 10 mm
   (b) 15 mm
   (c) 20 mm
   (d) 25 mm
65. IRC recommends spacing between two consecutive expansion joints should not be more than
   (a) 90 m
   (b) 120 m
   (c) 140 m
   (d) 160 m
66. If the width of a rigid pavement is more than ______ longitudinal joints are required.
   (a) 3 m
   (b) 4.5 m
   (c) 6 m
   (d) 8 m

67. In case of reinforced concrete pavements of 150 mm thickness, maximum spacing between any two longitudinal joints may be

(a) 4.5 m
(b) 7.5 m
(c) 11.0 m
(d) 13 m

68. Dowel bars are used in rigid pavements
(a) to distribute pressure on base
(b) to take care of temperature stresses
(c) to prevent warping
(d) all the above

69. IRC recommends use of dowel bars of diameter ______ of length ______ in case of 150 mm thick slabs.
(a) 25 mm, 500 mm
(b) 20 mm, 400 mm
(c) 18 mm, 350 mm
(d) 16 mm, 300 mm

70. In case of 150 mm thick rigid pavements, spacing of dowel bars should not exceed
(a) 150 mm
(b) 200 mm
(c) 250 mm
(d) 300 mm

71. In case of 200 mm thick rigid pavement spacing of dowel bars can be as high as
(a) 200 mm
(b) 250 mm
(c) 300 mm
(d) 400 mm

72. Longitudinal joints in rigid pavements should be of
(a) tongue and groove type
(b) butt type
(c) weakened plate type
(d) all of these

73. Longitudinal joints in rigid pavements
(a) divide the pavements into lanes
(b) help in laying out concrete in convenient widths
(c) take care of the unequal settlement of the sub-grade
(d) all the above

74. For an earthen road, desirable camber is
(a) 1 in 10 to 1 in 12
(b) 1 in 12 to 1 in 20
(c) 1 in 25 to 1 in 30

(d) 1 in 30 to 1 in 40

75. For an earthen road, the minimum desirable grade is
   (a) 1 in 12
   (b) 1 in 20
   (c) 1 in 80
   (d) 1 in 120

76. Mostly used road in India is
   (a) earthen road
   (b) WBM road
   (c) black top road
   (d) concrete road

77. In earthen roads, base material should not contain clay more than
   (a) 5 %
   (b) 10 %
   (c) 15 %
   (d) 30 %

78. In earthen road wearing coat should contain clay upto
   (a) 5 to 10 %
   (b) 10 to 18 %
   (c) 20 to 30 %
   (d) 30 to 40 %

79. Soil to be used for earth road should have liquid limit less than
   (a) 5 %
   (b) 15 %
   (c) 25 %
   (d) 35 %

80. The base course made of broken aggregates mechanically interlocked by rolling and voids filled with screening and binding materials with the assistance of water is for
   (a) earthen road
   (b) gravel road
   (c) WBM road
   (d) none of the above

81. After dry rolling and wet rolling _______ thick sandy clay is spread and rolled in case of WBM road construction.
   (a) 6 mm
   (b) 12 mm
   (c) 18 mm
   (d) 24 mm

82. In WBM road construction _______ tonne rollers are used.
   (a) 4 – 5
   (b) 6 – 10
   (c) 10 – 15

(d) 20 – 24

83. The type of bituminous road construction includes
   (a) surface dressing
   (b) grouted or penetrations macadam
   (c) built-up spray grout
   (d) all the above

84. When bituminous surfacing is done on already existing black top road the type of treatment to be given is
   (a) tack coat
   (b) prime coat
   (c) spraying emulsion
   (d) apply seal coat

85. In bituminous bound macadam roads a bituminous premix is prepared at
   (a) 27°C
   (b) 60°C
   (c) 100°C
   (d) 150°C

86. In the premix method of bitumen road construction, the aggregate is also heated
   (a) for easy spreading
   (b) for easy handling
   (c) to get a homogeneous mix
   (d) to reduce bitumen requirement

87. Seal coat in a bituminous road is
   (a) cement + bitumen
   (b) coarse sand + bitumen
   (c) adhesive mixed bitumen
   (d) water repellent agent

88. Before placing concrete for road works, the sub-grade should be kept moist at least for
   (a) 12 hours
   (b) one day
   (c) 3 days
   (d) 5 days

89. Joints in concrete roads are filled with
   (a) impervious elastic materials
   (b) impregnated fibre boards
   (c) cork bound with bitumen
   (d) any of the above

90. Which of the following is considered the highest quality construction of black top pavement?
   (a) Sheet asphalt
   (b) Mastic asphalt
   (c) Bituminous carpet

(d) Bituminous concrete

91. Traffic engineering deals with
(a) safe traffic
(b) rapid traffic
(c) efficient flow of traffic
(d) all the above

92. Equivalent passenger car unit in unit time of a truck is
(a) 0.5
(b) 1.0
(c) 3.0
(d) 6.0

93. Equivalent passenger car unit in unit time recommended by IRC for bullock cart is
(a) 0.5 to 1.0
(b) 2.0 to 3.0
(c) 4.0 to 6.0
(d) 6 to 8

94. Traffic volume is
(a) number of vehicles per unit length of road
(b) maximum number of vehicles passing a given road section in unit time in one direction
(c) number of vehicles passing through a section of road in either direction in unit time.
(d) none of the above

95. The instrument used to study 'spot speed' in traffic engineering is
(a) speedometer
(b) speed recorder
(c) enoscope
(d) enometer

96. Enoscope used for spot speed study is a
(a) manual counter
(b) automatic recorder
(c) electronic
(d) none of the above

97. Pick up odd statement: The origin and destination of traffic study may be carried out
(a) by interviewing drivers
(b) by observing number plates of vehicles
(c) by conducting post card survey
(d) by using ecoscope

98. Postcard survey may be used to study
(a) spot speed study
(b) speed and delay study
(c) origin destination study

(d) parking studies

99. Accident studies are useful for
(a) future improvements of roads
(b) for improving signal systems
(c) for making a road one way
(d) all the above

100. The capacity C of a highway per hour is given by
(a) $\frac{100V}{S}$
(b) $\frac{1000V}{S}$
(c) $\frac{100V}{60S}$
(d) $\frac{1000V}{60S}$
where V = Design speed in kmph
S = Centre to centre spacing of moving vehicles in metres

101. If the average centre to centre spacing of vehicle is 25 m, then the basic capacity of a traffic lane at a speed of 45 kmph is
(a) 1500
(b) 1800
(c) 2250
(d) 3000

102. A basic requirement of intersection at grade is
(a) the relative angle of approach should be high
(b) it should clearly guide the driver
(c) the area of conflict should be small
(d) the relative speed should be high

103. Intersection at grade should be so designed that any vehicle should safely travel for —— seconds after sighting other vehicle.
(a) 4
(b) 8
(c) 12
(d) 16

104. Crossing angles at grade intersections should not be in any case less than
(a) 30°
(b) 45°
(c) 60°
(d) 75°

105. At grade separated intersections for entry and exit from major road _______ are provided.
(a) diamond junction

(b) clover leaf
(c) rotary junction
(d) any one of the above

106. Which one of the following is not a regulatory sign?
(a) No U-turn
(b) Overtaking prohibited
(c) School zone
(d) No parking

107. Which one of the following is not a warning sign?
(a) No entry
(b) Curve ahead
(c) U-turn
(d) Narrow bridge ahead

108. Which one of the following is not a informatory sign?
(a) Speed limit
(b) Name of road
(c) Cross road ahead
(d) Name of destination

109. A channelization island should have
(a) small entry and large exit radius
(b) large entry and small exit radius
(c) equal radius at entry and exit
(d) large entry and exit radius

110. Maximum number of vehicles can be parked with
(a) 30° angle parking
(b) 45° angle parking
(c) 90° angle parking
(d) parallel parking

111. At a road junction at 90° with both-way traffic the number of conflict points are
(a) 6
(b) 8
(c) 12
(d) 16

112. Regulatory signs are shown at a height of ______ from road surface.
(a) 1.5 m
(b) 2.0 m
(c) 2.8 m
(d) 3.0 m

113. Warning signs are shown on a rectangular board of size
(a) 300 × 400 mm

(b) 400 × 400 mm

(c) 450 × 400 mm

(d) 500 × 400 mm

114. Warning signs are on plates of ______ shape.

(a) rectangular

(b) square

(c) circular

(d) diamond

II. *Match List I with List II, selecting the answer code given below each item from question nos. 115 to 118…*

115.

	List I		List II
	Soil content/properly for base material of earth road		**Percentage**
A.	Clay content	1.	60 to 80
B.	Silt content	2.	9 to 32 %
C.	Sand content	3.	< 5
D.	Plasticity index	4.	< 6

Codes:

(a)	A – 3	B – 2	C – 1	D – 4
(b)	A – 2	B – 3	C – 1	D – 4
(c)	A – 2	B – 1	C – 3	D – 4
(d)	A – 2	B – 1	C – 4	D – 3

116.

	List I		List II
	Soil property/content in wearing coat of earth road		**Percentage**
A.	Clay content	1.	4 to 10
B.	Silt content	2.	5 to 15
C.	Liquid limit	3.	10 to 18
D.	Plasticity index	4.	< 35

Codes:

(a)	A – 2	B – 3	C – 4	D – 1
(b)	A – 3	B – 1	C – 2	D – 4
(c)	A – 2	B – 3	C – 4	D – 1
(d)	A – 3	B – 2	C – 4	D – 1

117.

	List I		List II
	Type of vehicle		**EPCU**
A.	Bullock cart	1.	0.5
B.	Horse driven vehicle	2.	3.0
C.	Bus	3.	4.0
D.	Motor cycle	4.	6.0

Codes:

(a)	A – 1	B – 2	C – 3	D – 4
(b)	A – 2	B – 3	C – 4	D – 1
(c)	A – 4	B – 3	C – 2	D – 1
(d)	A – 3	B – 4	C – 1	D – 2

118.

	List I		List II
A.	Regulatory sign	1.	Curve ahead
B.	Warning sign	2.	Red, amber and green lights
C.	Informatory sign	3.	No entry
D.	Traffic signal	4.	Æ To New Delhi

Codes:

(a)	A – 4	B – 1	C – 3	D – 2
(b)	A – 3	B – 1	C – 4	D – 2
(c)	A – 4	B – 2	C – 3	D – 1
(d)	A – 2	B – 3	C – 4	D – 2

III. *State whether the following statements are true or false in item numbers 119 to 140.*

119. In case of fair-weather roads occasional overflowing of road is permitted.

120. On collector streets there are restrictions on parking.

121. The width of land acquired for the construction and future expansion of the road is known as right of way.

122. The slope of the road in the cross-sectional direction is known as gradient of road.
123. Coefficient of friction for determining stopping distance on roads depends upon the speed of the vehicle.
124. The minimum distance required for a vehicle to overtake a vehicle without interfering the velocity of a vehicle coming in opposite direction at design speed is known as overtaking sight distance.
125. If V is the velocity in kmph, its equivalent velocity in m/sec is 0.278 V.
126. As the radius of horizontal curve increases extra width to be provided for roads also increases.
127. In case of rigid pavement, structural capacity depends upon the strength of sub-grade to a great extent.
128. In case of flexible pavements, temperature stresses may be neglected.
129. According to IRC recommendations for designing flexible pavement CBR test should be a field test.
130. The wearing course of WBM road consists of 6 mm thick sandy clay.
131. While making concrete roads, the concrete is placed in alternate bays or in long strips.
132. Traffic volume is measured in terms of number of vehicles passing through a cross section of a road per hour.
133. In traffic engineering EPCU means equivalent passenger car unit in unit time.
134. The best way of speed delay study is to record time taken by vehicles passing through a stretch of road.
135. If the major road is over a minor road, it is called flyover.
136. If a minor road is over a major road is called over-crossing.
137. Traffic islands are the raised constructions provided to channelise traffic.
138. A road divider is a traffic island.
139. Amber colored light traffic signal indicates clearance time.
140. A traffic rotary is suitable when number of intersecting roads is 4 to 7.

Answers to Multiple-Choice Questions

1. (c)	2. (b)	3. (b)	4. (d)	5. (a)
6. (d)	7. (a)	8. (d)	9. (a)	10. (d)
11. (a)	12. (b)	13. (b)	14. (d)	15. (d)
16. (b)	17. (d)	18. (d)	19. (b)	20. (c)
21. (d)	22. (b)	23. (a)	24. (d)	25. (b)
26. (c)	27. (b)	28. (c)	29. (c)	30. (b)
31. (a)	32. (c)	33. (a)	34. (b)	35. (b)
36. (c)	37. (d)	38. (a)	39. (d)	40. (c)
41. (b)	42. (d)	43. (d)	44. (b)	45. (b)
46. (a)	47. (c)	48. (c)	49. (a)	50. (d)
51. (b)	52. (d)	53. (d)	54. (b)	55. (b)

56. (c)	57. (b)	58. (c)	59. (b)	60. (c)
61. (d)	62. (c)	63. (b)	64. (d)	65. (c)
66. (b)	67. (d)	68. (c)	69. (a)	70. (b)
71. (c)	72. (d)	73. (d)	74. (b)	75. (d)
76. (a)	77. (a)	78. (b)	79. (d)	80. (c)
81. (a)	82. (b)	83. (d)	84. (a)	85. (d)
86. (c)	87. (b)	88. (b)	89. (d)	90. (d)
91. (d)	92. (c)	93. (d)	94. (c)	95. (c)
96. (a)	97. (d)	98. (c)	99. (d)	100. (b)
101. (b)	102. (c)	103. (b)	104. (c)	105. (d)
106. (c)	107. (a)	108. (c)	109. (a)	110. (c)
111. (d)	112. (c)	113. (c)	114. (a)	115. (a)
116. (d)	117. (c)	118. (b)	119. True	120. False
121. True	122. False	123. True	124. True	125. True
126. False	127. False	128. True	129. False	130. True
131. True	132. True	133. True	134. False	135. False
136. False	137. True	138. True	139. True	140. True

15

Railway Engineering

15.1 INTRODUCTION

* Amongst the different modes of transports, railways take the uppermost place on account of the fact that it carries bulk of passenger and goods traffic.

* George Stephenson of England succeeded in running the first train on 27th September 1825 between Stockton and Darlington with steam engine.

* First train and four coaches and one steam engine was run in India on 16th April 1853 between Boribunder (Mumbai) and Thana.

* In the world India Railways are next only to Russian Railways under a single management.

* The Indian Railway have been divided into sixteen zonal divisions. The zonal divisions with their headquarters are:

1. Central Railways (Mumbai VT)
2. Western Railways (Mumbai Central)
3. North Western Railways (Jaipur)
4. Northern Railways (New Delhi)
5. North Central Railways (Allahabad)
6. North Eastern Railways (Gorakhpur)
7. Eastern Railways (Kolkata)
8. South Eastern Railways (Kolkata)
9. North Eastern Frontier Railways (Guwahati)
10. East Central Railways (Hazipur)
11. East Coast Railways (Bhubaneshwar)
12. South East Central Railways (Bilaspur)
13. West Central Railways (Jabalpur)
14. South Central Railways (Secunderabad)
15. Southern Railways (Chennai)
16. South Western Railways (Hubli).

Railway Gauges

* The clear distance between the innerfaces of rails near their tops is called railway gauge.

* The most widely used gauge in the world is the standard gauge which is equal to 1435 mm.

* In India the following gauges are used

1. Broad gauge (BG) = 1676 mm (5¢6≤)
2. Meter gauge (MG) = 1000 mm
3. Narrow gauge (NG) = 762 mm (2¢6≤) and = 610 mm (2¢0≤)

* Larger the gauge greater is the traffic capacity, speed and safety. However, it needs flatter gradients

and curves resulting into cost of construction.

* Break of gauge (using different gauge) has the following disadvantages:

1. Inconvenience to passengers
2. Delay and additional labour cost in transferring goods
3. Duplication of facilities like signals, platform, waiting halls, etc.
4. Additional maintenance cost.

Hence, nowadays India is going towards uni-gauge (BG).

Rail Sections

The three types of rail sections used are as shown in Fig. 15.1.

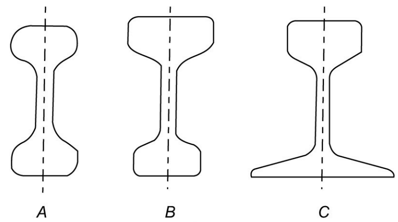


Fig. 15.1 Type of rails: A–double headed; B–bull headed; C–flat footed

1. *Double Headed Rail:* Both head are identical. It was developed with the hope of using upside down once a head is worn. However, it did not serve the purpose since due to impact the lower head in contact with sleeper also gets dented.
2. *Bull Headed Rail:* In this the foot is smaller than the head. To get required stability cast iron chairs are to be used. The provision of heavy cast iron chairs increased life of sleepers but resulted in heavy construction and maintenance.
3. *Flat Footed Rails:* It has better rigidity and stiffness to resist lateral and vertical forces. Chairs and keys are required to fix it to sleepers. Indian railway has adopted this type of rails now.

* The rail section is indicated by its weight per metre length. For broad gauge 52 kg/m section is generally used. However, 60 kg/m sections are recommended to take care of increased speeds on trunk routes.

* The approximate expression for rail sections should be $\frac{1}{510}$ × axle load. The following sections are used in Indian railways:

$$\text{B.G. } 55\ R = 55 \text{ kg/m}$$

$$\text{M.G } 45\ R = 45 \text{ kg/m}$$

$$35\ R = 35 \text{ kg/m}$$

$$\text{N.G } 30\ R = 30 \text{ kg/m}$$

$$25\ R = 25 \text{ kg/m}$$

Length of Rails

Longer the length lesser the joints and hence lesser fittings and maintenance cost. However with increase in length, transportation cost and manufacturing cost more. Indian Railways use 13 m and 12 m for BG and MG respectively. In America, England, France and Germany for standard gauges the length used are 11.89 m, 18.30 m, 24.0 m and 30 m. respectively.

Welding of Rails

Earlier concept that expansion joint should have a width of $L\ a\ T$ is found to be wrong, since the fixing of rails to sleepers give rise to axial forces which restrict free expansion. Hence, length of rails can be more which can be achieved effectively by welding. From the consideration of easy transport and manufacture, length may be kept 12 to 13 m but up to a length of 1300 m welded rails can be used. About 100 sleepers resist force generated in each rail. The rest of the long welded rails are not subjected to no movement under the temperature variation. These two end lengths of 100 sleepers is known as 'breathing length'.

Rail Joints

Requirement of a good joint:

1. Strength should be same as the original rail section.
2. It should withstand lateral forces without altering gauge distance.
3. It should provide sufficient elasticity so that vibration and shocks are absorbed.
4. It should provide for expansion.
5. Removal and replacement should be easy.
6. They should be simple, economical and durable.

* The various types of joints used are supported joint, suspended joint, bridge joint and semi-suspended joints (Refer Fig. 15.2).

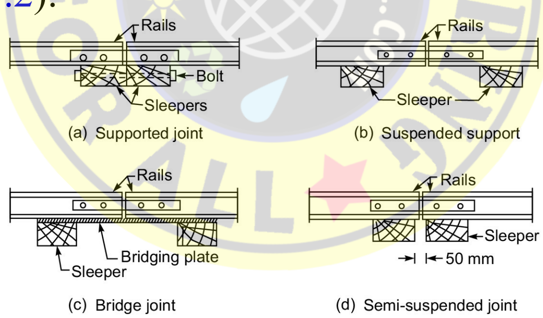


Fig. 15.2 Type of joints

Supported joints can stand more maintenance neglect but cause greater incidence of end batter. Suspended joints provide greater elasticity to the track but they require more maintenance. Semi-supported joints adopted in the Indian Railways provide a good workable via-media.

Coning of Wheels and Tilting of Rails

To prevent rubbing against the inside face of the rail, the distance between the flanges of wheel is slightly less than the gauge. If the rim of the wheels rest flat on the rails there will be lateral movement of the axle resulting in damage to the rails. Hence, to prevent this damage treads of wheels are given an outward slope of 1 in 20. This sloping of the wheel is known as coning of wheels.
To transfer the load from coned edge of wheel along the axis of rail, the rails are rested on inward slope of 1 in 20 on sleepers.

Hogging and Buckling of Rails

The ends of rail getting bent down due to wheel load is known as hogging of rails. This is mainly due to loose packing under the joint and loose fish plates. This is rectified either by improving by welding or by dehogging machines. In worst case the rails are to be changed. If sufficient expansion joint gap is not provided or the joint is very tight the rail may buckle under axial (longitudinal) forces developed. Lubrication of joints is necessary to prevent buckling.

Corrugation, Corrosion and Creep

* Heads of rails develop a wavy surface due to defects or poor maintenance of the track or the places where brakes are frequently applied. This defect is called rail corrugation. When trains pass on such rails a roaring noise is created and hence corrugated rails are also known as *roaring rails*.
* The corrosion of rails is predominant in the vicinity of industrial areas and tunnels where damp conditions exist. To reduce corrosion special steel alloys are used for making rails. Indian Railway practises application of rails with non-corrosive material which consists of one coat of zinc chromate over a red oxide priming coat and finishing with three coats of bituminous emulsion.
* **Creep:** It is permanent extension of rails due to longitudinal tractive forces. As a result of it gauge and alignment of rails is disturbed. Points and crossings get pulled resulting into difficult in operation of switches. It is either prevented or checked by pulling the rail backward if creep exceeds 150 mm or by using creep anchors.

Wear of Rails

Due to impact of moving wheels of train rail section may wear out. In India, the permissible limit of rail wear is 5 per cent by weight. The measures to reduce wear of rails are:

1. Satisfactory track maintenance
2. Inspection of expansion gap
3. Use of special alloy steel
4. Use of lubricants
5. Providing check rails for inner wheels in curved tracks
6. Exchange of inner and outer wheels at curves.

Fish Plates

The fish plates are a pair of plates used to join rails end to end to maintain continuity of rail. At joints they should have same strength as that of rails. These plates bear vertical and lateral forces. They are connected to rails-web by four bolts.

15.2 SLEEPERS

Requirements

1. It should be able to maintain required gauge.
2. It should provide adequate bearing area for the rails and ballast.
3. It should be strong enough to transfer the load from rail to ballast.
4. Its weight should not pose problems in handling.

5. It should be able to absorb the impact energy and damp the vibrations.
6. It should be economical and maintainance should be easy.

Sleeper Density

Sleeper on either side of joint is called a 'joint sleeper'. Next to joint sleeper is called shoulder sleeper and all other intermediate sleepers. Total number of sleeper per rail length is called sleeper density. It is described as $M + x$ where M is the number of metres in a rail length and x is number depending upon type of sleeper, axle load, speed permitted, etc.
If rail length is 13 m , $M + 5$ means 18 sleepers per rail length including joint sleepers and shoulder sleepers. The distance between two consecutive intermediate sleepers is same while that between joint sleeper and shoulder sleeper is little bit less. In India sleeper density is normally a minimum of $M + 4$ which works out to be as $\frac{17}{13}\times 1000 \approx 1308$ per km.

Types of Sleepers

1. Wooden sleepers
2. Steel sleepers
3. Cast iron sleepers
4. Concrete sleepers

1. Wooden sleepers The seasoned good quality wood free from defect may be used as sleepers. Teak wood is preferred in India only at girder bridge, since though it is the best, it is very costly. Sal wood is mostly used as sleeper.

* Standard sizes of wooden sleepers are as given blow :

Gauge	Size
B.G	2740 mm × 250 mm × 130 mm
M.G	1830 mm × 200 mm × 110 mm
N.G	1520 mm × 150 mm × 100 mm

* Merits of wooden sleepers:
  1. Has good energy and vibration absorption capacity.
  2. Fastening system is simple and easy.
  3. Damage is less during derailments.
* Demerits
  1. Gets worn out under beater packing
  2. Needs special treatment for fire protection
  3. It has less scarp value.
* Composite Sleeper Index

Forest Research Institute, Dehradun has brought out an index number for various timber to reflect sum total properties of a particular timber for fitness as a railway sleeper. The properties considered include strength and hardness. The minimum composite sleeper index (CSI) prescribed are as given below:

Bridge sleepers	1455
Crossing sleepers	1392
Track sleepers	383

2. Steel sleepers Shortage of timber led to use of steel sleepers. Now 30% of track in Indian Railways are provided with steel sleepers. They are made by rolling 12 mm steel plates formed into trough shape in order to prevent running of ballast. A cant of 1 in 20 is provided towards the inner side to receive coned treads of wheel. In these sleepers, holes are drilled and punched to hold jaws and keys.

* Advantages of steel sleepers:
1. Life is 30–40 years
2. Not susceptible to fire and fungi attack
3. Maintains gauge and level satisfactorily
4. It has high scarp value

* Disadvantages of steel sleepers:
1. Liable to corrode
2. Cracks may develop during maintenance

3. Cast iron sleepers After trying various cast iron sleepers like pot, plate and box between the years 1926 to 1935, Track Standard Committee (CST) of Indian Railways started using CST–9 type cast iron sleepers. The number 9 indicates the trial no. 9. It consists of two boxes held at gauge distance by mild steel tie bars. Mild steel cotters fix the boxes to tie bars and the rail is held to the sleeper by means of clip and double coil spring. Below the rail seat a rubber seating is provided. Service life of CST–9 sleepers is 35 to 50 years. Now with small improvements CST–10, CST–11, CST–12 and CST–13 sleepers have been developed. The use of cast iron sleepers now covers up to 50% in Indian railways.

* Advantages of cast iron sleepers:
1. No corrosion
2. Less cracking
3. High scrap value
4. Easy to manufacture

* Disadvantages of cast iron sleepers:
1. Lateral stability is less
2. Difficulties in maintaining gauge
3. Because of rounded bottom maintenance is difficult

4. Concrete sleepers The following four types of concrete sleepers have been tried:
1. R.C.C. sleepers similar to wooden sleepers
2. Two R.C.C. blocks connected by steel bar
3. Two prestressed blocks joined by steel bar

4. Prestressed concrete sleepers.

Advantages of concrete sleepers:

1. Maintains gauge accurately
2. Improves track modulus since it is heavy
3. Free from fire hazard
4. Long life
5. Maintenance cost is least

Disadvantages

1. Handling and transportation is difficult since they are heavy.
2. Heavy damage during derailment.
3. No scrap value

* Monoblock sleepers are 2750 mm long. Cross section is trapezoidal with a width of 154 mm at top, 250 mm at bottom and 196 mm high. The ultimate strength should not be less than 52.5 N mm^2. A cant of 1 in 20 is given for a distance of 175 mm to seat the rail.

* Two-block sleepers are of length 2478 mm. It consists of R.C.C. blocks each of 722 mm length, 295 mm wide and 251 mm thick, weighing 0.9 kN. They are connected by an annular tie bar of 75 mm × 75 mm × 10 mm size.

15.3 BALLAST

* It is a layer of broken stones, gravel, murram, etc. packed below and around the sleeper so that the load from sleeper is transferred to the formation.
* **Purposes of providing ballast are:**
  1. Transfer the load from sleeper to wider area of formation
  2. Absorb the shock and give comfort to passengers
  3. Improve drainage of the track
  4. Provide stability to the track
* **Ballast Section**
  1. *Depth of ballast* is based on the principle that load dispersion takes place at 45°. Hence, sleeper spacing = width of sleeper + 2 × depth of ballast. Minimum depth of ballast prescribed for B.G trunk routes is 250 mm.
  2. *Width of ballast*: It is on the requirement that adequate lateral stability is achieved. On straight track it is sleepers length + 2 × 300 mm at top which works out to be 3.35 m for BG. The side slope is 1.5 horizontal to 1 vertical.

* On curves extra width of 75 mm to 150 mm is provided.

* The ballast thrown around the sleepers and loosely filled on slope is called boxing of ballast.
* **Quantity of ballast** per kilometre length requirement is:
  1. 2600 m^3 on B.G double line
  2. 1300 m^3 on B.G single line

* *Type of ballast*
  1. *Broken stone:* Granite, quartzite and hard trap stones are suitable as ballast. For flat bottom sleepers and C.I. pot sleepers 50 mm size and for points and crossing 25 mm size stones are

suitable. For metal sleepers with rounded edges, 40 mm size stones are used.

2. *Gravel:* On soft formation gravel (rounded pieces obtained from the river bed) are used.

3. *Sand:* It has good drainage property but its drawback is that particles may get deposited on rail and get crushed at the same time causing excessive wear of rail.

4. Murram and cinder: Used as a blanket for black cotton soil over it regular ballast is provided.

Fittings

Fish Bolts Each pair of fish plate is joined by four bolts made from high carbon steel. They are tightened time to time.

Fittings for wooden sleepers Dog spikes, round spikes and screw spikes are used to fix rails to wooden sleepers.

Bearing plate Below the rails bearing plates are provided which are then fixed to wooden sleepers. As bearing plates distribute the load from rail over larger area stresses on sleepers is reduced. But the disadvantage is moisture may enter between rail and bearing plate and accelerate corrosion. If one spike is damaged all the spikes are to be removed. Flat M.S. bearing plate and cast iron anti-creep bearing plates are used by Indian Railways.

Two-way keys The keys tapered in both directions are known as two-way keys. They may be driven in either direction. They are used with pot sleepers, trough sleepers and CST–9 sleepers.

Cotters These are used for fixing the tie bars with cast iron sleepers. The length of these cotters is 150 mm and weight 3.5 N. The type of cotters used are: solid end cotter, bent plate cotter, side split cotter and centre split cotter.

M.S. tie bars These are the bars used to hold two CST–9 sleepers together.

Elastic fastener To reduce vibrations elastic fasteners are used to hold the rails to sleeper. Pandrol clip, INR-202 clip, IRN-304 clip, double shank elastic spike, lock spikes are the examples of elastic fasteners.

15.4 GEOMETRIC DESIGN

1. Slopes Side slopes for embankment and cutting are usually 2H :1 V to 1/2 H : 1 V.

2. Side drains On both sides of the embankment and cutting sufficiently wide drains should be provided. However in case of natural cross slope no drain is required on the lower side.

3. Gradient The rise or fall of the rail track level per unit length of the track is known as gradient. Gradient on railways may be classified as:

(i) Ruling gradient
(ii) Momentum gradient
(iii) Pusher gradient
(iv) Station yard gradient

(i) Ruling gradient To balance between efficient running of the train as well as to take care of drainage even on plane land suitable gradient should be given. Such gradient is called ruling gradient. In India ruling gradients are:

1 in 150 to 1 in 200 in plains.

1 in 100 to 1 in 190 in hilly areas.

However on curves grade compensation is provided to maintain the speed. Grade compensation provided is

0.04 % on B.G.

0.03 % on M.G.

0.02 % on N.G.

(ii) Momentum gradient When there is a change from falling gradient to rising gradient, falling gradient may be slightly increased to make use of momentum gained to climb rising gradient. This is called momentum of gradient. This stretch of track should not have any signal.

(iii) Pusher gradient In ghat section sometimes more gradient is provided. To climb this extra engine may be used. Between Mumbai and Poona a gradient of 1 in 37 is also provided. This is known as pusher gradient.

(iv) Station yard gradient At railway stations and yards for easy drainage gradients provided are a maximum of 1 in 400 and a minimum of 1 in 1000.

Superelevation

On curves superelevation required is

$$S = \frac{v^2 G}{gR}$$

where V = speed in m/sec, G = gauge in metre

R = radius in metre and $g = 9.81$ m/sec^2.

Maximum superelevation on broad gauge works out to be

For V = 100 kmph 140 mm

V = 120 kmph 165 mm

V = 160 kmph 185 mm

Cant deficiency It is the difference between necessary cant for design speed and actual cant. The maximum cant deficiency for speeds up to 100 kmph is

(a) On broad gauge = 76 mm

(b) On metre gauge = 51 mm

(c) On narrow gauge = 38 mm

15.5 CURVES

* Whenever the direction is to be changed, horizontal curves are to be provided and whenever gradient is to be changed vertical curves are required.

* Degree of curve is defined as the number of degree subtended by arc of a chain length at the centre. Earlier the chain of 100 ft (= 30.48 m) were used, which when converted to MKS units gives

degree of curves as.

$$D = \frac{1750}{R}, \text{ where } R \text{ is in metre}$$

* **Speed on Curves:**

* Maximum sanctioned speed of the section: This is the speed sanctioned for any section, which is not to be exceeded in any case.

* Safe speed on curves:

For BG and MG with transition curves

$$V = 4.4 \sqrt{R - 70}$$

where V = speed in kmph

R = radius in metre

For NG, with transition curves

$$V = 3.65\sqrt{R - 6}$$

If transition curves are not provided, the above values should be reduced to 80%, subjected to a maximum of 40 kmph.

On high speed tracks,

$$V = 4.58\sqrt{R} \text{ is permitted}$$

* Equilibrium speed: For maximum comfort on curves with superelevation, equilibrium speed is to be maintained, which is given by the formula

$$e = \frac{G}{127}\frac{V^2}{R}$$

where V = speed in kmph, R in metre

$g = 9.81 \text{ m/sec}^2$

G = gauge in metre

However, the maximum superelevation on a track is fixed as $\frac{1}{10} \times \text{gauge}$. This is necessary because all trains cannot achieve same speed.

* Maximum degree of curves permitted in Indian Railways are:

B.G 10°

M.G 15°

N.G 40°

* Length of transition curves: It shall be maximum of the following three:

1. $L = 0.008\ C_a\ V_m$
2. $L = 0.008\ C_d\ V_m$
3. $L = 0.72\ C_a$

where V_m = maximum permissible speed in kmph

C_a = actual cant on curves in mm

C_d = cant deficiency in mm

Vertical Curves:

* It is a parabolic curve, which has the rate of change of gradient is constant.

* Length of vertical curves is given by

$$L = \frac{a}{r}$$

where a = algebraic difference in successive gradients

r = rate of change of gradient in per cent. It is taken as 0.10 % for summit curves and 0.05 % for sag curves.

Plate Laying

The operation of laying out rails and sleepers over the compacted formation is known as plate laying. The point upto which track has been laid is known as the rail head. The method used for plate laying are:

1. Side method
2. Telescopic method
3. American method

Railway Stations

* A station is a field control place and the place for passenger facilities.

* Railway stations may be classified as follows:

(a) Block stations

(b) Non-block stations

(c) Special class stations

(a) Block stations For operational purpose track is divided into a number of blocks and at the end of block a station is located. These stations are divided into *A*, *B* and *C* classes.

A-class station: It is provided with

(i) Outer signal at a distance of 540 m for broad gauge and 400 m for metre gauge stations.

(ii) Home signal at the door of the station

(iii) Starter signal before which train has to stop and start only after the signal is given

(iv) Warner signal placed to indicate vicinity of home signal

B-class station: This is a block station where the track has to be cleared upto a specified distance beyond the outer signal before the train is permitted to approach the station. These stations have only outer and home signals.

C-class stations: They consist of a block hut only. They are provided with home signal and warner signals only.

(b) Non-block stations These stations do not have any signal and hence they cannot control train. They have crossing facility. They are also known as flag stations or *D*-class stations.

(c) Special class stations The stations which do not fall under any of class *A*, *B*, *C* and *D* are known as special class stations

(i) Terminal stations The stations at which a railway line or branch line terminates is known as terminal station.

(ii) Junction station The station where traffic flow is in 3 or more directions.

(iii) Way side station These stations are provided with facilities for crossing of up and down train or for overtaking a slower train by a faster train.

* A railway station should meet the requirements of public, traffic, loco departments and general requirements like approach roads, etc.

Platform

A. Requirement of passenger platforms

Table 15.1 Requirements of passenger platforms

Requirement of	*BG*	*MG*	*NG*
Height of platform	0.76 m to 0.84 m	0.31 m to 0.41 m	0.23 m to 0.41 m
Clearance between track and edge of platform	1.676 m	1.35 m	1.22 m

Length: Should be longer than the length of train expected. Minimum length = 180 m. In case of B.G it is 300 m. At Sonepur in north-eastern railway platform is 736 m.

Slope: 1 in 30

Width: Minimum of 3.66 m

Ramp: 1 in 6

B. Goods platform

Table 15.2 Requirement of goods platform

Requirement of	*BG*	*MG*	*NG*
1. Distance between centre line of track and adjacent building	4.72 m	3.18 m	3.05 m
2. Height	1.07 m	0.69 m	0.61 m

Station Yards

A system of track laid within the station complex is known as station yard. They may be classified as:

(a) Passenger yards
(b) Goods yard
(c) Marshalling yards
(d) Locomotive yards

(a) Passenger yard It includes passenger platforms and a number of tracks where idle trains can be accommodated, examined and cleaned.

(b) Goods yards It includes the platforms used for loading and unloading goods. It may be paved with concrete, bitumen or water bound mechadam. A transit shade with weight bridge is necessity in a goods yard.

(c) *Marshalling yard* The main functions of the marshalling yard are reception, sorting and reforming into designation-wise of goods trains. It needs a number of siding systems to sort out and rearrange goods wagons. Marshalling yard may be a flat yard, hump yard or gravitational yard. In case of flat yards, locomotive power is required for movement of wagons, whereas in case of hump yards and gravitational yards gravity force is also utilized. However, if gravity force is utilized for marshalling suitable breaking system should be provided.

(d) *Locomotive yards* These yards are provided by the side of marshalling yards for cleaning, repairing, servicing, watering, etc.

Points and Crossings

Points and crossing is an arrangement for a train to transfer from one track to another. Technical terms used in points are:

1. Stock rails: These are fixed rails.
2. Tongue rails: These are tapered rails which can be moved about a pivot point known as heel. By operating these the passage to desired track may be given. These rails are also known as switch rails.
3. Switch angle: It is the angle between the gauge faces of the stock rail and the tongue angle.
4. Throw of switch: It is the distance between the running face of the stock rail and the toe of the tongue rail. The specified throw of switch on BG is 95 mm and on MG it is 89 mm.
5. Check rails: These are the rails provided to guide the wheel flanges, while the opposite wheel is jumping the gap.
6. Heel clearance: It is the distance between the running edge of the stock rail and the switch rail at the switch heel. Its recommended value on BG is 133 mm.
7. Flange way clearance: It is the distance between the adjacent faces of the stock rail and the check rail. Its minimum value is 60 mm.

* Length of tongue rail and stock rail: The length of tongue rail should be longer than the rigid wheel base of a far wheel vehicle so that before a wheel leaves the tongue rail, another wheel from behind comes on the tongue rail. The length of tongue rails depends upon the crossing number, i.e., angle between the two rails at the crossing. Table 15.3 shows standard length of tongue rails.

Table 15.3 Standard length of tongue rails

	On BG			*On MG*	
Crossing number	1 in $8\frac{1}{4}$	1 in 12	1 in 16	1 in + 8 $\frac{1}{2}$	1 in 12
Length of tongue	4.72 m	6.4 m	9.76 m	3.96 m	5.49 m

Types of crossing:

A. On the basis of angle of crossings

1. Acute angle crossing

2. Obtuse angle crossing
3. Square crossing (90° crossing)

B. On the basis of assembly of crossings:
1. Spring or movable crossing
2. Ramped crossings

Road and Rail Level Crossings

* Crossing angle should be preferably 90° and in any case 45°
* Road should be straight at least for 30 m.
* Road width 7.5 m, levelled for vehicles to wait.

For Changing Direction of Engine

* Triangular track may be laid so that engine moves forward on one side, then backward on second side and again moves forward on third side of triangular track.
* Turntable may be used in which engine is stopped on turntable, then the table is rotated by 180° to change the direction of engine.

Traverse, Buffer Stops and Sand Hump

* Traverses are used to move position of wagons, coaches and engines sideway to shift from one track to another track.
* Buffer stops are provided to prevent the vehicles from moving beyond end rails.
* Sand humps are provided to prevent the movement of vehicles beyond the dead end sidings.

Track Maintenance

* Daily maintenance: A gang is employed to look after 5 to 8 km of track daily for
  1. General inspection
  2. Checking fastenings and fixtures
  3. Tightening of bolts
  4. Reporting any unusual occurrences
* Periodical maintenance is to
  1. Maintain track alignment
  2. Maintain drainage
  3. Maintain rails, sleepers and track fittings
  4. Maintain points and crossings
  5. Maintain level crossings
* A number of electronic and mechanical track recorders are used to check the track. Track tolerances are as shown in Table 15.4.

Table 15.4 Track tolerances

Parameter	*Value under floating condition*	*Value under loaded condition*

Cross levels	6 mm	10 mm
Longitudinal	6 mm	12 mm
Gauge	*G* mm	*G* + 1 to 1.5 mm
Alignment	*A* mm	*A* + 1 to 1.5 mm

Signalling

* The objective of signalling is to control and regulate movement of trains safely and efficiently.

* Signals may be audible signals or visual signals like semaphore type, disc type and the colour light.

* According to functional characteristics signals are classified as given below:

1. Stop or semaphore type: It consists of an indicator arm, which has horizontal position to indicate stop signal. When the signal arm is lowered by pulling a wire it is said to be in 'off' position and indicate "permitted to move". They are provided at a height 6.5 m.
2. Warner signal: Horizontal arm of a semaphore signal with V-shaped notch at the free end and V-shaped band is known as a warner signal. In horizontal position, i.e., 'On' position it indicates the stop signal ahead is at 'On' position, hence move slowly. When the warner signal is at 'Off' position, it indicates that signal ahead is at 'off' position and hence can move fast.
3. Shunting signals: These signals are in the form of circular discs with red bands on white background. They control shunting operations.
4. Colour light signals: Coloured light signals throw high intensity bean light. They are used in urban or suburban stations with heavy traffic.

* According to the location, signals may be classified as:

1. Outer reception signal
2. Inner reception signal (home signal)
3. Starter departure signal
4. Advanced starter signals

* Advanced starter signal is the last signal in the station which is located at 180 m from the station. After the train leaves this signal, the responsibility of the station master is over.

Signalling

1. Time interval system In this system a fixed time interval is maintained between the departure of two trains between two stations. This is still used in case of failure of telegraph system.

2. Polot guard system In this system a pilot guard proceeds by one train to the station ahead and returns by another train. No other train is allowed to proceed from the station till the pilot has returned.

3. Train staff or ticket system In this system train staff or ticket is issued by the station master to proceed and enter the section.

4. Absolute block or spice interval system In this system the track is divided into a number of sections. Generally, it is the distance between two stations. Block instruments are installed in the stations and are electrically connected. Only when two station masters agree token is released from the instrument and the train has to start with token.

5. ***Automatic block system*** In this system the track between two stations is divided into a number of blocks of 5 to 7 km. The signals are activated by trains themselves. When a train enters a block, the electric current conveyed through track puts the danger signal for this block until the train has gone for two blocks ahead.

6. ***Centralized traffic control system (CTC)*** In this system all signals are interlocked and are controlled from a centralised control room. In control rooms trains on track are traced and the position of signals displayed and they can be operated.

7. ***Automatic train control system (ATC)*** In this system track is electrically circulated. Electric fittings are provided at the wheel brakes. Even if the driver fails to notice signal, the fittings help in reducing the speed of trains and bring it to stop.

Interlocking

* Switches and signals are manipulated by levers at a convenient cabin. In the cabin levers are painted with red colour for stop signals, blue for locks, green for warner, yellow for crossing gate, black for points.

* **Method of interlocking:**

1. ***Key system/indirect interlocking*** In this system arrangement is such that at any time only one key can be removed to put a signal to on position.

2. ***Mechanical/Tapper and locks system*** In this system different levers are attached to tappers (steel bars) and moving tappers only one signal in the group can be activated.

3. ***Electrical interlocking/Route relay system*** In this system points and signals are electrically interlocked and operated. This is the modern and sophisticated system of interlocking.

MULTIPLE-CHOICE QUESTIONS

I. *Select correct option for the given question nos. 1 to 154*

1. Credit of hauling a train by steam engine goes to
(a) Johnson
(b) Steavenson
(c) Stephenson
(d) Williams

2. The first railway train ran between
(a) Stockton and Darlington
(b) New York and Washington
(c) Mumbai and Thana
(d) Paris and Berlin

3. The first railway train of the world rolled in the year
(a) 1825
(b) 1833

(c) 1843

(d) 1853

4. The first train in India was run in the year
(a) 1825
(b) 1833
(c) 1843
(d) 1853

5. The first train in India was run between
(a) Delhi and Kolkata
(b) Chennai and Vijaywada
(c) Mumbai and Thana
(d) Mumbai and Ahmedabad

6. Indian Railways has been divided into
(a) 8 zones
(b) 10 zones
(c) 12 zones
(d) 16 zones

7. In the world Indian Railways is ______ number under a single management.
(a) first
(b) second
(c) fourth
(d) fifth

8. Gauge is the distance between ______ of rails of track.
(a) centre to centre
(b) inner edge to edge between top edges
(c) outer edge to edge distance
(d) inner edge to edges between bottom edges

9. The most widely used gauge in the world is
(a) standard gauge
(b) broad gauge
(c) metre gauge
(d) narrow gauge

10. Standard gauge is ______ wide.
(a) 1676 mm
(b) 1435 mm
(c) 1000 mm
(d) 762 mm

11. Broad gauge is ______ wide.
(a) 1676 mm
(b) 1435 mm

(c) 1000 mm

(d) 762 mm

12. World's widest rail gauge is
(a) 1435 mm
(b) 1676 mm
(c) 1825 mm
(d) 1922 mm

13. World's narrowest gauge is
(a) 1000 mm
(b) 924 mm
(c) 762 mm
(d) 610 mm

14. Narrow gauge is adopted where
(a) terrain is hilly
(b) number of river crossings are more
(c) expected revenue earning is low
(d) acquisition of land is difficult

15. For developing a thinly populated area, the correct choice of gauge is
(a) standard gauge
(b) broad gauge
(c) metre gauge
(d) narrow gauge

16. The rail section, nowadays, used in India is
(a) bull headed
(b) double headed
(c) flat footed
(d) I-section

17. The rail section first designed in India was
(a) full headed
(b) double headed
(c) flot footed
(d) I-section

18. In bull headed rails
(a) foot is smaller than head
(b) foot is identical to head
(c) foot is bigger than head
(d) may be (b) or (c) of above

19. Head width of 52 R flat footed rail is
(a) 61.2 mm
(b) 64 mm

(c) 67 mm

(d) 70 mm

20. A rail section is designated by its
(a) cross-sectional area
(b) length
(c) total weight
(d) weight per metre length

21. The length of rails used in broad gauges in India is
(a) 13 m
(b) 15 m
(c) 17 m
(d) 20 m

22. 60 *R* rails are used in
(a) broad gauge
(b) merte gauge
(c) narrow gauge
(d) in all the above

23. In the world longest rails being used is
(a) 18 m
(b) 20 m
(c) 24 m
(d) 30 m

24. Breaking length of rails is approximately equal to the length between ______ sleepers.
(a) 40
(b) 60
(c) 80
(d) 100

25. Welded rails up to ______ have been used.
(a) 30 m
(b) 100 m
(c) 800 m
(d) 1300 m

26. Which one of the following is not correct? Requirement of good joint
(a) strength should be same as the original rail section
(b) it should withstand lateral pressure without altering the gauge length
(c) it should provide sufficient elasticity so that vibration and shocks are absorbed
(d) it should not allow for expansion.

27. The joint generally used in Indian Railways is
(a) supported joint
(b) suspended joint

(c) bridge joint

(d) semi-supported joint

28. The joint that cause greater incidence of rail end batter is
    (a) supported joint
    (b) suspended joint
    (c) bridge joint
    (d) semi-supported joint
29. The joint that requires more maintenance is
    (a) supported joint
    (b) suspended joint
    (c) bridge joint
    (d) semi-supported joint
30. Coning of wheels is at
    (a) 1 in 15
    (b) 1 in 20
    (c) 1 in 30
    (d) 1 in 35
31. Which of the following statement is wrong?
    (a) Coning of wheels is necessary to prevent rubbing of flange of wheel with rails.
    (b) Coning is provided at 1 in 20 slope.
    (c) In coning wheels are given an outward slope.
    (d) Coning of wheels is required only in curves.
32. The ends of rail getting bent down due to wheel load is known as
    (a) tilting
    (b) coning
    (c) hogging
    (d) buckling
33. If sufficient expansion joint gap is not provided or the joint is very tight the rail may ______.
    (a) tilt
    (b) hogg
    (c) develop corrugation
    (d) buckle
34. Non-corrosive material applied to rails consist of
    (a) red oxide coat
    (b) red oxide + zinc chromate coat
    (c) red oxide + aluminium coat
    (d) red oxide + zinc chlorite + bituminous emulsion
35. The longitudinal movement of the rails in a track is known as
    (a) tilting
    (b) hogging
    (c) buckling

(d) creeping

36. The adjustment of rails is usually required when creep exceeds
(a) 25 mm
(b) 50 mm
(c) 100 mm
(d) 150 mm

37. In India, the permissible limit of rail wear is
(a) 2%
(b) 5%
(c) 10%
(d) 15%

38. To hold the adjoining ends of rails in correct position, the rail fastenings to be used are
(a) anchors
(b) fish plates
(c) spikes
(d) bearing plates

39. Fish plates should be designed for
(a) vertical force
(b) horizontal forces
(c) longitudinal forces
(d) all the above

40. On Indian Railways fish plates are connected to the rails by _______ number of fish bolts.
(a) 2
(b) 4
(c) 6
(d) 8

41. Chief function of sleeper is to
(a) keep the rails at correct gauge
(b) support the rails
(c) distribute the load coming from rails
(d) all the above

42. Requirements of a good sleeper is
(a) provide adequate bearing area for the rails
(b) provide adequate bearing area to the ballast
(c) it should be easy to fix the rails
(d) all the above

43. The sleeper which has excellent ability to absorb shock is
(a) wooden sleeper
(b) steel sleeper
(c) cast iron sleeper
(d) concrete sleeper

44. Sleeper density is $M + 5$ in broad gauge route means number of sleepers supporting a rail length is
(a) 11
(b) 18
(c) 25
(d) 31

45. In India a minimum sleeper density is
(a) M
(b) $M + 2$
(c) $M + 4$
(d) $M + 5$

46. On broad gauge a sleeper density of $M + 4$ means, the number of sleepers to be used per kilometre length is
(a) 1660
(b) 1540
(c) 1308
(d) 1282

47. The spacing of sleepers is kept
(a) closer near the joints
(b) same throughout
(c) closer at the middle of rails
(d) none of these

48. The best wood for sleeper is
(a) deodar
(b) chir
(c) sal
(d) teak

49. In India, commonly used wooden sleeper is
(a) deodar
(b) chir
(c) sal
(d) teak

50. Standard size of wooden sleeper on broad gauge is
(a) 2740 × 250 × 130 mm
(b) 1830 × 200 × 110 mm
(c) 1520 × 150 × 100 mm
(d) 1830 × 150 × 100 mm

51. Which one of the following is the wrong statement about wooden sleeper?
(a) Gets worn out under beater packing.
(b) Needs special treatment for fire protection.

(c) Damage is more during derailment.

(d) Scrap value is less.

52. The composite sleeper index is the index of
(a) hardness and wear resistance
(b) toughness and wear resistance
(c) strength and hardness
(d) strength and toughness

53. The composite sleeper index determines the suitability of
(a) wooden sleepers
(b) cast iron sleepers
(c) steel sleepers
(d) concrete sleepers

54. Life of steel sleepers is
(a) 20 to 30 years
(b) 30 to 40 years
(c) 40 to 50 years
(d) 50 to 60 years

55. Which one of the following is not the correct statement about a sleeper?
(a) Maintains gauge and level satisfactorily.
(b) A cant of 1 in 20 is provided towards inner side.
(c) It is susceptible to fire.
(d) Cracks may develop during maintenance.

56. Ends of steel sleepers are
(a) bulb shaped
(b) flat and rectangular
(c) convex shaped
(d) concave shaped

57. Indian Railways are provided with ______ of track with steel sleepers.
(a) 30%
(b) 40%
(c) 50%
(d) 60%

58. Advantages of cast iron sleepers is
(a) less cracking
(b) high scarp value
(c) easy to manufacture
(d) all the above

59. Which one of the following statement is wrong? Disadvantage of cast iron sleepers is
(a) difficulties in maintaining accurate gauges
(b) less lateral stability

(c) high cracking chance
(d) maintenance is difficult

60. A CST–9 sleeper is
(a) pot sleeper
(b) plate sleeper
(c) box sleeper
(d) combination of all the above

61. In Indian Railways highly used sleeper is
(a) wooden sleeper
(b) steel sleeper
(c) cast iron sleeper
(d) concrete sleeper

62. The sleeper in the form of two bowls placed under each rail and connected by a tie bar is known as
(a) box sleeper
(b) pot sleeper
(c) plate sleeper
(d) none of the above

63. The number of keys used in CST–9 sleeper is
(a) 2
(b) 3
(c) 4
(d) 6

64. The number of cotters used in CST–9 sleepers is
(a) 2
(b) 3
(c) 4
(d) 6

65. Type of concrete sleepers tried is
(a) R.C.C. sleeper similar to wooden sleeper
(b) two R.C.C. blocks connected by steel bar
(c) Pre-stressed concrete sleeper
(d) all the above

66. Concrete sleeper is used in railways due to
(a) their ability to improve track modulus
(b) high resistance to fire
(c) long life
(d) all the above

67. Disadvantage of concrete sleeper is
(a) their heavy weight

(b) no scrap value
(c) heavy damage during derailment
(d) all the above

68. Monoblock concrete sleepers have ______ cross section.
(a) square
(b) rectangular
(c) trapezoidal
(d) channel type

69. The sleeper that needs the least maintenance is
(a) wooden sleeper
(b) steel sleeper
(c) cast iron sleeper
(d) concrete sleeper

70. Heaviest sleeper is
(a) wooden sleeper
(b) steel sleeper
(c) cast iron sleeper
(d) concrete sleeper

71. The purpose of providing ballast below sleepers is to
(a) transfer the load over wider area
(b) absorb the shocks
(c) improve drainage
(d) all the above

72. Minimum depth of ballast prescribed for BG routes is
(a) 200 mm
(b) 250 mm
(c) 300 mm
(d) 400 mm

73. Width of ballast on straight routes should be equal to
(a) sleeper width
(b) sleeper width + 300 mm
(c) sleeper width + 400 mm
(d) sleeper width + 600 mm

74. Width of ballast section for broad gauge is
(a) 2.0 m
(b) 2.45 m
(c) 3.3 m
(d) 4.25 m

75. Boxing of ballast is to prevent ______ of sleepers.
(a) lateral movement

(b) longitudinal movement
(c) both lateral and longitudinal movement
(d) none of the above

76. Compared to straight portion, on curves extra width of ballast required is
(a) nil
(b) 15 to 20 mm
(c) 40 to 50 mm
(d) 75 to 150 mm

77. On double line BG routes ballast required per kilometre length is
(a) 1300 m^3
(b) 2600 m^3
(c) 3900 m^3
(d) 5200 m^3

78. Ballast material generally used in India consists of
(a) broken stone
(b) gravel
(c) murram
(d) all of these

79. Size of broken stone ballast used for flat bottom sleepers is
(a) 25 mm
(b) 32 mm
(c) 40 mm
(d) 50 mm

80. The size of broken stone ballast used for metal sleepers with rounded edges is
(a) 25 mm
(b) 32 mm
(c) 40 mm
(d) 50 mm

81. For point and crossings, size of broken stone ballast used is
(a) 25 mm
(b) 32 mm
(c) 40 mm
(d) 50 mm

82. On soft formation ballast material preferred is
(a) stone
(b) gravel
(c) sand
(d) cinder

83. The ballast material that may cause excessive wear of rail is
(a) stone

(b) gravel

(c) sand

(d) cinder

84. On black cotton soil _______ is used as a blanket before regular ballast is provided.

(a) clay

(b) murram

(c) cinder

(d) both (b) and (c)

85. Fish bolts are made from

(a) wrought iron

(b) mild steel

(c) high carbon steel

(d) any of the above

86. Which one of the following is not used to fix rails to wooden sleepers?

(a) Fish bolt

(b) Dog spikes

(c) Round spike

(d) Screw spikes

87. Pick up correct statement about bearing plates.

(a) They distribute load from rail on wider area of sleeper.

(b) If one spikes is to be replaced all other spikes are to be removed.

(c) Chances of corrosion is more.

(d) All the above.

88. Two-way keys are not used with

(a) wooden sleeper

(b) steel sleeper

(c) cast iron sleeper

(d) concrete sleeper

89. Cotters are used to fix

(a) fish plates

(b) rail to sleeper

(c) bearing plate to sleeper

(d) tie bars to cast iron sleepers

90. Which one of the following is not elastic fastener?

(a) pandrol

(b) INR–202

(c) cotter

(d) lock spike

91. Side slopes for embankments is usually

(a) 1 vertical to 2 horizontal

(b) 1 vertical to 3 horizontal

(c) 2 horizontal to 1 vertical
(d) 3 horizontal to 1 vertical

92. In Indian Railways ruling gradient on plains is
(a) 1 in 100 to 1 in 150
(b) 1 in 150 to 1 in 200
(c) 1 in 200 to 1 in 300
(d) 1 in 300 to 1 in 400

93. Ruling gradient in Indian Railways on hilly areas is
(a) 1 in 100 to 1 in 150
(b) 1 in 150 to 1 in 200
(c) 1 in 200 to 1 in 300
(d) 1 in 300 to 1 in 400

94. On curves grade compensation provided in broad gauge is
(a) 0.02%
(b) 0.03%
(c) 0.04%
(d) 0.06%

95. Pusher gradient provided in Ghat section between Poona and Mumbai is
(a) 1 in 27
(b) 1 in 37
(c) 1 in 47
(d) 1 in 57

96. Maximum station yard gradient allowed is
(a) 1 in 200
(b) 1 in 300
(c) 1 in 400
(d) 1 in 600

97. Minimum station yard gradient to be provided is
(a) 1 in 250
(b) 1 in 500
(c) 1 in 750
(d) 1 in 1000

98. Maximum superelevation on broad gauge, if velocity permitted is 100 kmph is
(a) 40 mm
(b) 80 mm
(c) 120 mm
(d) 140 mm

99. The maximum cant deficiency for speed up to 100 kmph on broad gauge is
(a) 94 mm

(b) 76 mm
(c) 51 mm
(d) 38 mm

100. The maximum cant deficiency for speed up to 100 kmph on metre gauge permitted is
(a) 94 mm
(b) 76 mm
(c) 51 mm
(d) 38 mm

101. On degree of curve is equal to
(a) $\frac{1650}{R}$
(b) $\frac{1750}{R}$
(c) $\frac{1850}{R}$
(d) $\frac{1950}{R}$

where R is the radius of the curve.

102. Safe speed on curves in BG and MG is
(a) $3.65\sqrt{R-70}$
(b) $4.4\sqrt{R-70}$
(c) $4.58\sqrt{R}$
(d) $5.4\sqrt{R}$

103. Safe speed on narrow gauge with transition is
(a) $3.65\sqrt{R-6}$
(b) $4.4\sqrt{R-70}$
(c) $4.58\sqrt{R}$
(d) $5.4\sqrt{R}$

104. Maximum degree of curve permitted in Indian Railways in broad gauge is
(a) 10°
(b) 15°
(c) 20°
(d) 25°

105. Maximum degree of curve permitted in Indian railways on metre gauge is
(a) 10°
(b) 15°
(c) 20°
(d) 40°

106. The equilibrium superelevation to be provided is
(a) $\frac{GV^2}{126R}$

(b) $\frac{GV^2}{147R}$

(c) $\frac{GV^2}{167R}$

(d) $\frac{GV^2}{187R}$

where G = Gauge in metres, V = Velocity in kmph
R = Radius of curve in metres

107. Which one of the following is not correct? Length of transition curve shall be maximum of
(a) 0.008 C_a V_m
(b) 0.008 C_d V_m
(c) 0.72 C_a
(d) 0.72 C_d

where V_m = maximum permissible speed in kmph
C_a = actual cant on curve in mm
C_d = cant deficiency in mm

108. The shape of vertical curve used by Indian Railways is
(a) circular
(b) parabolic
(c) catenery
(d) lemniscate

109. For summit curve, the rate of change of gradients permitted is
(a) 0.005%
(b) 0.75%
(c) 0.10%
(d) 0.15%

110. For sag curves the rate of change permitted is
(a) 0.05%
(b) 0.75%
(c) 0.10%
(d) 0.15%

111. Which one of the following is not a method of plate laying?
(a) Side method.
(b) Telescope method.
(c) British method.
(d) American method.

112. In A-class block stations outer signal is provided at a distance ______ on broad gauge stations.
(a) 240 m
(b) 340 m
(c) 440 m

(d) 540 m

113. On metre gauge in A-class block station outer signal is provided at a distance ______ from station.
(a) 300 m
(b) 400 m
(c) 500 m
(d) 600 m

114. The station consisting of a block hut only and having home and warner signals is classified as
(a) A-class station
(b) B-class station
(c) C-class station
(d) D-class station

115. The stations which do not have any signal are known as
(a) A-class stations
(b) B-class stations
(c) crossing stations
(d) terminal stations

116. The stations which are provided to facilitate overtaking of trains are known as
(a) crossing stations
(b) way-side stations
(c) flag stations
(d) all the above

117. The station where traffic flow is in 3 or more directions is known as
(a) crossing station
(b) flag station
(c) terminal station
(d) junction

118. In broad gauge lines height of platform above the rails should be
(a) 0.23 m to 0.41 m
(b) 0.31 m to 0.41 m
(c) 0.76 m to 0.84 m
(d) 0.86 m to 0.96 m

119. The height of platform above the rails in narrow gauge station should be
(a) 0.23 m to 0.41 m
(b) 0.31 m to 0.41 m
(c) 0.51 m to 0.60 m
(d) 0.76 m to 0.84 m

120. In broad gauge stations clearance between track and edge of platform should be
(a) 1.35 m
(b) 1.67 m
(c) 1.8 m

(d) 2.0 m

121. In broad gauge stations minimum length of platform should be
(a) 180 m
(b) 240 m
(c) 300 m
(d) 400 m

122. At Sonepur in North-East Railways, length of platform is
(a) 460 m
(b) 520 m
(c) 666 m
(d) 736 m

123. In Indian Railways platforms are provided a slope of
(a) 1 in 20
(b) 1 in 30
(c) 1 in 40
(d) 1 in 50

124. Minimum width of platform specified is
(a) 3.66 m
(b) 4.66 m
(c) 5.66 m
(d) 6.66 m

125. At the end of platform, ramp should be provided with a slope of
(a) 1 in 4
(b) 1 in 6
(c) 1 in 8
(d) 1 in 10

126. The height of goods platform above top of rails should be
(a) 1.07 m
(b) 1.17 m
(c) 1.27 m
(d) 1.37 m

127. The maximum permissible gradient for a station yard is
(a) 1 in 800
(b) 1 in 600
(c) 1 in 400
(d) 1 in 300

128. The desirable gradient in a station yard is
(a) 1 in 400
(b) 1 in 600
(c) 1 in 800
(d) 1 in 1000

129. The yard for reception, sorting and reforming of goods trains is known as
(a) goods yard
(b) marshalling yard
(c) locomotive yard
(d) all of the above

130. A marshalling yard should be
(a) flat yard
(b) hump yard
(c) gravitational yard
(d) any of the above

131. The yard used for cleaning, repairing, servicing, watering, etc., is known as
(a) goods yard
(b) marshalling yard
(c) locomotive yard
(d) none of the above

132. The specified throw of switch on broad gauge is
(a) 89 mm
(b) 95 mm
(c) 104 mm
(d) 110 mm

133. Recommended value of heel clearance on broad gauge is
(a) 111 mm
(b) 122 mm
(c) 133 mm
(d) 144 mm

134. The minimum value of flange way clearance recommended is
(a) 60 mm
(b) 70 mm
(c) 80 mm
(d) 90 mm

135. When crossing number is 1 in $8\frac{1}{4}$, length of tongue rail on broad gauge should be
(a) 4.72 m
(b) 6.4 m
(c) 8.46 m
(d) 9.76 m

136. Which one of the following is not a type of crossing used in railways?
(a) square crossing
(b) rectangular crossing
(c) spring crossing
(d) ramped crossing

137. At road and rail level crossing, the crossing angle should not be less than

(a) 90°
(b) 60°
(c) 45°
(d) 30°

138. At road and rail level crossing, road should be straight at least for

(a) 30 m
(b) 40 m
(c) 50 m
(d) 75 m

139. For changing the direction of engine the device used is

(a) triangle
(b) turntable
(c) scotch block
(d) both (a) and (b)

140. The device used to move wagons sideway from one track to another track is

(a) turntable
(b) triangle
(c) traverse
(d) buffer stop

141. Beyond the dead end siding _______ provided to prevent the movement of vehicles

(a) buffer stop
(b) sand hump
(c) traverse
(d) any one of the above

142. Which one of the following is the duty of daily maintainance gang?

(a) Maintain track alignment.
(b) Maintain drainage.
(c) Maintain points and crossing.
(d) Check the fastenings and fixtures.

143. The tolerance on cross levels under loaded condition is

(a) 6 mm
(b) 8 mm
(c) 10 mm
(d) 12 mm

144. Tolerance on gauge under loaded condition is

(a) 1 to 1.5 mm
(b) 2 to 2.5 mm
(c) 3 to 3.5 mm
(d) 4 to 4.5 mm

145. An horizontal arm signal with V-shaped cut at free end and a V-shaped band is known as
(a) stop signal
(b) warner signal
(c) shunting signal
(d) starter signal
146. The signals in the form of circular discs with red bands on while backgrounds are
(a) stop signals
(b) warner signals
(c) shunting signals
(d) starter signals
147. In urban and suburban stations with heavy traffic, the type of signals preferred are
(a) semaphore type
(b) warner signals
(c) circular hands with bands
(d) colour light signals
148. The height of the centre of arm of a semaphore signal above the ground is
(a) 4.5 m
(b) 5.5 m
(c) 6.5 m
(d) 7.5 m
149. In a shunting signal if the red band is at 45°, it indicates
(a) stop
(b) proceed
(c) proceed cautiously
(d) none of the above
150. In emergencies the system of train operation is
(a) space interval system
(b) time interval system
(c) one engine system
(d) pilot guard system
151. In automatic block system of signalling the block length is
(a) from station to next station
(b) 15 to 20 km
(c) 10 to 15 km
(d) 5 to 7 km
152. In automatic block system when a train is in a block it puts the danger signal till the train moves over
(a) that block
(b) one more block
(c) two more signals

(d) none of the above

153. The system in which position of trains, and signals are displayed and controlled is known as
(a) absolute block system
(b) automatic block system
(c) centralised traffic control system
(d) automatic train control system

154. Which one of the following is the interlocking system used in railway signalling?
(a) Electronic system.
(b) Electrical system.
(c) Mechanical system.
(d) Key system.

II. *Match List I with List-II by selecting options given is item no. 155 and 156.*

155.

	List I		List II
A.	Suspended joint	1.	Cause greater incidence of rail end batter
B.	Supported joint	2.	Commonly adopted by Indian Railway
C.	Semi-supported joint	3.	Not used in India
D.	Bridging joint	4.	Need more maintenance

Codes:

(a)	A – 1	B – 3	C – 2	D – 4
(b)	A – 1	B – 2	C – 4	D – 3
(c)	A – 4	B – 1	C – 2	D – 3
(d)	A – 2	B – 1	C – 4	D – 3

156.

	List I		List II
A.	Stock rails	1.	Tapered rail at a point
B.	Tongue rails	2.	Distance between the running face tapered rail and fixed rail at a point
C.	Throw of switch	3.	Fixed rail at a point
D.	Check rail	4.	Rails provided while the opposite rail is jumping the gap

Codes:

(a)	A – 4	B – 1	C – 3	D – 2
(b)	A – 3	B – 1	C – 2	D – 4
(c)	A – 3	B – 2	C – 1	D – 4
(d)	A – 1	B – 2	C – 4	D – 3

III. *Select your answer according to the coding system given for the Assertion (A) and Reason (R) given in questions numbers 157 to 159.*

(a) Both A and R are true and R is the correct explanation of A.
(b) Both A and R are true but R is not the correct explanation of A.
(c) A is true but R is false.
(d) A is false but R is true.

157. Assertion A: Construction of larger gauges is costly.
Reason R: Larger gauges require flatter grades.

158. Assertion: Double headed rail was developed with the hope of using upside down, once a head is worn. But it did not serve the purpose.
Reason: Double headed rails workout to be heavy and hence costly.

159. Assertion: The expansion of rails is equal to $L\ a\ t$ is wrong.
Reason: Free expansion is prevented by the axial force developed due to fixing of rails to sleeper.

IV. *State whether the following statements are true or false question nos. 160 to 190.*

160. Break of gauge means widening of gauge in a track due to yielding of fish plates.
161. Initial cost is less but maintenance cost is more if breaking of gauge is adopted.
162. In bull headed rails foot is smaller than head.
163. The concept of expansion of rail is equal to $L\ a\ t$ is wrong.
164. The axial stress developed in rails due to rise in temperature is negligible.
165. Suspended joints provide greater elasticity to the track but they require more maintenance
166. In rails bridging joints are used on bridges only.
167. The distance between the flanges of wheels is slightly more than the gauge.
168. If the rim of wheels rests flat on the rails there will be lateral movement of the axle resulting in damage to the rails.
169. The rails are rested on inward slope of 1 in 20.
170. The surface of the rail, if becomes wavy is known as roaring rail.
171. Corrosion of rails is predominant in tunnels.
172. Exchange of inner and outer rails in curves is one of the means of reducing wear of rail.
173. Wear cannot be reduced by providing check rails for inner wheels in curved track.
174. Fish plates fit the web if rails.
175. CST–9 sleeper means trial No. 9 of committee for standard track.
176. CST–9 sleeper consists of two boxes connected by mild steel tie bar.
177. Two block concrete sleepers are having concrete blocks of trapezoidal sections.
178. The ballast thrown around the sleepers and loosely filled on slopes is called boxing of sleepers.
179. Bearing plates are used to connect rails at joints.
180. In case of natural cross slopes side drain is not required on higher side.
181. No signals are to be provided on momentum gradients.

182. In case of parabolic vertical curve the rate of change of gradient increases uniformly.

183. The operation of laying rails and sleepers over the compacted formation is known as plate laying method.

184. The yard used for reception, sorting and reforming of goods train is known as locomotive yard.

185. A station yard consists of passenger yard, goods yard, marshalling yard and locomotive yard.

186. The tapered rail at points is known as stock rail.

187. As crossing number increases the length of tongue rail also is to be increased.

188. If warner signal is in 'Off' position it indicates that stop signal ahead is at 'Off' position and hence can move first.

189. Electrical interlocking system is the modern and sophisticated system of interlocking:

Answers to Multiple-Choice Questions

1. (c)	2. (a)	3. (a)	4. (d)	5. (c)
6. (d)	7. (b)	8. (b)	9. (a)	10. (b)
11. (a)	12. (b)	13. (d)	14. (c)	15. (d)
16. (c)	17. (a)	18. (a)	19. (c)	20. (d)
21. (a)	22. (a)	23. (d)	24. (d)	25. (d)
26. (d)	27. (d)	28. (a)	29. (b)	30. (b)
31. (d)	32. (c)	33. (d)	34. (d)	35. (d)
36. (d)	37. (b)	38. (b)	39. (d)	40. (b)
41. (d)	42. (d)	43. (a)	44. (b)	45. (c)
46. (c)	47. (a)	48. (d)	49. (c)	50. (a)
51. (c)	52. (c)	53. (a)	54. (b)	55. (c)
56. (a)	57. (a)	58. (d)	59. (c)	60. (d)
61. (c)	62. (b)	63. (a)	64. (c)	65. (d)
66. (d)	67. (d)	68. (c)	69. (d)	70. (d)
71. (d)	72. (b)	73. (d)	74. (c)	75. (c)
76. (d)	77. (b)	78. (d)	79. (d)	80. (c)
81. (b)	82. (b)	83. (c)	84. (d)	85. (c)
86. (a)	87. (d)	88. (a)	89. (d)	90. (c)
91. (c)	92. (b)	93. (a)	94. (c)	95. (b)
96. (c)	97. (d)	98. (d)	99. (b)	100. (c)
101. (b)	102. (b)	103. (a)	104. (a)	105. (b)
106. (a)	107. (d)	108. (b)	109. (c)	110. (a)
111. (c)	112. (d)	113. (b)	114. (c)	115. (c)
116. (d)	117. (d)	118. (c)	119. (a)	120. (b)
121. (c)	122. (d)	123. (b)	124. (a)	125. (b)
126. (a)	127. (c)	128. (d)	129. (b)	130. (d)
131. (c)	132. (b)	133. (c)	134. (a)	135. (a)
136. (b)	137. (c)	138. (a)	139. (d)	140. (c)
141. (b)	142. (d)	143. (c)	144. (a)	145. (b)
146. (c)	147. (d)	148. (c)	149. (c)	150. (d)
151. (d)	152. (c)	153. (c)	154. (a)	155. (c)
156. (b)	157. (a)	158. (c)	159. (a)	160. False

161. True	162. True	163. True	164. True	165. True
166. False	167. False	168. True	169. True	170. True
171. True	172. True	173. False	174. True	175. True
176. True	177. False	178. True	179. False	180. False
181. True	182. False	183. True	184. False	185. True
186. False	187. False	188. True	189. True	

16

Tunnelling

* The first tunnel built in the world is in Babylon in 2000 BC. It was 900 m long with 3.6 m × 4.5 m in section.

* Advantages of tunnels are:
  1. Reduction in distance of travel
  2. Provision of easier gradients
  3. Reduction in maintenance cost
  4. Avoids interference with surface and air rights
  5. Freedom from snow and iceberg hazards

* Tunnel survey consists of
  1. Preliminary surveys
  2. Setting out of the tunnel centre-line on the surface
  3. In case of tunnels in hilly regions, tunnel ends should be established by triangulation.
  4. After the coordinates of various portals and shafts have been finalised setting out is started from various portals and shafts.
  5. Transfer the alignment through shafts.

* Gradient: Unless special provision is made for proper drainage, the gradient provided should not be less than 5%.

Methods of tunnelling in soft strata

1. In firm ground
   (a) Full face method
   (b) Top heading and benching
   (c) Drift method
2. Tunnelling in soft ground
   (a) Multiple drift method
   (b) Forepoling method
3. Tunnelling in running ground
   (a) Needle beam method
   (b) Flying arch method
   (c) Liner plate method

* Methods of supporting roof and sides in drift methods:
  1. American method
  2. English method
  3. Belgiam method
  4. German method

5. Austrian method.

Methods of tunnelling in rocks It involves drilling holes in the rock face, loading the holes with explosives, blasting, removing and disposing of broken rock. The commonly adopted methods are:

1. Full face method
2. Top heading and benching
3. Bottom heading and stoping
4. Drift method—top drift, bottom drift, side drift

Commonly adopted drilling patterns are:

1. Horizontal wedge cut
2. Pyramid cut
3. Fan out
4. V-cut
5. Cylinder cut
6. Burn cut

Explosives used are gelatine, ammonia dynamite and semi-gelatine.

* Depending upon the strength and durability requirements various materials are used for tunnel lining. Brick lining, stone masonry lining, timber lining, concrete lining, cast iron lining, cast steel lining, structural steel lining are commonly adopted.

* Pack grouting is required between rock and concrete lining and also between the steel lining and concrete lining. If fissures are seen and seepage of water is observed pressure grouting is required.

16.1 TUNNEL DRAINAGE

Drainage problems exist before starting, during construction and also after constructing the tunnel. Predrainage work involves diverting water entering the tunnel. During construction pumping of water may be resorted wherever necessary. Permanent drainage work is necessary to maintain tunnels. They are met by provision of longitudinal drains, continuous open gutters, concrete lining and grouting with cement chemicals.

Tunnel Ventilation, Lighting and Mucking

* Wherever natural ventilation is not possible mechanical ventilation should be resorted. Mechanical ventilation methods are blowing fresh air, providing exhaust air by ducts or combination of blowing in and exhaust system.

* Safe and sufficient lighting of tunnels should be provided for inspection of tunnels.

* For hauling of excavated materials during construction the following methods are employed:

1. Hauling on rails
2. Hauling on pneumatic tyres
3. Using conveyers, etc.

MULTIPLE-CHOICE QUESTIONS

I. *Select correct option from the list given below for each questions 1 to 20.*

1. First tunnel built in the world was in Babylon, in the year
(a) 2000 BC
(b) 200 BC
(c) 200 AD
(d) 600 AD

2. The length of the first tunnel built in the world of Babylon in the year 2000 BC was
(a) 300 m
(b) 500 m
(c) 700 m
(d) 900 m

3. In case of tunnels in hilly areas to align tunnel ends use
(a) direst ranging
(b) reciprocal ranging
(c) triangulation
(d) any one of the above

4. Which one of the following is not a method of tunnelling in firm soft strata?
(a) Needle beam method
(b) Full face method
(c) Top heading and benching
(d) Drift method

5. Which one of the following is not a method of tunnelling in running ground?
(a) Needle beam method
(b) Flying arch method
(c) Liner plate method
(d) Top heading and benching method

6. In tunnel, unless special provision is made for proper drainage, the gradient should not be more than
(a) 5%
(b) 7%
(c) 10%
(d) 12%

7. The method employing steel lined plates and air compressors for driving them is known as
(a) needle beam method
(b) tunnelling with liner plates
(c) shield method
(d) none of the above

8. Which one of the following is not a method of supporting roof and sides in multiple drift method of tunnelling?
(a) Belgium method
(b) German method
(c) Austrian method

(d) Japanese method

9. The method in which roof arch is completed before excavating a trench for laying muck track is known as
   (a) American method
   (b) English method
   (c) Belgium method
   (d) Austrian method

10. Drift method of tunnelling is used to construct tunnel in
   (a) soft ground
   (b) running ground
   (c) rocks
   (d) broken grounds

11. Which one of the following is not a drilling pattern adopted in tunnelling?
   (a) Fan cut
   (b) V-cut
   (c) Cylinder cut
   (d) Vertical wedge cut

12. The drilling pattern in which 3 to 4 converging holes are so directed that they meet at point further is known as
   (a) fan cut
   (b) pyramid cut
   (c) V-cut
   (d) burn cut

13. The explosive used in tunnelling is
   (a) blastic gelatine
   (b) semi-gelatine
   (c) ammonia dynamite
   (d) any one of the above

14. The explosive recommended for blasting a soft rock is
   (a) blasting gelatine
   (b) special gelatine 9 to 40%
   (c) ammonia dynamite
   (d) semi-gelatine

15. The method of lining in tunnels is
   (a) brick masonry lining
   (b) stone masonry lining
   (c) concrete lining
   (d) all the above

16. Pack grouting with concrete is required between
   (a) rock and concrete lining
   (b) steel lining and concrete lining

(c) both (a) and (b)

(d) none of the above

17. Which one of the following is not a permanent drainage work
(a) pumping water
(b) providing longitudinal drains
(c) concrete lining
(d) grouting with cement chemicals

18. Diverting water entering tunnel is
(a) predrainage work
(b) permanent drainage work
(c) drainage work during construction
(d) all the above

19. Mechanical ventilation method used in tunnels consists of
(a) blowing fresh air
(b) providing exhaust air by ducts
(c) both (a) and (b)
(d) none of the above

20. For mucking the method employed is
(a) hauling on rails
(b) hauling on pneumatic tyres
(c) using conveyers
(d) all the above

II. *Match List I with List II by selecting options given Question Nos. 21 and 22.*

21.

	List I		**List II**
	Methods of tunnellig		**Situation in which adopted**
A.	Full face method	1.	For large size tunnels by making pilot tunnel.
B.	Top heading and benching	2.	In case of soft soil requiring instantaneous support.
C.	Drift method	3.	For soft strata where excavated portion cannot hold itself till mucking and supporting is completed
D.	Forepoling method	4.	For small tunnels where soil is comparatively firm

Codes:

(a)	A – 3	B – 2	C – 1	D – 4
(b)	A – 2	B – 3	C – 4	D – 1
(c)	A – 4	B – 2	C – 1	D – 3
(d)	A – 4	B – 3	C – 1	D – 2

22.

	List I Tunnel shape		List II Suitable for
A.	Rectangular	1.	Soft soil
B.	Circular	2.	Soft rock
C.	Horseshoe	3.	Non-cohesive
D.	Segmental roof	4.	Sub-bags

Codes:

(a)	A – 3	B – 2	C – 1	D – 4
(b)	A – 2	B – 3	C – 1	D – 4
(c)	A – 3	B – 1	C – 2	D – 4
(d)	A – 1	B – 3	C – 4	D – 2

III. *Select your answer according to the coding system given for the Assertion (A) and Reason (R) given in question nos. 23 and 24*

(a) Both A and R are true and R is the correct explanation of A.
(b) Both A and R are true but R is not the correct explanation of A.
(c) A is true but R is false.
(d) A is false but R is true.

23. Assertion: Full face method is suitable for tunnelling in comparatively firm soil.
Reason: In comparatively firm soil, excavated portion can hold ifself for sufficient time to permit mucking and supporting operations to be completed.

24. Assertion: Tunnels in rock are provided with concrete lining.
Reason: Tunnel is to be given a neat finish.

IV. *State whether the following statements are True or False in question Nos. 25 and 26.*

25. Pack grouting is used to seal fissures and seepage points in tunnels.

26. Lighting in tunnels is necessary for the purpose of inspection.

Answers to Multiple-Choice Questions

1. (a)	2. (d)	3. (c)	4. (a)	5. (d)
6. (a)	7. (b)	8. (d)	9. (c)	10. (c)
11. (d)	12. (b)	13. (d)	14. (c)	15. (d)
16. (c)	17. (a)	18. (a)	19. (c)	20. (d)
21. (a)	22. (c)	23. (d)	24. (b)	25. False
26. True				

17

Docks and Harbour Engineering

* Harbour is a sheltered area of the sea in which vessels can be launched, built or taken for repair or could seek refuge in time of storm and provide facilities for loading and unloading of cargo and passengers.
* Port is a harbour where terminal facilities like stores, landing of passengers and cargo are added.

17.1 TYPES OF HARBOURS

1. *Natural harbour* It is an inlet protected from storms and waves by natural configuration of land. Mumbai, Kandla and Karwar are examples of natural harbours.

2. *Semi-natural harbour* The harbour in which natural configuration of land prefects the harbour on sides only and needs man-made protection at the entrance. Vishakhapatnam is a semi-natural harbour.

3. *Artificial harbour* It is harbours protected by man-made structures like breakwaters or by dredging. Chennai is a man-made harbour.

Classification Based on Utility

1. Harbour of refuge: Used to anchor ships in storms
2. Fisheries harbours
3. Commercial harbours
4. Military harbours: Seabird at Karwar is a military harbour

Classification Based on Location

1. Canal harbour
2. Lake harbour
3. River harbour
4. Sea harbour

Natural Phenomenon Influencing Location of Harbour on Seashore

1. *Littoral Drift* The process of carrying the drifting sand and depositing it on seashore is known as *littoral drift*. If a harbour is constructed in the path of the littoral drift, there will be accumulation of sand on one side and erosion on the other side of the harbour. Groynes are used to protect the shore by trapping littoral drift.

2. *Tides* The artificial rise and lower of mean sea level periodically is known as tide. It is observed that the general water level rises and falls, approximately in a period of twelve hours and twenty-five minutes. It is also observed that much higher water levels and much lower water levels occur on new and full moons. These tides are called *spring tides*. Water levels which occur about seven days from new and full moons are moderate and are called *neap tides*. The total height of spring tides is about 1.5 to 2.0 times that of neap tides.

3. *Waves and winds* Wind generates waves on water bodies. In maritime works, speed of wind is expressed in knots. One nautical mile is the length of one minute of arc of a meridian on earth surface. Since radius of earth of equator is about 6378 km, 1 nautical mile = 6378 >× $\frac{\pi}{180}$ >× $\frac{1}{60}$ km, i.e., 1 nautical mile is 1.852 km. Hence, one knot is 1.852 km/hour.

In 1805, Admiral Beafort of British Navy classified wind into 12 categories starting from calm (Beafort No. 0) to Hurricane (Beafort No. 12) depending upon velocity is km/hour. A wind is said to be calm if velocity is about 1.6 km and is said to be hurricane if it is above 120 km/hour.

* Height and length of wave: Thomas Stevenson gave a formula for estimating wave height in metres as $h = 0.34\sqrt{F}$, where F is the fetch in km. However, waves cannot attain full height in shallow water. No wave can have a height greater than the depth of water.

Berlin's formula for finding the wavelength is

$$L = \frac{t^2}{2\pi} \times g = 1.56\, t^2$$

where L = Length in metres and t = period in seconds.

17.2 FEATURES OF A HARBOUR

1. *Harbour entrance* Depth and width required at the entrance are more than those required in the channel since it is more exposed to waves. Entrance should be wide enough for navigational requirement. However, it should not be too wide to increase the wave height within the harbour.

2. *Approach channel* The dredged fairway through which ships proceed from the open sea to the harbour basin is known as approach channel. The depth should be sufficient for navigation of design vessels at all the time.

3. *Turning basin* It is the area required for manoeuvring the ship when it enters or leaves the berth, so that it moves head on.

4. *Sheltered basin* It is the area protected by shore and breakwaters.

5. *Breakwaters* The protective barrier constructed to enclose harbours and to keep the waters undisturbed by the rough sea are called breakwaters. Types of breakwaters used are

1. Heap or mound breakwater
2. Mound with superstructure
3. Upright wall breakwater.

Breakwaters should be designed to resist hydrostatic forces, action of wind and waves, solvent action of seawater and sea insects. The breakwater height is 1.2 to 1.25 times the height of the waves expected, above the mean sea level.

6. *Wharves and quays* The platforms provided along the shore or breakwater for ships to come close enough for loading or unloading are called wharves. Wharves along and parallel to the shore are generally called quays. Wharves and quays have backfill of earth or other materials and have wide platform at top.

*7. **Jetties*** A jetty is a narrow strip structure projecting from the shore into water with berths on one or both sides.

*8. **Lock and locked basin*** Locked basin is an enclosed basin wherein a number of vessels can be berthed and has an entrance controlled by lock gate.

*9. **Fender*** The cushion provided on the face of a jetty for absorbing shocks by ships is known as fender. They may be rubber strips, timber grills, concrete or rubber fenders.

*10. **Slip*** The space of water between two adjacent piers where ships are berthed is known as slip. For safe navigation and provide enough space for barges to load and unload, the slip should be three to four times the beam of largest ship to be accommodated.

*11. **Docks*** Docks are enclosed areas for berthing ships, to keep them afloat at a uniform level. There are two types of docks:

1. *Wet docks:* Docks used for berthing of vessels to facilitate loading and unloading of passengers and cargo.
2. *Dry docks:* The docks used for repairs of vessels are known as dry docks.

*12. **Aprons*** The open space left immediately in front of the berth is known as apron. It is used for loading, unloading and for installing railway track, road or conveyers. The width of apron usually varies from 10 m to 25 m, depending upon the traffic.

13. A dock requires transit sheds, warehouses, cold storages and guardhouse, etc.

Maintenance Dredging

Dredging is defined as excavation under water. To maintain navigation depth dredging is required.

* Types of dredges:
  1. Dipper dredger
  2. Grapple dredgers
  3. Bucket elevator or ladder dredgers
  4. Suction dredgers

Navigational Aids

For safe, efficient and comfortable travel of ships into harbour navigation aids are required. They are in the form of illuminated signals or lights. They may be classified as the following.

*1. **General lights*** They guide the ships along the coast and through rivers serving as approaches to more than one harbour. They may be light houses, or light ships.

*2. **Local lights*** They guide the ships to harbours through approach channels to the berths. They are light houses, fixed structures, channel markers, floating buoys, lights on shore, wharves, breakwaters, etc.

MULTIPLE-CHOICE QUESTIONS

I. *Select the correct option from the following questions 1 to 22.*

1. Kandla is a
   (a) military harbour
   (b) artificial harbour
   (c) natural harbour
   (d) semi-natural harbour

2. The process of carrying the drifting sand and depositing it on seashore is known as
   (a) slip
   (b) littoral drift
   (c) fender
   (d) none of the above

3. Which one of the following protects the shore by trapping littoral drift?
   (a) Sea walls
   (b) Groynes
   (c) Breakwaters
   (d) Wharves

4. Spring tides are the tides in
   (a) the noon
   (b) midnight
   (c) new and full moons
   (d) 7 to 8 days after new and full moons.

5. Neap tides are the tides in
   (a) noon
   (b) midnight
   (c) new and full moons
   (d) 7–8 days after new and full moons

6. The total height of tides is about ______ times that of neap tides.
   (a) 1.2 to 1.4
   (b) 1.5 to 2.0
   (c) 2 to 2.4
   (d) 2.5 to 3.0

7. 1 knot is
   (a) 1.252 kmph
   (b) 1.522 kmph
   (c) 1.852 kmph (c) 1.952 kmph

8. Beafort classified wind in ______ categories
   (a) 0 to 6
   (b) 0 to 8
   (d) 0 to 12
   (d) 0 to 15

9. Beafort number of hurricane is

(a) 6
(b) 8
(c) 10
(d) 12

10. Beafort number 12 for wind means more than

(a) 80 kmph
(b) 100 kmph
(c) 120 kmph
(d) 150 kmph

11. Thomas Stevenson's formula for estimating height of wave in metres is

(a) 0.22 $\sqrt{F}$
(b) 0.34 $\sqrt{F}$
(c) 0.42 $\sqrt{F}$
(d) 0.54 $\sqrt{F}$

where F is the fetch in km

12. If the fetch is 225 km, according to Thomas Stevenson, height of wave will be

(a) 5.1 m
(b) 6.8 m
(c) 8.1 m
(d) 9.6 m

13. Berlin's formula for finding wavelength in metres is

(a) 1.18 t^2
(b) 1.28 t^2
(c) 1.36 t^2
(d) 1.56 t^2

where t = period in seconds

14. The area required for manoeuvring the ship when it enters or leaves the berth so as to move head on is known as

(a) approach channel
(b) turning basin
(c) sheltered basin
(d) jetty

15. The protective barrier constructed to enclose harbours is known as

(a) breakwater
(b) wharves
(c) jetty
(d) quay

16. The breakwaters height is _______ times the expected wave heights above the mean sea level

(a) 1.2 to 1.25

(b) 1.3 to 1.35

(c) 1.4 to 1.45
(d) 1.5 to 1.55

17. Wharves are the platforms provided
(a) along shore
(b) along breakwaters
(c) perpendicular to shore
(d) both (a) and (b)

18. Quays are platforms provided
(a) along shore
(b) breakwaters
(c) perpendicular to shore
(d) both (a) and (b)

19. A narrow strip structure projecting from the store into water with berth on one or both sides is known as
(a) jetty
(b) wharves
(c) breakwaters
(d) dock

20. The space of water between two adjacent piers where ships are berthed is known as
(a) locked basin
(b) slip
(c) jetty
(d) fender

21 The minimum width of apron provided is
(a) 8 m
(b) 10 m
(c) 12 m
(d) 15 m

22. Which one of the following is not a type of dredger?
(a) Dipper dredger
(b) Grapple dredger
(c) Ladder dredger
(d) Compression dredger

II. *Match List I with List II by selecting the options given question No. 23.*

23.

	List I		List II
A.	Natural harbour	1.	Vishakapattanam
B.	Seminatural harbour	2.	Seabird at Karwar
C.	Artificial harbour	3.	Mumbai

D.	Military harbour	4.	Chennai

Codes:

(a)	A – 3	B – 1	C – 4	D – 2
(b)	A – 1	B – 4	C – 2	D – 3
(c)	A – 2	B – 3	C – 1	D – 4
(d)	A – 2	B – 4	C – 3	D – 1

III. *Select your answer according to the coding system given for the Assertion (A) and Reason (R) given below in question numbers 24 to 26.*

(a) Both A and R are true and R is the correct explanation of A.
(b) Both A and R are true but R is not correct explanation of A.
(c) A is true but R is false.
(d) A is false but R is true.

24. Assertion: 1 nautical mile is 1.852 km.
Reason: It is length of one minute of arc of a meridian on earth surface.

25. Assertion: Depth and width required at the entrance are less than those required in the channel.
Reason: Entrance is more exposed to waves than entrance channel.

26. Assertion: Large size stones are used in stone revetment in shore protection.
Reason: Resistance of stone to waves is proportional to its volume and wave force is proportional to the exposed area of stone.

IV. *State whether the following statements are True or False in question nos. 27 to 35.*

27. Harbour is a sheltered area for vessels where terminal facilities like storing, landing facilities for passengers and cargo are added.
28. Port is a sheltered area of the sea in which vessels can be launched and seek refuge in time of storm.
29. The artificial raise and lower of mean sea level periodically is known as tide.
30. Docks used for berthing of vessels to facilitate loading and unloading of passengers and cargo are known as dry rocks.
31. The docks used for repairs of vessels are known as dry docks.
32. The open space left immediately in front of a berth is known as apron.
33. The cushion provided on the face of a jetty for absorbing impact of ships is known as fender.
34. The lights guiding ships along the coast are classified as local lights.
35. Lights on shores, wharves and breakwaters are regarded as local navigation aids.

Answers to Multiple-Choice Questions

1. (c)	2. (b)	3. (b)	4. (c)	5. (d)
6. (b)	7. (c)	8. (c)	9. (d)	10. (c)
11. (b)	12. (a)	13. (d)	14. (b)	15. (a)
16. (a)	17. (d)	18. (a)	19. (a)	20. (b)
21. (b)	22. (d)	23. (a)	24. (a)	25. (d)
26. (a)	27. False	28. False	29. True	30. False
31. True	32. True	33. True	34. False	35. True

18

Bridge Engineering

* A bridge is a structure which provides a passage over an obstacle like river, channel, valley or a road, without closing the way underneath. The passage required may be for pedestrians, roads, railway or for a pipeline.

18.1 HISTORY OF BRIDGES

* Getting idea from fallen trees and monkeys jumping from one tree to another, the development of bridge engineering started along with civilization.
* Construction of wooden bridge dates back to 2650 BC in Egypt. India can boast of bridge built during Ramayana connecting India and Sri Lanka. Masonry bridge construction dates back to 100 to 500 BC in various parts of the world.

Types of Bridges

Bridges may be classified on the basis as given below:

1. **Purpose:** Road bridges, railway bridges, foot bridges, aqueduct (for carrying canal water).viaduct (for taking roads across valleys).
2. **Alignment:** Square bridge, if it is at right angles to obstacle, skew bridges if it is not at right angles to obstacle.
3. **Life period:** Permanent and temporary. Temporary bridges are built during military operations, during project execution or in rescue operations.
4. **Span:** Culverts – if less than 6 m
   Minor bridge – if 8 to 30 m
   Major bridge – if 30 to 230 m
   Long span bridges – if more than 120 m.
5. **Position of high flood level**
   Submersible – flow of water above bridge deck level permitted during heavy rains.
   Non-submersible – all permanent bridges have deck level above the high flood level.
6. **Fixed or movable:** Normally, fixed bridges are built but movable bridges are built across navigational channels so as to avoid obstacles to navigation. Movable bridges may be further classified as (a) swing bridges (b) lift bridges (c) bascule bridges. In case of bascule bridges entire superstructure is rotated in vertical plane to 70° to 80° suitable hinges and counterweights are provided for easy operations.
7. **Location of Bridge Floor:** Bridge is classified as deck, semi-through or through type depending upon whether the bridge is on top intermediate or at bottom level of the super- structure.
8. **Superstructure:** On this basis bridges may be classified as
   (a) girder bridge
   (b) portal frame bridge

(c) truss bridge
(d) cantilever bridge
(e) arch bridge
(f) suspension bridge.

9. **Materials:** On this basis bridges may be classified as timber bridges, masonry bridges, R.C.C. bridges, prestressed concrete bridges and steel bridges.

10. **Types of connection:** Under this steel bridges are classified as riveted, bolted and welded bridges.

11. **Low cost bridges:**
(a) wooden bridges
(b) floating bridges
(c) movable bridges

Terminology

1. **Pier:** It is an intermediate support of an multi-span bridge.
2. **Abutment:** End supports of the superstructure are known as abutments.
3. **Bed block:** It is the block on the top of pier or abutment which receives load from the bearings and disperses to the pier.
4. **Back fill:** The material used to fill the space at the back of abutment is known as back fill. Stone, gravel, sand, etc., are used for back filling. It should be well compacted.
5. **Kerb:** It is the raised portion of the edge of carriageway on both sides. It checks the vehicle going out of the carriageway. Width and height of kerbs are 600 mm and 225 mm. The roadside slope of kerb is 1 in 8 up to a height of 200 mm and the top portion is curved.
6. **Linear waterways:** For stream with non-erodible banks it is taken as the distance between banks at high flood level. In case of alluvial streams it is determined by Lacey's formula as $L = C\sqrt{Q}$ where C may vary from 4.5 to 6.3, depending upon local conditions.
7. **Effective linear way:** The total width of waterway minus effective width of foundation of piers is known as effective linear way.
8. **Effective span:** The centre-to-centre distance between any two adjacent supports is known as effective span.
9. **Economical waterway:** If a waterway is kept somewhat in excess of, the scour depth is normal and hence foundation depth is normal. If waterway is reduced cost of superstructure is reduced since length of the superstructure is reduced but it may increase scour depth and hence, foundation depth. Sometimes it may be necessary to provide stone protection in pitching, apron, toe walls, cut-off walls, etc. Therefore, there is limit beyond which confining a river should not be attempted.
10. **Wing walls:** They are retaining walls constructed to retain the earthwork of approach embankment behind the abutments.
11. **Curtain wall:** The floor provided between masonry walls below river bed is known as curtain wall.

12. **Bearings:** Bearings are the devices used in long span bridges to avoid development of high stresses in main girders due to temperature changes and deflections.

1. Shallow or fixed plate bearings are suitable for spans up to 12 m.
2. Deep cast base bearings are suitable for spans 12 to 20 m.
3. Rocker bearings are suitable for spans more than 20 m.
4. Sliding plate bearings are provided at one end of the girder of span 12 to 20 m.

18.2 SELECTION OF BRIDGE SITE

* An ideal site for a bridge across a stream/river should have the following characteristics:
  1. Stream should be straight.
  2. Stream should be narrow with well defined and firm banks.
  3. There should not be whirls and cross currents.
  4. There should be high banks above high flood level on each side.
  5. The site should be at reasonable proximity to the direct alignment of road.
  6. The site should be geologically sound.
  7. As far as possible it should not need river training works and avoid excessive under water construction works.
* Preliminary survey is carried out by studying toposheets and walkover survey. Two to three alternative sites selected and preliminary data about characteristics of the stream, subsoil conditions and cost of land acquisition collected. Looking at merits and demerits of all the alternative sites, the one which satisfies most of the requirements for an ideal site is selected.
* Detailed survey is then carried out of the selected site which includes.
  1. Plane table survey of 200 to 500 m upstream and downstream.
  2. Longitudinal section and cross sections at 50 m interval on upstream and downstream side is determined.
  3. Nature of stream and bed materials noted.
  4. Geological data of the site collected.
  5. Soil is investigated to determine type of foundation and depth of foundation.
  6. Survey of locally available material is carried out.
  7. Traffic survey on the existing and proposed route carried out. They may be straight, splayed or return type.

Bridge Design

* **Width of bridges:** It is based on traffic survey. It may be single lane or double lane with pedestrian platform on only one side or on both side.
* **Length of bridge:** It depends upon the waterway.
* **Height of bridge:** It is 1.2 to 1.5 m above HFL.
* **Spans:** It depends upon the type of superstructure proposed.

  Masonry arch : 3 to 15 m
  Slab bridges : Upto 9 m

Girder and beams : 10 to 60 m

Truss bridges : 30 to 375 m with simply supported ends.

Suspension bridges : Over 500 m so for maximum span built in 1990 m

Cable stayed bridges : 300 to 600 m

* **Abutments:** Commonly used abutments are shown in Fig. 18.1.

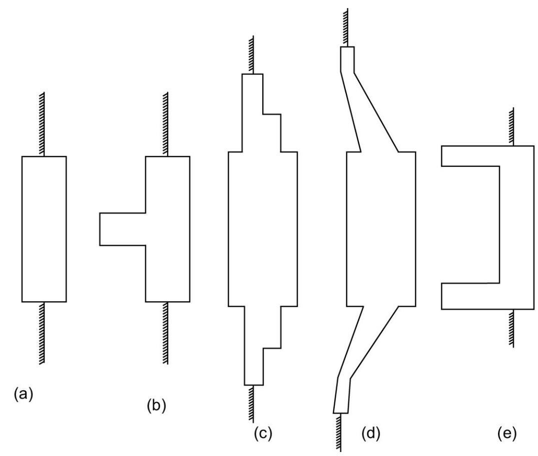


Fig. 18.1 Shape of abutments

(a) Straight abutment
(b) T-shaped abutment
(c) Abutment with straight wing walls
(d) Abutment with splayed wing wall
(e) U-abutment

* Abutments (a), (b), (c) are not suitable for waterways since water penetrates behind the abutment and damages embankment.

* **Piers:** Depending upon the waterways requirement, and type of superstructure, number of piers are determined. Types of piers generally used are:

1. Masonry piers
2. R.C.C. piers

1. Masonry piers May be with brick, stone or plain concrete. In concrete piers richer concrete may be used for skin and poor concrete for heart. Using plain concrete about 600 mm height may be built every day. All masonry piers are provided with rich concrete at top to serve as bed block to receive bearing and distribute load uniformly to the lower portion of pier. Various types of shapes of piers are used as shown in Fig. 18.2 commonly used pier shape is with end triangular shape making an angle of 30° to 60° with side.

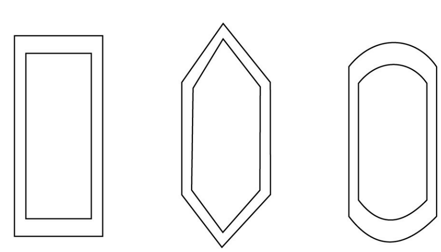


Fig. 18.2 Masonry piers

2. R.C.C. piers R.C.C. piers of various shapes are used. They may be rectangular, dumb-bell type or cylindrical. They may be with solid diaphragm connecting to portions of dumb-bells or with open diaphragm. Sometimes steel or R.C.C. trestle bents are also used.

* The forces acting on piers are:

1. Vertical load or inclined reaction from the superstructure
2. Water pressure
   (a) Static water pressure
   (b) Dynamic pressure due to flow of water
   (c) Impact due to cross currents
3. Tractive force
4. Wind pressure
5. Earthquake forces

Foundations

It may be spread foundation, pile foundation or well foundation. The choice of foundation depends upon load expected and soil properties.

Superstructures

Superstructures of various materials and types are designed for the following loads.

1. Dead load
2. Live load
3. Impact load
4. Wind load
5. Longitudinal forces
6. Temperature stresses
7. Seismic forces
8. Erection stresses
9. Horizontal thrust due to water for live loads an road bridges IRC loadings and for rail bridges the loads specified by the Railway Board may be referred.

Permanent Small Bridges

Causeways and culverts may be considered permanent small bridges.

1. Causeways It is a submersible bridge, provided across a nullah or stream. These are adopted for roads which are of minor importance. They do not have foundation, pier or abutment. They are concrete slabs and stone pitching at bed level or slightly higher level of stream. Causeways may be classified as:

1. Flush causeway
2. Low level causeway
3. High level causeway

2. Culverts Culvert is a small bridge, the maximum span not exceeding 6 m. It may have 3 to 4 spans. Types of culverts used are:

1. Pipe culvert

2. Box culvert

3. Slab culvert
4. Beam and slab culvert
5. Arch culvert

MULTIPLE-CHOICE QUESTIONS

I. *Select the correct choice from the following questions 1 to 34.*

1. Generally, a culvert has span less than
   (a) 3 m
   (b) 6 m
   (c) 9 m
   (d) 12 m
2. A bridge of span 25 m may be treated as
   (a) culvert
   (b) minor bridge
   (c) major bridge
   (d) long span bridge
3. A bridge of more than ______ span is treated as long span bridge.
   (a) 30 m
   (b) 60 m
   (c) 90 m
   (d) 120 m
4. As far as possible the alignment of a bridge should be
   (a) square
   (b) skew
   (c) curved
   (d) none of the above
5. Temporary bridges are built during
   (a) military operations
   (b) project executions
   (c) rescue operations
   (d) all the above
6. Movable bridges are built across
   (a) streams
   (b) rivers
   (c) channels
   (d) dry valley
7. A bascule bridge is a
   (a) fixed bridge
   (b) movable bridge

(c) deck bridge
(d) through bridge

8. Which one of the following is not a low cost bridge
(a) wooden bridge
(b) masonry bridge
(c) floating bridge
(d) movable bridge

9. The end supports of a bridge superstructure are known as
(a) wing walls
(b) piers
(c) abutments
(d) bed blocks

10. The floor provided between masonry walls below the river bed is known as
(a) wing wall
(b) curtain wall
(c) bed block
(d) kerb

11. Width and height of kerbs on bridges are generally ______ respectively.
(a) 600 mm and 225 mm
(b) 450 mm × 200 mm
(c) 225 mm × 600 mm
(d) 200 mm × 450 mm

12. The roadside slope of kerb is
(a) 1 in 5
(b) 1 in 8
(c) 1 in 10
(d) 1 in 15

13. In case of alluvial streams linear waterway is determined by Lucey's formula as $L = C\sqrt{Q}$ where Q is discharge and C is ______ depending upon the local conditions:
(a) 1.2 to 2.2
(b) 2.4 to 3.5
(c) 3.7 to 4.2
(d) 4.5 to 6.3

14. Which one of the following is not the correct statement? Bridge site
(a) be narrow
(b) should not possess high banks
(c) be at reasonable proximity to the direct alignment of road
(d) be geologically sound

15. Preliminary survey should be carried out to at least ______ distance on upstream and downstream side

(a) 200 to 500 m

(b) 500 to 1000 m
(c) 1000 to 1500 m
(d) 1500 to 2000 m

16. In preliminary survey cross sections at ______ interval should be determined.
(a) 20 m
(b) 35 m
(c) 50 m
(d) 65 m

17. Height of bridge is kept ______ above high flood level.
(a) 1.2 to 1.5 m
(b) 1.8 to 2.1 m
(c) 2.2 to 2.5 m
(d) more than 2.5 m

18. Masonry arch bridges are used to span
(a) less than 3 m
(b) 3 to 15 m
(c) 15 to 20 m
(d) 20 to 30 m

19. Slab bridges are used to a maximum span of
(a) 6 m
(b) 9 m
(c) 12 m
(d) 20 m

20. The cross section of a pier may be
(a) rectangular
(b) with triangular edges towards upstream and downstream sides
(c) with curved faces on upstream and downstream sides
(d) all the above

21. The height of concrete pier may be raised by ______ every day during the construction
(a) 600 mm
(b) 900 mm
(c) 1200 mm
(d) 1500 mm

22. R.C.C. piers of the following shapes are not used
(a) rectangular
(b) dumb-bell type
(c) trestle bent
(d) T-shape

23. In the design of piers, the water pressure to be considered is
(a) static pressure

(b) dynamic pressure
(c) impact due to cross current
(d) all the above

24. The most suitable foundation for a culvert is
(a) spread foundation
(b) pile foundation
(c) well foundation
(d) caisson foundation

25. For a major bridge usually the type of foundation is
(a) grillage foundation
(b) spread foundation
(c) well foundation
(d) caisson foundation

26. Bridge over a dry valley is known as
(a) causeway
(b) minor bridge
(c) vent
(d) viaduct

27. The bridge having its floor flush with bed of stream is known as
(a) causeway
(b) culvert
(c) viaduct
(d) minor bridge

28. Which one of the following is not a type of culvert?
(a) Pipe culvert
(b) Box culvert
(c) Through culvert
(d) Slab culvert

29. Minimum depth of foundation below the scour line in a arch bridge for piers should not be less than
(a) 1.2 m
(b) 1.8 m
(c) 2.4 m
(d) 3.0 m

30. The arrangement made to prevent entry of water at the site of pier construction is known as
(a) caisson
(b) cofferdam
(c) earthen dam
(d) none of the above

31. Fixed plate bearing plates are suitable for spans upto
(a) less than 6 m

(b) 12 m

(c) 18 m

(d) 24 m

32. Deep cast bearings are suitable up to ______ spans.

(a) 6 m

(b) 12 m

(c) 12 to 20 m

(d) 20 to 30 m

33. Rocker bearings are suitable for spans upto

(a) 6 m to 12 m

(b) 15 to 20 m

(c) more than 20 m

(d) not suitable for any span

34. If a rocker and roller bearing is provided at one end of a bridge girder, then the other end will be

(a) fixed end

(b) simple support

(c) free end

(d) rocker bearing

II. *Match List I with List II by selecting the options given in question nos. 35 and 36*

35.

	List I Type of Bridge		List II Span
A.	Girder bridge	1.	300 to 600 m
B.	Cable stayed bridge	2.	Over 500 m
C.	Truss bridge	3.	30 to 378 m
D.	Suspension bridge	4.	10 to 60 m

Codes:

(a)	A – 2	B – 3	C – 4	D – 1
(b)	A – 3	B – 2	C – 1	D – 4
(c)	A – 3	B – 4	C – 2	D – 1
(d)	A – 4	B – 1	C – 3	D – 2

36.

	List I		List II
A.	Causeway	1.	Movable bridge
B.	Culvert	2.	Bridge over a dry valley
C.	Viaduct	3.	Flush with bed of stream

D.	Basule bridge	4.	Span less than 6 m

Codes:

(a)	A – 2	B – 4	C – 1	D – 3
(b)	A – 3	B – 2	C – 4	D – 1
(c)	A – 3	B – 4	C – 2	D – 1
(d)	A – 4	B – 3	C – 1	D – 2

III. *Select your answer according to the coding system given for Assertion (A) and Reason (R) given below in the questions 37 to 39.*

(a) Both A and R are true and R is the correct explanation of A.

(b) Both A and R are true but R is not the correct explanation of A.

(c) A is true but R is false.

(d) A is false but R is true.

37. Assertion: If linear waterway is reduced depth of foundation is to be increased.
    Reason: There is increase in scour depth, if linear waterway is reduced.
38. Assertion: Straight abutments are not suitable for waterways.
    Reason: Water penetrates behind abutment and damages embankment.
39. Assertion: Usually skin of pier is with rich concrete and heart with poor concrete.
    Reason: It is to economise the construction cost.

IV. *State whether the following statements are True or False in questions 40 to 44.*

40. If bridge is at bottom level of superstructure, it is known as through bridge.
41. For streams with non-erodable banks effective linear waterway is taken as the distance between the banks at high flood level.
42. It is always possible to reduce the cost of bridge by reducing the linear waterway.
43. Reduction in waterway under bridge may necessitate stone protection in pitching, aprons, etc.
44. Commonly used pier cross section is with triangular shape ends on upstream and downstream sides.

Answers to Multiple-Choice Questions

1. (b)	2. (b)	3. (d)	4. (a)	5. (d)
6. (c)	7. (b)	8. (b)	9. (c)	10. (b)
11. (a)	12. (b)	13. (d)	14. (b)	15. (a)
16. (c)	17. (a)	18. (b)	19. (b)	20. (d)
21. (a)	22. (d)	23. (d)	24. (a)	25. (c)
26. (d)	27. (a)	28. (c)	29. (b)	30. (b)
31. (b)	32. (c)	33. (c)	34. (d)	35. (d)
36. (c)	37. (a)	38. (a)	39. (a)	40. True

41. False 42. False 43. True 44. True

19

Airport Engineering

19.1 INTRODUCTION

Wright brothers flew the first power driven airplane in 1903. The early planes were driven by propellers. Dakota was a popular propeller driven plane. Then came turboprops and later turbojets. Boeing 747 and Airbus 300 are wide-bodied jets capable of carrying more than 300 passengers. Dakota travelled at 250 to 300 kmph whereas modern planes can travel at a speed of 800–1000 kmph. Supersonic aircraft can fly at speeds greater than that of sound. For example, Concord travels at 2300 kmph.

Structure and Organisation of Air Transport

Directorate of Civil Aviation was set up in 1927 but it took up shape only in 1945. The Director General of Civil Aviation (DGCA) established National Airport Authority in 1986 to administer the domestic airports. To administer international airports, International Airport Authority of India (IAAI) was established in 1967. International Civil Aviation Organization (ICAO) was established in 1944. It provides international links between civil and military flying activities.

Classification

Airport classification helps the pilots in identifying the size and the services which an airport can provide. ICAO classifies airports by using code letters A to E, in which A type has the longest runway and E type has the shortest. Table 19.1 shows the requirements of runways.

Table 19.1 Runway and free area requirements

Airport Type	*Runway*			*Free area beyond runway*	
	Length	*Width*	*Gradient*	*Width*	*Length*
A	2100 m	45 m	1.5%	150 m	60 m
B	1500–2099 m	45 m	1.5%	150 m	60 m
C	900–1499 m	30 m	1.5%	150 m	60 m
D	750–899 m	22.5	2.0%	78 m	60 m
E	600–749 m	18.0	2.0%	78 m	60 m

Transverse gradient: ICAO recommends:

1. Transverse gradient of a runway pavement should not exceed 1.5% for A, B and C type and 2% for D and E type.
2. As far as possible, the transverse gradient of less than 0.5% should be avoided.
3. Shoulders of runway should be at least 75 m on either side from centre of runway. Its transverse gradient should not exceed 2.5%. Transverse gradient of remaining portion should not exceed 5%. These requirements are shown in Fig. 19.1.

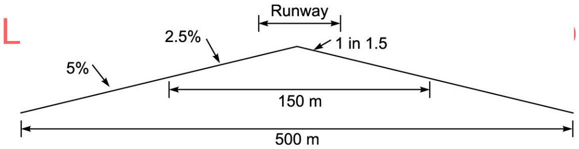


Fig. 19.1 Cross section of runway

Sight distance If two runways or a runway and taxiway intersect care should be taken to see that minimum sight distance is ensured. ICAO recommends that for A, B, C type airports, any two points 3 m above the surface of runway are mutually visible from a distance equal to half the runway length. For D and E type airports there should be minimum sight distance for half the length of runway from a point 3 m above to another point 2.1 m above the runway.

Gate capacity Gate capacity is the ability of a specified number of gates to accommodate aircraft loading and unloading operations under continuous demand. It depends upon mix of aircraft class and average occupancy time for the class. Capacity of gate may be determined as shown below

Aircraft class	Mix %	Average occupancy time in min
1	20	20
2	30	40
3	50	70

$$\text{Gate capacity} = \frac{1}{0.20 \times 20 + 0.30 \times 40 + 0.50 \times 70} = 0.02 \text{ aircraft/hour}$$

$$= 12 \text{ aircraft/hour}$$

* ***Runway configurations*** The following basic pattern of runways may be used:

1. Single
2. Parallel
3. Intersecting
4. Non-intersecting

The combinations of the above also may be used. A minimum of 1500 m spacing may be provided between two parallel runways.

Taxiway

The main function of a taxiway is to provide access to the aircraft from the runway to the loading apron or service hangar and back.

* Taxiway should be so arranged that the aircraft taxing towards the apron do not interfere with the aircraft taxing for take-off. They should not intersect runway also. The requirements of taxiway as per ICAO are shown in Table 19.2.

Table 19.2 Taxiway requirements

Class	*Width*	*Maximum longitudinal gradient*	*Minimum transverse gradient*	*Minimum rate of change of longitudinal gradient per 30 m*
A	22.5 m	1.5 %	1.5 %	1.0 %
B	22.5 m	1.5 %	1.5 %	1.0 %

C	15.0 m	3.0 %	1.5 %	1.0 %
D	9.9 m	3.0 %	2.0 %	1.2 %
E	7.5 m	3.0 %	2.0 %	1.2 %

Sight distance For a taxiway ICAO recommends that sight distance should be 300 m at 3 m height A, B, C type and 250 m for D and E type at a height of 2.1 m.

Turning radius The turning radius required for taxing is given by the expression

$$R = \frac{v^2}{125\,f}$$

where v = velocity in kmph and f = 0.13 is the coefficient of friction

For subsonic jets minimum R = 120 m

For supersonic jets minimum R = 180 m

Hornojet suggested a formula to find radius of horizontal curve for taxiway in terms of wheel base of aircraft and specified distance of main gear from the edge of the pavement as

$$R = \frac{0.388\,W^2}{T/2 - 5}$$

where W = wheel base of aircraft in metres

T = width of taxiway pavement in metres

S = distance between point midway of the main gears and the edge of taxiway pavement in metres.

19.2 TERMINAL AREA

It consists of

1. Building area
2. Apron
3. Vehicular circulation and parking area
4. Hangar

1. Building Area It offers a sheltered, convenient and direct access for passengers from street side to aircraft through checking, booking and waiting rooms. Deplaning passengers are also provided with direct route from the aircraft to the baggage claim counter to the vehicle platform. In the design care should be taken to see that

(a) Passengers walking distance should not be more than 180 m from the surface transportation to their boarding point.

(b) The distance of check-in point from the road transportation should not be more than 22.5 m.

(c) On arrival, the baggage delivery speed should be equal to the walking time of passengers from the aircraft to the bagge claim area.

(d) If volume of cargo is large, a separate building for handling and storage of cargo may be required. As far as possible, the location of the building should be such that aircraft can be positioned along the side of the building.

(e) The building should include control tower, weather bureau and other government services related to aviation.

2. *Apron* It is a paved area for parking of aircraft and loading and unloading of passengers and cargo. In aprons aircraft are parked in any of the following configurations:

(a) Nose-in (b) Angle nose-in

(c) Nose-out (d) Angle nose-out

(e) Parallel.

* Use of an angled nose-out parking configuration is preferable.

* A minimum clearance of 7.5 m is suggested as the desirable clearance while manoeuvring aircraft with respect to the terminal buildings and adjacent aircraft.

3. *Vehicular circulation and parking area* Access roads are planned to provide fast connection between the airport and the city. Short time parking for passenger cars should be provided close to terminal buildings. There should be sufficient and convenient circulation and parking lots. Separate parking area is required for the vehicles of the staff. It is suggested that parking facility should be based on 1.5 to 2 cars for each peak hour passenger.

4. *Hangar* Covered area provided for servicing and repairs of aircraft is known as hangar. They are usually constructed with steel frames and GI sheets. They are provided with stores for spare parts.

Markings and Lighting

The pilot should spot and identify the various airport elements and also know the wind directions during daytime as well as nights. For this purpose marking and lighting systems are standardised. Markings and lightings are grouped as shown below:

1. Runway
2. Taxiway
3. Shoulders of the above
4. Apron
5. Wind direction indicators
6. Landing direction indicator

Runway marking should clearly indicate runway threshold, runway touchdown zone, runway edge, centre line, runway number, etc.

Extensive use of radio and radar is made in controlling air traffic. These instruments are used for air surveillance, weather observations, monitoring of take-off and landing.

Heliports

* Helicopters can take-off or land in vertical position. There is a Public Secor Helicopter Corporation in India, known as Pawan Hans.

* 1 to 3 seater helicopters weigh 2 to 5 tonnes.
10 to 30 seater helicopters weigh 5 to 10 tonnes.
50 seater helicopter weighs above 15 tonnes.

They can travel at 150 to 200 kmph. The overall length is in the range of 10 to 25 m and the height is in the range of 2.5 to 7.5 m.

* Helicopters can land on ground, on top of buildings or on the sea (pontoon type).

* Heliport is a prepared ground for landing and take-off of helicopters. It may provide facilities for shelter, repair and servicing of helicopters apart from providing buildings for processing of cargo and passenger. Area is required for vehicular parking also.

* Landing area required for different helicopters is as given below:

1. For 2.7 tonne helicopter Square of 22.5 m or circle of equivalent area
2. 6.8 tonne helicopter 30 m square or circle of equivalent area
3. Multi engined helicopter 60 m × 120 m

* Heliport marking: Area of landing and take-off should be marked with letter *H* such that a clear vision is possible from all approachable directions. ICAO recommends the following:

Height of letter	3 to 4.5 m
Width of letter	2 to 3.5 m
Width of outlines	0.45 m

The recommended colour for painting is white with black outlines.

* Lighting

1. Landing and take-off area should be lighted by floodlight to provide an illumination level of 150 mm candle.
2. The periphery of landing and take-off area should be lighted by amber lights of medium intensity, spaced at 7.5 m centre to centre.
3. Aprons may be lighted by floodlights so as to provide illuminations level not less than 300 mm candle.

Stol Port

Short Take-off and Landing (STOL) ports are for small planes which climb steeply at an angle 6° (other planes climbs at 3°). They fly at low speed. The ICAO recommends the following for such ports.

1.	Length of runway	600 m
2.	Width of runway	30 m
3.	Length of stopway	30 to 120 m
4.	Length of landing strip	660 to 840 m
5.	Width of landing strip	90 to 150 m
6.	Width of taxiway	18 m

MULTIPLE-CHOICE QUESTIONS

I. *Select appropriate option in the following questions 1 to 48.*

1. Wright brothers flew the first power-driven plane in
   (a) 1853
   (b) 1873
   (c) 1903
   (d) 1933
2. International Civil Aviation Organization (ICAO) was established in
   (a) 1944
   (b) 1954
   (c) 1964
   (d) 1974
3. ICAO recommends length of runway for A type airports as
   (a) 1500 m
   (b) 1800 m
   (c) 2100 m
   (d) 2400 m
4. Length of runway for E-type airports specified is
   (a) 500 to 600 m
   (b) 600 to 750 m
   (c) 750 to 900 m
   (d) 900 to 1200 m
5. Width of runway for type A and B airports is specified as
   (a) 30 m
   (b) 45 m
   (c) 60 m
   (d) 75 m
6. Width of runway for E-type of airports is specified as
   (a) 18 m
   (b) 22.5 m
   (c) 30 m
   (d) 45 m
7. Longitudinal gradient for runway specified by ICAO for type A, B, C ports is
   (a) 1.0 %
   (b) 1.5 %
   (c) 2.0 %
   (d) 2.5 %
8. Longitudinal gradient specified by ICAO for D and E type airports is
   (a) 1.0 %
   (b) 1.5 %
   (c) 2.0 %

(d) 2.5 %

9. Free area beyond runway should have a width of ______ for A, B, and C type airport
   (a) 60 m
   (b) 90 m
   (c) 120 m
   (d) 150 m

10. Free area beyond runway should have a width of ______ for D and E type airports
   (a) 68 m
   (b) 98 m
   (c) 88 m
   (d) 98 m

11. Length of free area beyond runway in any port should be at least
   (a) 60 m
   (b) 80 m
   (c) 100 m
   (d) 120 m

12. As far as possible transverse gradient of less than ______ should be avoided in a runway.
   (a) 0.5 %
   (b) 1.0 %
   (c) 1.5 %
   (d) 2.0 %

13. Up to ______ from the centre of the runway the shoulders should have gradient less than 2.5 %.
   (a) 50 m
   (b) 75 m
   (c) 100 m
   (d) 125 m

14. From the centre of the runway, transverse gradient of shoulder from 75 to 150 m should not exceed
   (a) 1 %
   (b) 3 %
   (c) 4 %
   (d) 5 %

15. ICAO recommends that for A, B and C type airports, any two points 3 m above the surface of runway are mutually visible from a distance equal to ______ times the length of runway.
   (a) 0.4
   (b) 0.5
   (c) 0.6
   (d) 0.75

16. The following data is available for an airport.

Aircraft class	**Mix**	**Average occupancy times in minute**

1	20 %	20
2	30 %	40
3	50 %	70

The gate capacity is
(a) 12 aircraft/hour
(b) 15 aircraft/hour
(c) 18 aircraft/hour
(d) 24 aircraft/hour

17. If more than one runways are to be provided, the basic pattern of runway is
(a) parallel
(b) intersecting
(c) non-intersecting
(d) any of the above

18. If two parallel runways are to be provided, a minimum of ______ spacing should be provided between them.
(a) 500 m
(b) 1000 m
(c) 1500 m
(d) 2000 m

19. Required width for taxing in A and B type airports is
(a) 7.5 m
(b) 15.0 m
(c) 22.5 m
(d) 30 m

20. Requirement of width for taxiway in E type airports is
(a) 7.5 m
(b) 10 m
(c) 12 m
(d) 15 m

21. Maximum longitudinal gradient for taxiway in A and B type airports is
(a) 1 %
(b) 1.5 %
(c) 2 %
(d) 2.5 %

22. Maximum longitudinal gradient permitted for taxiway in E-type airports is
(a) 1.5
(b) 2.0 %
(c) 2.5 %
(d) 3 %

23. For taxiway ICAO recommends that sight distance at a height of 3 m for A, B and C type airports should be

(a) 300 m
(b) 400 m
(c) 500 m
(d) 600 m

24. For D and E type airports ICAO recommends that the sight distance at a height of 2.1 m should be at least

(a) 250 m
(b) 300 m
(c) 400 m
(d) 500 m

25. The turning radius required for taxing is given by

(a) $\frac{V^2}{100f}$

(b) $\frac{V^2}{125f}$

(c) $\frac{V^2 f}{100}$

(d) $\frac{V^2 f}{125}$

where V = velocity in kmph
f = coefficient of friction

26. For subsonic jets, turning radius at taxiway required is a minimum of

(a) 120 m
(b) 140 m
(c) 160 m
(d) 180 m

27. For supersonic jets, turning radius of taxiway required is a minimum of

(a) 100 m
(b) 140 m
(c) 180 m
(d) 220 m

28. Hornojet suggested the horizontal curve for taxiway should have a minimum radius

(a) $\frac{0.388 W^2}{T/2 - S}$

(b) $\frac{0.388 W^2}{T/2 + S}$

(c) $\frac{0.388 W}{T/2 - S}$

(d) $\frac{0.388 W}{T/2 + S}$

where W = wheel base of aircraft in metres

T = width of taxiway pavement in metres

S = distance between point midway of the main gears and the edge of taxiway pavement in metres

29. Passengers walking distance in a terminal should not be more than ______ from surface transportation point to the boarding point.
(a) 90 m
(b) 180 m
(c) 270 m
(d) 360 m

30. The distance of check in point in a terminal from the road transportation should not be more than
(a) 22.5 m
(b) 27.5 m
(c) 37.5 m
(d) 50.0 m

31. In aprons aircraft are parked in
(a) angle nose-in
(b) angle nose-out
(c) parallel
(d) any of the above pattern

32. The main disadvantage of nose out parking pattern in apron is
(a) overall apron area required is more
(b) rear loading door is far away from terminal building
(c) hot blast is directed towards the terminal building
(d) all the above

33. A minimum clearance of ______ is suggested as the desirable clearance while manoeuvring aircraft with respect to building and adjacent aircraft.
(a) 7.5 m
(b) 10 m
(c) 12.5 m
(d) 15 m

34. It is suggested that parking facility for cars in airport should be based on ______ for each peak hour passenger
(a) 0.5 to 0.75
(b) 0.75 to 1.25
(c) 1.25 to 1.5
(d) 1.5 to 2.0

35. Covered area provided for servicing and repairs of aircraft is known as
(a) apron
(b) hanger

(c) building area
(d) none of the above

36. Runway markings are to indicate
(a) centre line
(b) edge
(c) touchdown zone
(d) all the above

37. All markings on the runway are
(a) Black
(b) White
(c) Yellow
(d) Red

38. Runway threshold is indicated by a series of parallel lines staring from a distance of ______ from runway end.
(a) 3 m
(b) 6 m
(c) 9 m
(d) 12 m

39. One to three-seater helicopters weigh ______ tonnes.
(a) 2 to 5
(b) 5 to 8
(c) 10–12
(d) more than 15

40. The landing area required for multi-engined helicopters is
(a) 22.5 × 22.5 m
(b) 30 m × 30 m
(c) 30 × 60 m
(d) 60 × 120 m

41. Landing area required for 2.7 tonnes helicopter is
(a) 22.5 × 22.5 m
(b) 30 × 30 m
(c) 30 × 60 m
(d) 60 × 60 m

42. In heliports landing and take-off area should be marked as H with the size
(a) 3 to 4.5 m height and 2 to 3.5 m width
(b) 2 to 3.5 m height and 3 to 4.5 m width
(c) 2 × 3.5 m height and 1 to 2 m width
(d) 1 to 2 m height and 2 to 3.5 m width

43. In heliports landing and take-off area should be lighted with floodlights to provide an illumination level of
(a) 75 mm candle

(b) 100 mm candle

(c) 150 mm candle
(d) 200 mm candle

44. The periphery of landing and take-off area of heliports should be lighted with amber lights of medium intensity, spaced at
(a) 5 m
(b) 7.5 m
(c) 10 m
(d) 12 m

45. Aprons of heliports may be lighted by floodlights so as to provide illumination level not less than
(a) 100 mm candle
(b) 200 mm candle
(c) 300 mm candle
(d) 400 mm candle

46. Length of STOL ports runway should be
(a) 500 m
(b) 600 m
(c) 800 m
(d) 1000 m

47. In STOL ports width of runway should be
(a) 20 m
(b) 25 m
(c) 30 m
(d) 40 m

48. In STOL ports, width of taxiway is
(a) 18 m
(b) 21 m
(c) 24 m
(d) 30 m

II. *Select your answer according to the coding system given below for the Assertion (A) and Reason (R) given in the item no. 49 and 50.*
(a) Both A and R are true and R is the correct explanation of A.
(b) Both A and R are true but R is not correct explanation of A.
(c) A is true by R is false.
(d) A is false but R is true.

49. Assertion: In STOL ports length of runway is less compared to in airports.
Reason: Such ports handle planes of small size.

50. Assertion: In STOL ports width of runway is less compared to in airports.
Reason: The speed of planes on such ports is less.

III. *State whether the following statements are True or False in item no. 51 to 54*

51. The function of taxiway in airports is to direct road taxis to proceed to parking area after dropping passengers at terminals.

52. Minimum transverse gradient and maximum longitudinal gradient permitted in A and B type airports is the same.

53. On arrival, the baggage delivery speed should be equal to the walking time of passengers from the aircraft to the baggage claim.

54. Use of an angled nose-out pattern of parking configuration is preferred.

Answers to Multiple-Choice Questions

1. (c)	2. (a)	3. (c)	4. (a)	5. (b)
6. (a)	7. (b)	8. (c)	9. (d)	10. (b)
11. (a)	12. (a)	13. (b)	14. (d)	15. (b)
16. (a)	17. (d)	18. (c)	19. (c)	20. (a)
21. (b)	22. (d)	23. (a)	24. (a)	25. (b)
26. (a)	27. (c)	28. (a)	29. (b)	30. (a)
31. (d)	32. (c)	33. (a)	34. (d)	35. (b)
36. (d)	37. (b)	38. (b)	39. (a)	40. (d)
41. (a)	42. (a)	43. (c)	44. (b)	45. (c)
46. (b)	47. (c)	48. (a)	49. (b)	50. (b)
51. False	52. True	53. True	54. True	

Table of Contents

1. Geological classification On the process of formation, rocks are classified as igneous rocks, sedimentary rocks and metamorphic rocks.
2. Physical classification Based on the structure, rocks may be classified as stratified, unstratified and foliated rocks.
3. Chemical classification

Quarrying It is the process of extracting stones from rockbed, located near the earth's surface and exposed to sun.

Dressing of stones The aim of preliminary dressing is to bring the size of stone approximately to the required size and reduce the transportation cost to great extent. Final dressing is as per the requirement of the user. The different methods of final dressing are:

Seasoning of stones The process of removing sap from the pores is known as seasoning. The best method of seasoning is to allow the stones to dry for a period of 6 to 12 months in a shed.

Preservation of stones The following preservatives are used:

Tests on stones

Common building stones Basalt, granite, sandstones, limestones, marble, quartzite, laterite and slate. Solid and hollow concrete blocks are known as artificial stones.

Classification

Seasoning of timber Seasoning is the process of reducing moisture content in a freshly cut tree to the desired level. Seasoning makes timber more durable and stable. The various methods of seasoning used are:

Conversion of timber Market names of converted timber are battens, plank, pole, scanting, beams, etc. They are available in different sizes and length. They are obtained by sawing logs. The various methods adopted for sawing are: ordinary, quarter, tangential and radial.
Defects in timber Defects may be due to natural forces, attack by fungi or insects or due to erroneous seasoning. The defects due to natural causes are knots, shakes, rind galls, upsets, twisted fibres, wind cracks, burls, dead wood, foxiness and stain.
Preservation of timber The widely used preservatives are coal tar, solignum paints, chemical salt, creosote and ASCU. ASCU is a special preservative developed by FRI, Dehradun.
Industrial timber Veneers, plywood, fibreboards, particle boards, block boards, hard boards and Glulam.
Indian timber trees Babul, bamboo, casurina, Deodar, Jack, Mango Mahogany, Rosewood, Teak, sandalwood, Sisso.

• Classification of Bricks
• Tests on bricks

1. Tiles Different types of tiles used are roofing tiles, ceiling tiles, ridge tiles, flooring and wall tiles, drain tiles.
2. Terracotta Terracotta means baked earth. It may be manufactured in different colours also. There are two types of terracotta, viz. porous terracotta and polished terracotta. They are used for making art pieces and lavatory fittings.
3. Earthenware It is a type of terracotta in which the moulded product is burnt at low temperature to get semi-vitrified surface. These products are used for making cheap lavatory fittings and drain pipes.
4. Stoneware These are the pipes manufactured from refractory clays to which ground flint and crushed pottery are added and ground. During grinding pigments are also added. They are produced under pressure and then burnt at high temperature. They are used for making wash-basins, gully traps, jars and sewer pipes.

1. Cast iron Carbon content is 2 to 4%. The varieties of cast iron are: Grey cast iron, white cast iron, molten cast iron, chilled cast iron, toughened cast iron, ductile cast iron and malleable cast iron. Cast irons are coarse, crystalline and fibrous. They cannot be welded. They are used for water pipes, sanitary pipes and manhole covers. They are also used for making ornamental castings like gates, lamp posts, spiral railings, rail chairs etc.
2. Wrought iron It contains less than 0.15% carbon. It is fibrous and has silky lustre. It can absorb shocks. It is used for making nails, nuts, bolts, chains, roofing sheets, grills and straps.
3. Steel It contains 0.25 to 1.5% carbon. It is equally strong in tension and compression. It is suitable for all construction purposes. The types of steel are mild steel, medium carbon steel, high carbon steel. In the market they are available as rolled steel sections, tubes, flats, plates, sheets, corrugated sheets, expanded metal, bars and weld meshes. Thermo-mechanically treated (TMT) bars are manufactured by sudden quenching of red hot steels by spraying water, which results into high strength at the surface while the core portion is mild steel. These are ideally suited for R.C.C. works.

1. Copper By roasting, smelting, converting and electrolytic refining copper ores like cuprite, glance, malachite or copper pyrites, copper is produced. Market forms of copper are ingots sheets, wires and tubes. Copper is brown in colour but becomes greenish when exposed to atmosphere. It is malleable, ductile, a good conductor of heat and electricity, copper wires are used as electric cables. Copper straps are used as electric conductors and for closing

construction joints. It is used as an alloy for making brass and bronze.
2. Aluminium Aluminium is extracted mainly from bauxite (Al_2O_3 $2H_2O$). It is silvery white with bluish tinge. Its strength-weight ratio is favourable for construction. It is marketed in the following forms:
3. Zinc Zinc ores are zinc calamine ($ZnCO_3$) which contains 65% zinc and zinc blende (ZnS) which contains 50% zinc. When heated at 1100°C, zinc is liberated in the form of vapour which is collected and condensed. Zinc is a bluish white metal which is a good conductor of heat and electricity. It is used for making electrical cells and batteries, for galvanizing iron plates and in making paints and brass.
4. Lead Lead is extracted from the ore galena (PbS), which contains 86% lead. The ore is roasted, mixed with coke, smelted in blast furnace and reverberatory furnace. It is bluish grey in colour. It is poisonous. It is used as pigments in paints, for making storage battery solders and for making sanitary fittings.
5. Tin Tin ore is found as cassiterite (SnO_2). The ore is crushed, roasted, smelted and refined by electrolysis. It is a silvery white lustrous metal. It withstands corrosion. It is used to provide protective coating to iron, copper, brass and lead. It is used for silvering mirrors and its foils are used for protecting food products.
1. Aluminum alloys
2. Copper alloys Brass and bronze are copper alloys. Brass is the alloy of copper and zinc. White brass, yellow brass, red brass, delta metal, cartridge brass and low brass are different types of brasses. Bronze is an alloy of copper, tin and minor percentage of other materials. Beryllium bronze, prospher bronze, green metal, bell metal, speculum metal are different types of bronzes.
3. Alloys of steel Alloying of steel with other metals is made to increase strength, hardness, toughness, resistance to wear. Varieties of steel alloys found in market are:
Fine and Coarse Aggregates
Different concrete works
Tests on concrete
Painting
1. Plastered surfaces Emulsion paints may be applied after a curing period of 4 – 6 weeks. Final coat is to be applied after 6 – 12 months only. Before painting the surface should be made dust free. For new surfaces primer coat is required.
2. Concrete surface Usually, two coats of cement paint are required. Painted surface should be cured for 10 – 15 days.
3. Wood surface Before painting a new surface all nail heads should be punched to a depth of 3 mm. The surface should be made free from loose particles, dust and grease. Knots if any should be levelled and two coats of varnish applied. Fill all cracks, dents, loose joints with putty. Apply primer, two undercoats before the finishing coat. In case of old wood works clean the surface with sand paper and pumice stone wash with caustic soda solution of 200 gm in a litre of water. apply primary coat, undercoat and finishing coats.
4. Iron and steel surface Remove dust with wire brushes. Remove grease by washing with caustic soda. Then apply the coats.
1. Glass and glass wool It is manufactured by fusion of silica with varying proportions of oxides of sodium, calcium, potassium and magnesia. They are fabricated by blowing, drawing, pressing, rolling or casting. After annealing they are given treatment by tempering, opaque

making, silvering, bonding or cutting. It can be made stronger than steel and lighter than cork.
2. Plastics Plastic is a natural synthetic material, which has a property of being plastic at some stage of its manufacture. Synthetic material nay be phenol, formaldehyde, cellulose vinyl, etc. At present there are more than 1000 varieties of plastic.
3. Glass fibre reinforced plastics (GFRP) In these glass fibres provide stiffness and strength while resin provides a matrix to transfer load to fibres. GFRP is used for door and window frames, partition walls, roofing sheets, skylights, water tanks, for making chairs and tables.
4. Asbestos Asbestos is a naturally available mineral substance. It is fire-proof, acid-proof. It is a good insulator of heat and electricity. It is used with cement to produce asbestos cement sheets for roofing, wall panelling, to cover fuse and electric boxes, for making downtake pipes, etc.
5. Bitumen, asphalt and tar These are called bituminous materials and their main constituent is hydrocarbon.
6. Fly Ash It is a by-product in coal based thermal plants. Its particles can fly in ordinary air. At one time it was considered a nuisance but now it is used as a useful material in manufacturing bricks, for stabilizing soil and to improve workability of concrete.
7. Steel Putty It is a plaster filler which can be applied with knife to fill dents in steel plates. It has good adhesive property and dries hard.
8. Adhesive, sealants and joint fillers
9. Heat, electrical and sound insulating materials
10. Waterproofing and damp-proofing materials
11. Thermocol It is a general-purpose crystal polysterene. It can be cut easily with knife or saw. It contains 3–6 million discrete cells/litre. It has insulating efficiency against heat, sound, humidity and shock. It is used as packing material and display board.
12. Epoxy It is a thermosetting polymer. It possesses excellent mechanical and adhesive properties. It is used with paints also.
13. Polyurethene It is a product produced by mixing polymeric diol or triol with a silicon surfactant and a catalyst. This has elasticity of rubber, combined with the toughness of metal. It is used for making gaskets, tiers, bushings, shoe soles, pipes, waterproofing chemicals, etc.
14. Geosynthetics These are synthetic materials made of nylon, PVC, polypropylene etc. They last long even when buried under soil. Geotextiles, geogrids, geomembranes and geocomposites are commonly used geosynthetics. These materials are used for soil stabilization.
15. Ferrocement Wire meshes embedded with cement and baby jelly is known as ferrocement. They are used for making door/window frames and shutters, partition walls, signboards, furnitures and even boats.
16. Cladding materials Cladding materials are used to enhance aesthetic appeal of walls, kitchen slab, stairs, roofs, ceiling, etc. Slate, granite, marble, clay tiles, mosaic, glass, wall papers etc. are the commonly used cladding materials in buildings.
17. PVC building products Polyvinyl chloride (PVC) is versatile plastic. Its properties can be easily modified by addition of other compounds. PVC pipes, door and window frames, partition walls, kitchen cabinets, tiles and false ceiling are very popular products.
Stones
Timber
clay products
Ferrous Materials
Non-ferrous Materials

Alloys

1. Classifications as per NBC of India
2. Classification based on the method of load transfer According to this buildings may be classified as load bearing structures and framed structures. load bearing structures are suitable for one- or two-storey residential buildings only.
3. Classification According to materials Structures may be classified as wooden structures, R.C.C. structures, steel structures, etc.
4. Classification according to fire resistance NBC of India classifies buildings as Type 1 to Type 4 on the basis of fire resistance.
Building Planning
Terminology
1. Building height It is vertical distance between the centre line street in front and the highest point of building including parapet at terrace. If building is sloping towards the street, the building height is considered upto the point where the external wall touches the sloping roof. In case of gable facing the street, it is considered upto the midpoint of gable end.
2. Building line It is the least horizontal distance of the permanent portion of the building from the centre line of the street.
3. Setbacks setbacks are lines parallel to the boundaries of the site.
4. Covered or built-up area The area covered by the building immediately above the plinth level is called covered area or built-up area. It does not include well, storage tank, open verandah, portico, ramp, steps, compound wall, watchman's booth, uncovered staircase.
5. Floor area It is equal to plinth area minus the area occupied by walls and columns.
6. Floor-area-ratio (FAR)
Important By-laws
1. Distances from power supply main
2. Exterior open spaces
3. Floor area ratio (FAR) It is different for different occupancy buildings.
4. Height of buildings The height and number of stories are related to the requirements of FAR and open space. It is also limited by the width of the street in front of the building. The height is limited to 1.5 times the width of front road plus the front open space. The height of buildings in the vicinity of an airport is fixed in consultation with the civil aviation authority.
Other requirements of buildings
1. Plinth height It should be 0.45 m above the surrounding ground level. It should be at least 0.15 m above the nearest street.
2. Habitable rooms The requirements are shown in table 2.3.
3. Kitchen Minimum size requirements of a kitchen are as shown in table 1.4.
4. Bathroom and water closet At least one wall should abut the exterior open space. Should have impervious floor and wall. Other requirements are shown in Table 2.5.
5. Storeroom In a residential building storeroom size shall not be less than 3.2 m2. Minimum height 2.2 m.
6. Parapet Not less than 1.05 m high and not more than 1.2 m above the finished floor level.
7. Compound wall Maximum height 1.5 m above the centre line of the front street. Upto 2.4 m also permitted if the top 0.9 m is open type. In case of corner plots, the lower 0.75 m may be of solid type but the top 0.75 m should be open type at least for a distance of 10 m.
Elementary principles of planning

1. Aspects Kitchen-eastern aspect, Dining-southern aspect, Drawing and living rooms-Southern or South-eastern. Bed rooms–western aspect.

2. Prospects It is about locating and selecting the type of doors and windows in the outer walls so as to reveal the pleasant features and hide undesirable features.
3. Roominess Length to width ratio should be 1.2 to 1.5. If it is nearly square, there will be wastage due to circulation area and if it is more than 1.5 it gives tunnel effect.
4. Furniture requirement Position of chairs, sofas, tables, beds, wardrobes, etc., should be drawn and checked for circulation area.
5. Groupings A dining room should be close to kitchen, sanitary blocks should be close to bed-rooms. In offices administrative block is located centrally.
6. Circulation Circulation refers to the space provided for movement. Passages, lobbies and wells serve as horizontal circulation area, while stairs and lifts serve as vertical circulation area. Circulation area should be least but sufficient also.
7. Elegance It refers to the effect felt by a viewer from outside. The width, length, height, balconies and projection contributes to elegance of a building.
8. Sanitation It includes good lighting, ventilation and sanitary conveniences.
9. Flexibility A study room may be planned for using as guestroom; by providing partition, living room and dining room may be utilized for family functions, whenever necessary. By providing independent access to backyard from the kitchen, backyard can be used for hosting dinners.
10. Privacy By the proper grouping of rooms privacy of rooms from one to other and from outside can be achieved.
11. Practical considerations Economy is major practical consideration. Future provisions should be made to improve flooring, extending building and improving elevation without dismantling any part of the building.

Stone Masonry

Brick Masonry

Concrete Block Masonry and Composite masonry

Partitions and Cavity Walls

Doors, Windows and Ventilators

Lintel and Arches

Floor and Flooring

Flat roofs They may have slight slope (not more than 10°) in order to drain rainwater. The following types of flat roofs are popular in India: Punjab terrace roofs, Maharashtra and M.P. terrace roofs, Madras terrace roofs, Bengal terrace roofs and R.C.C. roofs.

Vertical Transportation

Stairs A stairs is a series of steps arranged to connect different floors of a building. The space housing the stairs is called staircase.

Ramps A ramp is a sloping surface connecting two floors. The slope of a ramp should not be more than 1 in 15. Whenever the direction of ramp changes, a level landing equal to the width of the ramp should be provided. At door opening, at least 1.1 m landing is required. For hospitals such landing should be at least 2.25 m. Ramps are usually provided at railway stations, stadiums, shopping malls, hospitals and multistorey car parkings.

Escalators Escalators are electronically operated moving steps. The speed of escalators is usually 25 to 30 m/minute. Their inclination is kept 30° to the horizontal. They handle heavy traffic of persons and require no operators. They are used in commercial complexes, airports

and underground railways stations.
Lifts Lifts may be classified as passenger lifts, goods lifts, hospital lifts, service lifts. It is mandatory to provide lifts in buildings with more than four storeys. Lifts of different capacities are available in the market, ranging from 4 to 20 persons. For designing lifts, the weight of a person is considered to be 68 kg. Is : 14665 gives guidelines to find capacity of lift and number of lifts required for multistorey building. The lift well usually extends from 1.6 to 2.6 m below the bottom landing. The opening of 2 m height is required for entry of people at every floor.
Plastering and Pointing
1. Mud plaster It is for low cost houses in which brickwork is also in mud. Ten per cent of clay content should pass through 2.36 mm sieve and not less than 75 per cent should pass through 850 micron sieve. for making mortar, soil is mixed with water and left for 1–2 weeks. Then dried and reduced to powder and mixed with 33 kg of chopped straw is mixed and plenty of water.
2. Lime plaster Hydraulic lime should be ground dry with sand in the ratio 1 : 2 and left for 2–3 weeks before regrounding and using. In case of fat lime the mix proportion used is 1 : 3 or 1 : 4 which are wet mixed. To improve binding property a kind of gum known as gugal is added to lime. The gugal added is about 16 n/m3. About 10 N of fibres of jute also added to per cubic metre of mortar. The mortar so prepared is kept for weathering for two days.
3. Cement mortar 1 : 4 or 1 : 6 mortar is used for plastering external and internal walls respectively. To make mortar waterproof, pulverized alum is added. Soap water containing 0.75 N of soft soap/litre water is added.
4. Lime-cement plaster To improve plasticity and at the same time to maintain strength cement : lime : sand mortar is used. Mix proportions of cement : lime : sand is usually 1 : 1 : 8 or 1 : 2 : 8. Fat lime is preferred over hydraulic lime.
Temporary works
1. Form work The temporary works used to mould concrete elements like slab, beams, lintels and columns are known as formworks. Temporary work for arches is centring. The cost of form-work is as high as 30–40 per cent of the cost of concrete. The form work should be strong enough to take care of weight concrete, labourers, equipment used for placing concrete and vibrations. It should be easy to remove formwork after concrete hardens. Wood or steel formworks are generally used. Formwork should be rigid. Slip forms are preferred for the construction of shafts, chimneys, towers, piers, etc.
2. Scaffolding When the work is at a height more than 1.5 m, temporary platforms are required for masons and materials. These are known as scaffolding. If the scaffolding is at a height more than 2 m, guard rails should be provided. The vertical posts are known as standards. The horizontal members parallel to the wall are ledgers. Diagonal members fixed on standards are braces. Horizontal members normal to wall are putlogs. Putlogs, if supported on both ends are known as transforms. The plates provided below standards to distribution load over ground are known as base plate or sole plate. Types of scaffolding used are (a) single scaffolding or bricklayers scaffolding (b) double scaffolding or masons scaffolding, (c) cantilever scaffolding, (d) suspended scaffolding and (e) trestle scaffolding.
3. Shoring Temporary support provided to prop up a building for repair is known as shore and such works are known as shoring. Types of shores are (a) raking or inclined shores, (b) flying or horizontal shores, (c) dead or vertical shores.
4. Underpinning It means giving support from below. In civil engineering it refers to repair, strengthening or renewal of the foundation of an existing building. Pit method or pile method of

underpinnings are normally carried out.

Plumbing Services
Electric Supply
Damp-proofing and Waterproofing
Antitermite Treatment
Ventilation, Air conditioning and Thermal Insulation
1. Ventilation
Accoustics of Buildings
Fire-Resistive Construction
Earthquake-Resistant Buildings
Equipment for building constructions
1. Excavating equipment Bulldozers fitted with S, U, S–U type blades and rippers, power shovel excavator, drag line excavators, trenchers loaders and scrapers.
2. Earth compaction equipment They consist of heavy rollers. Sheep foot rollers compact the soil by kneeding.
3. Concrete construction equipment Concrete mixers of rotating non-fitting, rotating tilling, pan type, paddle type, pumps vibrators.
4. Bar bending machines
5. Hauling equipment Tractors, trucks, damp trucks, dampers, trailors, elevators and conveyors.
6. Hoisting equipment Forklift trucks, cranes, gin wheels.
7. Drilling equipment Abrasion drill, percussion drill with drill bits.
Mass Housing Schemes
Green Buildings
Construction Management
1. Earliest event time It is the time at which an event can be completed earliest. Naturally, it depends upon the completion of its proceeding activities.
2. Latest finish time The latest time by which an event should be completed to avoid any delay in the project, is worked out by tracking the events in the reverse order.
3. Slack or float The difference between latest finish time and earliest finish time is slack.
4. Critical path It is the line connecting the activities with zero slack.
Classification
1. On the basis of nature of the field
2. On the basis of object of survey
3. On the basis of instruments used
Measurements of Horizontal Distance with chain and Tape
Chain surveying
Angle and Direction measurements
Plane Table Surveying
Contouring
Theodolite Surveying
Trigonometric Levelling
Computation of Areas
Computation of Volumes
1. From cross sections The first step in computation of volumes is to determine the cross-sectional areas.

2. From spot levels If a pit of area A is made and the depth of four corners from earth surface is h1, h2, h3 and h4, then

3. Volumes from contours If h is contour interval and area measured between a set of consecutive contours are A1, A2,… A4, then by trapezoidal rule

Minor Instruments

Tacheometry

Elements of simple curve

Setting out simple circular curves

Compound curves A compound curve consists of two or more simple curves of different radii. In practice it normally consists of two curves. This type of curve is used to avoid the obstruction.

Reverse curves In a reverse curve two circular arcs having radius of curvatures in opposite directions meet at a point tangentially. The common point is called the point of reverse curvature or contrary flexure. As far as possible such curves should be avoided.

Transition curves

Vertical curves

Precise theodolites Precision of theodolites may be obtained by:

Total station

Resultant and Equilibrium of Coplanar non-concurrent Forces

Analysis of Pin-Jointed Plane Frames

Law of Machine

Load This is the resistance to be overcome by the machine

Effort This is the force required to overcome resistance

Input It is work done by effort = P ¥ D

Output Useful work got out of the machine = Wd.

Efficiency h =

Ideal machine h = 1, i.e., MA = velocity ratio.

Ideal effort Effort required by ideal machine

Ideal Load Load that can be lifted by ideal machine

Reversibility of a machine If the removal of effort while lifting results in lowering of the load, the machine is said to be reversible. It can be shown that a lifting machine is reversible, if its efficiency is more than 50 per cent and is self-locking if h < 50%.

Virtual Work Method

Centroid and Moment of Inertia

Dynamics

Projectile If, u = velocity of projection,

Relative velocity Relative velocity of A with respect to B is the vector difference between the velocities of and B.

Resultant velocity It is the vector sum of the velocities caused by different forces acting on a body.

D'Al emberts Principle It states that the system of forces acting on a body in motion is in dynamic equilibrium with the inertia force

Impulse Momentum

Impact of Elastic Bodies

Circular Motion of Rigid Bodies

* Kinetics of Rigid Body Rotation

* Mechanical Vibration
General Plane Motion of Rigid Bodies
Simple Shear
Elastic constants
Strain Energy
Principal Strain
Strain Gauges
1. Maximum principal stress theory (Rankine's Theory) According to this theory a material in complex state of stress fails, when the maximum principal stress in it reaches the value of stress at elastic limit in simple tension. This theory is reasonably good for brittle materials.
2. Maximum shear stress theory (Coulomb's Theory) According to this theory, a material in complex state of stress fails when the maximum shearing stress in it reaches the value of shearing stress at elastic limit in uniaxial tension test.
3. Maximum strain theory (St. Venant's Theory) According to this theory, failure in complex system occurs when the maximum strain in it reaches the value of the strain in uniaxial stress at elastic limit.
4. Maximum strain energy theory (Beltrami and Haigh's Theory) According to this theory, a material in a complex stress system fails when the maximum strain energy per unit volume at a point reaches the value of strain energy per unit volume at elastic limit in simple tension test. The condition reduces to
5. Maximum distortion energy theory (Von-Mises Criteria) According to this theory, part of strain energy causes changes only in volume and the rest causes distortion. At failure the energy causing distortion per unit volume is equal to the distortion energy per unit volume at elastic limit in uniaxial tensile test. The condition reduces to
Assumptions
Composite Beams/Flitched Beams
Beams of uniform strength
Shearing Stresses in beams
Deflection of Beams
Other useful Equations
Boundary conditions
Moment Area Theorems
Conjugate Beam
Deflections by Energy Methods
Castigliano's Theorem
Maxwell's Reciprocal Theorem of Displacement
Thick Cylinders
Thin Spheres
Thick spherical shells
Assumptions
Law of superposition It means the structure can be analysed for different loads separately and the results be superposed to get the final results due to different load combinations.
Conditions of equilibrium In case of three-dimensional structure are
Compatibility conditions It means requirement of continuity at joints.
A system is called linear systems if its material has linear stress-strain relation and deflections

are small.

ILD for simply supported Beams
ILD for cantilever Beams
ILD for Overhanging Beams
ILD for Double overhanging Beams
1. In case of concentrated loads for
where, Wi are concentrated loads, y; are the ordinates to the ILD for shear force and y¢; are the ordinates in the ILD for bending moment.
2. In case of udl smaller than the span,
1. Maximum SF and BM at point z from the end due to single concentrated load:
2. Max SF and BM at the given section when UDL is longer than the span
3. UDL smaller than the span
4. A train of concentrated loads
ILD for Bridge Trusses
Three-Hinged Arch
Suspension Bridge with Three-Hinged stiffening Girder
Suspension Cable with Two-Hinged stiffening Girder
Degree of Static Indeterminancy
Consistant Deformation Method of Analysing Indeterminate structures
Three-moment equation
If there is sway
Moment distribution procedure Find fixed end moments and distribution factors. Balance each joint. Carry-over distributed moment to far ends. Stop the procedure when carry-over moments are negligible.
If there is sway in the frame
Kani’s Method of Rotation Contribution
Substitute frame method In this method it is assumed that moment transferred from one floor to another floors are negligible. Hence, a substitute frame consists of floor beams and columns above or below it in a storey. The columns are assumed fixed at top and lower floor levels.
Approximate methods for horizontal Forces
(i) Portal Method Assumption:
(ii) Cantilever method Assumptions:
(iii) Factor method It is an approximate slope deflection method presented in steps using simple instructions like:
Fixed Arches
Elastic centre method
Column analogy method There is hardly any difference between column analogy method and elastic centre method. The difference lies only the way in which equations are looked into. If analogous column is treated as the one which has the same curve as the arch and width at any point equal to and loaded with diagram. For symmetric fixed arch
Beams Curved in Plan
Unsymmetric Bending and Shear Centre
Steps involved in flexibility method
Stiffness matrix method
Element approach of stiffness matrix

Shape factor
Basic theorems for finding collapse loads
1. Static theorem For a given structure and loading. If there exists any distribution of bending moment throughout the structure which is both safe and statically admissible with a set of loads W, the value W must be less than or equal to the collapse load Wc.
2. Kinematic theorem For a given structure subjected to a set of loads W, the value of W found to any assumed mechanism must be either greater or equal to the collapse load WC.
Uniqueness theorem If for a given structure and loading at least one safe and statically admissible bending moment distribution can be found and in this distribution the bending moment is equal to the fully plastic moment at enough cross sections to cause failure of the structure due to unlimited rotations at plastic hinges, the corresponding load will be equal to the collapse load WC.
Methods of Plastic Analysis
1. Statical method It consists of drawing statically admissible bending moment diagram and equating bending moment at sufficient points to plastic moment, so that collapse mechanism is formed.
2. Kinematic method For assumed mechanisms find collapse load. Try all possible mechanisms, which give least WC is real collapse load.
1. Working Stress Method The designer aims at keeping stresses at working loads as close to permissible stresses as possible but without exceeding them. Permissible stress is defined as the ultimate stress divided by a factor of safety in case of concrete. Factor of safety in concrete is taken as 3. In case of steel permissible stress is yield stress or 0.2% proof stress divided by factor of safety. Factor of safety is taken as 1.75 to 1.85 only, since steel is a more reliable material. Modular ratio is taken as
2. Load Factor Method (LFM) In this method ultimate load is used as design load and the collapse criteria for the design. Ultimate load is defined as load factor times the working load. A load factor of 2 was used.
3. Limit State Method (LSM) This is a comprehensive method which takes care of the structure not only for its safety but its fitness throughout the period of service. Various limit states to be considered are:
Characteristic Load
Characteristic Strength
Partial Safety Factor for Loads
Partial Safety Factor for Materials
Idealized Stress-Strain curves
Flanged Section in Flexure
Strength of R.C. Section in shear, Torsion and Bond
Design of Beams
Size of Beam
Cover to reinforcement
Design of Slab
Design of Columns
Design of Stairs
Design of flat slabs
Design of Continuous Beams

Design of Grid Floors
Design of Portal Frames
Combined Footings
Retaining Walls
Bunkers and Silos
Design of Chimneys
Water Tanks
Advantages It has high strength per unit mass. Its quality is assured speed of construction is high. It can be strengthened at any other time, if there is need. It can be fabricated in workshop and transported to site. Material is reusable.
Disadvantages It is susceptible to corrosion. Maintenance cost is high.
Types of steel
Properties of steel
Rolled Steel Sections
Considerations in steel design
Loads
Methods of Design
Design Requirements
Limit states
* Characteristic actions It is defined as the values of different actions which are not expected to be exceeded with more than 5 per cent probability, during the life of the structure. In the absence of statistical analysis, the loads presented in IS 875 and other codes may be considered as characteristic actions.
* Design Actions (Loads) To take care of uncertainties involved in analysis, design and construction, code specifies taking design actions as partial safety factor times the characteristic actions. Table 4 of IS 800–2007 gives partial safety factor gf for limit state.
* Design strength To take care of manufacturing defects, IS 800–2007 recommends reduction in the strength of material by a partial safety factor gm, where
* Deflection Limits
Fire Resistance Fire resistance level is specified in terms of minutes depending upon the purpose for which the structure is used and the line taken to evacuate in case of fire. For detailed specifications refer to section 16 of Is. 800–2007.
1. Unfinished Bolts The shank is unfinished, i.e., it is rough as rolled. These bolts are designated as M 16, M 20, M 24, etc., in which the number indicates diameter of bolts. The yield strength of commonly used bolts is 240 N/mm2 and ultimate strength 400 N/mm2.
2. Finished Bolts These bolts are formed from hexagonal rods, which are finished by turning to a circular shape. Actual dimensions of these bolts are 1.2 mm to 1.3 mm larger than nominal diameter. Bolt hole is kept 1.5 mm larger than nominal diameters. These bolts are used in special jobs like connecting machine parts subjected to dynamic loading. Black bolts and turned bolts are also known as bearing type bolts.
3. HSFG Bolts Instead of mild steel, for these bolts high strength steel rods are used. These bolts are tensioned using calibrated wrenches and then bolts are tightened. As a result of it bolts exert high pressure on plates connected and friction grip is achieved. Bolts are subjected to shear, only after friction grip force is exceeded. Commonly available nominal diameter HSFG bolts are 16, 20, 24, 30 and 36 mm.

1. Pitch of the bolts (p) It is centre-to-centre spacing of bolts in a row, measured along the direction of load.
2. Gauge distance (g) It is the distance between the two consecutive bolts of adjacent rows and is measured at right angles to the direction of load.
3. Edge distance (e) It is the distance of centre of bolt hole from the adjacent edge of plate.
4. End distance (e) It is the distance of the nearest bolt hole from the end of the plate.
5. Staggered distance (Ps) It is the centre-to-centre distance of staggered bolts measured obliquely.

Design of Bolted Connections

1. Tensile strength of plate
2. Shear capacity of bolts
3. Bearing capacity of bolts

Eccentric Connection

HSFG Bolts

Prying Forces

Advantages

Disadvantages

Types of welded joints

* Butt welds Square, V, U, J welds, may be single or double.
* Fillet welds Approximately triangular connections when the cross section of fillet weld is isoceles triangle with face at 45°, it is known as a standard fillet weld. In this case t = = 0.7s where s is size and t is throat thickness.
* Slot weld and plug weld To make slot weld a circular hole is made in one plate, kept on another plate and fillet welding is made along the periphery of the hole.

Important specifications for welding

Butt weld It is specified by throat thickness

Fillet Weld

Plug weld The effective area of a plug weld shall be considered the nominal area of the hole.

* Design stresses

Tension member splices

Lug Angles

Design of Laced columns

Design of Battened column

Column Bases

1. Slab-base If the load carried by column is not much, the column is directly connected to the base plate through cleat angles
2. Gussetted Base For columns carrying heavy loads gussetted bases are used. In this case the column is connected to the base through gussets, which transfers the load to the base party through bearing and partly through gussets. Design procedure is as follows:

Design procedure

Bending strength

Web Buckling Strength Certain portion of beam at support acts as a column to transfer the load from beam to support and hence there is a chance for buckling of web. In this case dispersion angle of beam may be taken as 45°. there is no need to check it for rolled section since the web thickness are sufficient to avoid such buckling failures web buckling strength is given by

Web crippling Near the support web of the beam may cripple due to lack to bearing capacity. Crippling occurs at the root of the radius.

Design of Purlins
Design of Bolted Beam Connections
1. Flexible Connection Types
2. Rigid/moment Resistant Connection If moment to be transferred is small clip angle or split beam connection may be made. If moment to be transferred is large, bracket connection may be used.
Design of Welded Beam Connections
Design of Plate Girders
(a) Transverse (vertical stiffeners)
(b) Longitudinal (horizontal) Stiffeners
Design of Gantry Girders
Design of Roof Trusses
* Roof trusses are supported on walls or a series of columns
* Bracings In the end panel of roof level bracings are to be provided using ISA 9060, 8 mm. Diagonal bracings are provided in the last but one panel at bottom chord level. For very long buildings additional diagonal bracings are provided at every 4 to 5 days.
* Members of Trusses
* Pitch of truss
* Spacing
* Purlins
* If angles are used outstanding legs should be at top
* Sheetings 1 G.I. sheets
* A.C. sheets
Surface Tension
Capillary Action
Vapour Pressure
Incompressible and compressible fluids
Fluid Statics
Mass transport
Heat Transport
Momentum Transport
Newton’s Laws of Motion
First law Every body remains in its state of either rest or of uniform motion unless its state is changed by external forces impressed upon it.
Second law The rate of change of momentum is proportional to the impressed force and takes place in the direction of that force.
Third law To every action there is always an equal and opposite reaction.
Laws of Thermodynamics
First law The change in total energy DE of a system is equal to the amount of heat dQ added to the system to the system minus the work dW done by the system.
Second law The change of entropy equals or exceeds the heat exchange divided by absolute temperature.
Equations of Motion

Pitot tube The pitot tube is used to measure velocity of flow in pipes. In using it, a piezometer is also required. A piezometer installed on the pipe boundary gives static pressure. The pitot tube having a 90° bend of shorter length is directed upstream. On account of stagnation pressure so caused, the liquid rises in the vertical limb. It h is the difference between piezometer and vertical limb of pitot tube,

Venturimeter A venturimeter is a device for measuring rate of flow in a pipeline.
It consists of:
Orifice flow Orifice is the opening through which reservoir water flows. The reservoir is very large compared to the size of opening. Hence, the velocities of all points in the reservoir are negligibly small. Therefore the velocity of flow in the jet is
Boundary Layer Flow
Laminar Flow
Water Hammer
Flow through Open Channels
Non-Uniform Flow
Flow Measurements
* Impulsive Turbine In an impulse turbine the total energy at the inlet is only kinetic energy. The pressure of water both at entering and leaving the vanes is atmospheric only. Pelton wheel is an impulsive turbine. In impulsive turbine:
• Reaction Turbines If at the inlet of a turbine, the total energy is kinetic as well as pressure energy, the turbine is called reaction turbine.
* In reaction turbines
* Draft tube It is a pipe of gradually increasing area used for discharging water from the exit of a reaction turbine.
• Specific speed It is the speed at which a turbine when working under unit head develops unit power
Unit speed It is the speed of a turbine, when the head on the turbine, is 1 metre.
Unit discharge It is a discharge through a turbine when the head on the turbine is unity.
Unit power It is the power developed by a turbine when the head on the turbine is unity
Performance curves The turbines are designed for particular values of
Constant head characteristics For constant head the curves are plotted between unit discharge-unit speed, unit power-unit speed and efficiency-unit speed
Constant speed characteristics In this study speed is constant and curves are plotted between the efficiency and the percentage of full load.
Constant efficiency From these curves, for a given head and power, the speed and the gate opening can be determined for the best performance.
Cavitation
• Effects of cavitation
* Methods of reducing formation of cavity
Centrifugal Pumps
1. Volute pumps In this type of pumps, the impeller is surrounded by a spiral casing, the outlet boundary of which is a curve, called volute. Since cross-sectional area of the passage of fluid gradually increases, part of its kinetic energy gets converted into the pressure energy.
2. Diffuser or Turbine Pumps In this type of pump, the impeller is surrounded by a series of stationary guidevanes mounted on a diffuser ring. The guidevanes provide gradually enlarging

passages so as to result in gradual reduction in velocity. Due to gradual reduction in velocity, less energy is wasted in eddies and hence, increase in efficiency.
Definitions
Static Head It is the difference between the liquid levels in sump and high level reservoir. It consists of suction head and delivery head.
Total Head It includes static head, head loss and velocity head in the delivery pipe.
Manometric head The difference in the piezometric head between a point on the discharge side and a point on the suction side of the impeller, both as close to the pump as possible is known as manometric head. The difference of head is as shown by the manometers connected between the inlet and outlet flanges of the pump.
Manometric efficiency It is the ratio of the manometric head to the head delivered to the liquid by the impeller.
Characteristic curves for centrifugal pumps
Reciprocating Pump
Air Vessels
Miscellaneous Hydraulic Devices
* Hydraulic press It is a simple device by which larger loads can be lifted by applying smaller forces. The efficiency of a hydraulic press is given by
* Hydraulic crane It is a device used to lift heavy loads. It is widely used in warehouse, foundries, heavy industries and in docks.
* Hydraulic lift It is a device used to carry persons and loads from one floor to another in multistorey buildings. It consists of a cage which is secured to the top of a vertical ram sliding in fixed vertical cylinder. Water from delivery pipe enters the bottom of the cylinder and works underside of cylinder. As a result of it lift moves upwards.
* Hydraulic ram It is a device used to lift small quantity of water to a greater height when a large quantity is available at smaller height. It does not need any external power like electricity. It works on the principle of water hammer.
* Hydraulic accumulator Hydraulic accumulator consists of a fixed vertical plunger with a central vertical hole. The fixed plunger is surrounded by a brass sleeve which is further surrounded by an inverted movable cylinder. The water pumped moves up the vertical tube and exerts an upward pressure on the annular area of the loaded cylinder. The pressure energy so stored may be supplied to a machine later on.
* Hydraulic intensifier It increases the intensity of pressure of a given liquid with the help of low pressure liquid of large quantity.
* Hydraulic coupling It is a device in which power is transmitted from driving shaft to driven shaft without any change of torque.
Sediment when fine sand from water is deposited on sandy soils, the fertility is improved. If the sediment has been derived from eroded areas, it may reduce the fertility.
Soluble Salts The critical self-concentration in the irrigation water depends upon many factors.
Sodium ions to other cations (Sodium Absorption Ratio)
Concentration of toxic Elements
Bacterial contamination
Water Requirement of crops
Some Definitions
Relation between delta (D) and duty (D)

Lining of canal

Rivers Training
Canal Escapes
Canal outlet or Module
Cattle crossings In remote village areas where no major movement is involved arrangements are made so that cattle, bullock carts, etc., can cross the canal. Such crossings are called cattle crossings.
Bed bars Bed bars are masonry or concrete toe wall like structure constructed along unlined canal, so as to serve as permanent reference marks, and thus to indicate the correct alignment and theoretical bed levels of the canal.
Cross-Drainage Works
Soils of India
1. Red soil It is formed by decomposition of granite, gneiss, quartzite and feldspar rocks rich in iron and magnesium bearing minerals. It does not contain soluble and calcareous materials.
2. Moorum It is a powdered rock which includes all kinds of disintegrated rock.
3. Desert soil It is mainly sand covering an irregular rocky floor. In most of the area, the sand is piled up into dunes.
4. Alluvial soil Alluvial soil is formed due to sediment deposits by stream and rivers. Indo-Ganges plain is the biggest alluvial soil deposit. The older alluvial is generally darker in colour. They contain impure calcium carbonate. They are loamy soils possessing high degree of fertility.
5. Lateritic soil It is a product of tropical alteration suffered by alkali rocks and sedimentary rocks. The soil is rich in iron and aluminium content. When fresh it can be easily cut but after weathering it turns into a hard stone.
6. Saline and alkaline soils These soils contain high salt concentration. They are often found in areas of poor drainage with high evaporation.
7. Black cotton soil The name is due to its colour and its immense fertility for growing cotton. It covers about 20% of total area of India. It is an expansive soil. The thickness of this soil deposit varies from 0.3 m to 15 m. It usually contains high alumina, lime and magnesia.
8. Clay It is an aggregate of mineral particles of very fine particles (microscopic). It may be organic or inorganic.
9. Loam It is a mixture of sand, silt and clay.
10. Shale This is a material in the stage of transformation from clay to slate.
11. Kaolin It is a pure form of white clay. It is known as china clay. It is used in ceramic industry.
12. Peaty and marshy soils This type of soil is formed in the waterlogged area. They are rich in organic materials.
Structure of Soils
Basic Terms
Important Relations
Determination of Specific Gravity
Determination of water content
1. Shape of Grains
2. Size of Grains
Sieve Analysis It is carried out by sieving about 500 gm of dry soil sample through a set of standard gives arranged one over the other is ascending order of their sizes. The percentage of

sample retained on each sieve is determined by weight and the percentage finer than the sieve size found. The result is plotted in the form of a graph on a semi-log paper with the percentage finer on arithmetic scale and the particle size on logarithmic scale. A smooth curve is drawn through the points to see grain size distribution as shown in Fig. 12.3.
Sedimentation Analysis The particle size distribution of soil fraction less than 75m is determined by sedimentation analysis, which is based on Stokes' law. According to this law, fine particles settle in liquid at different rates according to their size. Coarser size particles settle quickly.
Density Index of Cohesionless Soils
Consistency of cohesive Soil
Seepage velocity Flow can occur through voids only, i.e., it cannot occur through solids. Hence, the velocity inside the soil pores is different form velocity of flow. The actual velocity through the pores is known as seepage velocity. If Av is cross-sectional area of the voids, then
Laplace Equation
Flow Net
Applications of Flow nets
Piping
Coefficient of volume compressibility The change in volume of soil per unit initial volume due to a given increase in the pressure is called the coefficient of volume compressibility
Coefficient of consolidation It is used to indicate the combined effects of permeability and compressibility of a soil on the rate of volume change. It is given mathematically as
Degree of consolidation It is the ratio of settlement of clay at a particular time to the final settlement when the process of consolidation is complete. It depends upon:
Time Factor It is a dimensionless constant and is defined by the equation
At the end of compaction and consolidation
Water content-density curve Figure 12.5 shows water content and density curve for cohesive and moderately cohesive soils. Figure 12.6 shows such curve for cohesionless sandy.
Bearing Capacity of Soil
1. Ultimate bearing capacity It is the maximum gross pressure on soil at the base of footing at which soil fails in shear.
2. Net bearing capacity It is the maximum net pressure at which soil fails in shear and is equal to ultimate bearing capacity minus overburden pressure
3. Net safe bearing capacity
4. Gross safe bearing capacity
5. Safe settlement pressure It is the net pressure which the soil can carry safely without exceeding the allowable settlement.
6. Allowable bearing pressure It is the maximum allowable net bearing pressure from the consideration of shear failure and settlement failure. It is also known as allowable bearing capacity of soil.
Settlements of Foundation
Plate Load Test
Hydrology
Surface sources
Groundwater
Water Demand

Quality of Water
Water treatment
Filtration
Disinfection
Water softening
Pumps and Pumping
Conveyance of water
Distribution system
Water supply for Buildings
Collection and Conveyance of Refuse
Quantity of Sewage
Hydraulic Design of sewers
Construction of sewers
Sewer Appurtenances
Sewage Pumping
Characteristics of Sewage
Sewage Disposal
Sewage Treatment
1. Preliminary treatment This is to remove floating materials, settlable inorganic solids, fats, oils and grease. Various units used in this process are:
2. Primary treatment It is to remove large suspended organic matter. Primary sedimentation tanks or primary settling tanks or primary clarifiers used for this treatment.
3. Secondary treatment This is to remove organic matter and the residual suspended material by biological unit processes.
4. Tertiary treatment This is to remove dissolved and suspended materials such as inorganic compounds of nitrogen and phosphorous residual organic matter, etc.
Sedimentation
Sewage Filters
Disposal of sludge
1. Economical growth Connecting producing centres to marketing centres avoids wastage of materials. By this both producer and consumer are benefitted. More industries will come up to cater to various needs of the public.
2. Social effects More frequent travels by people make them broadminded and reduce sectionalism. National and international integration improve. Antisocial activities come down.
3. Safety laws and order efficient transportation of law enforcing forces bring safety to the public. The internal and external safety of the nation improve.
4. Disaster management If good transportation facility exists, in case of distress due to natural calamities, suffering of the affected people can be minimized by rushing aid.
Modes of Transportation
Historical Development of Roads
Classification of Roads
I. Based on the usage of roads during any season They may be classified as (i) all weather road and (ii) fair weather roads. In case of fair weather roads overflowing of streams across the road is permitted during peak mansoon season.
II. Based on the type of pavement: The roads may be classified as

III. Based on width and quality: Roads road are classified as follows:

Principles of road alignment
Surveys to be conducted
Drawings and Reports
Components of a Divided Highway
Width of formation (Road way) It is shown in table 14.1.
Recommended right of way for different roads It is as shown in table 14.2.
Indian road congress recommendation of camber These are given in table 14.3.
Gradient
Sight Distance
1. Stopping sight distance It is the minimum distance required by a driver to stop his vehicle while running at design speed of the road when the obstruction on the road is sighted. For this height of line of sight of driver is taken as 1.2 m and height of obstruction 0.15 m above road surface. Its value depends upon:
2. Overtaking sight distance (OSD) The minimum distance/safe passing-sight distance required for a vehicle to overtake a vehicle without interfering with a vehicle coming in opposite direction at design speed of road is as shown in table 14.6.
3. Sight distance at intersections From safety considerations, the sight distance at uncontrolled intersections should satisfy the conditions given below:
Classification of Terrain
Horizontal curves
On a flat curve skidding of vehicle takes place when
Superelevation
Transition Curves
Vertical Curves
Flexible and Rigid pavement
Flexible Pavement Design
Design of Rigid Pavements
Joints in Concrete Pavements
1. Earth road and gravel roads
2. Gravel road Camber 1 in 30 to 1 in 25.
3. WBM road In this case the pavement base course is made of broken aggregates mechanically interlocked by rolling and voids filled with screening and binding materials with the assistance of water. it may be used as sub-base, base course or surfacing course. It consists of a number of courses of thickness 75 mm to 100 mm. 120 to 180 mm broken stones are packed so that their pointed ends are upward. Hollow spaced of packed stones are filled with broken stones or gravel and rolled with 10 tonne rollers. Screenings are then spread and dry rolled. Then they are wet rolled. after a day 6 mm thick sandy clay is spread and rolled. Road is opened for traffic only after 10 days curing.
4. Bituminous pavements The following types of bituminous construction are practised:
Cement Concrete Roads
Traffic Survey
Traffic volume study It is measured in terms of vehicles passing through a cross section of road during unit time. Thus, the volume is expressed as vehicles/second, vehicles/hour or vehicles/days etc.

In design not only number of vehicles but type of vehicle is also important. Hence, it is preferred to express the volume in terms of equivalent passenger car unit (EPCU) in unit time. The ministry of transport has given the following EPCU:
Speed study Two types of speed studies are carried out (a) spot speed study (b) speed and delay study.
Spot speed study is measured on the time taken to travel a fixed distance. Earlier enoscopes were used to measure time taken to cross two fixed points, but now efficient electronic equipment are used. This study is used in geometric design and to control speed as per regulation.
Origin and destination of traffic These studies help in planning expansion of roads, bye passes, alternate routes, etc. These studies are carried out by observing number plates of vehicles or interviewing drivers or by conducting postcard surveys.
Parking studies Parking studies are carried out
Accident studies Every minor and major accident should be studied for future improvements of roads and signal system or making a street one way.
Traffic Islands
Road Intersections
Traffic Controls
1. Traffic signs Traffic signs are provided in the form of symbols or inscriptions mounted on fixed or portable supports.
2. Traffic signals These are provided at intersections of roads. They consist of three lights—red to indicate stop, amber to indicate clear and green to indicate 'go' signal. In some places the signal indicates how long the red signal will be there. To guide pedestrian the signals are provided at all these signal points.
3. Road markings Road markings are necessary to guide road users. Some of the markings are:
Railway Gauges
Rail Sections
Length of Rails
Welding of Rails
Rail Joints
Coning of wheels and Tilting of rails
Hogging and buckling of rails
Corrugation, corrosion and creep
Wear of rails
Fish plates
Requirements
Sleeper Density
Types of sleepers
1. wooden sleepers The seasoned good quality wood free from defect may be used as sleepers. Teak wood is preferred in India only at girder bridge, since though it is the best, it is very costly. Sal wood is mostly used as sleeper.
2. Steel sleepers shortage of timber led to use of steel sleepers. Now 30% of track in Indian railways are provided with steel sleepers. They are made by rolling 12 mm steel plates formed into trough shape in order to prevent running of ballast. A cant of 1 in 20 is provided towards the inner side to receive coned treads of wheel. In these sleepers, holes are drilled and punched to

hold jaws and keys.
3. Cast iron sleepers After trying various cast iron sleepers like pot, plate and box between the years 1926 to 1935, track standard committee (CST) of Indian railways started using CST–9 type cast iron sleepers. The number 9 indicates the trial no. 9. It consists of two boxes held at gauge distance by mild steel tie bars. Mild steel cotters fix the boxes to tie bars and the rail is held to the sleeper by means of clip and double coil spring. Below the rail seat a rubber seating is provided. Service life of CST–9 sleepers is 35 to 50 years. Now with small improvements CST–10, CST–11, CST–12 and CST–13 sleepers have been developed. The use of cast iron sleepers now covers up to 50% in Indian railways.
4. Concrete sleepers The following four types of concrete sleepers have been tried:
Fittings
Fish Bolts Each pair of fish plate is joined by four bolts made from high carbon steel. They are tightened time to time.
Fittings for wooden sleepers Dog spikes, round spikes and screw spikes are used to fix rails to wooden sleepers.
Bearing plate Below the rails bearing plates are provided which are then fixed to wooden sleepers. As bearing plates distribute the load from rail over larger area stresses on sleepers is reduced. But the disadvantage is moisture may enter between rail and bearing plate and accelerate corrosion. If one spike is damaged all the spikes are to be removed. Flat M.S. bearing plate and cast iron anti-creep bearing plates are used by Indian railways.
Two-way keys The keys tapered in both directions are known as two-way keys. They may be driven in either direction. They are used with pot sleepers, trough sleepers and CST–9 sleepers.
Cotters These are used for fixing the tie bars with cast iron sleepers. The length of these cotters is 150 mm and weight 3.5 N. The type of cotters used are: solid end cotter, bent plate cotter, side split cotter and centre split cotter.
M.S. tie bars These are the bars used to hold two CST–9 sleepers together.
Elastic fastener To reduce vibrations elastic fasteners are used to hold the rails to sleeper. Pandrol clip, INR-202 clip, IRN-304 clip, double shank elastic spike, lock spikes are the examples of elastic fasteners.
1. Slopes Side slopes for embankment and cutting are usually 2H :1 V to 1/2 H : 1 V.
2. Side drains On both sides of the embankment and cutting sufficiently wide drains should be provided. However in case of natural cross slope no drain is required on the lower side.
3. Gradient The rise or fall of the rail track level per unit length of the track is known as gradient. Gradient on railways may be classified as:
Superelevation
Cant deficiency It is the difference between necessary cant for design speed and actual cant. The maximum cant deficiency for speeds up to 100 kmph is
Plate Laying
Railway Stations
(a) Block stations For operational purpose track is divided into a number of blocks and at the end of block a station is located. These stations are divided into A, B and C classes.
(b) Non-block stations These stations do not have any signal and hence they cannot control train. They have crossing facility. They are also known as flag stations or D-class stations.
(c) Special class stations The stations which do not fall under any of class A, B, C and D are known as special class stations

(i) Terminal stations The stations at which a railway line or branch line terminates is known as terminal station.
(ii) Junction station The station where traffic flow is in 3 or more directions.
(iii) Way side station These stations are provided with facilities for crossing of up and down train or for overtaking a slower train by a faster train.
Platform
A. Requirement of passenger platforms
B. goods platform
Station Yards
(a) Passenger yard It includes passenger platforms and a number of tracks where idle trains can be accommodated, examined and cleaned.
(b) Goods yards It includes the platforms used for loading and unloading goods. It may be paved with concrete, bitumen or water bound mechadam. A transit shade with weight bridge is necessity in a goods yard.
(c) Marshalling yard The main functions of the marshalling yard are reception, sorting and reforming into designation-wise of goods trains. It needs a number of siding systems to sort out and rearrange goods wagons. Marshalling yard may be a flat yard, hump yard or gravitational yard. In case of flat yards, locomotive power is required for movement of wagons, whereas in case of hump yards and gravitational yards gravity force is also utilized. However, if gravity force is utilized for marshalling suitable breaking system should be provided.
(d) Locomotive yards These yards are provided by the side of marshalling yards for cleaning, repairing, servicing, watering, etc.
Points and crossings
Road and Rail Level Crossings
For changing direction of engine
Traverse, Buffer stops and sand hump
Track Maintenance
Signalling
Signalling
1. Time interval system In this system a fixed time interval is maintained between the departure of two trains between two stations. This is still used in case of failure of telegraph system.
2. Polot guard system In this system a pilot guard proceeds by one train to the station ahead and returns by another train. No other train is allowed to proceed from the station till the pilot has returned.
3. Train staff or ticket system In this system train staff or ticket is issued by the station master to proceed and enter the section.
4. Absolute block or spice interval system In this system the track is divided into a number of sections. Generally, it is the distance between two stations. Block instruments are installed in the stations and are electrically connected. Only when two station masters agree token is released from the instrument and the train has to start with token.
5. Automatic block system In this system the track between two stations is divided into a number of blocks of 5 to 7 km. The signals are activated by trains themselves. When a train enters a block, the electric current conveyed through track puts the danger signal for this block until the train has gone for two blocks ahead.
6. Centralized traffic control system (CTC) In this system all signals are interlocked and are

controlled from a centralised control room. In control rooms trains on track are traced and the position of signals displayed and they can be operated.
7. Automatic train control system (ATC) In this system track is electrically circulated. Electric fittings are provided at the wheel brakes. Even if the driver fails to notice signal, the fittings help in reducing the speed of trains and bring it to stop.
Interlocking
1. Key system/indirect interlocking In this system arrangement is such that at any time only one key can be removed to put a signal to on position.
2. Mechanical/Tapper and locks system In this system different levers are attached to tappers (steel bars) and moving tappers only one signal in the group can be activated.
3. Electrical interlocking/Route relay system In this system points and signals are electrically interlocked and operated. This is the modern and sophisticated system of interlocking.
Methods of tunnelling in soft strata
Methods of tunnelling in rocks It involves drilling holes in the rock face, loading the holes with explosives, blasting, removing and disposing of broken rock. The commonly adopted methods are:
Tunnel ventilation, lighting and mucking
1. Natural harbour It is an inlet protected from storms and waves by natural configuration of land. Mumbai, Kandla and karwar are examples of natural harbours.
2. Semi-natural harbour The harbour in which natural configuration of land prefects the harbour on sides only and needs man-made protection at the entrance. Vishakhapatnam is a semi-natural harbour.
3. Artificial harbour It is harbours protected by man-made structures like breakwaters or by dredging. Chennai is a man-made harbour.
Classification Based on Utility
Classification based on location
Natural Phenomenon Influencing Location of Harbour on seashore
1. Littoral Drift The process of carrying the drifting sand and depositing it on seashore is known as littoral drift. If a harbour is constructed in the path of the littoral drift, there will be accumulation of sand on one side and erosion on the other side of the harbour. Groynes are used to protect the shore by trapping littoral drift.
2. Tides The artificial rise and lower of mean sea level periodically is known as tide. It is observed that the general water level rises and falls, approximately in a period of twelve hours and twenty-five minutes. It is also observed that much higher water levels and much lower water levels occur on new and full moons. these tides are called spring tides. Water levels which occur about seven days from new and full moons are moderate and are called neap tides. The total height of spring tides is about 1.5 to 2.0 times that of neap tides.
3. Waves and winds Wind generates waves on water bodies. In maritime works, speed of wind is expressed in knots. One nautical mile is the length of one minute of arc of a meridian on earth surface. Since radius of earth of equator is about 6378 km, 1 nautical mile = 6378 ¥ ¥ km, i.e., 1 nautical mile is 1.852 km. Hence, one knot is 1.852 km/hour.
1. Harbour entrance Depth and width required at the entrance are more than those required in the channel since it is more exposed to waves. Entrance should be wide enough for navigational requirement. However, it should not be too wide to increase the wave height within the harbour.
2. Approach channel The dredged fairway through which ships proceed from the open sea to the

harbour basin is known as approach channel. The depth should be sufficient for navigation of design vessels at all the time.

3. Turning basin It is the area required for manoeuvring the ship when it enters or leaves the berth, so that it moves head on.
4. Sheltered basin It is the area protected by shore and breakwaters.
5. Breakwaters The protective barrier constructed to enclose harbours and to keep the waters undisturbed by the rough sea are called breakwaters. Types of breakwaters used are
6. Wharves and quays The platforms provided along the shore or breakwater for ships to come close enough for loading or unloading are called wharves. Wharves along and parallel to the shore are generally called quays. Wharves and quays have backfill of earth or other materials and have wide platform at top.
7. Jetties A jetty is a narrow strip structure projecting from the shore into water with berths on one or both sides.
8. Lock and locked basin Locked basin is an enclosed basin wherein a number of vessels can be berthed and has an entrance controlled by lock gate.
9. Fender The cushion provided on the face of a jetty for absorbing shocks by ships is known as fender. They may be rubber strips, timber grills, concrete or rubber fenders.
10. Slip The space of water between two adjacent piers where ships are berthed is known as slip. For safe navigation and provide enough space for barges to load and unload, the slip should be three to four times the beam of largest ship to be accommodated.
11. Docks Docks are enclosed areas for berthing ships, to keep them afloat at a uniform level. there are two types of docks:
12. Aprons The open space left immediately in front of the berth is known as apron. It is used for loading, unloading and for installing railway track, road or conveyers. The width of apron usually varies from 10 m to 25 m, depending upon the traffic.
13. A dock requires transit sheds, warehouses, cold storages and guardhouse, etc.

Maintenance Dredging

Navigational Aids

1. General lights They guide the ships along the coast and through rivers serving as approaches to more than one harbour. They may be light houses, or light ships.
2. Local lights They guide the ships to harbours through approach channels to the berths. They are light houses, fixed structures, channel markers, floating buoys, lights on shore, wharves, breakwaters, etc.

Types of Bridges

Terminology

Bridge Design

1. Masonry piers May be with brick, stone or plain concrete. In concrete piers richer concrete may be used for skin and poor concrete for heart. Using plain concrete about 600 mm height may be built every day. All masonry piers are provided with rich concrete at top to serve as bed block to receive bearing and distribute load uniformly to the lower portion of pier. Various types of shapes of piers are used as shown in fig. 18.2 commonly used pier shape is with end triangular shape making an angle of 30° to 60° with side.
2. R.C.C. piers R.c.C. piers of various shapes are used. They may be rectangular, dumb-bell type or cylindrical. They may be with solid diaphragm connecting to portions of dumb-bells or with open diaphragm. Sometimes steel or R.C.C. trestle bents are also used.

Foundations

Superstructures
Permanent Small Bridges
1. Causeways It is a submersible bridge, provided across a nullah or stream. These are adopted for roads which are of minor importance. They do not have foundation, pier or abutment. They are concrete slabs and stone pitching at bed level or slightly higher level of stream. Causeways may be classified as:
2. Culverts Culvert is a small bridge, the maximum span not exceeding 6 m. It may have 3 to 4 spans. Types of culverts used are:
Structure and Organisation of Air Transport
Classification
Sight distance If two runways or a runway and taxiway intersect care should be taken to see that minimum sight distance is ensured. ICAO recommends that for A, B, C type airports, any two points 3 m above the surface of runway are mutually visible from a distance equal to half the runway length. For D and E type airports there should be minimum sight distance for half the length of runway from a point 3 m above to another point 2.1 m above the runway.
Gate capacity Gate capacity is the ability of a specified number of gates to accommodate aircraft loading and unloading operations under continuous demand. It depends upon mix of aircraft class and average occupancy time for the class. Capacity of gate may be determined as shown below
* Runway configurations The following basic pattern of runways may be used:
Taxiway
Sight distance for a taxiway ICAO recommends that sight distance should be 300 m at 3 m height A, B, C type and 250 m for D and E type at a height of 2.1 m.
Turning radius The turning radius required for taxing is given by the expression
1. Building Area It offers a sheltered, convenient and direct access for passengers from street side to aircraft through checking, booking and waiting rooms. Deplaning passengers are also provided with direct route from the aircraft to the baggage claim counter to the vehicle platform. In the design care should be taken to see that
2. Apron It is a paved area for parking of aircraft and loading and unloading of passengers and cargo. In aprons aircraft are parked in any of the following configurations:
3. Vehicular circulation and parking area Access roads are planned to provide fast connection between the airport and the city. Short time parking for passenger cars should be provided close to terminal buildings. There should be sufficient and convenient circulation and parking lots. Separate parking area is required for the vehicles of the staff. It is suggested that parking facility should be based on 1.5 to 2 cars for each peak hour passenger.
4. Hangar Covered area provided for servicing and repairs of aircraft is known as hangar. They are usually constructed with steel frames and GI sheets. They are provided with stores for spare parts.
Markings and Lighting
Heliports
stol port