Basic Civil Engineering

Fourth Edition

About the Author

MS Palanichamy is currently serving as the Vice Chairman of the Tamil Nadu State Council for Technical Education. He holds a bachelor's degree in Civil Engineering from PSG College of Technology and MTech and PhD degrees from the Indian Institute of Technology, Chennai. His teaching experience spans a period of over 35 years.

Dr Palanichamy was a faculty of Anna University in the Structural Engineering Department for a decade. He served as Professor and Head of the Civil Engineering Department and then as the Principal of Mepco Schlenk Engineering College, Sivakasi. Later, he served as the Vice Chancellor of Tamil Nadu Open University, Chennai, for two terms. He has published four books and 60 papers in his professional career. Also, four candidates have obtained their PhD degrees under his guidance.

He is a member of various professional bodies like American Concrete Institute (AUI), Indian Roads Congress (IRC), Indian Buildings Congress (IBC), Institution of Engineers (India), Indian Concrete Institute (ICI), Institution of Values, Indian Geotechnical Society, Institution of Public Health Engineers (India), Indian Institute of Public Administration, etc. He has also served as a member of National Executive Council of the Indian Society of Technical Education, All India Council for Technical Education and the Engineering Accreditation Committee, NBA, New Delhi. He was the Chairman, Board of Studies (Civil Engineering) of Madurai Kamaraj University, Anna University, Coimbatore Institute of Technology, Coimbatore, and Thiagarajar College of Engineering, Madurai, under the autonomous system. He has also served in the governing councils of many technical institutions and private universities in Tamil Nadu.

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M S Palanichamy
Vice Chairman
Tamil Nadu State Council for Technical Education
Chennai, Tamil Nadu

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Contents

Preface

Basic Civil Engineering, taught at the first-year level enables the students to get a good glimpse of all the major concepts of civil engineering. These topics would be dealt with in greater detail in the higher semesters. This book has been revised to meet the requirements of a first-year course on Basic Civil Engineering offered by the major technical universities and institutions across the country. It provides a concise coverage of all the major concepts in one single volume in a lucid style. This book will be useful not only to the first-year BE students, but also to the Diploma and AMIE students. It will also serve as a good reference material for those preparing for competitive examinations.

Key Features

- New chapter on Interior Design and Landscaping
- New sections on Building Types and Components; Water Sources; Water Purification: Chlorination; Water Demand Estimation; Sanitary Engineering: Definition and Terms; Solid Waste Management; Methods of Constructing a Concrete Road; Caisson Foundation; Sand and Testing of Sand; Brick Testing
- Adequate coverage of all the key fundamental topics
- Lucid writing style
- Rich pedagogy:
  - 219 Illustrations
  - 212 Short Answer Questions
  - 220 Exercise Questions
  - 65 Solved examples

Chapter Organisation

The book is organized in 15 well-written chapters. Civil Engineering and Materials are introduced in **Chapter 1**. **Chapters 2 to 6** are devoted to Buildings, Superstructures, Dams, Bridges and Tall Structures respectively. Simple Stresses and Strains are explained in **Chapter 7**. The principles and techniques of Surveying are covered in **Chapter 8**. Environmental protection and upkeep is a major concern of the twenty-first century.

Keeping this in view, Water and Environmental Engineering are discussed in **Chapter 9**. **Chapters 11 to 14** can be treated as a group and are dedicated to Roads, Railways, Airports, and Docks and Harbours. Finally, Interior Designing and Landscaping are taken up in **Chapter 15**.

The book is presented in a simple, but comprehensive manner. Solved problems and illustrative diagrams have been included to explain the various concepts. Exercises are appended at the end of each chapter to provide adequate practice to the students and to help them comprehend the subject.

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I am deeply indebted to Tata McGraw Hill Education, particularly to Mr H R Nagaraja, for the speedy publication and excellent quality of the book.

I hope that this book will be well received by students and teachers alike. Any suggestions from the readers for the improvement of the book are welcome.

M S Palanichamy

Feedback

Constructive suggestions and criticism always go a long way in enhancing any endeavour. We request all readers to email us their valuable comments/views/feedback for the betterment of the book at *tmh.corefeedback@gmail.com*, mentioning the title and author name in the subject line. Also, please feel free to report any piracy of the book spotted by you.

Chapter 1
CIVIL ENGINEERING AND MATERIALS

1.1 INTRODUCTION

Engineers have probably contributed more to the shaping of civilisation than any other professional group. In every society, the role of engineers is to develop technological applications to meet practical needs. For example, the application of an electrical system is to provide power to a city, a water wheel is to run a mill, an artificial heart is to prolong life, etc. The systems that supply our food, water, fuel, power, transportation network, communication and other conveniences are the products of engineering skill. Despite the essential part engineers play in the above progress and in the well-being of humanity, their exact role is imperfectly understood.

Engineering is the art of converting knowledge into useful practical applications. An engineer is a person, who plays the key role in this process of conversion. Since engineering is the profession which serves people, their environment is an important consideration. Often, there have been difficulties in distinguishing engineers from scientists. It is difficult to determine where the work of the scientist ends and that of the engineer begins.

The basic distinction between the linked professions of science and engineering lies in their goals. Scientists aim to invent while engineers strive to use the inventions effectively to cater to the needs of mankind. For example, the German physicist Heinrich Hertz discovered radio waves while Guglielmo Marconi developed wireless telegraphy using radio waves, a feat of engineering. And after the scientific principles of nuclear fission were established, the hard work of creating atomic weapons and useful power plants was accomplished by electrical, chemical and mechanical engineers.

1.1.1 History of Civil Engineering

In earlier times, the work of an engineer was confined to public works (surveying, construction, roads, water supply, irrigation, transport, etc.) simple mechanics (using only the force of water or human and animal power) and to military needs. This continued until the late 19th century. However, the modern developments in technology led to the grouping of engineering into several branches, each requiring specific knowledge related to the particular branch. Mining and metallurgy was the first to be recognised as a separate branch in 1871. Mechanical engineering in 1880, electrical engineering in 1884 and chemical engineering in 1908 were the next to be recognised as separate branches. Since then, numerous other branches have come into being.

The history of development of housing facilities reveals that humans have been moulding their environment throughout the ages for more comfortable living. Egyptians constructed huge pyramids. Romans developed arches for vaults and domes. During the Gothic period of architecture (1100–1500 AD), churches with pointed arches and ribs supporting masonry vaults were constructed. The arched ribs were supported by stone pillars. These structures led to the idea of development of framed structure.

1.2 CIVIL ENGINEERING

Civil engineering is that branch of engineering which aims to provide a comfortable and safe living for the people. Shelter, one of the primary needs of mankind, is provided by civil engineers. The efficient planning of water supply and irrigation systems increases the food production in a country. Shelters, apart from just being shelters, have been constructed by civil engineers to provide a peaceful and comfortable life. The engineering marvels of the world, starting from the pyramids to today's thin shell structures, are the results of the development in civil engineering. Communication lines like roads, railways, bridges, etc., without which development is impossible, are fruits of civil engineers' work.

1.2.1 Scope of Civil Engineering

Any discipline of engineering is a vast field with various specialisations. The major specialisations of civil engineering are listed below:

1. Structural engineering
2. Geotechnical engineering
3. Fluid mechanics, hydraulics and hydraulic machines
4. Transportation engineering
5. Water supply, sanitary and environmental engineering
6. Irrigation engineering
7. Surveying, levelling and remote sensing

Structural Engineering Structural engineering is the most important specialisation in civil engineering. The construction of a structure needs efficient planning, design and method of construction to serve the purpose fully. Generally there are five major steps in any construction project. These include the following:

1. Positioning and arranging the various parts of the structure into a definite form to achieve best utilisation.
2. Finding out the magnitude, direction and nature of various forces acting on the structure.
3. Analysing the structure to know the behaviour of the various parts of the structure subjected to the above forces.

4. Designing the structure such that its stability under the action of various loads is ensured.
5. Executing the work with selected construction materials and skilled workers.

Geotechnical Engineering For the efficient functioning of any structure built on earth, the behaviour of soil must be known. Geotechnical engineering gives the basic idea about the soil. This branch also deals with the following aspects:

1. The properties and behaviour of soil as a material under "soil mechanics".
2. The various types of foundations for a structure, for a machine, etc. and their suitability.

Geotechnical engineering also deals with the analysis, design and construction of foundation.

Fluid Mechanics, Hydraulics and Hydraulic Machines Fluid mechanics deals with the properties and behaviour of fluids at rest or in motion. The principles of fluid mechanics can be applied to daily life as in the case of the flight of planes, the movement of fish in water, and the circulation of blood in the veins.

The design of hydraulic structures, such as dams and regulators, require the force exerted by water and the behaviour of water under pressure.

Machines which utilise the hydraulic energy are called hydraulic machines. For example, turbines use potential energy of water to generate power. Pumps are devices which utilise mechanical energy to lift water. The efficient working of the above machines depends upon the fluid behaviour which is dealt with in this discipline.

Transportation Engineering The development of a nation mainly depends on the communication facilities available. A nation's wealth is measured in terms of the road and railway facilities available. There are three modes of transportation, viz. land, water and air. This specialisation deals with the design, construction and execution of the communication routes.

The different branches of transportation engineering include the following: highway engineering deals with the planning and designing of roads, railway engineering deals with the railway tracks, harbour engineering deals with the harbours and airport engineering deals with the airports.

Water Supply, Sanitary and Environmental Engineering Without food man can survive for days but not without water. The responsibility of providing potable (drinking) water to the public and disposing the waste water safely is that of a civil engineer. The sources of water are precipitation and underground water.

Water supply engineering deals with the location, collection of water, its treatment methods, tests for standard limits and efficient supply of water.

Used water, solid wastes, toxic wastes, etc., cannot be disposed directly since these affect the environment. Hence these have to be treated and tested for the standard limits and then disposed. Sanitary engineering deals with the collection of used water, their treatment methods and effective disposal which safeguards the whole world. The natural and artificial wastes generated and released into the atmosphere have upset the natural equilibrium. Anthropogenic or human-induced pollutants have overloaded the system.

The role of an environmental engineer is to build a bridge between biology and technology by applying all the techniques to the job of cleaning the debris. Environmental engineering deals with the methods of protecting the environment from the deleterious effects of human activity which would result in the improvement of environmental quality for the well-being of mankind.

Irrigation Engineering Irrigation may be defined as the process of supplying water by man-made methods for the purpose of land cultivation. Irrigation engineering includes the study and design of works related to the control of river water and the drainage of waterlogged areas. Thus, irrigation engineering deals with the controlling and harnessing of various resources of water, by constructing dams, reservoirs, canals, head works and distribution channels to the cultivable land.

Surveying, Levelling and Remote Sensing Before starting any important civil engineering project, such as the construction of railways, highways, dams and buildings, it becomes necessary to have a detailed survey map showing accurate boundary of the project area. Surveying is defined as an art of collecting data for mapping the relative positions of points on the surface of the earth. Levelling is the process of determining the relative heights of the points on the surface of earth in a vertical plane.

The main purpose of the survey work is to prepare the plan of the object to be surveyed. Various instruments are used to measure and collect the necessary information to draw the plan. Remote sensing uses the technique of obtaining the data about an area by taking aerial photographs. The intelligent interpretation gives a clear picture of the terrain.

1.2.2 Functions of a Civil Engineer

Civil engineering incorporates activities such as construction of structures like buildings, dams, bridges, roads, railways, hydraulic structures, water supply and sanitary engineering.

Various functions of a civil engineer are listed below.

1. Investigation The first function of a civil engineer is to collect the necessary data that is required before planning a project.

2. Surveying The objectives of surveying is to prepare maps and plans to locate the various structures of a project on the surface of earth.

3. Planning Depending on the results obtained from investigation and surveying, a civil engineer should prepare the necessary drawing for the project with respect to capacity, size and location of its various components. On the basis of this drawing, a preliminary estimate should be worked out.

4. Design After planning, the safe dimension of the components required are worked out. With this dimension a detailed drawing is prepared for various components and also for the whole structure and a detailed estimate is also calculated.

5. Execution This function deals with the preparation of schedules for construction activities, floating of tenders, finalisation of contracts, supervision of construction work, preparation of bills and maintenance.

6. Research and Development In addition to the above-mentioned works, a civil engineer has to engage himself in research and development to achieve economy and to improve the efficiency to meet the present and future needs.

1.3 CONSTRUCTION MATERIALS—BRICKS

1.3.1 Introduction

As an engineer, one must know about the materials used in the construction site. All structures are constructed of materials known as engineering materials or building materials. It is necessary for an engineer to be conversant with the properties of such materials.

The service conditions of buildings demand a wide range of materials with specific properties. Hence the properties of the materials are to be studied properly to select suitable building materials. In this section and in the subsequent sections, the properties and uses of some building materials, such as bricks, stones, cement, concrete and steel are discussed.

The common brick is one of the oldest building materials and it is extensively used at present because of its durability, strength, reliability, low cost, etc. Bricks are obtained by moulding clay in rectangular blocks of uniform size, then by drying and burning these blocks in brick kilns.

1.3.2 Qualities of Good Bricks

1. Bricks should have perfect edges, well-burnt in kilns, copper coloured, free from cracks with proper rectangular shape and of standard size (19 × 9 × 9 cm).
2. Bricks should give a clear ringing sound when struck with each other.
3. Bricks must be homogeneous and free from voids.
4. The percentage absorption of water by weight should not be greater than 20 per cent for first-class bricks and 22 per cent for second-class bricks when soaked in cold water for 24 hours.
5. Bricks should be sufficiently hard, i.e., no nail impression must be present when scratched. The average weight of bricks should be 3–3.5 kg.
6. Bricks should not break when dropped from a height of 1 m.
7. Bricks should have low thermal conductivity and should be soundproof.
8. Bricks should not show deposits of salts when immersed in water and dried.
9. The minimum crushing strength of bricks must be 3.5 N/mm^2.

1.3.3 Classification of Bricks

Bricks are classified based on the manufacturing process adopted. The classification is given as follows:

1. First-class bricks are table-moulded and of standard shape. These comply with all good qualities of bricks and are used for superior and permanent works.
2. Second-class bricks are ground-moulded and burnt in kilns. The surfaces of such bricks are rough and are slightly irregular in shape. Such bricks are used with a coat of plaster.
3. Third-class bricks are ground-moulded and are burnt in clamps. These bricks are not hard but rough with irregular and distorted edges. These give a dull sound when struck with each other. They are used for unimportant and temporary structures and at places where there is less rainfall.
4. Overburnt bricks with irregular shape and dark colour are classified as the fourth class bricks. These are used as aggregates for concrete in foundations, floors, roads, etc.

1.3.4 Uses of Bricks

1. Bricks are mainly used for the construction of walls.
2. Bricks when moulded in the shape of a gutter can be used as drains.
3. Bricks with cavities known as hollow bricks can be used for insulation purposes and because of their light weight they are more useful in speedy constructions.
4. Paving bricks prepared from clay containing higher percentage of iron can be used for pavements, since they resist abrasion in a better way.
5. Bricks with holes are used in multi-storied framed structures.
6. Fire bricks made of fire clay can be used as a refractory material.
7. Sand-lime bricks are used for ornamental work.
8. Bricks are used in the construction of compound walls, columns, etc. Broken pieces of bricks are used as aggregates in concrete.
9. Bricks of superior quality can be used in the facing of a wall.
10. Bricks are used in the construction of chimneys and other special works.

1.3.5 Constituents of a Brick

1. Alumina It is the chief constituent of clay. A good brick should have 20–30 per cent of alumina. This imparts plasticity to the earth.

2. Silica It exists in clay in a free or combined form. A good brick earth should contain about 50–60 per cent of silica. The presence of silica prevents cracking, shrinking and warping of raw bricks. It imparts uniform shape to bricks. The durability depends on proper proportion of silica.

3. Lime Up to 5 per cent of lime is desirable in good brick earth. It prevents shrinkage in raw bricks. Sand alone is infusible, but it fuses at kiln temperature due to the presence of lime. Bricks may melt and lose their shape due to excess of lime content.

4. Oxide of iron This gives the red colour to bricks. A small quantity of iron oxide up to 5 or 6 per cent is desirable.

5. Magnesia This imparts yellow tints to bricks and it reduces shrinkage.

Advantages of using bricks

The following are the advantages of bricks over other construction materials, like stone, concrete, etc.

(a) Bricks are cheaper and easy to handle.
(b) They are of standard size and hence easy to have proper bonding.
(c) Consumes less mortar when compared to stone masonry.
(d) Labour required for brick masonry is less.
(e) Brick walls can be raised to a larger height, when compared to stone masonry.
(f) Because of regular size the surface of wall will be plane and given a neat appearance.
(g) Brick masonry consumes, less mortar for plastering.
(h) Easy to drill holes for fixing service connection line.
(i) Bricks have low thermal conductivity and high sound insulation properties.
(j) They possess very high resistance to fire.
(k) They are non-combustible and non-inflammable.

Disadvantages of using bricks

(a) The compressive strength of brick is less compared to stone and concrete.
(b) Water absorption is more than that of stone or concrete.
(c) Only a selected variety of clay can be used for manufacture of bricks.
(d) Kilns are required to be constructed for manufacturing bricks.
(e) It has got a very low tensile strength compared to other building materials.

1.3.6 Tests on Bricks

The following are the field tests by judgment for assessing the quality of bricks.

Field tests

1. The bricks should be truly rectangular in shape with sharp edges and plane faces and of the same size.
2. They should be hard and well burnt and should give a metallic ringing sound when struck with a steel rod.

3. They should be of uniform red colour and of fine texture.
4. When the bricks are dropped on the ground from one metre height, they should not crack or break.
5. They should be free from cracks, fissures, pebbles or nodules of free lime.

Lab tests

1. Test for water absorptions

(a) 3 samples of clean well dried bricks are taken and their dry weight is found out individually.
(b) The bricks are then immersed in water for 24 hours.
(c) After 24 hours, the bricks are taken out, surface dried and weighed in a balance and wet weight found out.
(d) If the wet weight of each bricks is W_2, the percentage water absorption of each brick

$$= \frac{W_2 - W_1}{W_1} \times 100$$

(e) The average percentage of water absorption of three samples is the water absorption of the bricks.

Required standard The average absorption should not be greater than 20%. Too much of water absorption indicates under-burnt condition and poor strength.

2. Test for efflorescence (For the presence of salt)

Salts like sulphates of calcium, magnesium, sodium and potassium present in the brick will cause efflorescence on the brick surface, when they get dissolved in water. Bricks containing too much of salt are less resistant to weathering and will have poor strength.

1. Three samples of bricks are immersed in good water for 24 hours.
2. After 24 hours, the bricks are taken out and examined for white patches of salt on the surfaces.
3. If the white patches of salt present are heavy, the bricks are poor and are to be rejected.
4. If the white patches present are small to medium, the bricks can be accepted.

3. Test for compressive strength

The load carrying capacity of bricks is increased, as the compressive strength increases.

(a) Three samples of bricks are taken and immersed in good water for 24 hours.
(b) After 24 hours of immersion, the bricks are taken out and surface dried.
(c) Each brick is placed on the compression testing machine and the load on the brick is gradually increased until the brick fails. The failure load of each brick is found out.
(d) Average failure load of the 3 bricks is the compressive strength of the bricks.

Requirement standards

1. Country Bricks → 35 to 50 kg/cm^2
2. II Class bricks → 50 to 75 kg/cm^2
3. I Class bricks → 75 to 125 kg/cm^2

1.3.7 Manufacture of Bricks

The following are the four processes involved in the manufacture of bricks.

1. Preparation of brick earth
2. Moulding of bricks
3. Drying of bricks
4. Burning of bricks

1. Preparation of Brick Earth

Preparation of brick earth involves the following operations.

(i) Removal of loose soil
(ii) Digging, Spreading and Cleaning
(iii) Weathering
(iv) Blending
(v) Tempering

(i) Removal of loose soil The top layer of the loose soil about 20 cm depth contains lot of impurities and hence it should be taken out and thrown away.

(ii) Digging, spreading and cleaning The earth is then dug out from the ground. This earth is spread into heaps about 60 cm to 120 cm height. All the undesirable matters like stones, vegetable matter, etc. are removed. Lumps of clay should be converted into powder form.

(iii) Weathering The earth is then exposed to atmosphere for softening. The period of exposure varies from weeks to full season.

(iv) Blending The clay is then mixed with suitable ingredients. It is carried out by taking a small portion of clay every time and by turning it up and down in vertical direction.

(v) Tempering This is done to make the whole mass of clay homogeneous and plastic. Required water is added to clay and the whole mass is kneaded under the feet of men or cattle.

When bricks are manufactured on a large scale, tempering is usually done in a pug mill. A pug mill consists of a conical iron tub with cover at its top. A vertical shaft with horizontal arms is provided at the centre of iron tub. Several cutting blades are attached to this horizontal arm. The clay with water is put inside the mill and the vertical shaft is rotated by bullocks or stream, diesel or electric power. Due to the action of the horizontal arms the clay is thoroughly mixed and tempered.

2. *Moulding of Bricks*

The tempered clay is then sent for the next operation of moulding. There are two methods of moulding.

(i) Hand moulding
(ii) Machine moulding

1. *Hand Moulding* This is done by a mould which is a rectangular box with open at top and bottom. It may be of wood or steel.

   Following are the ways of hand moulding:

   (a) Ground moulding (b) Table moulding

   (a) Ground moulding First a small portion of ground is cleaned and levelled. Fine sand is sprinkled over it. Moulding is started from one end of the ground. Mould is dipped in water and kept on the ground and clay is pressed by hand nicely so that all is again dipped in water and it is placed just near the previous brick to prepare another brick. Process is repeated till the ground is covered with bricks. A mark of depth about 10 mm to 20 mm is placed on raw brick by a pallet during moulding. This mark is called as frog. After the bricks become sufficiently dry, they are sent for the next process of drying.

   (b) Table moulding This should be done by an experienced supervisor. The moulder stands near a table of size about 2 m × 1 m. Clay, mould water pots, stock board, strikes and pallet boards are placed on this table. Bricks are moulded on the table and sent for the next process of drying.

2. *Machine moulding* When bricks are manufactured in huge quantity at the same spot then moulding is done by machines. These machines contain a rectangular opening of size equal to the length and width of the brick. The Tampered clay is placed in the machine and as it comes out through the opening under pressure it is cut into strips by wire fixed in frames. Arrangement is made in such a way that strips of thickness equal to that of the brick are obtained.

   The machine moulded bricks have sharp edges and corners, smooth external surface and uniform texture.

3. Drying of Bricks

After the bricks are moulded they are dried. This is done on specially prepared drying yards. Bricks are stacked in the yard with 8 to 10 bricks in each row. Bricks are dried for a period of 5 to 12 days.

During drying it must be protected from wind, rain and direct sun. Sometimes, bricks, are dried artificially by hot gases from kiln. But there is change of warping of bricks in case of artificial drying. After drying, the bricks are sent for the next operation of burning.

4. Burning of Bricks

Burning imparts hardness and strength to bricks and makes them dense and durable. It must be done carefully and properly because underburnt bricks remain soft and hence cannot carry loads and overburnt bricks become brittle and hence, break easily. Burning of bricks is done either in clamp or in kilns.

1.4 STONES

Building stones are obtained from rocks. It is essential to have some knowledge about rocks in order to study the properties of stones. Rocks are mainly classified into igneous rocks, sedimentary rocks and metamorphic rocks. Igneous rocks are formed by the cooling of the molten material from beneath the earth's surface. Stones from these rocks are said to be harder. Granite which is widely used in building constructions is a good example.

Sedimentary rocks are formed by the deposition of weathering products on existing rocks. Deposits are in layers and when load is applied along the layers these rocks easily split.

Metamorphic rocks are formed by the change in character of the pre-existing rocks. These will be hard if the basic rock is an igneous rock.

1.4.1 Qualities of Good Stone

1. The crushing strength of stone should be greater than 100 N/mm^2. All igneous rocks have a strength around 100 N/mm^2 and some of the metamorphic rocks also satisfy this requirement. Sedimentary rocks have a lower strength.
2. Stones must be decent in appearance and be of uniform colour. Light coloured stones resist weathering action in a better way and hence preferred.
3. Stones must be durable. For the stones to be durable, their natural bed must be perpendicular to the direction of pressure.
4. Stones should be such that these can be easily carved and dressed. This property is opposed to strength and hardness but this depends upon the situation in which the stone is used.
5. For a good building stone its fracture should be sharp and clear.
6. If the stone is to be used in road work, it should be hard enough to resist wear and tear.
7. A good building stone must have a wear less than 3 per cent. If it is equal to 3 per cent, it is just tolerable while if it is more than 3 per cent it is not satisfactory.
8. Stones must be fire resistant, i.e. these must retain their shape when a fire occurs. Limestone resists fire up to about 800°C. Sandstones can resist fire in a better way. Argillaceous stones are poor in strength, but resist fire to some extent.
9. A good stone should not contain quarry sap which is nothing but moisture present in the stones.
10. A good building stone must have a specific gravity greater than 2.7.
11. A good stone must have a compact, fine, crystalline structure, strong and durable.
12. A good stone should not absorb water more than 0.6 per cent by weight. It must be capable of withstanding effects of atmosphere.
13. A good building stone must be acid resistant and free from any soluble matter.

Stones with exposed faces are acted upon by various atmospheric agencies such as wind, frost, living organisms, alternate wetness and drying, movement of chemicals and rain water. Stones can be prevented from the effects of these agencies if preserved properly. Coal tar, linseed oil, paint, paraffin, a solution of alum and soap, and a solution of baryta are some of the commonly used preservatives.

1.4.2 Uses of Stones

Stones are used

1. In the construction of buildings from the very ancient times.
2. For foundations, walls, columns, lintels, arches, roofs, floors, damp-proof courses, etc.
3. For facing works in brick masonry to give a massive appearance.
4. Since stones are hard, these can be used for pavements.
5. As a basic material for concrete, moorum of roads, calcareous cements, etc.
6. As ballast in railways, flux in blast furnaces, blocks in construction of bridges, piers, abutments, retaining walls, lighthouses, dams, etc.

1.4.3 Quarrying of Stones

Quarrying is the process of extracting stone blocks from existing rocks. It is done at some depth below the top surface of rock where the effects of weathering are not found. Quarrying of soft and hard rocks is done by the following methods:

1. ***Digging, heating or wedging*** In soft rocks like limestone and marble, stones are obtained by digging, heating or wedging using hand tools, namely, pick-axes, hammers, chisels, etc.
2. ***Blasting*** In hard and dense rocks, stones are obtained by blasting using explosives.

1.4.4 Dressing of Stones

Stones obtained after quarrying have rough surfaces and are irregular in shape and size. Dressing is the process of cutting the stones to a regular shape and size and the required surface finish. The purposes of dressing are:

1. To prepare the stones for a suitable size for any handling and transport.
2. To prepare the stones into a regular shape and pleasing appearance, with neat horizontal and vertical mortar joints between the adjacent stones.
3. To make hammer-dressed surface, tooled surface, polished surface, rubbed surface or cut-stone surface to suit a particular stone masonry.
4. To secure proper bedding in stone masonry.

1.4.5 Testing of Building Stones

To determine the suitability of stones for construction work, the following tests are conducted:

1. ***Hardness test*** Hardness of a stone is tested by a pen knife which will not be able to produce a scratch on a hard stone. Hardness number is determined using Mohr's scale of hardness.

2. ***Impact test*** Impact test is carried out on an Impact Testing Machine to determine the toughness of a stone. In this test, a cylinder of 25 mm diameter and 25 mm height is taken out from the sample of the stone. A steel hammer of 2 kg weight is allowed to fall axially on the cylinder from 1 cm height for the first blow, 2 cm height for the second blow, 3 cm height for the third blow, and so on. The blow at which the specimen breaks is noted. If it is the n^{th} blow, n represents the Toughness Index of the stone.
3. ***Test for crushing strength*** In this test, a cube of sample stone of size 40 mm × 40 mm × 40 mm is tested in a compression Testing Machine. The rate of axial loading on the cube is 13.7 N/mm^2/ minute. The maximum load at which the stone crushes is noted. Crushing strength of the stone per unit area is the maximum load at which its sample crushes or fails divided by the area of the bearing face of the specimen.

   That is, Crushing Strength of stone $= \dfrac{\text{Maximum load at failure}}{\text{Area of bearing face}}$
4. ***Fire resistance test*** The stone, which is free from calcium carbonate, can resist fire. The presence of calcium carbonate in the stone can be detected by dropping a few drops of dilute sulphuric Acid which will produce bubbles.
5. ***Electrical resistance/ Water absorption test*** As the electrical resistance of a wet stone is less, the stone should be non-absorbent. In this test, a stone of known weight is immersed in water for 24 hours. Then, it is weighed again. Percentage absorption of water by weight after 24 hours = (Increase in weight/Original weight of the stone).
6. ***Attrition test/Abrasion test*** Attrition test is carried out to determine the percentage of wear of stones used for the construction of road. It is carried out in Deval's Attrition Testing Machine.

   In this test, some known weight of stone pieces are taken and put in the Deval's Attrition Test Cylinder. The cylinder is rotated about its horizontal axis at the rate of 30 rpm for 5 hours. Then, the contents of the cylinder are sieved. The quantity of material retained on the sieve is weighted. Percentage Wear = (Loss in Weight/ Initial Weight) × 100.
7. ***Acid Test*** In this test, a specimen stone is kept for 1 week in the solution of sulphuric acid and hydrochloric acid. The corners of stones with high alkaline content turn roundish and loose particles will get deposited on its surface. Such types of stones are unsuitable for smoky atmosphere.
8. ***Smith's test*** This test indicates the presence of earthly matter in the stone. In this test, the sample of the stone is broken into small pieces and put into a test-tube containing clear water. The test-tube is then shaken vigorously. The direct colour will directly show the presence of argillaceous matter.
9. ***Crystallization test*** This test determines the durability or weathering quality of a stone. In this test, a sample of stone is immersed in the solution of sodium sulphate

and dried in hot air. The process of wetting and drying is carried out for 2 hours. The difference in weight, if any, is recorded. Little difference in weight indicates durability and good weathering quality of the stone.

10. ***Microscopic test*** This is a geologist's test. In this test, the sample of stone is subjected to microscopic examination to study the following properties:
    - Mineral constitution
    - Texture of stone
    - Average grain size
    - Nature of cementing material
    - Presence of pores, fissures and veins.
11. ***Freezing and thawing test*** In this test, the specimen stone is kept in water for 34 hours. It is then placed in a freezing mixture at –12° C for 24 hours. It is then thawed (warmed) to atmospheric temperature. The procedure is repeated several times and the behaviour of the stone is studied.

1.4.6 Types of Building Stones and their Uses

1. ***Granite*** It is obtained from igneous rocks. It is hard, durable and available in different colours. It is highly resistant to weathering and has good crushing strength. It can take mirror-like polish.

   Uses: Granite is used for the construction of walls, columns and bridge piers. It is used for steps, sills and facing works. Also, it is used as ballast for road metal, rail metal, rail track and coarse aggregate for concrete. It is unsuitable for carving.
2. ***Basalt and Trap*** Basalt and Trap are also quarried from igneous rocks. These are hard, tough and durable and available in different colours.

   Uses: Basalt and Trap are used for constructing masonry floors, ornamental or decorative works and as road metal.
3. ***Chalk*** Chalk belongs to sedimentary variety. It is pure white stone, soft and easy to form powder.

   Uses: Chalk is used in preparing glazer's putty and also as colouring material in the manufacture of Portland cement.
4. ***Limestone*** It is derived from sedimentary rocks. It is easy to work. It consists of a high percentage of calcium carbonate.

   Uses: Limestone is used for the manufacture of cement. It is also used for floors, steps, walls and as road metal.
5. ***Sandstone*** It belongs to sedimentary variety. Its structure shows sandy grains. It is easy to work and dress. It is available in different colours. Its strength is low.

   Uses: It is used for different building works like facing works, carving, steps, walls, columns and as road metal.

6. ***Laterite*** It is derived from metamorphic rocks. It is sandy clay stone. It is porous and soft. It can easily be quarried in blocks. It contains high percentage of iron oxide.

   Uses: It is used for wall construction, rough stone masonry work and as road metal.

7. ***Gneiss*** Gneiss is metamorphic in nature. It is easy to work and splits into thin slabs.

   Uses: It is used as thin slabs for flooring, street paving, rough stone masonry work. etc.

8. ***Marble*** Marble is metamorphic. It can take good polish. It can be easily cut with saw and carved. It is available in different colours.

   Uses: Marble is used for flooring in the form of slabs, wall lining, facing work, steps, columns, etc. It is used for interior decoration and such ornamental works. Taj Mahal is built fully of white marbles.

9. ***Gravel*** It is available in river beds in the form of pebbles of any kind of stone.

   Uses: It is used for surfacing road. It is also used in concrete.

10. ***Slate*** Slate is metamorphic. It is black in colour and can be split easily.

    Uses: It is used as roofing tiles, paving works and as damp-proof course in buildings.

11. ***Quartzite*** It is metamorphic. It is hard, durable, brittle and crystalline. It is difficult to work.

    Uses: It is used in rubble masonry, concrete aggregate, retaining walls and as road metal.

1.5 CEMENT

Cement is obtained by burning at a very high temperature a mixture of calcareous and argillaceous materials. The calcined product is known as *clinker*. A small quantity of gypsum is added to the clinker and is pulverised into very fine powder known as cement. On setting, cement resembles a variety of sandstone found in Portland in England and is, therefore, called Portland cement.

1.5.1 Good Qualities of Cement

1. The colour should be uniform.
2. Cement should be uniform when touched. Cement should be cool when felt with hand. If a small quantity of cement is thrown into a bucket of water, it should sink.
3. Cement should be free from lumps.
4. Cement mortar at the age of three days should have a compressive strength of 11.5 N/mm^2 and tensile strength of 2 N/mm^2. Also, at the age of seven days, compressive

strength should not be less than 17.5 N/mm^2 and tensile strength should not be less than 2.5 N/mm^2.

5. In cement, the ratio of percentage of alumina to that of iron oxide should not be less than 0.66.
6. When ignited, cement should not lose more than 4 per cent of its weight.
7. The total sulphur content of cement should not be greater than 2.75 per cent.
8. The weight of insoluble residue in cement should not be greater than 1.5 per cent.
9. Weight of magnesia in cement should not exceed 5 per cent.
10. The specific surface of cement as found from the fineness test should not be less than 2250 mm^2/gm.
11. The initial setting time of cement should not be less than 30 minutes and the final setting time shall be around 10 hours.
12. The expansion of cement should not be greater than 10 mm when soundness test is conducted.

1.5.2 Uses of Cement

1. Cement mortar, a mixture of cement and sand, is used for masonry work, plastering, pointing and in joints of pipes, drains, etc.
2. Cement is the binding material in concrete used for laying floors, roofs and constructing lintels, beams, weather sheds, stairs, pillars, etc.
3. Construction of important engineering structures, such as bridges, culverts, dams, tunnels, storage reservoirs, lighthouses and docks needs cement.
4. The manufacture of precast piles, pipes, garden seats, artistically designed urns, flower pots, dust bins, fencing post, etc., requires cement.
5. For underwater construction, quick setting cement is used. Rapid hardening cement is used for structures requiring early strength.
6. White and coloured cements are used for imparting coloured finishes to the floors, panels and exterior surfaces of buildings.
7. Expansive cements, which expands while setting, can be used in repair works of cracks.

1.5.3 Types of Cement

By changing the chemical composition and by using different raw materials and additives, many types of cements can be manufactured to cater to the need of the construction industry for specific purposes. Different types of cements are classified as Portland and Non-Portland cement.

1. Rapid-hardening Cement This cement is similar to the ordinary Portland cement. As the name suggests, it develops strength rapidly. The rapid rate of strength development is attributed to the higher fineness of grinding. This cement is used where high strength is required instantly in initial stages. For example, repair works, early removal of formwork, etc.

2. Sulphate-resisting Cement Ordinary Portland cement has less resistance to the attacks of sulphates. This type of cement with higher silicate content is effective in fighting back the attacks of sulphates. This is used for the construction of sewage treatment works, marine structures and foundations in soils having large sulphate content.

3. Low-heat Cement This cement hardens slowly but produces less heat than the other cements while reacting with water. This can be used in mass concreting works like construction of dams, etc.

4. Quick-setting Cement This cement sets very quickly. This is due to the reduction of gypsum content in the normal Portland cement. It is used for underwater construction and also for grouting operation.

5. Portland pozzolana Cement Pozzolana is a siliceous material. Portland pozzolana cement is produced by grinding Portland cement clinker and pozzolana with gypsum. It produces less heat of hydration and offers greater resistance to the attack of aggressive water.

6. High-alumina Cement This cement generates high heat while reacting with water and causes high early strength development. So this cement can be used for generating high early strength in cold climates.

7. Air-entraining Cement This cement is produced by mixing a small amount of an air-entraining agent with ordinary Portland cement. By adding this, the properties of concrete can be changed and it also increases the frost resistance of hardened concrete.

8. Masonry Cement This cement has great plasticity, workability and water retentivity as compared with ordinary Portland cement. This is used for masonry constructions in making mortars and plasters.

9. Expansive Cement This cement produces an expansion in concrete during curing. As a result of expansion, cracks due to shrinkage of concrete are avoided. So, this can be used for filling the cracks by grouting and also to overcome cracks formation in reinforced cement concrete structures.

10. Hydrophobic Cement This is a water-repellent cement and is of great utility when the cement has to be stored for longer duration in wet climatic conditions. This cement also improves the workability of concrete.

11. Coloured Cement Coloured cement consists of ordinary Portland cement with 5 to 10 per cent of pigment for colouring. This is used for aesthetic purposes.

12. White Cement The colour of this cement is white and it has the same properties of ordinary Portland cement. This can be used for architectural purposes and for manufacturing coloured concrete, flooring tiles, etc.

13. High-strength Cement Certain special works require high strength concrete. To improve the strength a higher content of C_3S and higher fineness are incorporated in ordinary Portland cement. This cement can be used for railway sleepers, prestressed concrete, precast concrete and air-field works.

1.5.4 Mortar

1. Definition The term mortar is used to indicate a paste prepared by adding required quantity of water to a mixture of binding material (cement or lime) and fine aggregate (sand). The above two components of mortar, namely, the binding material and fine aggregate are sometimes referred to as the matrix and adulterant respectively. The matrix binds the particles of the adulterant. The durability, quality and strength of mortar will mainly depend on the quantity and quality of the matrix. The combined effect of the two components of mortar is that the mass is able to bind the bricks or stones firmly.

2. Types of Mortars The mortars are classified on the basis of the following:

(a) Bulk density
(b) Type of binding material
(c) Nature of application
(d) Special mortars

(a) Bulk density According to the bulk density of mortar in dry state, there are the following two types of mortars.

(i) Heavy mortars The mortars having bulk density of 15 kN/m^3 or more are known as heavy mortars and they are prepared from heavy quartzes or other sands.

(ii) Lightweight mortars The mortars having bulk density less than 15 kN/m^3 are known as lightweight mortars and they are prepared from light porous sands, pumice and other fine aggregates.

(b) Type of binding material The type of binding material used for a mortar is according to several factors such as expected working conditions, hardening temperature, moisture conditions, etc. According to the type of binding material, the mortars are classified into the following five categories.

(i) Lime mortar In this type of mortar, lime is used as binding material. The lime may be fat lime or hydraulic lime. The fat lime shrinks to a great extent and hence, it requires sand to the extent of about 2 to 3 times its own volume. The lime should be slaked before use. This mortar is unsuitable for water-logged areas or in damp situations.

The lime mortar has a high plasticity and it can be placed easily. It possesses good cohesiveness with other surfaces and shrinks very little. It is sufficiently durable, but it hardens slowly. It is generally used for lightly loaded above-ground parts of buildings.

(ii) Surkhi mortar This type of mortar is prepared by using only *surkhi* instead of sand or by replacing half of sand in case of fat lime mortar. The powder of *surkhi* should be fine enough to pass BIS No. 9 sieve and the residue should not be more than 10 per cent by weight.

Surkhi mortar is used for ordinary masonry work of all kinds in foundation and superstructure. But it cannot be used for plastering or pointing since *surkhi* is likely to disintegrate after some time.

(iii) Cement mortar In this type of mortar, cement is used as binding material. Depending upon the strength required and importance of work, the proportion of cement to sand by volume varies from 1:2 to 1:6 or more. It should be noted that *surkhi* and cinder are not chemically inert substances and hence, they cannot be used as adulterants with matrix as cement. Thus, only sand can be used to form cement mortar. The proportion of cement with respect to sand should be determined with due regards to the specified durability and working conditions. The cement mortar is used where a mortar of high strength and water-resisting properties is required such as underground constructions, water-saturated soils, etc.

(iv) Gauged mortar To improve the quality of lime mortar and to achieve early strength, cement is sometimes added to it. This process is known as gauging. It makes lime mortar economical, strong and dense. The usual proportion of cement to lime by volume is about 1:6 to 1:8. It is also known as a composite mortar or lime-cement mortar and it can also be formed by the combination of cement and clay. This mortar may be used for bedding and for thick brick walls.

(v) Gypsum mortar These mortars are prepared from gypsum binding materials such as building gypsum and anhydrite binding materials.

(c) Nature of application According to the nature of application, the mortars are classified into the following two categories.

(i) Bricklaying mortars The mortars for bricklaying are intended to be used for brickwork and walls. Depending upon the working conditions and type of construction, the composition of masonry mortars with respect to the kind of binding material is decided.

(ii) Finishing mortars These mortars include common plastering work and mortars for developing architectural or ornamental effects. The cement or lime is generally used as binding material for ordinary plastering mortar. For decorative finishing, the mortars are composed of suitable materials with due consideration of mobility, water retention, resistance to atmospheric actions, etc.

(d) Special mortars Following are the various types of special mortars which are used for certain conditions.

(i) Fire-resistant mortar This mortar is prepared by adding aluminous cement to the finely crushed powder of fire-bricks. The usual proportion is one part of aluminous cement to two parts of powder of fire-bricks. This mortar is fire-resistant and is, therefore, used with fire-bricks, for lining furnaces, fire places, ovens, etc.

(ii) Lightweight mortar This mortar is prepared by adding materials such as saw dust, wood powder, etc. to the lime mortar or cement mortar. Other materials which may be added are asbestos fibres, jute fibres, coir, etc. This mortar is used for sound-proof and heat-proof construction.

(iii) Packing mortar To pack oil wells, special mortars possessing the properties of high homogeneity, water resistance, predetermined setting time, ability to form solid waterproof plugs in cracks and voids of rocks, resistance to subsoil water pressure, etc. have to be formed. The varieties of packing mortars include cement-sand, cement-loam and cement-sand-loam. The composition of packing mortar is decided by taking into consideration the hydrogeologic conditions, packing methods and type of timbering.

(iv) Sound-absorbing mortar To reduce the noise level, the sound-absorbing plaster is formed with the help of sound-absorbing mortar. The bulk density of such a mortar varies from 6 to 12 kN/m^3 and the binding materials employed in its composition may be Portland cement, lime, gypsum, slag, etc. The aggregates are selected from lightweight porous materials such as pumice, cinders, etc.

(v) X-ray shielding mortar This type of mortar is used for providing the plastering coat to walls and ceiling of X-ray cabinets. It is a heavy type of mortar with bulk density over 22 kN/m^3. The aggregates are obtained from heavy rocks and suitable Admixtures are added to enhance the protective property of such a mortar.

3. Properties of Mortar Following are the properties of a good mortar:

1. It should be capable of developing good adhesion with the building units such as bricks, stones, etc.
2. It should be capable of developing the designed stresses.
3. It should be capable of resisting penetration of rain water.
4. It should be cheap.
5. It should be durable.
6. It should be easily workable.
7. It should not affect the durability of materials with which it comes into contact.
8. It should set quickly for speedy construction.
9. The joints formed by mortar should not develop cracks and they should be able to maintain their appearance for a sufficiently long period.

4. Uses of Mortar Following are the uses of mortar:

1. To bind the building units such as bricks, stones, etc. into a solid mass.
2. To carry out pointing and plaster work on exposed surfaces of masonry.
3. To form an even and soft bedding layer for building units.
4. To form joints of pipes.
5. To improve the general appearance of a structure.
6. To prepare moulds for coping, corbels, cornice, etc.
7. To serve as a matrix or cavity to hold coarse aggregates, etc.
8. To distribute uniformly the super incumbent weight from the upper layer to the lower layer of bricks or stones.
9. To hide the open joints of brickwork and stonework.
10. To fill up the cracks detected in the structure during maintenance process, etc.

5. Selection of Mortar Depending upon the nature of civil engineering work, suitable type of mortar should be selected or recommended. Table 1.1 shows the types of mortars to be used for various civil engineering constructions.

Table 1.1 Selection of mortars

S.No.	Nature of work	Type of mortar
1.	Construction work in waterlogged areas and exposed positions	Cement or lime mortar in the proportion 1:3, lime being eminently hydraulic lime
2.	Damp-proof courses and cement concrete roads	Cement mortar in the proportion 1:2
3.	General RCC work such as lintels, pillars, slabs, stairs, etc.	Cement mortar in the proportion 1:3, the concrete mix being 1:2:4
4.	Internal walls and surfaces of less importance	Lime cinder mortar proportion, being 1:3. Sand is replaced by ashes or cinder
5.	Mortar for laying fire-bricks	Fire-resisting mortar consisting of 1 part of aluminous cement to 2 parts of finely crushed powder of fire-bricks.
6.	Partition walls and parapet walls	Cement mortar in the proportion 1:3 or lime mortar proportion 1:1. Lime should be moderately hydraulic lime
7.	Plaster work	Cement mortar in the proportion 1:3 to 1:4 or lime mortar proportion 1:2
8.	Pointing work	Cement mortar in the proportion 1:1 to 1:2
9.	Reinforced brickwork	Cement mortar in the proportion 1:3
10.	Stone masonry with best varieties of stones	Lime mortar in the proportion 1:2, lime being eminently hydraulic lime
11.	Stone masonry with ordinary stones, brickwork, foundations, etc.	Lime mortar in the proportion 1:2 or cement mortar proportion 1:6. Lime should be eminently hydraulic lime or moderately hydraulic lime
12.	Thin joints in brickwork	Lime mortar in the proportion 1:3, lime being fat lime

1.5.5 Sand

1. Classification of sand According to the nature of source, sand is classified into two groups:

(a) Natural Sand (b) Artificial Sand

(a) Natural sand Is the one which is carried by the river water and is quarried from the river bed, when the river becomes dry.

(b) Artificial sand Is the one which is the outcome of crushing and breaking stones into different sizes of stone aggregates in a stone crushing plant (or) crushed gravel sand.

2. Qualities of Good Sand

(a) Sand should be clean, hard and durable and preferably dry.

(b) It should be free from mica, chemical salts, organic and inorganic impurities and outer foreign matters.

(c) It should preferably be free from clay, silt and fine dust. In case if the presence of them is unavoidable, they should not be present by more than 5% by weight (or 7% by volume).

(d) Sand particles should be well graded and shall have sizes ranging from (150 micron) 0.15 mm to 4.75 mm.

(e) The fineness modulus of sand shall be from 1.6 to 3.5.

3. Uses of Sand

(a) It is used for making mortar and concrete

(b) It is used for filling in the basement of buildings to receive the flooring concrete.

(c) It is used as a binding material on the top of bituminous road.

(d) It imparts mechanical strength to the mortar and prevents shrinkage and cracking of mortar while setting.

(e) It forms major portion of mortar and reduces the cost of mortar.

(f) It is mixed with expensive clay soils to stabilise them and prevent cracking of clay soils due to seasonal moisture changes.

4. Tests on Sand The following tests are conducted to find out the suitability of sand.

(a) Sieve analysis and fineness modulus test

(b) Test for bulkage of sand

(c) Test for silt content

(a) Sieve analysis and fineness modulus test The sand is sieved through 1. S. Sieves 4.75 mm 2.36 mm, 1.18 mm, 600 micron, 300 micron and 150 micron sieves and percentage retained in each sieve is found out.

Fineness modulus of sand = sum of the percentages retained in each sieve divide by 100.

Requirement A fineness modulus of 1.6 to 2.0 for sand for plastering mortar and a fineness modulus of 2.5 to 3.5 for sand for concrete and a fineness modulus of 2.0 to 3.0 for sand for masonry mortar may be sufficient.

(b) Test for bulkage of sand: bulking of sand The volume of dry sand will increase due to the presence of water in the sand up to about 25% of water content and thereafter it will decrease and become equal to its dry volume, when it is saturated with water. This increase in volume of sand is known as bulking of sand.

River sand will generally be wet and its volume will be more than the dry volume. Hence, it is necessary to know the bulking of sand to allow for its increase in volume in the volume batching of concrete and mortar. The increase in volume of sand is found out from the test for bulkage of sand.

Test for bulkage A small quantity of wet sand is poured into a glass measuring jar and rammed by a small rod of dia 6 mm. and level of sand is noted (say $H1$). Now water is poured into the cylinder until the sand is submerged and the glass jar is well shaken and now the level of sand is noted. (say $H2$). $H2$ will be less than $H1$ and sand is saturated when it is submerged.

$$\text{Percentage bulkage of sand} = \frac{(H1 - H2)}{H2} \times 100$$

(c) Test of silt content A small quantity of sand is poured into a glass measuring jar. Now water is poured until sand is well submerged in water. The glass jar is now shaken several times so that the silt and dust layer floats at the top of sand layer. The level of sand layer (excluding silt layer) is noted (say $H2$). The top level of silt layer above sand is noted. (say $H1$).

$$\text{The percentage of silt by volume} = \frac{(H1 - H2)}{H2} \times 100$$

1.6 CEMENT CONCRETE

Cement concrete is a mixture of cement, sand, crushed rock and water which when placed in the skeleton of forms and allowed to cure, becomes hard such as stone. Concrete has attained the status of a major building material in all branches of modern construction and hence it is necessary to know the properties and uses of concrete.

1.6.1 Properties of Concrete

1. It has a high compressive strength and its strength depends on the proportion in which cement, sand, stones and water are mixed.
2. It is free from corrosion and there is no appreciable effect of atmospheric agents on it.
3. It hardens with age and the process of hardening continues for a long time after the concrete has attained sufficient strength.
4. As it is weak in tension, steel reinforcement is placed in it to take up the tensile stresses. This is termed as 'Reinforced Cement Concrete'.
5. It shrinks in the initial stage due to loss of water through forms. The shrinkage of cement concrete occurs as it hardens.
6. It has a tendency to be porous. This is due to the presence of voids which are formed during and after its placing.
7. It forms a hard surface, capable of resisting abrasion.

1.6.2 Uses of Concrete

1. Concrete can be made impermeable by using hydrophobic cement. This is used for the construction of RCC flat-roof slabs.
2. Coloured concrete is used for ornamental finishes in buildings, park lanes, separating lines of road surfaces, underground pedestrian crossings, etc.
3. Light weight concrete is used in multi-storeyed constructions.
4. No-fines concrete is one in which sand is eliminated. This can be used for *cast-in-situ* external load bearing walls of single and multi-storey houses, retaining walls, damp-proofing material, etc.

5. Concrete is mainly used in floors, roof slabs, columns, beams, lintels, foundations and in precast constructions.
6. It is used in massive structures, such as dams and bridges.
7. Concrete is used in the construction of roads, runways, playgrounds, water tanks and chimneys.
8. It is used in the construction of sleepers in railways.
9. Prestressed concrete is a relatively new type of concrete which is used in many constructions particularly in the construction of bridges.
10. Concrete trusses are also used in factory constructions.
11. Concrete is used in the construction of bunkers, silos, etc.
12. It finds a place in the construction of nuclear reactors because of its high shielding capacity for the radioactivity.
13. Thin economical shell construction are possible with the use of concrete.

1.6.3 Reinforced Concrete

Plain concrete is very weak in tension and cannot be used in the construction of lintels, roof slabs, beams, etc. in which the bottom fibres of them are subjected to tensile stresses. Figure 1.1 explains how a loaded beam or a slab is subjected to a flexural action when it is laid over an opening known as span. The top portion is compressed while the bottom portion is stretched. As concrete withstands compression but not tension, steel rods are embedded in the bottom portion to withstand the tension. A combination of concrete and steel is known as reinforced cement concrete and is widely used in various situations. Reinforcing bars are available from 6–32 mm diameter and of 22 feet length. They may be of mild steel or Tor steel and may be plain or twisted.

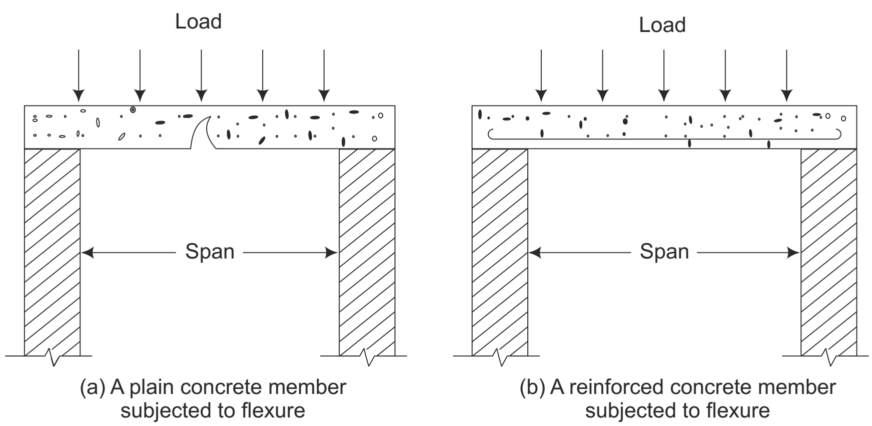


Fig. 1.1 ***Flexure action***

1.6.4 Advantages of Reinforced Concrete

1. Reinforced concrete is a versatile building material and can be used for casting members of any shape.
2. It has good resistance to fire, temperature and weathering actions.
3. RCC construction is easy and fast.
4. The component materials used for preparing RCC are easily available.
5. Monolithic construction is possible with the use of RCC. This increases the stability and rigidity of the structure.
6. RCC is tough and durable.
7. Maintenance of RCC construction is very cheap.
8. With proper cover, RCC can be made free from rusting and corrosion.

1.6.5 Types of Concrete

1. Light-weight concrete One of the disadvantages of normal concrete is the high self-weight which has a density of 2200 to 2600 kg/m^3. This heavy self-weight causes heavy load and increases the haulage and handling costs. In order to make an economical concrete, attempts were made in the past to reduce the self weight of concrete. As a result the light weight concrete was developed whose density varies from 300–1850 kg/m^3.

Advantages of light-weight concrete

(a) It has low density.
(b) It has low thermal conductivity.
(c) It lowers haulage and handling costs.

Types of light-weight concrete

(a) Light-weight aggregate concrete
(b) Aerated concrete
(c) No-fine concrete

(a) Light-weight aggregate concrete By replacing the usual mineral aggregate by cellular porous or light weight aggregate, light-weight aggregate concrete can be produced. Light-weight aggregate can be classified into two categories namely natural and artificial light-weight aggregate.

Natural light-weight aggregates are

(i) Pumice
(ii) Diatomite
(iii) Scoria
(iv) Volcanic cinders
(v) Saw dust
(vi) Rice husk

Artificial light-weight aggregates are

(i) Artificial cinders

(ii) Foamed slag

(iii) Bloated clay

(iv) Sintered fly ash

(b) Aerated concrete By introducing gas or air bubbles in mortar, aerated concrete can be produced. This concrete is a mixture of water, cement and finely crushed sand with air or gas introducing agents.

There are several ways in which aerated concrete can be manufactured. One important way is by the formation of gas or air bubbles using finely powdered metal (usually aluminium powder). Chemical reaction takes place in the concrete and finally large quantity of hydrogen gas is liberated which gives the cellular structure.

(c) No-fine concrete By omitting sand fraction from the aggregate, no-fine concrete can be produced. This concrete is made up of only single-sized aggregate of size passing of 20 mm and retained on 10 mm coarse aggregate, cement and water. The single sized aggregate makes a good no-fine concrete, which in addition gives large voids and hence is light in weight. It also offers an architecturally attractive look.

Out of the three main groups of light-weight concrete, the light-weight aggregate concrete and aerated concrete are more often used than the no-fine concrete.

2. High-density concrete The concrete whose unit weight ranges from about 3360–3840 kg/m^3 and which is about 50 per cent higher than the unit weight of normal concrete is known as high-density concrete.

The high-density concrete is mainly used in the construction of radioactive shields. High-density concrete is made by using such a heavy-weight aggregate whose specific gravity is more than 3.5. The aggregates used in this type of concrete should be clean, strong, inert and relatively free from deleterious material. Normally barite, magnetite, lemonite are used to make high-density concrete. To produce high density and high strength concrete, it is necessary to control the water–cement ratio, correct admixture and vibrators for good compaction.

3. Polymer Concrete Air voids and water voids are present in the conventional concrete due to improper compaction, high water-cement ratio and some other causes. Due to compaction, these voids are formed and the strength of the concrete is naturally reduced. There are number of methods available to reduce the air voids but none of these methods could really help to reduce the water voids. The impregnation of monomer and subsequent polymerisation is the latest technique adopted to reduce the inherent porosity of the concrete, to improve the strength and other properties of concrete. This type of concrete is known as polymer concrete.

Types of polymer concrete

1. Polymer Impregnated Concrete (PIC)

2. Polymer Cement Concrete (PCC)
3. Polymer Concrete
4. Partially impregnated and surface coated polymer concrete

The following are the monomers normally used in polymer concrete.

1. Methyl melthacrylate (MMA)
2. Styrene
3. Acrylonitrite
4. t-butyl styrene

Impregnation of these monomers improves the compressive strength, tensile strength, flexural strength of concrete and gives the concrete a high freeze thaw resistance and also high resistance to sulphate and acid attack.

Applications of polymer impregnated concrete

1. Prefabricated structural elements
2. Prestressed concrete
3. Marine works
4. Desalination plants
5. Nuclear power plants
6. Sewage works—pipes and disposal works
7. For waterproofing of structures
8. Industrial applications

4. Fibre-reinforced concrete Plain concrete possesses a very low tensile strength, limited ductility and little resistance to cracking. Due to its poor tensile strength, internal micro cracks are present in concrete which leads to brittle fracture. To improve the tensile strength of concrete one of the method used is that of the conventional reinforced steel bars and the other way is by introducing fibres in the concrete and thereby increasing the inherent tensile strength of concrete. In order to reduce the microcracks, addition of small, closely spaced and uniformly dispersed fibres are used. These fibres act as crack arrester and substantially improve its static and dynamic properties. This type of concrete is known as Fibre Reinforced Concrete (FRC). Some of the fibres used are steel fibres. polypropylene, nylons, asbestos, coir, glass and carbon. The property of concrete may vary depending upon the type, diameter, length and volume of fibres.

Steel fibre is one of the most commonly used fibres. Most of the times round fibres are used. The diameter of such fibres may vary from 0.25–0.75 mm. The use of steel fibres may improve the flexural, impact and fatigue strength of concrete.

Applications of fibre-reinforced concrete Normally, FRC are used in air field, road pavements, industrial floorings, bridge decks, canal lining, explosive resistant structures, refractory linings, etc. It can also be used in pre-cast products like pipes, boats, beams, staircase steps, wall panels, roof panels, manhole covers, etc.

1.6.6 Testing of Fresh and Hardened Concrete

1. Testing of fresh concrete Fresh concrete or plastic concrete is a freshly mixed material which can be moulded into any shape. The most important property of fresh concrete is its workability.

Workability The term *workability* is used to describe the ease or difficulty with which the concrete is handled, transported and placed between the forms with minimum loss of homogeneity. However, this gives a very loose description of this vital property of concrete which also depends on the means of compaction available. For instance, the workability suitable for mass concrete is not necessarily sufficient for thin, inaccessible or heavily reinforced sections. The compaction is achieved either by ramming or vibrating. The workability, as a physical property of concrete alone irrespective of a particular type of construction, can be defined as the amount of useful internal work necessary to produce full compaction.

If the concrete mixture is too wet, the coarse aggregates settle at the bottom of the concrete mass and the resulting concrete has a non-uniform composition. On the other hand, if the concrete mixture is too dry, it will be difficult to handle and place it in position. To correlate these two conflicting conditions proportions of various components of concrete mixture should be carefully decided. The important facts in connection with workability are as follows:

1. If more water is added to attain the required degree of workmanship, it results into concrete of low strength and poor durability.
2. If the strength of concrete is not to be affected then, the degree of workability can be obtained in following ways:
   (i) by slightly changing the proportions of fine and coarse aggregates, in case the concrete mixture is too wet.
   (ii) by adding a small quantity of water cement paste in the proportion of original mix, in case the concrete mixture is too dry.
3. A concrete mixture for one work may prove to be too stiff or too wet for another work. For instance, stiff concrete mixture will be required in case of vibrated concrete work while wet concrete mixture will be required for thin sections containing reinforcing bars.
4. The workability of concrete is affected mainly by water content, water–cement ratio and aggregate–cement ratio.
5. The workability of concrete is also affected by the grading, shape, texture and maximum size of the coarse aggregates used in the mixture.

In order to measure the workability of concrete mixture, various tests are developed. Tests such *as flow test* and *compaction test* are used mostly in laboratory. The *slump test*, which is commonly used in the field, is briefly described below. It should, however, be remembered that numerous attempts have been made to correlate workability with some easily determinable physical measurement. Although they may provide useful information within a range of variation in workability but none of these tests is fully satisfactory. At the same time, the slump test does not measure the workability of concrete. It is simply useful in detecting variations in the uniformity of a mix of given nominal proportions.

Slump test

The standard slump cone, as shown in Fig. 1.2 is placed on the ground. The operator holds the cone firmly by standing on the foot pieces. The cone is filled with about one-fourth portion and then rammed with a rod which is provided with bullet nose at the lower end. The diameter of the rod is 16 mm and its length is 60 mm. The strokes to be given for ramming vary from 20 to 30. The remaining portion of the cone is filled in with similar layers and then the top of concrete surface is struck off such that the cone is full of concrete. The cone is then gradually raised vertically and removed. The concrete is allowed to subside and then the height of concrete is measured. The slump of concrete is obtained by deducting the height of concrete after subsidence from 30 cm.

Table 1.2 shows the recommended slumps of concrete for various types of concrete and Table 1.3 shows the classification of concrete mixes on the basis of slump.

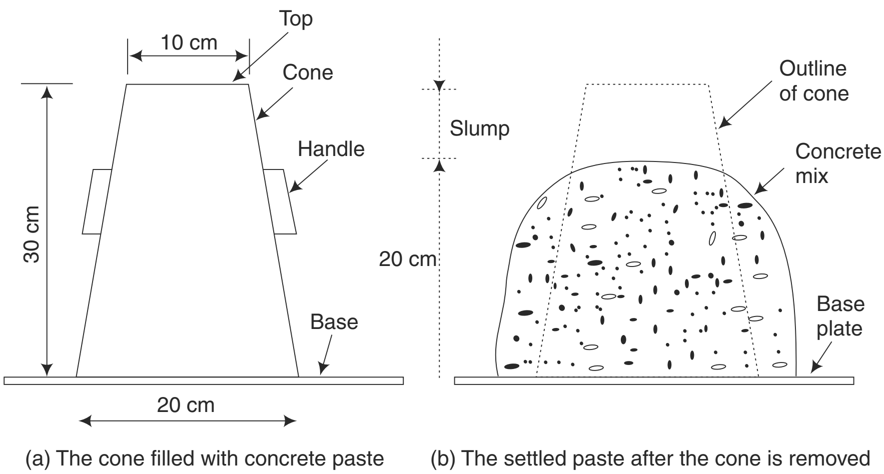


Fig. 1.2 *Slump test*

2. Testing of Hardened Concrete

1. Compressive Strength It may be defined as the maximum compressive load that can be taken by concrete per unit area. It has been shown that with special care and control, concrete can be made to bear loads as high as 80 N/mm^2 or even more. In practice, however, concrete with compressive strength between 10–50 N/mm^2 can be easily made on the site for common type of construction.

Table 1.2 Recommended slumps of concrete

S.No.	Type of concrete	Slump
1.	Concrete for road construction	20 to 40 mm
2.	Concrete for tops of curbs, parapets, piers, slabs and walls that are horizontal	40 to 50 mm
3.	Concrete for canal linings	70 to 80 mm
4.	Concrete for arch and side walls of tunnels	90 to 100 mm
5.	Normal RCC work	80 to 150 mm
6.	Mass concrete	25 to 50 mm
7.	Concrete to be vibrated	10 to 25 mm

Table 1.3 Classification of concrete mixes

Slump	Nature of concrete mix
No slump	Stiff and extra stiff mix
From 10 to 30 mm	Poorly mobile mix
From 40 to 150 mm	Mobile mix
Over 150 mm	Cast mix

The compressive strength, also called the crushing strength of concrete is determined by loading axially cube shaped (or cylindrical shaped) specimens made out of the concrete. The tests are carried out 3 days, 7 days and 28 days after the casting of the samples. It is the 28 days compressive strength which is taken as a standard value for concrete of a particular batch.

It has been observed that the compressive (crushing) strength of concrete is influenced by a very large number of factors. The most important of these factors are the following:

(i) Types of cement The composition, quality and age of the cement used in making concrete influences its strength. Thus, cement that has been stored for considerable time make concrete of lower strength despite all the other factors being the same. Cement with higher proportions of tri-calcium silicates produce concrete that show higher strengths, at least in earlier stages. Similarly, finer the particle size of the cement, higher is the ultimate compressive strength.

(ii) Nature of aggregates Sand and coarse aggregates are the other two essential components of concrete. A good bond between cement and the aggregate is possible only when the latter have sharp edges, clean surfaces and rough texture. Smooth and rounded aggregates result in comparatively poor bonds. Similarly, the aggregates used in concrete making should have in themselves, good compressive strength. For example, if chalk (very soft limestone) is used in making concrete instead of massive limestone, the resulting concrete will be weak in compressive strength because of the poor strength of the aggregate.

(iii) Water–cement ratio The compressive strength decreases, in general, with increasing water–cement ratio (other things being the same). Hence, when minimum water just to ensure complete hydration of the cement is used, the resulting concrete will give maximum compressive strength on proper compaction.

(iv) Curing conditions Great importance is attached to proper curing of concrete after its laying for obtaining maximum compressive strength. Incomplete curing and intermittent drying of concrete during the curing period may cause a loss in the compressive strength to the extent of 40 per cent or even more.

(v) Weather conditions The same concrete placed in different weather conditions like extremely cold, dry and hot, may develop different strength values. The cause is related to incomplete hydration of the cement in the concrete.

(vi) Admixtures Certain admixtures are added to the concrete at the mixing stage for some specific purposes. It has been observed that certain admixtures especially calcium chloride, increase the compressive strength. Some other admixtures (e.g. air entraining agents), however, affect the compressive strength adversely if proper controls are not maintained on water–cement ratio.

(vii) Methods of preparation Improper mixing of the concrete and careless transport and storing may result in poor strength despite best cement and aggregates used in it. It is the workmanship that determines the quality of the concrete work in ultimate analysis. A skilled worker can produce best concrete works despite some other deficiencies. An incompetent worker, however, may spoil the entire work despite being given the best designed concrete mix. The voids left in the concrete on compaction and curing have a profound influence on the strength of the concrete.

2. Tensile strength Plain concrete (without steel reinforcement) is quite weak in tensile strength which may vary from 1/8 to 1/20 of the ultimate compressive strength. It is primarily for this reason that steel bars (reinforcement) are introduced into the concrete at the laying stage so as to get a concrete which is very strong in compression as well as in tension. In plain concrete, tensile strength depends to a great extent on the same factors as the compressive strength does.

Tensile strength of concrete becomes an important property when it is to be used in road making and runways. It is determined by using indirect methods.

In one of such methods, it is derived from the *flexural strength tests.* In these tests, a beam of concrete is cast in standard dimensions depending upon the nominal size of the aggregate. The beam is properly cured and tested after 28 days. It is simply supported from below and equally loaded at its one-third span points from both supports till failure. The bending moments, obviously, induce compressive stresses at the top and tensile stresses at the bottom of beam. The beam fails in tension. Modulus of rupture or flexural strength is then calculated by using the usual beam formula given below:

$$fc = \frac{FL}{bd^2}$$

where

fc = flexural strength

F = maximum applied load
L = distance between supports
b = breadth
d = depth

In the second indirect method, called the *split cylinder method* as shown in Fig. 1.3, a cylinder of specified dimensions is made to fail under tension by applying compressive load across the diameter. This is termed as splitting tensile strength. The testing machine is adjusted to distribute the load along the entire length of the cylinder. From the load at failure, tensile strength is calculated using the following relationship.

$$f_t = \frac{2P}{\pi/d}$$

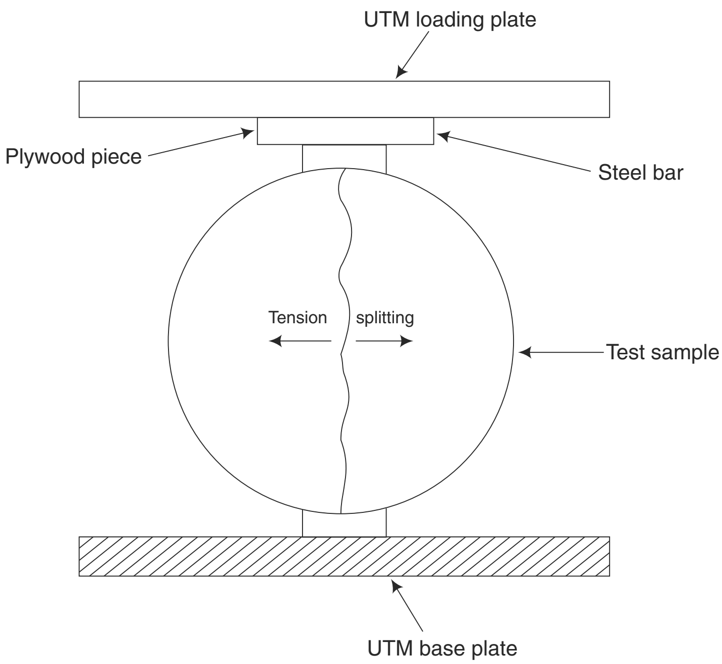


Fig. 1.3 *Split cylinder testing for tensile strength*

where

f_t = splitting tensile strength in N/mm^2
P = maximum applied load in N
l = length of the cylinder (mm)
d = diameter of the cylinder (mm)

For approximate use, tensile strength of concrete may be taken between 10–12 per cent of its (cube) compressive strength.

3. Non-destructive tests for concrete Estimation of concrete or member strength is the most common requirement of *in-situ* investigations but unfortunately, none of the available methods can be used to provide a reliable value in every situation.

Non-destructive tests with all their limitations play a vital role in strength determination. Two such test methods normally available are the following:

(a) Rebound test method
(b) Ultrasonic method

(a) Rebound test method

Rebound test equipment and operation A Swiss engineer, Ernst Schmidt, developed a practicable rebound test hammer in the late 1940s for the first time and modern versions are based on this test. Figure 1.4 shows the basic features of a typical type of hammer which weighs less than two kg.

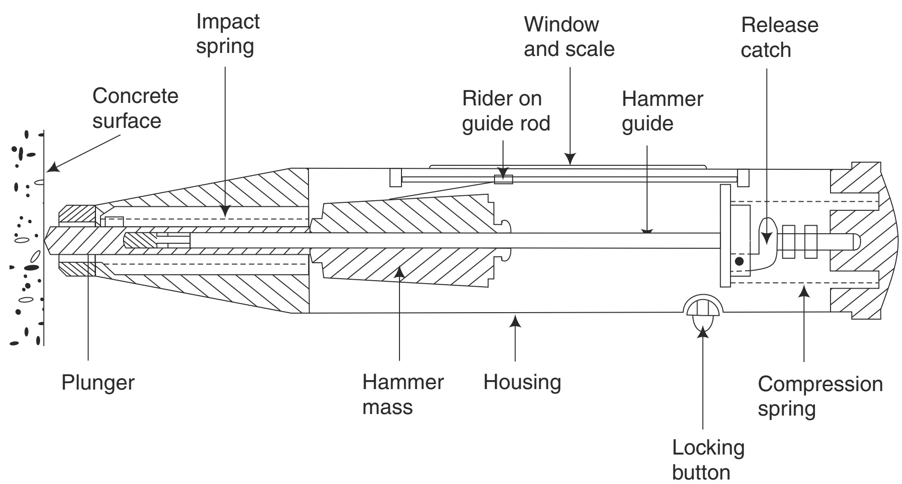


Fig. 1.4 *Typical rebound hammer*

The spring-controlled hammer mass slides on a plunger within a tubular housing. The plunger rotates against a spring when pressed against a concrete surface and this spring is automatically released when tensioned, causing the hammer mass to impact against the concrete through the plunger. When the spring controlled mass rebounds it takes with it a rider which slides along a scale and is visible through a small window in the side of the casing. The rider can be held in position on the scale by depressing the locking button. The equipment is very simple to use. The scale reading is known as the rebound number and is an arbitrary measure as it depends on the energy and the mass used. With this number, the compressive strength of concrete can be obtained from the graph attached with the instrument.

Procedure The reading is very sensitive to local variations of the concrete, especially aggregate particles close to the surface. It is therefore necessary to take several readings at each test location and to find their average between 9 and 25 readings taken over an area not exceeding 300 mm with the impact points not less than 20 mm from each other or from the edge. The use of grid to locate these points reduce operator bias. The surface must be smooth, clean and dry and properly formed. In case rough surfaces are unavoidable they should be rubbed smooth with carborundum stone.

(b) Ultrasonic method In ultrasonic pulse velocity method, the time of travel of an ultrasonic pulse, passing through the concrete to be tested is measured. This is shown in Fig. 1.5. The pulse generator circuit consists of an electronic circuit for generating pulses and also a transducer which transforms these electronic pulses into mechanical energy having vibration frequencies in the range of 15–50 kHz. The time of travel between initial onset and the reception of the pulse is measured electronically. The path length between transducer when divided by the time of travel, gives the average velocity of wave propagation.

With the velocity of wave propagation, the quality and compressive strength of concrete can be obtained as per the classification in Table 1.4.

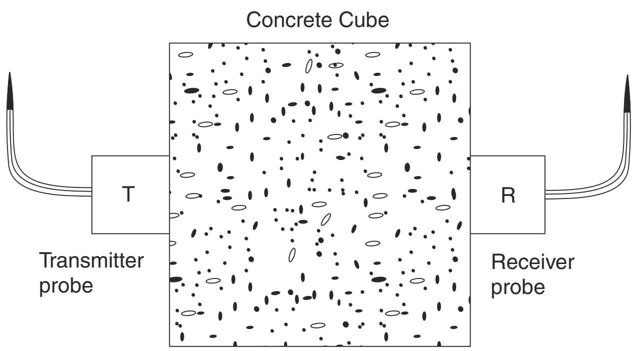


Fig. 1.5 *Direct transmission of ultrasonic waves*

Table 1.4 Quality gradings for concrete

Velocity km/s	*Classification (Quality)*	*Overall in-situ compressive strength N/mm²*
4.0 and above	Very good	30 to 35
3.5 to 4.0	Good	25 to 30
3.0 to 3.5	Medium	20 to 25
3.0 and below	Poor	15 to 20

1.7 STEEL SECTIONS

Steel is very ductile and has elastic properties. Mild steel having a carbon content of 0.1 – 0.25 per cent is used for structural work. To be used in construction works steel must be available in a certain forms. These are called market forms and are discussed below.

1.7.1 Bars

Bars are the common form of steel in building construction. These may have either round or square cross sections. Square sections of size 5–32 mm are commonly used in building works. These square bars are used as railings in buildings and for grillwork. Square bars are designated as ISSQ (an acronym for Indian Standard Square) bars.

Bars are available in lengths varying from 10–12 m. The common round bars vary from 6–32 mm in diameter. These round bars are used in reinforced concrete and reinforced brickwork constructions. Certain special type of bars having slight projections on its surface are also used as reinforcement. These are called as deformed bars. Their size generally varies from 8–32 mm.

1.7.2 Plates

Rolled plates have a maximum area of 30 m^2. The thickness of the plates varies from 5–28 mm. Plates thinner than 5 mm are called *sheets*. Larger plates are thicker at the centre than at the edges. These plates are used as webs and flanges for deep beams, column flanges, column bases, etc.

1.7.3 Flats

These are rolled as in the case of plates but are much longer and have shorter width. The width varies from 18 – 500 mm and the thickness varies from 3 – 80 mm. Flats are costlier than plates. These are also used in grill works and railings.

1.7.4 Angle Sections

Angle sections may be of equal legs or unequal legs as shown in Fig. 1.6. Equal angle sections are available in sizes varying from 20 mm × 20 mm × 3 mm to 200 mm × 200 mm × 25 mm. The corresponding weights per metre length are 9.0 N and 736.0 N respectively. Unequal angle sections are available from 30 mm × 20 mm × 3 mm to 200 mm × 150 mm × 18 mm. The weights per metre length are 11.0 N and 469.0 N respectively.

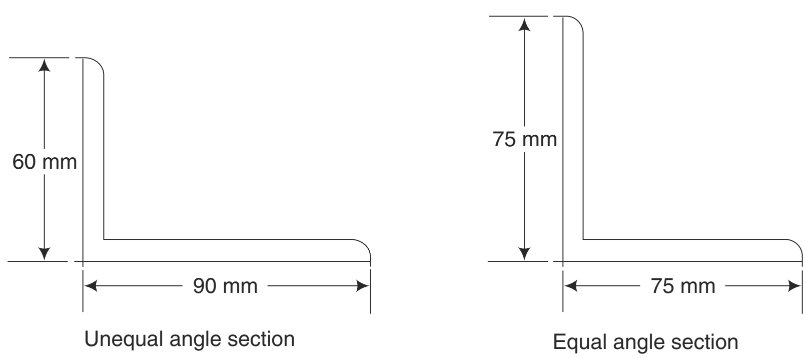


Fig. 1.6 *Angle sections*

Angle sections are used in the construction of steel roof trusses, filler joist floors, steel columns, steel beams and as stiffeners in huge girders. They are mainly used in the construction of steel bridges.

1.7.5 Channel Sections

A channel section consists of a web with two equal flanges as shown in Fig. 1.7. Typically a channel section is designated by the height of web and the width of flange. These sections are available from 100 mm × 45 mm to 400 mm × 100 mm with weight per metre length of 58.0 N and 494.0 N respectively.

Channel sections are widely used as structural members of the steel-framed structures. These are used in the construction of built-in columns, crane girders, beams and steel bridges.

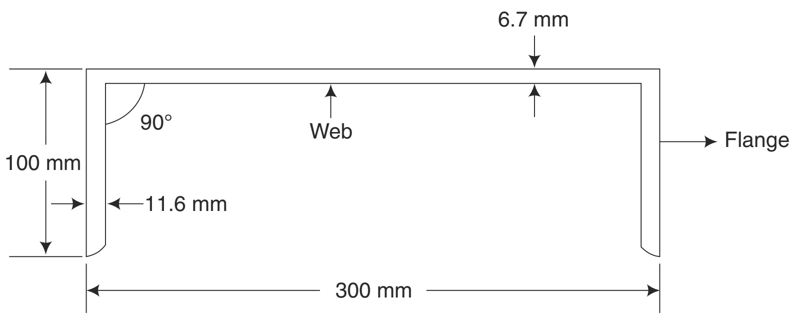


Fig. 1.7 *Channel section*

1.7.6 I-sections

These are popularly known as rolled steel joists (RS joists) or beams. An I-section consists of two flanges connected by a web as shown in Fig. 1.8(a). It is designated by overall depth, width of flange and weight per metre length. These are available in various sizes from 75 mm × 50 mm at 61 N/m to 600 mm × 210 mm at 995 N/m. Wide flange beams are available in sizes varying from 150 mm × 100 mm at 170 N/m to 600 mm × 250 mm at 1451 N/m. Sections suitable for columns are available in H-sections which vary in sizes from 150 mm × 150 mm at 271 N/m to 450 mm × 250 mm at 925 N/m as shown in Fig. 1.9(b).

RS joists are economical in material and are suitable for floor beams, lintels, columns, etc. The economic use of material is achieved by concentrating the material in the two flanges where bending stresses are maximum. Heavy weights with unequal I-sections are used as rails.

1.7.7 T-Sections

A T-section consists of a web and a flange as shown in Fig. 1.8(c). It is designated by its overall dimensions and thickness.

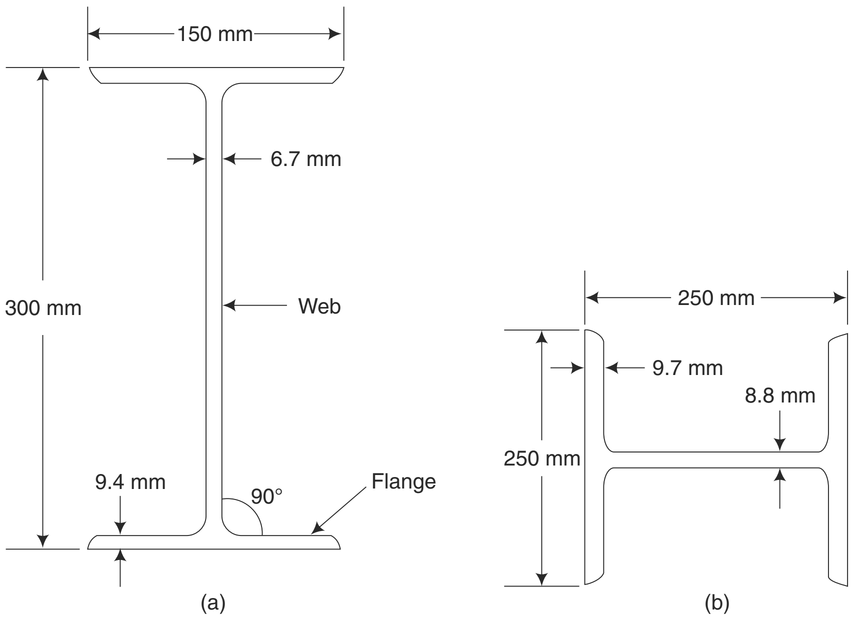


Fig. 1.8 (a) *I-section,* (b) *H-section,* (c) *T-section*

The sections are available in sizes varying from 20 mm × 20 mm × 3 mm to 150 mm × 150 mm × 10 mm with corresponding weights of 9.0 N/m and 228.0 N/m respectively. Special T-sections with unequal sides, bulbs at the bottom edge of web, etc. are also available.

T-sections are widely used as members of steel roof trusses and to form built-up sections. These are also used in T-connections in steel water tanks. These sections are used in steel chimneys, steel bridges, etc.

In addition to the above sections, miscellaneous sections such as acute and obtuse angle sections, trough sections and Z-sections are also available. These sections are used to a limited extent in the structural steel work.

1.7.8 Expanded Metal

This material is formed by cutting and expanding either plain sheets or ribbed sheets of steel. The manufactured sheets are known as diamond mesh or rib mesh as shown in Fig. 1.9. Diamond mesh has sizes from 30–150 mm across the shorter length of the mesh and is obtainable from 1–3 m long and 5 m wide.

Expanded metal is used as a ferrocement reinforcement for concrete, plaster, pavement formation and as partition wall interiors.

Welded fabric which is also known as BRC fabric is a rectangular or square mesh with an aperture of about 75–300 mm. It is made of high tensile, mild steel wires in rolls or sheets as shown in Fig. 1.9.

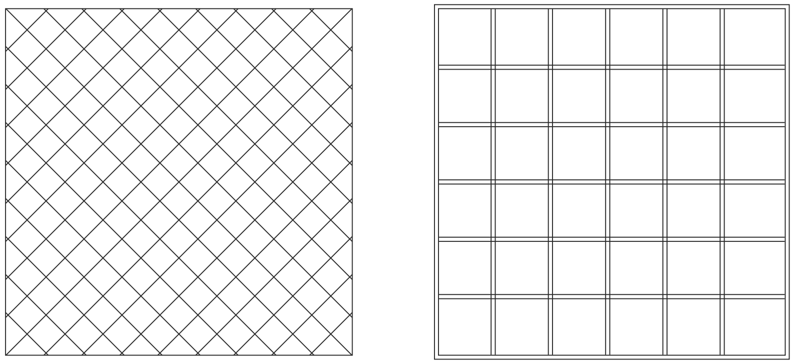


Fig. 1.9 *Expanded metal*

1.7.9 Steel as a Reinforcing Material

1. Reasons for steel to be considered as a good reinforcing material

(i) It develops a good bond with concrete and hence the stresses are transferred from one material to another.

(ii) It has high tensile strength.

(iii) It has high modulus of elasticity.

(iv) Its temperature coefficient of expansion and contraction is same as that of concrete and so thermal stresses do not develop.

(v) It is cheap and readily available.

2. Choice of reinforcing steel

(a) Reinforcing steel should be chosen such that it can be incorporated in the concrete to form a monolithic structure.

(b) The reinforcing steel should be of the smaller section to avoid stress concentration.

3. Forms of reinforcing steel

(a) Round bars It is a commonly adopted form of reinforcing steel.

(b) Flat bars It is more useful in tanks and pipes as they increase effective thickness.

(c) Square bars

(d) Reinforcement in the form of fabric It is used in roads, walls and floor slabs where tensile stresses develop more than in one direction. It is more convenient than placing individual bars at right angles to each other. It claims more tensile strength, better bond with concrete, checking of shrinkage and temperature cracks.

4. Types of reinforcing steel

(a) Mild steel

(b) High yield strength deformed bars or Tor steel

(a) Mild steel

1. Stress-strain curve From the tension test on mild steel, load vs extension or stress-strain diagram is plotted as in Fig. 1.10.

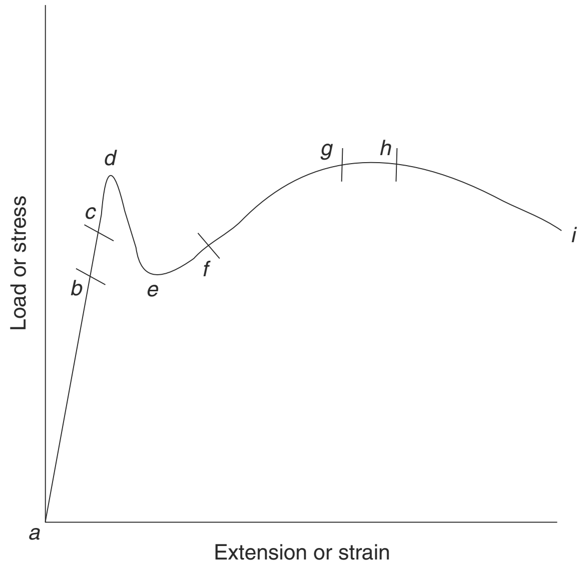


Fig. 1.10 *Stress–strain curve for mild steel*

(i) Elastic stage (a to c) Load is increased gradually in the region (*a* to *b)* where the stress is directly proportional to strain. That is, the material obeys Hooke's, law. It works up to *b* which is known as the limit of proportionality.

Beyond the limit of proportionality, material ceases to obey Hooke's law, i.e. the curve falls away from straight line *ab* produced. However, material remains elastic up to *c* which is called elastic limit though for all practical purposes *b and c* are the same.

(ii) Yield stage (d to e) Beyond the elastic limit load on the specimen increases with strain till the point *d* is reached. Beyond *d,* there is a sudden drop in load from *d* to *e. d* is known as upper yield point and *e* is denoted as lower yield point. Large deformation with no increase in load occurs in *ef* which is called plastic yielding.

(iii) Ductile stage (f to g) Beyond *f,* the material offers resistance to further straining up to the point *g and fg* is called ductile stage.

(iv) Plastic yielding stage (g to h) Specimen extends almost at constant load. From *g* to *h,* the deformation is called plastic yielding, *h* being ultimate load point where the load is the highest and corresponding stress is called ultimate stress.

(v) Load extension stage (hi) Final stage *hi* occurs very rapidly. In this stage specimen extends under decreasing load. At the breaking point *i,* the neck forms and it breaks down into two pieces.

2. Properties of mild steel Following are the properties of mild steel.

1. It can be magnetised permanently.
2. It can be readily forged and welded.
3. It cannot be easily hardened and tempered.
4. It has fibrous structure.
5. It is malleable and ductile.
6. It is not easily attacked by salt water.
7. It is tougher and more elastic than wrought-iron.
8. It is used for all types of structural work.
9. It rusts easily and rapidly.
10. Its melting point is about 1400°C.
11. Its specific gravity is 7.80.
12. Its ultimate compressive strength is about 80–120 kN per cm^2.
13. Its ultimate tensile and shear strengths are about 60–80 kN per cm^2.
14. Chemical composition: Sulphur 0.06%
    Phosphorous 0.065%
    Carbon up to 0.1%

3. Usage It is observed that steel is required for the existence of the heavy and light engineering industries, ship building, railways and rolling stock, automobiles, sheet metal industries, power generation and electrical industries, etc. It should also be noted that the entire range of electrical engineering industry depends upon the property of magnetism of steel.

(b) High yield strength deformed bars or Tor steel

1. Definition To increase the resistance to slipping between steel bars and the concrete, the surface of the bars is sometimes roughened. Such bars are known as deformed bars or ribbed tor steel or HYSD bars.

2. Manufacturing It is manufactured by controlled cold twisting of hot rolled deformed bars.

3. Chemical composition Carbon—0.3%; Sulphur—0.055%; Phosphorous—0.055%.

4. Grades Tor 40 with a yield strength of 415 N/mm^2; Tor 50 with a yield strength of 500 N/mm^2.

5. Economy It is given in Table 1.5.

Table 1.5

	Mild steel	*Tor steel*	*Per cent of saving in weight*	*Total saving*
Tension	100%	60%	40%	
Compression	100%	70%	30%	33%
Shear distribution	100%	75%	25%	
Reinforcement	100%	80%	20%	

6. Properties

(i) Tor steel is weldable.

(ii) Ultimate strength is 55000 N/mm^2.

(iii) Elongation is 12 per cent.

(iv) Stress–strain curve is shown in Fig. 1.11.

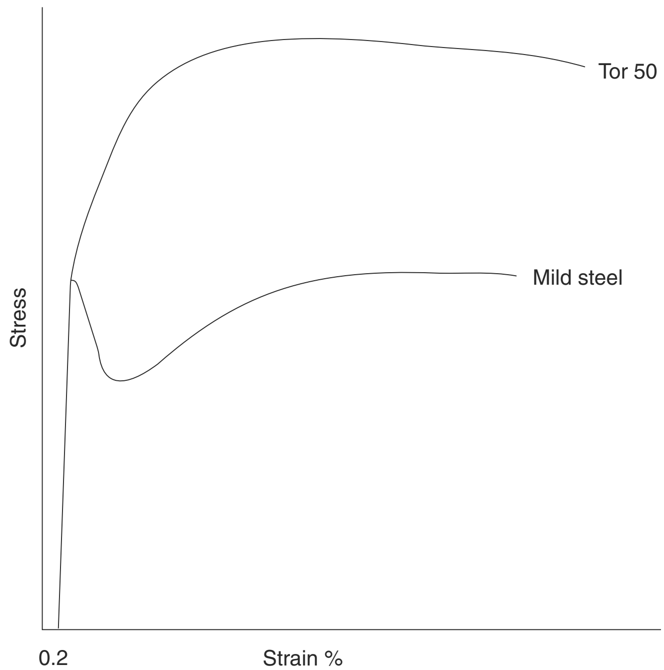


Fig. 1.11 *Stress–strain curve for Tor steel and mild steel*

7. Usage Tor steel is a safe, efficient, economical reinforcement suitable for all types of RCC constructions such as buildings, roads, bridges, reservoirs, irrigation projects, hydroelectric, thermal and nuclear power projects, docks and harbours, marine structures, pile foundations, public health engineering works, precast concrete, etc.

8. Advantages

(i) It has 65 per cent greater yield strength.

(ii) It has 100 per cent greater bond strength.

(iii) It has highest fatigue strength.

(iv) It has high bendability.

(v) It has satisfactory and easy weldability.

(vi) It gives lesser crack width.

(vii) It provides 20 per cent more factor of safety due to hyper resistance.

(viii) It is suitable for both tension and compression reinforcement.

(ix) It does not need end hooks.

(x) Net economy is achieved in cost of reinforcing steel up to 40 per cent in tension and up to 30 per cent in compression.

1.8 WOOD

Timber is a form of wood suitable for building or engineering purposes. It is obtained from trees. All trees are divided into the following two groups based on their mode of growth.

(i) *Endogenous trees* are those which grow by the formation of layers of new wood crossing and penetrating the fibres of the wood previously formed, e.g. bamboo, palmyrah, coconut, etc.

(ii) *Exogenous trees* are those which grow outwards by the addition of rings of young wood, e.g., teak, sal, etc. The cross-section of these trees shows distinct concentric rings, called annual rings. Timbers obtained from the exogenous trees are mainly used in engineering works. Exogenous trees are again sub-divided into

  (a) *Conifers* or evergreen trees which yield soft wood, e.g. pine, deodar, etc.

  (b) *Deciduous* or broad-leaf trees which yield hard wood, e.g., teak, sal, etc.

Timbers used for engineering works are mostly derived from deciduous trees.

1.8.1 Characteristics of Soft Timber

(i) Soft timber is light in weight.

(ii) It is light in colour.

(iii) It is resinous.

(iv) It has straight fibres.

(v) It has distinct annual rings.

(vi) It is comparatively weak.

(vii) It can be split easily.

1.8.2 Characteristics of Hard Timber

(i) Hard timber is heavy in weight.

(ii) It is dark in colour.

(iii) It is non-resinous.

(iv) It is close grained.

(v) It does not show clear annual rings.

(vi) It is strong.

(viii) It is durable.

1.8.3 Structure of an Exogenous Tree

The cross-section of an exogenous tree is shown in Fig. 1.12.

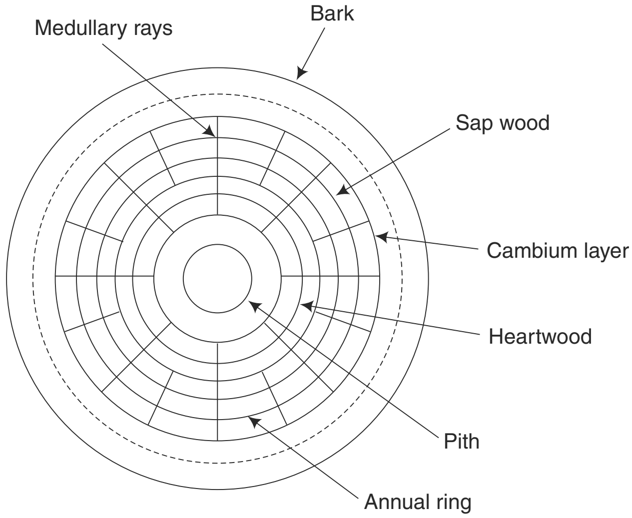


Fig. 1.12 *Cross-section of wood*

Pith is the innermost, central portion of a tree. It consists of cellular tissues.

Heartwood is the inner annual rings surrounding the pith. Heartwood is darker in colour and is strong and durable. Heartwood is used for all engineering works.

Sapwood is the portion containing the outer annual rings between the cambium layer and the heartwood. It is light in colour as compared to heartwood. Sapwood cannot be used for any engineering work because it contains large amount of moisture and is liable to decay quickly.

Cambium layer is the soft ring surrounding the outermost ring of sapwood.

Bark is the outermost layer or skin of the trunk which covers the wood.

Medullary rays are the thin radial fibres extending from pith to cambium layer.

1.8.4 Seasoning of Timber

The process of reducing the moisture from timber is known as seasoning. Freshly felled tree contains large amount of moisture. If the percentage of moisture is more than 20 per cent then different types of fungus and insects attack the wood. Hence timber needs seasoning. Following methods can be used for seasoning the timber.

1. Natural Seasoning or Air Seasoning In this method, sawn pieces of timber are stacked on stone or brick supports, a little above the ground in layers with sufficient space between them under a shed. They are left this way to get free circulation of air for a long period (two to four years). This is a slow method of seasoning but it is cheap and simple.

2. Water Seasoning In this method, the logs of wood are immersed in water, preferably in the running water of stream or river for two to four weeks. By doing so, sapwood is removed. The logs are then taken out and kept in open air to dry out. Such logs neither warp nor develop cracks but become brittle and their strength is also reduced.

3. Boiling In this method, the timber is either boiled in water or exposed to the action of water for about four hours. It is then taken out and slowly dried. Even though the period of seasoning is less, it is an expensive method.

4. Electrical Seasoning In this method, high frequency alternating current is passed through the timber. The timber gets heated and dries out. This method results in uniform seasoning of wood but the capital cost of equipment needed is more. This method is used in the manufacture of plywood.

5. Chemical Seasoning In this method, green timber is soaked in saturated salt solution, then removed and seasoned in the ordinary way. The interior moisture is drawn out by the saturated salt solution and the timber part dries before the outer one.

6. Kiln Seasoning In this method, the timber is stacked in a chamber or kiln. The chamber is artificially heated to 40° to 90°C by passing hot air in it for three to 12 days. The time and temperature required for seasoning depends on the type of the timber. This is one of the best artificial methods for seasoning wood. By using this method, moisture content in wood can be lowered to a large extent in a shorter period. This method also ensures the availability of well-seasoned wood throughout the year.

1.8.5 Properties of Wood

Most important properties of wood may be discussed under the following general headings.

1. Colour and Odour Most trees are characterised with a typical colour and odour. A freshly cut teakwood has a golden yellow shade. The softwoods like deodar and pine show light (white) colours. As regards to odour (smell), quite a few woods are immediately identified by their characteristic smell. Teak wood has an aromatic smell.

2. Specific Gravity Wood is a very light material, its specific gravity being always less than one (that of water). Woods show good deal of variation in their specific gravity. Some varieties may be as light as 0.3 whereas in other varieties of timber, the specific gravity may be up to 0.9. This depends on their structure and presence of pores in them.

3. Moisture Content All woods are hygroscopic in nature. They gain moisture from atmosphere. Wood may absorb moisture more than 2–2.5 times than its own weight. A moisture content of 12–15 per cent in air-seasoned woods is considered quite safe for timber being used in any construction.

4. Grain In a normal wood, the tracheids and vessels (collectively called as fibres) grow parallel to the length of the tree trunk. This type of structure is called a straight grain. The fibres may be very tightly and closely packed giving rise to a fibre grained texture in wood. In other cases, they may be broad and quite wider (comparatively). Such a structure is then termed as coarse grained. Sometimes the fibres do not grow essentially parallel to the trunk. These may grow in a twisted, spiral or interlocked manner. Such structure is called cross-grained.

5. Shrinkage and Swelling The newly cut wood loses moisture when made to dry naturally or artificially. On drying, the wood undergoes a shrinkage. Similarly, dry wood on getting rain soaked or wetted may undergo considerable swelling. Thick-walled cells shrink more than the thin walled cells. It is for this reason that the hardwoods shrink more than the softwoods.

6. Strength The most important fact about the strength of timber is that it is not the same in all the directions. The strength of wood is determined with reference to the direction of grain of the wood under load. Besides grain, many other factors also influence the strength of timber. These are

(a) Density—Higher the density of timber, greater will be its strength.

(b) Moisture content—Higher the moisture content, lower is the strength of timber.

(c) Presence of defects—There may be a number of natural and artificial defects in timber such as cross-grain, knots and shakes, etc. All of them cause a decrease in the strength of the timber.

1.8.6 Uses of Timber

(i) It is used for door and window frames, shutters of doors and windows, roofing materials, etc.

(ii) It is used for formwork of cement concrete, centering of an arch, scaffolding, etc.

(iii) It is used for making furniture, agricultural instruments, sports goods, musical instruments, etc.

(iv) It is used for making railway coach wagons.

(v) It is used for making toys, engraving work, matches, etc.

(vi) It is used for railway sleepers, packing cases, etc.

(vii) It is used for temporary bridges and boat construction.

1.8.7 Plywood

The meaning of term *ply* is a thin layer. Plywoods are boards which are prepared from thin layers of wood or veneers. Three or more veneers in odd numbers are placed one above the other such that the direction of grains of successive layers are at right angles to each other. They are held in the desired position by application of suitable adhesives. The placing of veneers normal to each other increases the longitudinal and transverse strength of plywoods.

Plywoods are used for various purposes such as ceilings, doors, furniture partitions, panelling walls, packing cases, railway coaches, formwork for concrete, etc.

Forms of Plywood Plywoods are available in different commercial forms such as batten board, lamin board, metal faced plywood, multi-ply, three-ply, veneered plywood, etc.

Batten Board It is a solid block with core sawn thin wood as shown in Fig. 1.13. The thickness of core is about 20 mm to 25 mm and the total thickness of board is about 50 mm. These boards are light and strong. They do not crack or split easily.

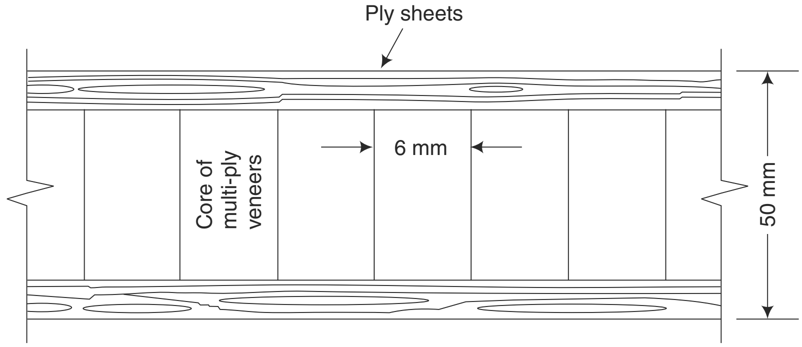


Fig. 1.13 *Batten board*

Lamin Board It is similar to batten board except that the core is made of multi-ply veneers as shown in Fig. 1.14. The thickness of each veneer does not exceed 6 mm and the total thickness of the board is about 50 mm.

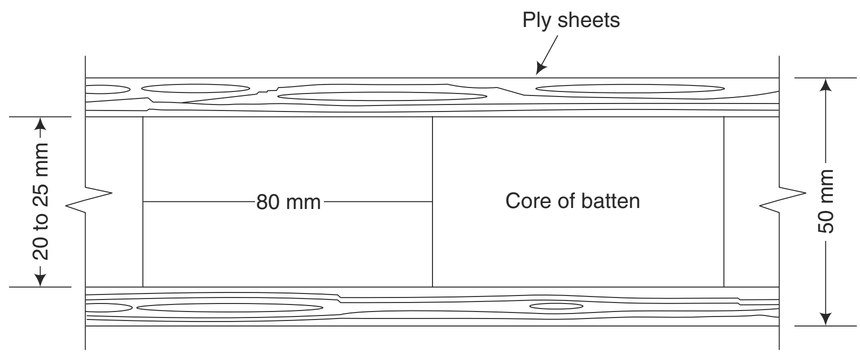


Fig. 1.14 *Lamin board*

In metal faced plywood, the core is covered by a thin sheet of aluminium, copper, bronze, steel, etc. This plywood is rigid and it is cleaned.

The plywoods made from more than three plies are designated as multi-ply. The number of veneers is odd. The thickness may vary from 6 mm to 25 mm or more.

The plywoods prepared from three plies only are known as three-ply. In veneered plywood, the facing veneer is of decorative appearance and it is used to develop an ornamental effect.

Advantages

1. Plywoods are light in weight.
2. They are available in different sizes.
3. Plywoods do not split in an axial direction.
4. They possess uniform tensile strength in all directions.
5. They are not easily affected by moisture.

1.9 PLASTICS

Plastics are organic substances which consist of resins in combination with a moulding compound. The synthetic resins may be phenol, vinyl, cellulose, etc. and the moulding compound may be fillers, plasticizers, solvents, pigments, hardeners, etc.

Advantages

1. They have high resistance to corrosion.
2. They are light in weight and hard.
3. They are not affected by fungus, vermins and rot.
4. They can be used as thermal and electrical insulations.
5. They can be easily moulded.
6. They have good shock-absorbing capacity.
7. They have pleasing appearance.
8. They are cheap.

Types of Plastics

1. Thermoplastics
2. Thermo-setting plastics

1.9.1 Thermoplastics

Plastics which become soft when heated and hard when cooled are called thermoplastics. The process of softening and hardening may be repeated for an indefinite time. It is possible to shape and reshape these plastics by means of heat and pressure. One important advantage of this variety of plastics is that the scrap obtained from old and worn out articles can be effectively used again.

The following are some of the important thermoplastics.

1. Acrylic Methylmethacrylate is an important constituent of this class of plastics. These are more transparent, rough and strong and do not shudder under impact. It is not affected by moisture and light acids. It is used in place of glass doors and windows and safety glass in automobile and aircrafts.

2. Cellulose acetate They are made from cotton seed and used as electric cables, hand rails, etc.

3. Polythene Transparent, chemically unaffected by moisture and temperature. Used for making pipes, covers for curing of cement and moisture-proof packings.

4. Perpex Formed in the shape of sheets which do not break easily. Used as lamp shades, electric fittings and various other building usages.

5. Polyvinyl chloride It is a product obtained from vinyl chlorides and acetate. It resists attacks by acids and alkalis. It is light weight and withstands wear and tear. It is used as drainage pipes, floor-finish, emulsion paints, etc.

1.9.2 Thermo-setting Plastics

The thermo-setting plastics are the plastics which become rigid when moulded at suitable pressure and temperature. This type of plastic passes originally through thermo plastic stage. Thermo-setting plastics are strong, durable and hard. They are mainly used in engineering applications of plastics.

The commonly used thermo-setting plastics are phenol formaldehyde, phenol-furfuraldehyde and urea-formaldehyde plastics.

Phenol formaldehyde It is formed by heating phenol and benzene in the presence of suitable catalysts.

Phenol-furfuraldehyde It is formed by digesting husks of rice, oat, ground-nut with H_2SO_4 distilling the mixture to separate the furaldehyde vapour and allowing the vapours to react with phenol in presence of catalysts.

Urea-formaldehyde Urea reacts with formaldehyde in presence of catalysts. These are used for making dishes, drinking glasses, plates, etc.

Uses

1. They are used for making plumbing fixtures, fittings and water storage tanks.
2. They are used for making floor and wall tiles.
3. They are used to produce pipes.
4. They are used to form flat sheets used for enclosure panels.
5. Foamed plastics are used for roofing.
6. They are used for doors and window frames.
7. Plastics are used as an insulating material.

1.10 PROPERTIES OF BUILDING MATERIALS

1.10.1 Introduction

Building materials are found to be the basic elements for all engineering structures. So the behaviour of the structure depends on the behaviour of the basic elements, i.e. on the various characteristics and properties of the building material. Such properties may be classified into various categories as follows.

1. Physical properties
2. Mechanical properties
3. Chemical properties
4. Electrical properties

5. Magnetic properties
6. Optical properties
7. Thermal properties

From constructional aspects, the physical and mechanical properties are predominant. Hence it is essential for a civil engineer to have knowledge on the various physical and mechanical properties of building materials.

1.10.2 Physical Properties

Various physical properties of a building material are as follows.

(i) Bulk density
(ii) Chemical resistance
(iii) Coefficient of softening
(iv) Density
(v) Density index
(vi) Durability
(vii) Porosity
(viii) Specific heat
(ix) Thermal conductivity
(x) Thermal capacity
(xi) Water absorption
(xii) Permeability

(i) Bulk Density It is defined as the mass per unit volume of material in its natural state, i.e., including volume of pores and voids. Table 1.6 lists bulk densities of different building materials.

(ii) Chemical Resistance The ability of the material to resist against the action of acids, alkalies, gases and salt solution is known as its chemical resistance. Chemical resistance is carefully examined while selecting material for sewer pipes, hydraulic engineering installations, sanitary facilities, etc.

Table 1.6 Bulk densities of common building materials

S.No.	*Building materials*	*Bulk density in kN/m^3*
1.	Clay brick	16 to 18
2.	Dense limestone	18 to 24
3.	Granite	25 to 27
4.	Gravel	14 to 17
5.	Heavy concrete	18 to 25
6.	Light concrete	5 to 18
7.	Sand	14.5 to 16.5
8.	Steel	78.5

(iii) Coefficient of Softening It is the ratio of compressive strength of material saturated with water to that in dry state. Materials having coefficient of softening more than or equal to 0.8 are referred to as the water-resisting materials.

(iv) Density It is defined as the mass per unit volume of the material in its homogeneous state, i.e. neglecting the volume of pores and voids.

(v) Density Index The ratio of bulk density of the material to its density is known as its density index. Thus, it denotes the degree to which its volume is filled up with solid matter. Density index for most of the building materials is less than unity.

(vi) Durability The property of a material to resist the combined action of atmospheric and other factors is known as its durability. The life and maintenance cost of any structure depends upon the durability of the materials which it is composed of.

(vii) Porosity The degree by which the volume of material is occupied by pores is termed as porosity. It is the ratio of volume of voids to the total volume of the specimen.

(viii) Specific Heat The term specific heat indicates the quantity of heat (expressed in kilocalories) required to heat one N of material by one degree centigrade.

(ix) Thermal Conductivity Thermal conductivity of a material is defined as the amount of heat in kilocalories, that will flow through a unit area of the material with unit thickness in unit time and when the difference of temperature on its faces is also unity. The reciprocal of thermal conductivity of a material is termed as its thermal resistivity.

(x) Thermal Capacity The property by which the material absorbs heat is termed as its thermal capacity. It is obtained by the following equation

$$T = H/(M \times (t_1 \sim t_2))$$

where

T = thermal capacity in J/N °C

H = quantity of heat required to increase the temperature of a material from t_1 to t_2 in J

M = mass of material in N

$t_1 \sim t_2$ = temperature difference of material before and after heating in °C

(xi) Water Absorption The ability of a material to absorb and retain water is termed as its water absorption. It is expressed either as percentage of weight or percentage of volume of dry material. It mainly depends on the bulk density and porosity of the material.

(xii) Permeability The capacity of a material to allow water to pass through it under pressure is referred as its permeability. It denotes the quantity of water that will pass through a unit cross-sectional area of the material in one hour at constant pressure.

1.10.3 Mechanical Properties

The various mechanical properties of building material are as follows.

(i) Abrasion

(ii) Elasticity
(iii) Plasticity
(iv) Strength
(v) Impact strength
(vi) Wear
(vii) Fatigue
(viii) Hardness
(ix) Brittleness
(x) Ductility
(xi) Malleability
(xii) Toughness

(i) Abrasion It is the property of a material by which it resists the action of moving load. It is found by dividing the difference in weights of the specimen, before and after abrasion with the area of abrasion.

(ii) Elasticity The property by which a material regains its original shape and position after the removal of external load is known as elasticity.

(iii) Plasticity It is the property of a material, by which no deformation vanishes, when it is relieved from the external load.

(iv) Strength The ability of a material to resist failure under the action of external load is known as its strength. The loads to which a material is commonly subjected to are compression, tension and bending. The corresponding strength is obtained by dividing the ultimate load with the cross-sectional area of the specimen.

(v) Impact strength It is defined as the quantity of work required to cause failure per unit of its volume. Thus, the impact strength indicates the toughness of the material.

(vi) Wear The failure of a material under the combined actions of abrasion and impact is known as its wear. It is usually expressed as a percentage of loss in weight and it is very important to decide the suitability of a material for use of road surfaces, railway ballast, etc.

(vii) Fatigue When the materials are subjected to repetitive fluctuating stress, they will fail at a stress much lower than that required to cause fracture under steady loads. This property is known as fatigue.

(viii) Hardness It is the ability of a material to resist penetration by a harder body. It plays an important role in deciding the workability and use of a material for floors and road surfaces. For stone materials, hardness can be determined with the help of Mohr's scale of hardness. It is a list of ten materials arranged in the order of increasing hardness as shown in Table 1.7. The level of hardness of a material lies between the hardnesses of two materials, i.e. the one which scratches and the other which is scratched by the material to be tested.

(ix) Brittleness A material is said to be brittle when it cannot be drawn into a wire by tension. A brittle material fails suddenly under pressure without appreciable deformation preceding the failure. Concrete, glass, cast-iron, rock materials, etc. are some of the examples of brittle materials.

(x) Ductility It is a property of a material by which it can be drawn into a wire by tension.

(xi) Malleability The property by which a material can be uniformly extended in a direction without rupture is known as malleability. This property finds its applications in many operations such as forging, hot rolling, etc.

(xii) Toughness Toughness is the property of a material that enables it to absorb energy without fracture. This property is useful in shock loading.

Table 1.7

S.No.	*Material*	*Remarks*
1.	Talcum	Readily scratched by finger nail
2.	Rock-salt or gypsum	Scratched by finger nail
3.	Calcite	Readily scratched by a steel knife
4.	Fluorite	Scratched by a slightly pressed steel knife
5.	Apatite	Scratched by a heavily pressed steel knife
6.	Feldspar	Slightly scratches glass and is not scratched by a steel knife
7.	Quartz	Readily scratches glass and is not scratched by steel knife
8.	Topaz	Readily scratches glass and is not scratched by steel knife
9.	Corundum	Readily scratches glass and is not scratched by steel knife
10.	Diamond	Readily scratches glass and is not scratched by steel knife

Short-Answer Questions

1. Give examples for igneous, sedimentary and metamorphic rocks.
2. How are igneous rocks formed?
3. What are the major operations involved in the manufacture of bricks?
4. What are the dimensions of a standard brick?
5. What are the raw materials used in manufacture of cement?
6. Why gypsum is added during the manufacture of cement?
7. What is meant by hydration of cement?
8. What is the need for reinforcement in RCC?
9. Draw stress–strain diagram for mild steel.
10. What is meant by M15 concrete?
11. How are bricks classified?
12. How are rocks classified based on its formation?

13. What do you mean by reinforced concrete? What is the necessity of reinforcing the concrete?
14. What is expanded metal and where is it used?
15. What are the uses of channel and T-sections?
16. What are the main functions of a civil engineer?
17. What are the objectives of surveying?
18. What are the constituents of a brick.
19. List various types of cement.
20. What are the advantages of reinforced cement concrete?
21. What are the types of light weight concrete and polymer concrete?
22. What is the main disadvantage of normal concrete?
23. What are the several ways in which aerated concrete is manufactured?
24. What do you mean by no-fine concrete?
25. What is high density concrete and where is it mainly used?
26. List the monomers normally used in polymer concrete.
27. What are the applications of PIC?
28. What is meant by FRC?
29. What are the functions of fibres in FRC? State the different types of fibres.
30. Define workability.
31. Define compressive strength of concrete.
32. What are the functions of admixtures?
33. What do you understand by non-destructive testing of concrete?
34. List out the test methods normally available for non-destructive testing of concrete.
35. What is the main advantage of using tor steel?
36. Draw the stress–strain curve for tor steel.
37. Write down the chemical composition of tor steel. What are the grades of tor steel?
38. What are endogenous and exogenous trees?
39. Draw the cross-section of an exogenous tree.
40. Define the following terms.
    (i) Pith
    (ii) Cambium
    (iii) Bark
    (iv) Medullary rays
    (v) Heartwood
    (vi) Sapwood

41. What is seasoning of timber?
42. What are the uses of timber?
43. What are plywoods?
44. Define plastics. What are the different types of plastics?
45. Give examples for thermoplastics and thermo-setting plastics.
46. Define hardness.
47. Define fatigue and ductility.
48. Define porosity.
49. Define water absorption.
50. Define thermal conductivity.
51. Define mortar
52. What is gauged mortar?
53. What is the type of mortar used for plastering and pointing works?
54. Why steel is considered as a good reinforcing material?
55. What are the various forms of reinforcing steel?

Exercises

1. List the uses of the following construction materials: bricks, stones, cement, cement concrete and steel.
2. What are the qualities of a good brick?
3. What are the requirements for a stone which is to be used as a building material?
4. Explain the properties of cement.
5. Which are the normal steel sections available in the market? Give neat sketches.
6. Explain in detail, the functions of a civil engineer.
7. Explain the constituents of brick.
8. Describe the various types of cement, specifying the applications for each.
9. Briefly explain the different types of light weight concrete and list out its advantages.
10. Write short notes on the following types of concrete.
    (i) High-density concrete
    (ii) Polymer concrete
    (iii) Fibre-reinforced concrete
11. Describe briefly the factors affecting workability.
12. Explain, how you will measure the workability of the concrete mixture.
13. Briefly explain about the testing of hardened concrete.
14. Explain the various factors affecting the compressive strength of concrete.
15. Explain the methods of testing the tensile strength of concrete with a neat sketch.

Chapter 2
SIMPLE STRESSES AND STRAINS

2.1 DEFINITION OF MECHANICS

Mechanics is a physical science dealing with forces and the effect of forces on bodies. Mechanics is divided into two main branches of study: *statics* and *dynamics*. Statics is the study of forces and the effect of forces acting upon bodies, in a state of equilibrium. On the other hand, dynamics deals with motion and the effect of forces acting on bodies in motion.

2.2 UNITS

A unit is defined as a numerical standard used to express the qualitative measure of a physical quantity. Mechanics deals with four fundamental quantities: *length*, *mass*, *force* and *time*. Although there are a number of different systems of units in existence, only the International System of units, abbreviated as SI, will be used in this text. The four fundamental quantities and their units along with the symbol are summarised in Table 2.1. They are called *basic units* and they are independent of all other units.

Table 2.1 Basic units

Quantity	*Dimension*	*SI Units*	
		Unit	*Symbol*
Mass	M	Kilogram	kg
Length	L	Metre	m
Time	T	Second	s
Force	F	Newton	N

Other units which are expressed in terms of the basic units are called *derived units*, for example, area, volume, velocity, work and power. Table 2.2 presents the various SI units used in mechanics.

Table 2.2 SI units used in mechanics

Quantity	*Unit*	*SI symbol*
Basic Units		
Length	metre	m
Mass	kilogram	kg
Time	second	s
Derived Units		
Linear acceleration	metre/second^2	m/s^2
Angular acceleration	radian/second^2	rad/s^2
Area	metre^2	m^2
Density	kilogram/metre^3	kg/m^3
Force	Newton	N
Frequency	Hertz	Hz
Impulse, linear	Newton-second	N.s
Impulse, angular	Newton-metre-second	N.m.s.
Moment of force	Newton-metre	N.m.
Moment of inertia	metre^4	m^4
Momentum, linear	kilogram-metre/sec.	kg.m/s
Power	Watt	W
Pressure, stress	Pascal	Pa (N/m^2)
Spring constant	Newton/metre	N/m
Velocity, linear	metre/second	m/s
Velocity, angular	radian/second	rad/s
Volume	metre^3	m^3
Work, energy	Joule	J(N.m)

Table 2.3 gives the prefixes for various units.

Table 2.3 SI units prefixes

Prefix	*Symbol*	*Multiplication factor*
terra	T	10^{12}
giga	G	10^9
mega	M	10^6
kilo	k	10^3
hecta	h	10^2
deka	da	10
deci	d	10^{-1}
centi	c	10^{-2}
milli	m	10^{-3}
micro	μ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}

2.3 EXTERNAL FORCES

Forces which act on a body due to external causes are called external forces. These external forces constitute what is called the load on a structure or a machine.

2.3.1 Load Classification

1. Classification of loads according to the manner of the application

(a) Static loads are those which are applied gradually from zero to their final value. Such loads produce practically no vibration in the structure.

(b) Dynamic loads are those which are applied rapidly. Such loads vary with time. These loads produce vibration in the structure, and equilibrium is not established until the vibration ceases, usually by natural damping forces. The effect of dynamic loads may be many times that of the static loads.

2. Classification of loads according to the duration of their action on the structure

(a) Sustained loads or dead loads are those which remain constant and act on the structure for a long period of time. This type of load is treated as a static load; for example, the self-weight of a structure.

(b) Live loads are those which are applied to the structure for a short period of time. Loads which change their magnitude and direction with time are treated as live loads. For example, the vehicular traffic on a bridge.

3. Classification of loads with respect to the area over which they are distributed

(a) Concentrated loads or point loads are those which are assumed to act at a point. Strictly speaking, there exists no concentrated load in nature. However, a load distributed over a relatively small area compared with the dimensions of the loaded member may be assumed to be a concentrated load for the purpose of analysis. For example, the load transferred by the truck wheel on the rail may be treated as a point load acting at the point of contact of the wheel with the rail.

(b) Distributed loads are those which are distributed along the length of the loaded member (e.g., self-weight of a beam) or over a definite area (e.g., wind load on a structure). The distribution may be uniform or non-uniform.

2.4 INTERNAL FORCES

2.4.1 Stress

When external forces or loads act on a body or a material, the body or the material undergoes deformation, i.e. change in dimension or in the shape of the body or both simultaneously. While undergoing deformation, the particles of the material exert a resisting force. When this resisting force equals applied load, the equilibrium condition exists and hence deformation stops. This internal resistance is called the stress. The internal resistance or internal force per unit area of cross-section is called intensity of stress. The unit of stress is N/m^2. This unit is sometimes known as Pascal (Pa).

Types of stresses

1. Tensile Stress When a load is such that it tends to pull apart the particles of the material causing extension in the direction of application of load, it is called a tensile load and the corresponding stress is called a tensile stress. Figure 2.1(a) shows a bar subjected to the tensile force *P*. Figure 2.1(b) shows the resisting forces at the section *XX*. For equilibrium to exist, the resisting force *P′* = the load *P*. Figure 2.1(c) shows an element in the material which is subjected to tensile stress. Even though the stress is shown by a line, it should be taken as applied over the entire cross-section.

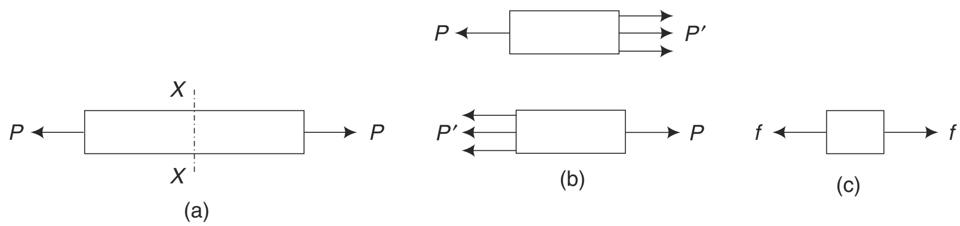


Fig. 2.1 *Tensile stress*

From the definition of stress,

$$\text{Tensile stress } f = \frac{\text{Resisting force } P'}{\text{Cross-sectional area } A}$$

$$\text{Since } P' = P$$

$$\text{Stress } = \frac{P'}{A} \text{ N/m}^2 = \frac{\text{Tensile load}}{\text{Cross-sectional area}}$$

2. Compressive Stress When the load is such that it pushes the particles of the material nearer, causing shortening in the direction of the load, it is called a compressive load and the corresponding stress is called a compressive stress. Figure 2.2 shows a bar and element subjected to a compressive load.

$$\text{Compressive stress } = \frac{\text{Resisting force } P'}{\text{Cross-sectional area } A}$$

But, $P' = P$

$$f = \frac{P}{A} = \frac{\text{Compressive load}}{\text{Cross-sectional area}}$$

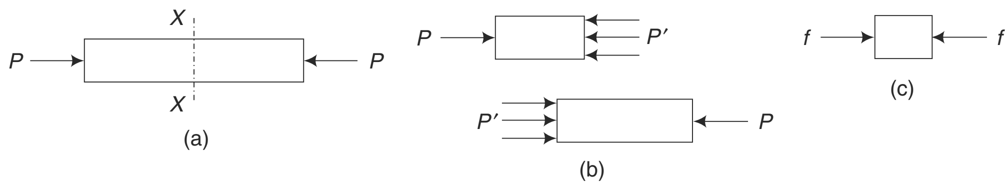


Fig. 2.2 *Compressive stress*

3. Shear Stress Shear stress exists between two parts of a body in contact, when the two parts exert equal and opposite force on each other laterally in a direction tangential to their surface of contact.

In Fig. 2.3 (a), the section of a rivet is subjected to equal and opposite forces P acting tangentially to the resisting section. Such forces which are equal, opposite and act tangentially across the section causing sliding of the particles one over the other are called shearing forces and the corresponding stresses are called shearing stresses. It is usually denoted by q or f_s or T.

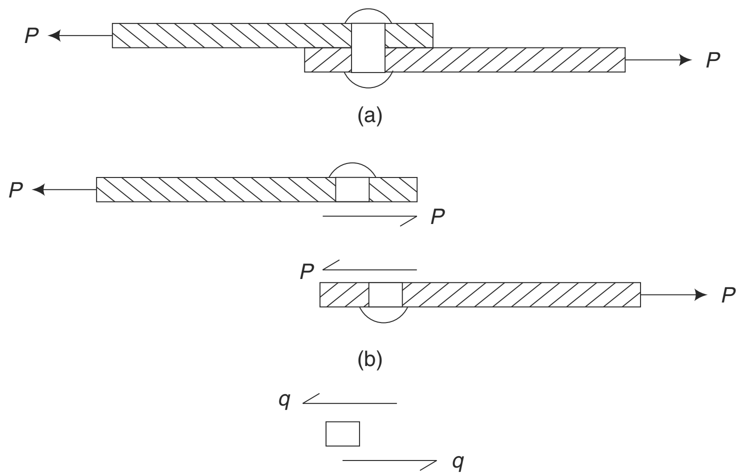


Fig. 2.3 *Shear stress*

From Fig. 2.3(b), it is clear that the resisting force of the rivet must be equal to P. Hence, the shearing stress is given by

$$q = \frac{P}{A} = \frac{\text{Total tangential force}}{\text{Cross-sectional area}}$$

The tensile stress and compressive stress are known as direct stresses and shearing stress as tangential stress.

2.4.2 Strain

When a load acts on the material, it will undergo deformation. Strain is a measure of the deformation produced by the application of the external forces.

In the case of tensile force, the member elongates and in the case of compressive force, the member shortens in its length. Hence, the deformations are elongation and shortening respectively.

Strain is measured as the ratio of the change in length, to the original length. It is the linear change in length per unit length. It is usually denoted by e or ε. If l is the original length and dl is the change in length, then,

$$\text{Strain} = e = \frac{\text{Final length} - \text{Original length}}{\text{Original length}}$$

$$= \frac{\text{Change in length}}{\text{Original length}} = \frac{dl}{l}$$

Types of strains

1. Tensile Strain Let AB be the initial length of the bar before the application of the load. After a tensile load P is applied, let its final length be equal to AC as shown in Fig. 2.4(a).

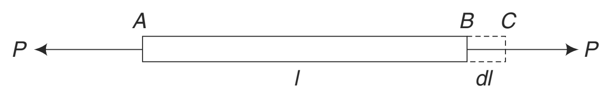


Fig. 2.4(a) *Tensile strain*

$$\text{Extension or change in length} = (AC - AB)$$

$$= BC = dl$$

$$\text{Original length} = l$$

$$\text{Tensile strain} = \frac{\text{Extension}}{\text{Original length}} = \frac{dl}{l}$$

2. Compressive Strain Consider a uniform bar AB of initial length l which is subjected to a compressive force P. The length of the bar reduces to AC as shown in Fig. 2.4(b).

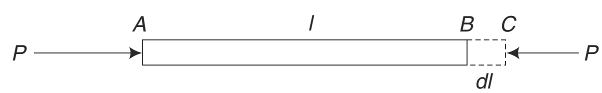


Fig. 2.4(b) *Compressive strain*

$$\text{Shortening or change in length} = (AB - AC) = BC = dl$$

$$\text{Compressive strain, } e = \frac{\text{Shortening}}{\text{Original length}}$$

$$e = \frac{dl}{l}$$

3. Shear Strain If an element *ABCD* as shown in Fig. 2.4(c) is subjected to shearing stresses on faces *AB* and *CD,* then, it undergoes deformation which is different from other types of strains mentioned above. This deformation is expressed in terms of the angular displacement and it is the tangent of the angle of deformation ϕ.

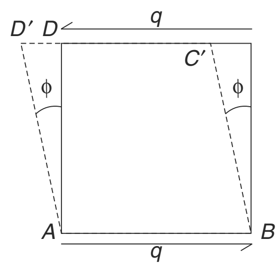


Fig. 2.4(c) *Shear strain*

$$\text{Shear strain} = \frac{DD'}{AD}$$

$$= \tan \phi$$

The shear deformations are so small that there is no error in approximating tan ϕ to ϕ, where ϕ is measured in radians.

$$\text{Hence, shear strain} = \phi = \frac{DD'}{AD}$$

Apart from these three types of strains, there are two more types:

(a) $\text{Volumetric strain} = \dfrac{\text{Change in volume}}{\text{Original volume}}$

(b) $\text{Superficial strain} = \dfrac{\text{Change in area}}{\text{Original area}}$

2.4.3 Elasticity

Every material undergoes deformation under the action of external loads. The degree of deformation depends upon the nature of the material. Consider a material which is being subjected to a gradually increasing load within certain limits. When the external load is removed, the material regains its original size and shape. This property of the material is known as elasticity. Experimentally, it is observed that the elasticity for material exists only to a certain limit of stress, beyond which if the material is loaded and then unloaded it will not regain its original shape and size completely, but there will be some permanent deformation known as *permanent set*. This limiting stress up to which the material regains its original shape and size is known as *elastic limit*.

Hooke's law (Young's modulus)

It has been experimentally established that in many structural materials, up to a certain limit, the strain is directly proportional to the stress producing it.

$$\text{Strain} \propto \text{Stress}$$

It is the usual practice to write that stress is proportional to strain.

$$\frac{\text{Stress}}{\text{Strain}} = \text{Constant} = E$$

where, the constant of proportionality E is known as the modulus of elasticity or Young's Modulus.

Deformation of a bar of uniform cross-section under axial load

Consider a bar of uniform cross-section 'A' and length 'l' subjected to an axial tensile force 'P'. Let 'dl' be the elongation. Then we have,

$$\text{Stress, } f = \frac{P}{A}$$

$$\text{Strain, } e = \frac{dl}{l}$$

Since,

$$\frac{\text{Stress}}{\text{Strain}} = E$$

$$\frac{P/A}{dl/l} = E$$

$$\frac{Pl}{Adl} = E$$

Deformation or elongation $dl = \dfrac{Pl}{AE}$

Modulus of rigidity or shear modulus

The ratio of shear stress to shear strain is called modulus of rigidity. It can also be defined as the intensity of shear stress that causes unit rotation (shear strain) when the member is under pure shear. It is denoted by N or G.

Rigidity modulus, $N = \dfrac{\text{Shear stress}}{\text{Shear strain}}$

Bulk modulus of elasticity

When a body is subjected to three similar direct stresses (f) of equal intensity in three mutually perpendicular directions, the ratio of the direct stress (f) to the volumetric strain (e_v) is defined as the bulk modulus of elasticity. It is usually denoted by K.

Bulk modulus, $K = \dfrac{\text{Direct stress}}{\text{Volumetric strain}}$

where, volumetric strain $= \dfrac{\text{Change in volume}}{\text{Original volume}} = \dfrac{dv}{V}$

2.4.4 Poisson's Ratio

When a body is subjected to axial load or direct stress, besides the axial strain or longitudinal strain, there will be lateral strain of opposite nature in all directions at right angles. The ratio of the lateral strain to the axial strain is a constant known as Poisson's ratio and it is denoted by $1/m$ or Γ or μ. Its value lies between 0.25–0.33 for most of the materials. In other words, the value of m lies between three and four.

$$\text{Poisson's ratio} = \frac{1}{m} = \frac{\text{Lateral strain}}{\text{Axial or longitudinal strain}}$$

Factor of safety

In practice, the members of a structure are loaded well within the elastic limit of the material since one cannot take the risk of loading a member to its ultimate strength. The maximum stress to which the material of a member is subjected in practice and which is used for designing the member is called the working stress (permissible or allowable or safe or design stress). To avoid permanent set in the members, working stress is kept below the elastic limit. The ratio of the yield stress to the working stress is called the *factor of safety* and the ratio of the ultimate load to the working load is called the *load factor*. Sometimes, the factor of safety is taken as the ratio of the ultimate stress to the working stress. The value of the factor of safety varies from three (in case of steel) to as high as 20 (in case of timber subjected to suddenly applied loads). The value of factor of safety depends upon the following factors:

1. Type and nature of loading whether static or dynamic, dead or live load whether acting in one direction or reversing
2. Accuracy in the analysis of the structure
3. Reliability of the material
4. Effect of corrosion and wear
5. Possible manufacturing errors or fabrication errors
6. Type of maintenance that is possible

Relation between elastic constants

Relationship between Young's modulus (E) and rigidity modulus (N) Consider a square element *ABCD* which is distorted to *ABEF* due to shear stresses acting as shown in Fig. 2.5.

A state of simple shear produces tensile stress on the diagonal *BD* and compressive stress on the diagonal *AC*.

Strain of diagonal,
$$BD = \frac{q}{E} - \left[-\frac{q}{mE}\right]$$
$$= \frac{q}{E}\left[1 + \frac{1}{m}\right] \qquad (2.1)$$

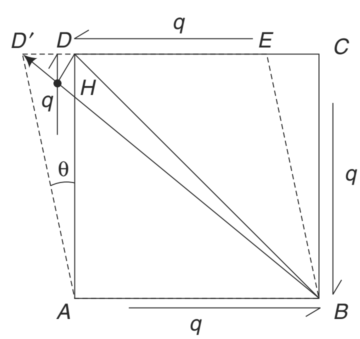


Fig. 2.5 *Relationship between E and N*

Let this shear stress cause a shear strain ϕ resulting in the diagonal BD to distort to BF. Draw DH perpendicular to BF.

Strain of diagonal, $$BD = \frac{BF - BD}{BD}$$

$$= \frac{BF - BH}{BD} \quad \text{(since distortion is very small)}$$

$$= \frac{FH}{BD}$$

As the angle of distortion is very small, we can assume that

Angle $BFD = 45°$

Strain of diagonal $$BD = \frac{FH}{BD} = \frac{FD \cos 45}{\sqrt{2}\, AD} = \frac{1}{2}\frac{FD}{AD}$$

Since, the angle ϕ is very small, $\tan \phi = \phi = \frac{FD}{AD}$ = shear strain

Strain of diagonal $$BD = \frac{1}{2}\frac{FD}{AD} = \frac{\phi}{2}$$

By definition, rigidity modulus $N = \frac{\text{Shear stress}}{\text{Shear strain}} = \frac{q}{\phi}$

Strain of diagonal, $$BD = \frac{\phi}{2} = \frac{q}{2N} \qquad (2.2)$$

From eqs. (2.1) and (2.2),

$$\frac{q}{E}\left[1 + \frac{1}{m}\right] = \frac{q}{2N}$$

$$E = 2N\left[1 + \frac{1}{m}\right] \qquad (2.3)$$

Relationship between Young's modulus (e) and bulk modulus (k) Consider a cube subjected to three mutually perpendicular tensile stresses of equal intensity 'f' as shown in Fig. 2.6.

Strain in X-direction $$e_x = \frac{f}{E} - \frac{f}{mE} - \frac{f}{mE}$$

$$= \frac{f}{E}\left[1 - \frac{2}{m}\right]$$

Similarly, $$e_y = \frac{f}{E}\left[1 - \frac{2}{m}\right]$$

$$e_z = \frac{f}{E}\left[1 - \frac{2}{m}\right]$$

Volumetric strain $$\frac{dv}{V} = (e_x + e_y + e_z)$$

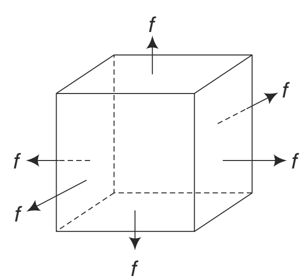


Fig. 2.6 *Relationship between E and K*

$$= 3\frac{f}{E}\left[1-\frac{2}{m}\right] \quad (2.4)$$

From the definition,

Bulk modulus,

$$K = \frac{f}{(dv/v)}$$

$$\frac{dv}{v} = \frac{f}{K} \quad (2.5)$$

Equating Eq. (2.4) and Eq. (2.5),

$$\frac{f}{K} = 3\frac{f}{E}\left[1-\frac{2}{m}\right]$$

$$E = 3K\left[1-\frac{2}{m}\right] \quad (2.6)$$

Relation between E, N and K From Eqs. (2.3) and (2.6),

$$2N\left[1+\frac{1}{m}\right] = 3K\left[1-\frac{2}{m}\right]$$

$$2N + \frac{2N}{m} = 3K - \frac{6K}{m}$$

$$2N - 3K = \frac{1}{m}(-6K - 2N) = -\frac{1}{m}(6K + 2N)$$

$$\frac{1}{m} = -\frac{(2N-3K)}{(6K+2N)} = +\frac{(3K-2N)}{(6K+2N)} \quad (2.7)$$

Substituting Eq. (2.7) in (2.3),

$$E = 2N\left[1+\frac{1}{m}\right]$$

$$= 2N\left[1+\frac{(3K-2N)}{(6K+2N)}\right]$$

$$= 2N = \left[\frac{9K}{6K+2N}\right]$$

$$E = \frac{9\,KN}{3K+N} \quad (2.8)$$

2.5 COMPOUND MEMBER

If two or more different members of the same material are joined together and are used to carry the force jointly, then the combination is called a compound member. Figure 2.7 shows the cross-section of a compound member. This consists of three different members of the same material, i.e. two steel plates and a steel 'I' section.

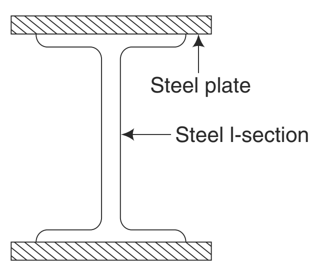


Fig. 2.7 *Compound member*

2.6 COMPOSITE MEMBER

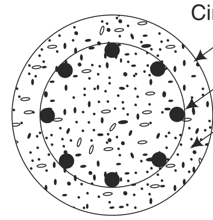


Fig. 2.8 *Composite member*

If two or more members of different materials are connected together and are used for carrying the force jointly, then the combination is called a composite member. Figure 2.8 shows the cross-section of a composite member. The two materials are steel and concrete.

2.6.1 Analysis of Composite Bars

Figure 2.9 shows a composite bar made up of two different materials.

Let

P = total load on the composite bar

l = length of composite bar and also length of bars of different materials

A_1 = area of cross-section of Bar 1

A_2 = area of cross-section of Bar 2

E_1 = Young's modulus of Bar 1

E_2 = Young's modulus of Bar 2

P_1 = load shared by Bar 1

P_2 = load shared by Bar 2

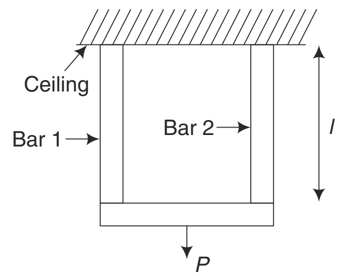


Fig. 2.9 *Analysis of composite bar*

Now the total load on the composite bar is equal to the sum of the load carried by the two bars.

Therefore, Total load = Load shared by Bar 1 + Load shared by Bar 2

i.e., $$P = P_1 + P_2 \tag{2.9}$$

Since, the ends of the two bars are rigidly connected, each bar will change in length by the same amount.

Therefore, change in length in Bar 1 = Change in length in Bar 2

i.e., $$\delta l_1 = \delta l_2$$

$$\left(\frac{Pl}{AE}\right)_1 = \left(\frac{Pl}{AE}\right)_2 \qquad \left(\because\ \delta l = \frac{Pl}{AE}\right)$$

$$\left(\frac{P_1\, l_1}{A_1\, E_1}\right) = \left(\frac{P_2\, l_2}{A_2\, E_2}\right)$$

$$\frac{P_1\, l}{A_1\, E_1} = \frac{P_2\, l}{A_2\, E_2} \qquad (\because\ l_1 = l_2 = l)$$

$$\frac{P_1}{A_1\, E_1} = \frac{P_2}{A_2\, E_2}$$

$$P_1 = P_2 \left(\frac{A_1 E_1}{A_2 E_2} \right) \tag{2.10}$$

From Eqs. (2.9) and (2.10), the loads P_1 and P_2 can be determined.

2.6.2 Modular Ratio

The ratio E_1/E_2 is called the modular ratio of the first material to the second.

2.7 TORSION

In industries, a turning force is always applied to transmit energy by rotation. This force is applied either to the rim of the pulley keyed to the shaft or at some other point at some distance from the axis of shaft. The product of this turning force to the distance of application of the force and the axis of shaft is known as *torque*, i.e. twisting moment or turning moment and the shaft is said to be subjected to torsion.

Pure torsion A shaft of circular section is said to be in pure torsion when it is subjected to equal and opposite end couples whose axes coincide with the axis of the shaft.

2.7.1 Assumptions in Theory of Torsion

The following assumptions are made in the theory of torsion.

1. The material of the shaft is uniform throughout.
2. The shaft is of uniform circular cross-section throughout.
3. Stresses do not exceed the limit of proportionality.
4. The twist along the shaft is uniform.
5. Normal cross-section of the shaft which were plane and circular before twist, remain plane and circular after twist.

2.7.2 Comparison between Solid and Hollow Shafts

Consider two shafts made of the same material, having same lengths, transmitting the same torque and where one is of solid section and the other hollow. Both reach the same permissible maximum shear stress.

Let

Outside diameter of hollow shaft $= D$

Inside diameter of hollow shaft $= d$

Diameter of solid shaft $= d_s$

Length of both shafts $= l$

Density of material for both shafts $= \rho$

Weight of solid shaft $= W_s$

Weight of hollow shaft $= W_H$

Then

$$\frac{W_H}{W_s} = \frac{\text{Volume of hollow shaft} \times \text{density of shaft material}}{\text{Volume of solid shaft} \times \text{density of shaft material}}$$

$$= \frac{\frac{\pi}{4}(D^2 - d^2) \times l \times \rho}{\frac{\pi}{4} d_s^2 \times l \times \rho}$$

$$= \frac{(D^2 - d^2)}{d_s^2}$$

Also, % saving in material $= \left(\frac{W_s - W_H}{W_s}\right) \times 100$

$$= \frac{\left[\frac{\pi}{4} d_s^2 \times l \times \rho - \frac{\pi}{4}(D^2 - d^2)\, l \times \rho\right]}{\left(\frac{\pi}{4} d_s^2 \times l \times \rho\right)} \times 100$$

$$= \frac{[d_s^2 - (D^2 - d^2)]}{d_s^2} \times 100$$

2.7.3 Torsion Equation

The torsion equation is given as

$$\frac{T}{J} = \frac{\tau}{r} = \frac{C\theta}{l}$$

where T = torque applied in N-mm

J = polar moment of inertia in mm^4

$= \frac{\pi}{32} d^4$ (For a solid shaft of diameter d)

$= \frac{\pi}{32}(D^4 - d^4)$

(for a hollow circular shaft of external diameter D and internal diameter d)

τ = maximum shear stress intensity in N/mm^2

r = radius of the shaft in mm

C = modulus of rigidity of the shaft material in N/mm^2

θ = angle of twists in radians

l = length of the shaft in mm

2.7.4 Power Transmitted by a Shaft

Shafts are used for transmitting power. Power is calculated as work done per unit time. Work done by torque is the product of torque and angular displacement in radians.

Consider a shaft carrying torque T and rotating at N revolutions per minute (rpm). As one revolution = 2π radians, angular displacement in one minute is $2\pi N$ radians.

Therefore,

$$\text{Work done in one minute} = 2\pi NT$$

Therefore,

$$\text{Work done per second} = \frac{2\pi NT}{60}$$

Therefore,

$$\text{Power, } P = 2\pi \frac{NT}{60}$$

This is the torque–power relation.

In the above relation, if torque T is in N–m, then unit of power is watt because 1N–m/sec = 1 watt.

2.7.5 Maximum Torque

As the speed of rotation fluctuates, the maximum torque on a shaft may exceed the average (or mean) value. If it exceeds by 40 per cent, then the maximum torque is 1.40 times the mean.

To find the shear stress or angle of twist or diameter of the shaft, the maximum value of torque is used in the torsion equation, while in the torque–power relation, T is the average torque.

Illustrative Examples

Example 2.1 A steel rod of 20 mm diameter and 1 m length is subjected to an axial pull of 50 kN. Determine the stress, strain and elongation of the rod taking Young's modulus $E = 2 \times 10^5$ N/mm^2.

Solution

1. To find stress f

$$\text{Stress } f = \frac{\text{Load}}{\text{Area of cross-section}}$$

$$\text{Load} = 50 \text{ kN (axial pull)} = 50 \times 1000 \text{ N}$$

$$\text{Area of cross-section} = \frac{\pi d^2}{4} \ (d = \text{diameter of rod} = 20 \text{ mm})$$

$$= \frac{\pi \times 20^2}{4} = 314 \text{ mm}^2$$

$$\text{Stress } f = \frac{50 \times 1000}{314} = 159.236 \text{ N/mm}^2$$

2. To find strain e

$$\text{Strain } e = \frac{\text{Stress}}{\text{Young's Modulus}}$$

$$= \frac{159.236}{2 \times 10^5} = 7.962 \times 10^{-4}$$

3. To find elongation

$$\text{Elongation} = dl$$

We know that, $\text{strain} = \dfrac{dl}{l}$

$$dl = l \times \text{strain} \; (l = 1 \text{ m} = 1000 \text{ mm})$$

$$= 1000 \times 7.962 \times 10^{-4}$$

$$= \mathbf{0.796 \text{ mm.}}$$

Example 2.2 A 20 m steel tape of 10 mm × 0.8 mm cross-section is subjected to a pull of 120 N. Find the actual length of the tape, if $E = 2 \times 10^5$ N/mm^2.

Solution The tape is subjected to a pull. Hence, it will elongate.

$$\text{Actual length} = 20 + \text{Change in length}$$

$$\text{Change in length} = \text{Elongation} = dl$$

$$dl = \frac{Pl}{AE}$$

$$P = \text{applied pull} = 120 \text{ N}$$

$$l = \text{length of tape} = 20 \text{ m} = (20 \times 1000) \text{ mm}$$

$$A = \text{Area of cross-section}$$

$$= 10 \text{ mm} \times 0.8 \text{ mm} = 8 \text{ mm}^2$$

$$E = 2 \times 10^5 \text{ N/mm}^2 \; (\textit{given})$$

$$dl = \frac{120 \times (20 \times 1000)}{8 \times 2 \times 10^5}$$

$$= 1.5 \text{ mm} = 1.5 \times 10^{-3} \text{ m}$$

$$\text{Actual length} = 20 + dl$$

$$= 20 + 0.0015 = \mathbf{20.0015 \text{ m}}$$

Example 2.3 A steel rod of 20 mm diameter is tested in a universal testing machine. Using the following particulars, calculate the strain and modulus of elasticity of the rod material.

Load applied = 70 kN

Actual length = 200 mm

Extension observed = 220 divisions

1 division of extensometer used = 0.001 mm

Solution

1. To find strain *e*

$$e = \frac{dl}{l}$$

$$dl = 220 \times 0.001 = 0.22 \text{ mm}$$

$$l = 200 \text{ mm}$$

$$e = \frac{0.22}{200} = \mathbf{1.1 \times 10^{-3}}$$

2. To find modulus of elasticity

$$E = \frac{\text{Stress}}{\text{Strain}} = \frac{f}{e}$$

$$f = \frac{P}{A} = \frac{70 \times 1000}{(\pi \times 20^2/4)} = 222.82 \text{ N/mm}^2$$

$$e = 1.1 \times 10^{-3}$$

$$E = \frac{222.82}{1.1 \times 10^{-3}} = \mathbf{2.026 \times 10^5\ N/mm^2}$$

Example 2.4 A load of 120 kN was applied over a specimen of 20 mm diameter and 120 mm length in a compression testing machine. The reduction in length due to the compressive force was 0.15 mm. Determine the modulus of elasticity.

Solution

$$E = \frac{Pl}{A \cdot dl}$$

$$= \frac{(120 \times 1000) \times 120}{\dfrac{\pi \times 20^2}{4} \times 0.15}$$

$$= \mathbf{3.056 \times 10^5\ N/mm^2}$$

Example 2.5 A hollow steel column has to carry a load of 1500 kN. Find the external diameter of the column if the internal diameter is 180 mm and the ultimate stress is 500 N/mm^2. Adopt a factor of safety of 5.

Solution

$$\text{Stress} = \frac{\text{Load}}{\text{Area of cross-section}}$$

$$\text{Area of cross-section } A = \frac{\text{Load}}{\text{Stress}}$$

$$\text{Load} = 1500 \text{ kN} = 1500 \times 10^3 \text{ N}$$

$$\text{Stress} = \text{Working stress} = \frac{\text{Ultimate stress}}{\text{Factor of safety}}$$

$$= \frac{500}{5} = 100 \text{ N/mm}^2$$

$$A = \frac{1500 \times 10^3}{100} = 15{,}000 \text{ mm}^2$$

$$A = \frac{\pi}{4}(D^2 - d^2)$$

where D and d are external and internal diameters of the column.

$$\frac{\pi}{4}(D^2 - 180^2) = 15000$$

$$D^2 = 51498.59$$

Hence, $\quad$ $\boldsymbol{D = 226.93}$ **mm**

Example 2.6 The following observations were made using a 15 mm diameter steel rod:

Gauge length	= 250 mm
Extension under the load of 20 kN	= 0.20 mm
Load at yield point	= 30 kN
Ultimate load	= 55 kN
Breaking load	= 45 kN
Length between the gauge marks after failure	= 264 mm
Diameter at the neck	= 12 mm

Evaluate

1. Young's modulus
2. Yield stress, ultimate stress, nominal and true stresses at breaking point
3. Percentage elongation
4. Percentage reduction in area

Solution

1. To find Young's modulus

Within elastic limit, $\quad E = \dfrac{\text{Stress}}{\text{Strain}}$

$$\text{Stress} = \frac{20 \times 1000}{\frac{\pi}{4} \times 15^2} = 113.18 \text{ N/mm}^2$$

$$\text{Strain} = \frac{dl}{l} = \frac{0.20}{250} = 8 \times 10^{-4}$$

$$E = \frac{113.18}{8 \times 10^{-4}}$$

$$= \mathbf{1.415 \times 10^5\ N/mm^2}$$

2. To determine yield stress

$$\text{Yield stress} = \frac{\text{Load at yield point}}{\text{Area of cross-section}}$$

$$= \frac{30 \times 1000}{\frac{\pi}{4} \times 15^2} = \mathbf{169.77\ N/mm^2}$$

3. To find ultimate stress

$$\text{Ultimate stress} = \frac{\text{Ultimate load}}{\text{Area of cross-section}}$$

$$= \frac{55 \times 1000}{\frac{\pi}{4} \times 15^2} = \mathbf{311.24\ N/mm^2}$$

4. Nominal stress at breaking load

$$\text{Nominal stress} = \frac{\text{Breaking load}}{\text{Area of cross-section}}$$

$$= \frac{45 \times 1000}{\frac{\pi}{4} \times 15^2} = \mathbf{254.65\ N/mm^2}$$

$$\text{Actual stress} = \frac{\text{Breaking load}}{\text{Area of cross-section at neck}}$$

$$= \frac{45 \times 1000}{\frac{\pi}{4} \times 12^2} = \mathbf{397.89\ N/mm^2}$$

5. Percentage elongation $= \dfrac{\text{Final length} - \text{Original length}}{\text{Original length}} \times 100$

$$= \frac{264 - 250}{250} \times 100 = \mathbf{5.6\%}$$

6. Percentage reduction in area

$$= \frac{\text{Original area} - \text{Final area}}{\text{Original area}} \times 100$$

$$= \frac{\frac{\pi}{4} \times 15^2 - \frac{\pi}{4} \times 12^2}{\frac{\pi}{4} \times 15^2} \times 100 = \mathbf{36\%}$$

Example 2.7 A bracket is connected to a tie bar by means of four bolts. The permissible shear stress in the bolts is 100 N/mm^2. Find the minimum diameter of bolts if the maximum load in the bar is 75 kN.

Solution $\text{Shear stress } q = \dfrac{\text{Force}}{\text{Area of cross-section of bolts}}$

$$\text{Area of cross-section of bolts} = \frac{F}{q}$$

$$= \frac{75 \times 1000}{100} = 750 \text{ mm}^2 \qquad (2.11)$$

Actual area of cross-section of four bolts

$$= 4 \times \frac{\pi \times d^2}{4} = \pi d^2 \qquad (2.12)$$

Equating (2.11) and (2.12)

$$\pi d^2 = 750$$

$$\boldsymbol{d = 15.45 \text{ mm}}$$

Hence, adopt 16 mm diameter bolts.

Example 2.8 An axial load of 50 kN is applied over a metal tube of external diameter 30 mm and internal diameter of 25 mm. The extension observed over a gauge length of 75 mm was 0.08 mm. The decrease in the outer diameter was 0.008 mm. Determine the values of E, Poisson's ratio and change in volume if length of the tube is 500 mm.

Solution

1. To determine E

$$A = \frac{\pi}{4}(30^2 - 25^2) = 215.98 \text{ mm}^2$$

$$f = \frac{P}{A} = \frac{50 \times 1000}{215.98} = 231.5 \text{ N/mm}^2$$

$$e = \frac{dl}{l} = \frac{0.08}{75} = 1.067 \times 10^{-3}$$

$$E = \frac{f}{e} = \frac{231.5}{1.067 \times 10^{-3}} = \mathbf{2.17 \times 10^5 \text{ N/mm}^2}$$

2. To determine Poisson's ratio

$$\text{Poisson's ratio} = \frac{1}{m} = \frac{\text{Lateral strain}}{\text{Longitudinal strain}}$$

$$\text{Lateral strain} = \frac{\text{Change in diameter}}{\text{Original diameter}}$$

$$= \frac{dD}{D}$$

$$= \frac{0.008}{30} = 2.67 \times 10^{-4}$$

$$\text{Longitudinal strain} = \frac{dl}{l} = 1.067 \times 10^{-3}$$

$$\text{Poisson's ratio } \frac{1}{m} = \frac{2.67 \times 10^{-4}}{1.067 \times 10^{-3}} = \mathbf{0.25}$$

3. To find change in volume

$$\text{Volumetric strain} = \frac{dv}{V} \qquad (2.13)$$

$$\text{Also, volumetric strain} = \frac{f}{E}\left[1 - \frac{2}{m}\right]$$

$$= e\left[1 - \frac{2}{m}\right]$$

$$= 1.067 \times 10^{-3}\ (1 - 2 \times 0.25)$$

$$= 5.335 \times 10^{-4} \qquad (2.14)$$

Equating (2.13) and (2.14),

$$\frac{dv}{V} = 5.335 \times 10^{-4}$$

$$dv = 5.335 \times 10^{-4} \times V$$

$$V = \text{Area} \times \text{Length}$$

$$= 215.98 \times 500 = 107990 \text{ mm}^3$$

Hence,

$$dv = 5.335 \times 10^{-4} \times 107990$$

$$= 57.613 \text{ mm}^3$$

$$\text{Change in volume} = \mathbf{57.613\ mm^3}$$

Example 2.9 A bar of certain material of size 60 mm × 60 mm is subjected to an axial pull of 200 kN. The extension observed over a gauge length of 150 mm is 0.10 mm and the decrease in each side is 0.008 mm. Determine the Young's modulus, Poisson's ratio, rigidity modulus and bulk modulus.

Solution

1. To find Young's modulus

$$E = \frac{f}{e}$$

$$f = \frac{P}{A} = \frac{200 \times 1000}{60 \times 60} = 55.56 \text{ N/mm}^2$$

$$e = \frac{dl}{l} = \frac{0.10}{150} = 6.67 \times 10^{-4}$$

$$E = \frac{55.56}{6.67 \times 10^{-4}} = 0.833 \times 10^5 \text{ N/mm}^2$$

2. To find Poisson's ratio

$$\frac{1}{m} = \frac{\text{Lateral strain}}{\text{Longitudinal strain}}$$

$$\text{Lateral strain} = \frac{\text{Change in lateral dimension}}{\text{Original lateral dimension}}$$

$$= \frac{0.008}{60} = 1.33 \times 10^{-4}$$

$$\text{Longitudinal strain } e = 6.67 \times 10^{-4}$$

$$\frac{1}{m} = \frac{1.33 \times 10^{-4}}{6.67 \times 10^{-4}} = \mathbf{0.20}$$

3. To find rigidity modulus *N*

By the relation between elastic constants,

$$E = 2N\left[1 + \frac{1}{m}\right]$$

$$N = \frac{E}{2\left[1 + \frac{1}{m}\right]}$$

$$= \frac{0.833 \times 10^5}{2(1 + 0.20)} = \mathbf{0.347 \times 10^5\ N/mm^2}$$

4. To find bulk modulus *k*

Also, we have,

$$E = 3K\left[1 - \frac{2}{m}\right]$$

$$K = \frac{E}{3\left[1 - \frac{2}{m}\right]}$$

$$= \frac{0.833 \times 10^5}{3(1 - 2 \times 0.2)} = \mathbf{0.463 \times 10^5\ N/mm^2}$$

Example 2.10 A 50 mm diameter bar is subjected to an axial pull of 500 kN. The extension observed over a gauge length of 200 mm is 0.30 mm and the decrease in diameter is 0.03 mm. Find the Young's modulus and rigidity modulus of the material of the bar.

Solution

1. To find Young's modulus

$$f = \frac{P}{A}$$

$$= \frac{500 \times 1000}{\frac{\pi}{4} \times 50^2} = 254.65\ \text{N/mm}^2$$

$$e = \frac{dl}{l} = \frac{0.30}{200} = 1.5 \times 10^{-3}$$

$$E = \frac{f}{e} = \frac{254.65}{1.5 \times 10^{-3}} = \mathbf{1.698 \times 10^5\ N/mm^2}$$

2. To find rigidity modulus

$$E = 2N\left[1 + \frac{1}{m}\right]$$

$$N = \frac{E}{2\left[1 + \frac{1}{m}\right]}$$

$$E = 1.698 \times 10^5\ \text{N/mm}^2$$

$$\frac{1}{m} = \frac{\text{Lateral strain}}{\text{Longitudinal strain}}$$

$$\text{Lateral strain} = \frac{dD}{D} = \frac{0.03}{50} = 6 \times 10^{-4}$$

$$\text{Longitudinal strain} = 1.5 \times 10^{-3}$$

$$\frac{1}{m} = \frac{\text{Lateral strain}}{\text{Longitudinal strain}} = \frac{6 \times 10^{-4}}{1.5 \times 10^{-3}} = 0.4$$

Hence,
$$N = \frac{1.698 \times 10^5}{2(1 + 0.4)} = \mathbf{0.606 \times 10^5\ N/mm^2}$$

Example 2.11 A mild steel rod of 20 mm diameter and 300 mm length is enclosed centrally inside a hollow copper tube of 30 mm external diameter and 25 mm internal diameter. The ends of the tube and rod are brazed together and the composite bar is subjected to an axial pull of 40 kN. If Young's modulus for steel and copper are 200×10^3 N/mm^2 and 100×10^3 respectively, find the stresses developed in the rod and tube. Also, find the extension of the composite bar.

Solution

Diameter of steel rod		= 20 mm
External diameter of copper tube		= 30 mm
Internal diameter of copper tube		= 25 mm
Length	l	= 300 mm
Load	P	= 40 kN
Young's modulus for steel	E_s	= 200×10^3 N/mm^2
Young's modulus for copper	E_c	= 100×10^3 N/mm^2

(Refer to Fig. 2.10.)

Let

P_s = Load shared by steel rod
P_c = Load shared by copper tube

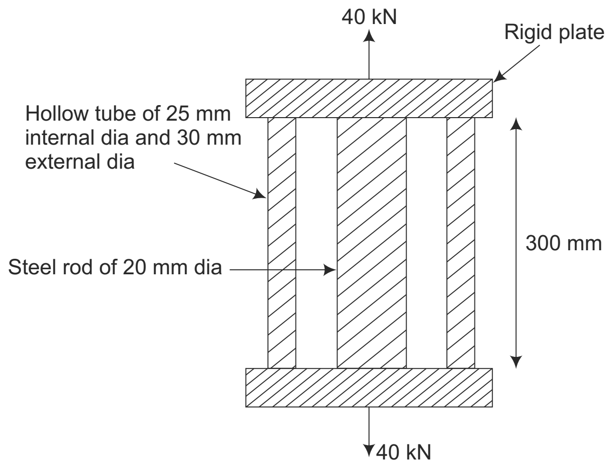


Fig. 2.10

Since, the total on the composite bar is equal to the sum of the loads ends, we have

$$\text{Total load applied} = P_s + P_c$$

Therefore, $$40 = P_s + P_c \tag{2.15}$$

Since, the two ends of the composite system are rigidly connected at their ends, we have

Change in length in steel rod = Change in length in copper tube

Therefore,

$$\left(\frac{Pl}{AE}\right)_{\text{steel}} = \left(\frac{Pl}{AE}\right)_{\text{copper}}$$

$$\frac{P_s\, l_s}{A_s\, E_s} = \frac{P_c\, l_c}{A_c\, E_c}$$

$$\frac{P_s \times 300}{\frac{\pi}{4} \times 20^2 \times 200 \times 10^3} = \frac{P_c \times 300}{\frac{\pi}{4}(30^2 - 25^2) \times 100 \times 10^3}$$

On solving, $$P_s = 2.91\, P_c \tag{2.16}$$

Substituting the value of P_s in Eq. (2.15), we get

$$40 = 2.91\, P_c + P_c$$

Therefore, $P_c = 10.23$ kN

Therefore, $P_s = 2.91\ P_c = 2.91 \times 10.23 = 29.769$ kN

Now

$$\text{Stress in steel rod} = \frac{\text{Load in steel rod}}{\text{Area of steel rod}}$$

$$= \frac{29.769 \times 10^3}{\frac{\pi}{4} \times 20^2}$$

$$= \mathbf{94.758\ N/mm^2}$$

$$\text{Stress in copper tube} = \frac{\text{Load in copper tube}}{\text{Area of copper tube}}$$

$$= \frac{10.23 \times 10^3}{\frac{\pi}{4} \times (30^2 - 25^2)}$$

$$= \mathbf{47.365\ N/mm^2}$$

Since, the extension of both rod and tube are same, so we determine it for any one of them, say for the steel rod. Thus,

Extension of the composite bare = Extension of steel rod

$$= \left(\frac{Pl}{AE}\right)_{\text{steel}}$$

$$= \frac{29.769 \times 10^3 \times 300}{\frac{\pi}{4} \times 20^2 \times 200 \times 10^3}$$

$$= \mathbf{0.142\ mm}$$

Example 2.12 A reinforced concrete column, 500 mm × 500 mm in section, is reinforced with 4 steel bars of 25 mm diameter, one in each corner. The column is carrying a load of 2000 kN. Find the stresses in the concrete and steel bars. $E_{\text{steel}} = 2.1 \times 10^5$ N/mm^2 and $E_{\text{concrete}} = 0.14 \times 10^5$ N/mm^2.

Solution

Size of the column = 500 mm × 500 mm

Diameter of one steel bar = 25 mm

Total load, $P = 2000$ kN $= 2000 \times 10^3$ N

Young's modulus of steel, $E_{\text{steel}} = 2.1 \times 10^5$ N/mm^2

Young's modulus of concrete, $E_{\text{concrete}} = 0.14 \times 10^5$ N/mm^2

(Refer to Fig. 2.11.)

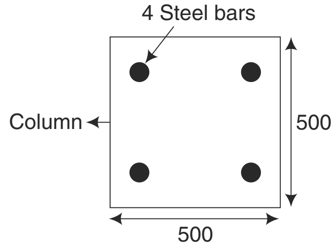


Fig. 2.11

$$\text{Area of the column} = 500 \times 500 = 25 \times 10^4 \text{ mm}^2$$

$$\text{Area of one steel bar} = \frac{\pi}{4} \times 25^2 = 490.874 \text{ mm}^2$$

Therefore,

$$\text{Area of 4 steel bars, } A_s = 4 \times 490.874 = 1963.496 \text{ mm}^2$$

$$\begin{aligned} \text{Area of concrete alone, } A_c &= (\text{Area of column} - \text{Area of 4 steel bars}) \\ &= (25 \times 10^4 - 1963.496) \\ &= 248036.504 \text{ mm}^2 \end{aligned}$$

Let,

P_s = Load shared by 4 steel bars

P_c = Load shared by concrete

The total load is equal to the sum of the loads shared by the two materials, i.e.,

Total load = (Load shared by steel bars + load shared by concrete)

$$2000 \times 10^3 = P_s + P_c \tag{2.17}$$

Since, the column is a composite member,

Change in length in steel rod = Change in length in concrete

i.e.,

$$\left(\frac{Pl}{AE}\right)_{\text{steel}} = \left(\frac{Pl}{AE}\right)_{\text{concrete}}$$

$$\frac{P_s\, l_s}{A_s\, E_s} = \frac{P_c\, l_c}{A_c\, E_c}$$

$$\frac{P_s}{1963.496 \times 2.1 \times 10^5} = \frac{P_c}{248036.504 \times 0.14 \times 10^5} \qquad (\because \quad l_s = l_c = l)$$

On solving,

$$P_s = 0.1187\, P_c \tag{2.18}$$

Substituting the value of P_s in Eq. (1), we get

$$2000 \times 10^3 = 0.1187\, P_c + P_c$$

Therefore, $P_c = 1787789.4$ N

Therefore,

$$\begin{aligned} P_s &= 0.1187\, P_c \\ &= 0.1187 \times 1787789.4 \text{ N} \\ &= 212210.6 \text{ N} \end{aligned}$$

Now

$$\text{Stress in steel bar} = \frac{\text{Load in steel bars}}{\text{Area of steel bars}}$$

$$= \frac{212210.6}{1963.496}$$

$$= \mathbf{108.08\ N/mm^2}$$

$$\text{Stress in concrete} = \frac{\text{Load in concrete}}{\text{Area of concrete}}$$

$$= \frac{1787789.4}{248036.504}$$

$$= \mathbf{7.21\ N/mm^2}$$

Example 2.13 Two vertical wires, each having 2.5 mm diameter and 5 m length jointly support a weight of 2.5 kN. One wire is steel and the other is of a different material. If the wires stretch elastically up to 6 mm, find the load taken by each and the value of Young's modulus for the second wire if that of steel is 2×10^5 N/mm^2.

Solution

Diameter of each wire $d = 2.5$ mm

Length of each wire $l = 5 \text{ m} = 5 \times 10^3$ mm

Elongation of each wire $\delta l = 6$ mm

Young's modulus of the first wire $E_1 = 2 \times 10^5$ N/mm^2

Total load $P = 2.5 \text{ kN} = 2.5 \times 10^3$ N

$$\text{Area of each wire} = A_1 = A_2 = \frac{\pi}{4} d^2$$

$$= \frac{\pi}{4} \times 2.5^2$$

$$= 4.909 \text{ mm}^2$$

Let

P_1 = Load shared by first wire

P_2 = Load shared by second wire

Now

$$\text{Total load} = P_1 + P_2$$

$$2.5 \times 10^3 = P_1 + P_2 \qquad (2.19)$$

Also,

Elongation of first wire, $\delta l = 6$ mm

i.e.

$$\left(\frac{Pl}{AE}\right)_{\text{first wire}} = 6$$

$$\frac{P_1\, l_1}{A_1\, E_1} = 6$$

$$\frac{P_1 \times 5 \times 10^3}{4.909 \times 2 \times 10^5} = 6$$

$\therefore$ P_1 = **1178.16 N**

Substituting the value of P_1, in Eq. (2.19), we get

$$2.5 \times 10^3 = 1178.16 + P_2$$

Therefore,

P_2 = **1321.84 N**

Let

E_2 = Young's modulus of the second wire

Again,

Elongation of second wire, δl = 6 mm

i.e.,
$$\left(\frac{Pl}{AE}\right)_{\text{second wire}} = 6$$

$$\frac{P_2 \, l_2}{A_2 \, E_2} = 6$$

$$\frac{1321.84 \times 5 \times 10^3}{4.909 \times E_2} = 6$$

Therefore, $E_2 = 224390.58 \text{ N/mm}^2$ (Ans.)

Example 2.14 Determine the power transmitted by a shaft rotating at 120 rpm with an average torque of 3×10^6 N–mm.

Solution

Speed of the shaft, N = 120 rpm

Average torque, $T = 3 \times 10^6$ N–mm

$= 3 \times 10^3$ N–m ($\because$ 1 m = 1000 mm)

Let

P = Power transmitted by the shaft

Using the relation

$$\text{Power, } P = \frac{2\pi NT}{60}$$

$$= \frac{2\pi \times 120 \times 3 \times 10^3}{60}$$

= 37699.11 W ($\because$ 1kW = 1000 watts)

= **37.699 kW**

Example 2.15 Calculate the power transmitted by a shaft of 100 mm diameter running at 250 rpm, if the shear stress in the shaft material is not to exceed 75 N/mm^2.

Solution

Diameter of the shaft $d = 100$ mm

Speed of the shaft $N = 250$ rpm

Shear stress $\tau = 75$ N/mm^2

Polar moment of inertia

$$J = \frac{\pi}{32} d^4$$

$$= \frac{\pi}{32} \times 100^4$$

$$= 9.8175 \times 10^6 \text{ mm}^4$$

Using the relation,

$$\frac{T}{J} = \frac{\tau}{r}$$

$$\frac{T}{9.8175 \times 10^6} = \frac{75}{(100/2)}$$

Therefore, $$T = \frac{75}{50} \times 9.8175 \times 10^6$$

$$= 14726250 \text{ N–mm}$$

$$= 14726.25 \text{ N–m}$$

Again using the relation

Power $$P = \frac{2\pi NT}{60}$$

$$= \frac{2 \times \pi \times 250 \times 14726.25}{60}$$

$$= 385532.32 \text{ watts}$$

$$= \mathbf{385.53\ kW}$$

Example 2.16 450 kW of power has to be transmitted at 100 rpm. Find (i) the necessary diameter of a solid circular shaft, and (ii) the necessary diameter of hollow circular section, the internal diameter being 3/4 of the external diameter. Take allowable shear stress as 75 N/mm^2.

Solution

Power $P = 450$ kW

Speed $N = 100$ rpm

Shear stress $\tau = 75$ N/mm^2

Internal diameter = 3/4 external diameter

Using the relation

Power $$P = \frac{2\pi NT}{60}$$

$$450 \times 10^3 = \frac{2\pi \times 100 \times T}{60}$$

Therefore, $$T = 42971.83 \text{ N–m}$$

$$= 42971.83 \times 10^3 \text{ N–mm}$$

For a solid section

Let d_s be the diameter of the solid shaft.

Using the relation,

$$\frac{T}{J} = \frac{\tau}{r}$$

$$\frac{42971.83 \times 10^3}{\frac{\pi}{32} d_s^4} = \frac{75}{\left(\frac{d_s}{2}\right)} \qquad \left(\because \quad r = \frac{d_s}{2}\right)$$

$$d_s^3 = \frac{32 \times 42971.83 \times 10^3}{\pi \times 75 \times 2}$$

$$= 2918049.774 \text{ mm}^3$$

Therefore,

$$d_s = \mathbf{142.89 \ mm}$$

For a hollow circular section

Let

D = External diameter d = Internal diameter

Again using the relation,

$$\frac{T}{J} = \frac{\tau}{r}$$

$$\frac{42971.83 \times 10^3}{\frac{\pi}{32}(D^4 - d^4)} = \frac{75}{\frac{D}{2}}$$

Note: The shear stress is maximum at the outer surface, where $r = D/2$.

$$\frac{42971.83 \times 10^3}{\left[\frac{\pi}{32} D^4 - \left(\frac{3}{4} D\right)^4\right]} = \frac{75}{\frac{D}{2}} \qquad \left(\because \quad d = \frac{3}{4} D\right)$$

$$\frac{\left[D^4 - \left(\frac{3}{4}D\right)^4\right]}{D} = \frac{32 \times 42971.83 \times 10^3}{\pi \times 75 \times 2}$$

$$\frac{\left[D^4 - \frac{3^4}{4^4}D^4\right]}{D} = 2918049.774$$

$$\left(D^3 - \frac{3^4}{4^4}D^3\right) = 2918049.774$$

$$D^3 = \frac{2918049.774}{\left(1 - \frac{3^4}{4^4}\right)}$$

$$D^3 = 4268689.955$$

$$D = \mathbf{162.22\ mm}$$

Therefore,

$$d = \frac{3}{4} \times 162.22 = \mathbf{121.67\ mm}$$

Example 2.17 Calculate the maximum intensity of shear stress induced and the angle of twist in degrees for a length of 10 m for a solid shaft of 125 mm diameter transmitting 110 kW at 150 rpm. Take $C = 0.82 \times 10^5$ N/mm^2 for the material of the shaft.

Solution

Length $l = 10 \text{ m} = 10 \times 10^3 \text{ mm}$

Diameter $d = 125 \text{ mm}$

Power $P = 110 \text{ kW} = 110 \times 10^3 \text{ W}$

Speed $N = 150 \text{ rpm}$

Modulus of rigidity $C = 0.82 \times 10^5 \text{ N/mm}^2$

Using the relation

Power $P = \frac{2\pi NT}{60}$

$$110 \times 10^3 = \frac{2\pi \times 150 \times T}{60}$$

Therefore,

$$T = 7002.817 \text{ N–m}$$

$$= 7002.817 \times 10^3 \text{ N–mm}$$

Again, using the relation

$$\frac{T}{J} = \frac{\tau}{r} = \frac{C\theta}{l}$$

Taking the first two terms, we get

$$\frac{T}{J} = \frac{\tau}{r}$$

$$\frac{7002.817 \times 10^3}{\frac{\pi}{32} d^4} = \frac{\tau}{\left(\frac{d}{2}\right)}$$

$$\frac{7002.817 \times 10^3}{\frac{\pi}{32} \times 125^4} = \frac{\tau}{\left(\frac{125}{2}\right)}$$

Therefore,

$$\tau = \frac{32 \times 7002.817 \times 10^3 \times 125}{\pi \times 125^4 \times 2}$$

$$= \mathbf{18.26\ N/mm^2}$$

Again taking the first and last terms, we get

$$\frac{T}{J} = \frac{C\theta}{l}$$

$$\frac{7002.817 \times 10^3}{\frac{\pi}{32} \times 125^4} = \frac{0.82 \times 10^5 \times \theta}{10 \times 10^3}$$

Therefore,

$$\theta = \frac{32 \times 7002.817 \times 10^3 \times 10 \times 10^3}{\pi \times 125^4 \times 0.82 \times 10^5}$$

$$= 0.0356 \text{ radians} \qquad [\because \pi \text{ radians} = 180°]$$

$$= \frac{180}{\pi} \times 0.0356$$

$$= \mathbf{2° \, 2' \, 23.03''}$$

Example 2.18 A hollow circular shaft is required to transmit 40 kW power at 200 rpm. The maximum torque may exceed the mean by 60 per cent. Shear stress in the shaft is not to exceed 55 N/mm^2. Determine the cross-section of the shaft, if the external diameter is 1.5 times the internal diameter.

Solution

Power $P = 40 \text{ kW} = 40 \times 10^3$ W

Speed $N = 200$ rpm

Maximum torque = 1.60 times mean torque

Shear stress $\tau = 55$ N/mm^2

External diameter $D = 1.5$ times internal diameter $= 1.5\,d$

Using the relation

Power, $$P = \frac{2\pi NT}{60}$$

$$40 \times 10^3 = \frac{2\pi \times 200 \times T}{60}$$

Therefore,

$$T = 1909.859 \text{ N–m}$$

$$= \mathbf{1909.859 \times 10^3 \text{ N–mm}}$$

This is the mean value of the torque.

Therefore,

$$\text{Maximum torque} = 1.6 \times 1909.859 \times 10^3$$

$$= 3055774.4 \text{ N–mm}$$

Again using the relation,

$$\frac{T}{J} = \frac{\tau}{r}$$

$$\frac{3055774.4}{\frac{\pi}{32}(D^4 - d^4)} = \frac{55}{\left(\frac{D}{2}\right)}$$

$$\frac{32 \times 3055774.4}{\pi[(1.5\,d)^4 - d^4]} = \frac{2 \times 55}{1.5\,d}$$

$$\frac{32 \times 3055774.4}{\pi \times 2 \times 55} = \frac{(1.5^4\,d^4 - d^4)}{1.5\,d}$$

$$282962.3859 = \frac{d^4(1.5^4 - 1)}{1.5\,d}$$

$$\frac{1.5 \times 282962.3859}{(1.5^4 - 1)} = d^3$$

Therefore, $$d^3 = 104478.4194$$

Therefore, $$d = \mathbf{47.098 \text{ mm}}$$

Therefore, $$D = 1.5 \times 47.098 = \mathbf{70.647 \text{ mm}}$$

Example 2.19 Two shafts of the same material and of equal length reach the same maximum shear stress when subjected to same torque. If the first shaft is of solid section and the second shaft is of hollow section with internal diameter equal to 2/3 of the external diameter, compare the weights of the two shafts.

Solution

Material is same for both shafts.

Length is same for both shafts.

Maximum shear stress developed is same in both the shafts.

Torque is same in both the shafts.

Internal diameter of hollow shaft = 2/3 external diameter

Let

$$D = \text{external diameter of hollow section}$$
$$d = \text{internal diameter of hollow section}$$
$$d_s = \text{diameter of solid section}$$

For solid section

Using the relation,

$$\frac{T}{J} = \frac{\tau}{r}$$

$$T = \frac{\tau}{r} J$$

$$= \frac{t}{\left(\dfrac{d_s}{2}\right)} \frac{\pi}{32} d_s^4$$

$$= \frac{\tau}{d_s} \frac{\pi}{16} d_s^4$$

$$= \frac{\pi \tau d_s^3}{16} \tag{2.20}$$

For hollow section

Again using the relation,

$$\frac{T}{J} = \frac{\tau}{r}$$

$$T = \frac{\tau}{r} J$$

$$= \frac{\tau}{\left(\dfrac{D}{2}\right)} \frac{\pi}{32} (D^4 - d^4)$$

$$= \frac{\tau}{D} \frac{\pi}{16} \left[D^4 - \left(\frac{2}{3} D\right)^4\right]$$

$$= \frac{\tau}{D} \frac{\pi}{16} \left[D^4 - \frac{2^4}{3^4} D^4\right]$$

$$= \frac{\tau}{D} \frac{\pi}{16} D^4 \left[1 - \frac{2^4}{3^4}\right]$$

$$= \frac{\tau\pi D^3}{16}\left[1 - \frac{2^4}{3^4}\right] \quad (2.21)$$

Since, the shafts are subjected to the same torque, therefore equating (2.20) and (2.21), we get

$$\frac{\tau\pi d_s^3}{16} = \frac{\tau\pi D^3}{16}\left[1 - \frac{2^4}{3^4}\right]$$

$$\frac{D^3}{d_s^3} = \frac{1}{\left[1 - \frac{2^4}{3^4}\right]}$$

$$\frac{D^3}{d_s^3} = 1.246 \text{ or } \left(\frac{D}{d_s}\right)^3 = 1.246 \text{ (or) } \frac{D}{d_s} = (1.246)^{1/3}$$

Therefore,

$$\frac{D}{d_s} = 1.076$$

Now,

$$\frac{W_H}{W_S} = \frac{\text{Weight of hollow shaft}}{\text{Weight of solid shaft}} = \frac{(D^2 - d^2)}{d_s^2}$$

$$\frac{\left[D^2 - \left(\frac{2}{3}D\right)^2\right]}{d_s^2} = \frac{\left[D^2 - \left(\frac{4}{9}D^2\right)\right]}{d_s^2} \qquad \left(\because \quad d = \frac{2}{3}D\right)$$

$$= \frac{D^2\left(1 - \frac{4}{9}\right)}{d_s^2}$$

$$= \left(\frac{D}{d_s}\right)^2\left(1 - \frac{4}{9}\right)$$

$$= (1.076)^2\left(1 - \frac{4}{9}\right) \qquad \left(\because \frac{D}{d_s} = 1.076\right)$$

$$= \mathbf{0.643}$$

Example 2.20 A hollow shaft having inner diameter 0.6 times the outer diameter is to replace a solid shaft of the same material to transmit 550 kW at 220 rpm. The permissible shear stress is 80 N/mm^2. Calculate the diameters of the hollow and solid shafts. Also, calculate the percentage saving in material.

Solution Inner diameter of hollow shaft = 0.6 times its outer diameter

Material is same for both shafts

Power $P = 550 \text{ kW} = 550 \times 10^3 \text{ W}$

Speed $N = 220 \text{ rpm}$

Shear stress $\tau = 80 \text{ N/mm}^2$

Using the relation

Power $$P = \frac{2\pi NT}{60}$$

$$550 \times 10^3 = \frac{2\pi \times 220 \times T}{60}$$

Therefore,

$$T = 23873.24 \text{ N–m}$$

$$= 23873.24 \times 10^3 \text{ N–mm}$$

Solid shaft

Let d_s be the diameter of the solid shaft.

Using the relation,

$$\frac{T}{J} = \frac{\tau}{r}$$

$$\frac{23873.24 \times 10^3}{\frac{\pi}{32} \times d_s^4} = \frac{80}{\left(\frac{d_s}{2}\right)}$$

$$\frac{32 \times 23873.24 \times 10^3}{\pi \times 2 \times 80} = \frac{d_s^4}{d_s}$$

$$d_s^3 = 1519817.66 \text{ mm}^3$$

Therefore,

$$d_s = \mathbf{114.97 \text{ mm}}$$

Hollow shaft

Let

D = Outer diameter of hollow shaft

d = Inner diameter of hollow shaft

Again using the relation,

$$\frac{T}{J} = \frac{\tau}{r}$$

$$\frac{23873.24 \times 10^3}{\frac{\pi}{32} \times (D^4 - d^4)} = \frac{80}{\left(\frac{D}{2}\right)} \qquad \left(\because \; r = \frac{D}{2}\right)$$

$$\frac{32 \times 23872.24 \times 10^3}{\pi \times 2 \times 80} = \frac{(D^4 - d^4)}{D}$$

$$\frac{(D^4 - d^4)}{D} = 1519817.66$$

$$\frac{[D^4 - (0.6\,D)^4]}{D} = 1519817.66$$

$$\frac{D^4[1 - 0.6^4]}{D} = 1519817.66$$

Therefore, $D^3 = 1746114.04$

Therefore, $D = \mathbf{120.42\ mm}$

$$d = 0.6\,D$$

$$= 0.6 \times 120.42$$

$$= \mathbf{72.25\ mm}$$

Therefore,

$$\text{Percentage saving in material} = \frac{[d_s^2 - (D^2 - d^2)]}{d_s^2} \times 100$$

$$= \frac{[114.97^2 - (120.42^2 - 72.25^2)]}{114.97^2} \times 100 = \mathbf{29.79}$$

Short-Answer Questions

1. How are loads classified according to the manner of application?
2. How are loads classified according to the duration of their action on the structure?
3. How are loads classified with respect to area on which they are distributed?
4. What are the types of strains?
5. What is meant by volumetric strain?
6. What is meant by superficial strain?
7. Define working stress.
8. Differentiate between external and internal forces.
9. Define
   (a) Elasticity (b) Elastic limit
10. Differentiate between a compound member and composite member.

11. Define modular ratio.
12. What do you mean by pure torsion?
13. List the assumptions made in the theory of torsion.
14. Write down the torsion equation.
15. Give the expression for the power transmitted by the shaft.
16. Define maximum torque.

Exercises

1. (a) Define stress, strain and Young's modulus.
   (b) A steel rod of 15 mm diameter and 0.8 m length is subjected to an axial pull of 40 kN. Calculate the stress, strain and elongation of the rod. Take $E = 2.1 \times 10^5$ N/mm^2.
2. (a) State and explain the different types of stresses.
   (b) Show that the elongation of a bar of uniform cross-section under axial load is *Pl/AE.*
3. (a) State Hooke's law.
   (b) A steel rod of 30 mm diameter and 100 mm length is subjected to a compressive load of 130 kN. The change in length due to compression was 0.2 mm. Calculate the Young's modulus of the rod material.
4. Draw neatly the stress–strain diagram for a mild steel specimen indicating the salient points in it. Explain them briefly.
5. The following observations were made in a tension test with a 25 mm diameter steel specimen:

Gauge length	= 200 mm
Extension under a working load of 25 kN	= 0.25 mm
Yield load	= 30 kN
Ultimate load	= 60 kN
Breaking load	= 50 kN
Length of specimen after failure	= 240 mm
Diameter after failure	= 16 mm

   Compute
   (a) Modulus of elasticity
   (b) Yield stress
   (c) Ultimate stress
   (d) Nominal and true stresses at breaking point
   (e) Percentage elongation and percentage reduction in area.

6. (a) What do you mean by factor of safety?
   (b) A hollow steel column is subjected to a working load of 1200 kN. If the internal diameter is 0.6 times the external diameter and the ultimate stress is 400 N/mm^2, determine the external and internal diameters. Take factor of safety = 4.
7. Define the following:
   (a) Poisson's ratio
   (b) Bulk modulus
   (c) Rigidity modulus
8. Derive the relationship between the elastic constants using first principles.
9. A bar of 80 mm × 80 mm size is subjected to an axial pull of 250 kN. The extension of the bar is 0.20 mm and the gauge length is 200 mm. Determine the Young's modulus, Poisson's ratio, rigidity modulus and bulk modulus, if the change in dimension of each side is 0.010 mm.
10. Evaluate the bulk modulus and Poisson's ratio of a material having $E = 2.1 \times 10^5$ N/mm^2 and $N = 0.8 \times 10^5$ N/mm^2.
11. A bar of certain material that is 150 mm wide, 20 mm thick and 2 m long is subjected to a pull of 160 kN. Find the extension in length and change in volume of the bar. $E = 250$ kN/mm^2, $1/m = 0.28$.
12. A tensile test was carried out on a mild steel specimen and the following results were recorded:

Original diameter of test piece	= 30 mm
Original gauge length	= 240 mm
Load at elastic limit	= 65 kN
Elongation at elastic limit	= 0.16 mm
Maximum load reached	= 150 kN
Load at fracture	= 85 kN

   Calculate
   (a) Modulus of elasticity
   (b) Ultimate stress
   (c) Stress at fracture
   (d) Working stress for a factor of safety 3.
13. Calculate the force required to punch a hole of 30 mm diameter in a metal plate of thickness 18 mm. The permissible shear stress in the material is 3400 N/mm^2.
14. A circular bar of 25 mm diameter and 200 mm length is subjected to a tensile force of 60 kN and the elongation is 0.20 mm. Calculate modulus of elasticity and rigidity modulus.

15. A cable consists of 6 aluminium wires, each 3 mm in diameter stranded together. Compute the elongation of 14 m length of this cable under an axial pull of 800 N. For aluminium, $E = 80\ kN/mm^2$.
16. A weight of 300 kN is supported by a short concrete column of dimension 250 × 250 mm. The column is strengthened by 4 steel bars in the corners of total cross-sectional area 6000 mm^2. If the modulus of elasticity for steel is 15 times that for concrete, find the stresses developed in steel and concrete.
17. A wire strand consists of a steel wire of 2.7 mm diameter, covered by 6 bronze wires each of 2.5 mm diameter. The tensile modulus of steel is $2 \times 10^5\ N/mm^2$ and it is $8 \times 10^4\ N/mm^2$ for bronze. If the working stress for bronze is 65 N/mm^2, calculate the strength of the strand.
18. Two vertical rods, one made of steel and the other of copper are each rigidly fixed at the top and are 50 cm apart. Diameter and lengths of each rod are 2 cm and 4 cm respectively. A cross-bar fixed to the rods at the lower ends carries a load of 5 kN such that cross-bar remains horizontal even after loading. Find the stress in each rod. Take E for steel = 200 GPa and E for copper = 100 GPa.
19. A 100 cm long solid aluminium shaft having 5 cm diameter is to be replaced by a tubular steel shaft of the same length and same outside diameter so that either of the shafts could carry the same torque and have same angle of twist over the total length. What must be the inner diameter of the tubular steel shaft? Modulus of rigidity of steel = $0.85 \times 10^5\ N/mm^2$ and that of aluminium = $0.28 \times 10^5\ N/mm^2$.
20. The internal diameter of a hollow shaft is 2/3 of its external diameter. Compare its resistance to torsion with that of a solid shaft of the same weight and material.
21. What diameter of a shaft will be required to transmit 80 HP at 60 rpm if the maximum torque is 30 per cent greater than the mean and the limit of torsional stress is to be 56 N/mm^2? If the modulus of rigidity is $0.84 \times 10^5\ N/mm^2$, what is the maximum angle of twist in 3 metre length?
22. A hollow shaft with a diameter ratio of 3/5 is required to transmit 800 HP at 110 rpm, the maximum torque being 20 per cent greater than the mean. The shear stress is not to exceed 63 N/mm^2 and the twist in a length of 3 metres is not to exceed 1.4°. Calculate the minimum external diameter satisfying these conditions: $C = 0.84 \times 10^5\ N/mm^2$.
23. A hollow shaft is of 5 cm external diameter and 3 cm internal diameter. An applied torque of 1600 Nm is found to produce an angular twist of 0.4° measured on a length of 20 cm of the shaft. Calculate the value of modulus of rigidity. Also, calculate the maximum horse power which could be transmitted by the shaft at 2000 rpm if the maximum shear stress is 65 N/mm^2.
24. Compare the weight of solid shaft with that of a hollow one to transmit a given horse power at a given speed with a given maximum shear stress, the inside diameter of the hollow shaft being 2/3 of its outside diameter.

Chapter 3
GEOMETRIC PROPERTIES OF SECTIONS

3.1 CENTRE OF GRAVITY

The centre of gravity of a body is that point through which the resultant of the system of parallel forces formed by the weights of all the particles of the body passes, for all positions of the body. The weight of the body acts through the centre of gravity.

Let the weights W_1, W_2, W_3, W_4, ... of the particles of a lamina act at points whose coordinates be (x_1, y_1), (x_2, y_2), (x_3, y_3), (x_4, y_4) respectively as shown in Fig. 3.1. Let $\bar{x}$ and $\bar{y}$ be the coordinates of the centre of gravity (G). Let W be the resultant of all forces (weight) acting through G. Taking moment of forces about OY.

$$\bar{x} \, . \, W = W_1x_1 + W_2x_2 + W_3x_3 + W_4x_4$$

$$\bar{x} = \frac{W_1x_1 + W_2x_2 + W_3x_3 + W_4x_4}{W}$$

Similarly

$$\bar{y} = \frac{W_1y_1 + W_2y_2 + W_3y_3 + W_4y_4}{W}$$

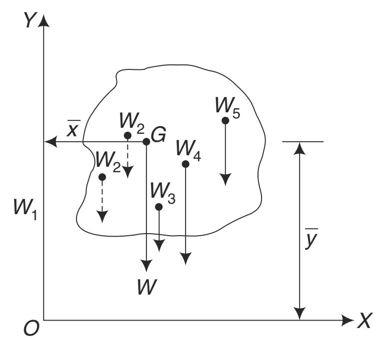


Fig. 3.1 *Centre of gravity of a body*

3.1.1 Centroid or Centre of Gravity of the Plane Area

Let us consider a plane area A in the xy plane as shown in Fig. 3.2. Let the coordinates (x, y) define an elementary area (dA) and the coordinates $(\bar{x}, \bar{y})$ define the centroid of the area A. Then the centroid of the area A is defined mathematically as follows:

$$\bar{x} = \frac{\int x \, dA}{A}$$

$$\bar{y} = \frac{\int y \, dA}{A}$$

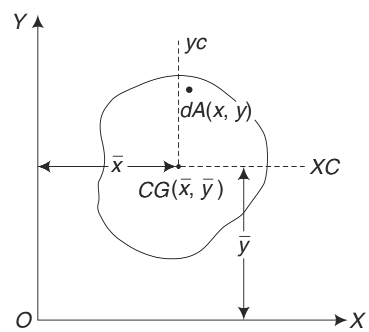


Fig. 3.2 *Centroid of plane area*

where $\int x\,dA$ is called the first moment of area about y axis and $\int y\,dA$ is the first moment of area about the x axis.

If the area A is split up into smaller areas a_1, a_2, a_3, etc.

$$\bar{x} = \frac{\text{Moment of the individual areas about } OY}{\text{Total area}}$$

$$= \frac{\Sigma ax}{\Sigma a} = \frac{a_1x_1 + a_2x_2 + a_3x_3 \ldots}{a_1 + a_2 + a_3 \ldots}$$

Similarly

$$\bar{y} = \frac{\Sigma ay}{\Sigma a} = \frac{a_1y_1 + a_2y_2 + a_3y_3 \ldots}{a_1 + a_2 + a_3 \ldots}$$

where x_1, x_2, x_3... are the centroidal distances of the areas a_1, a_2, a_3 from the axis OY and y_1, y_2, y_3 are the centroidal distances of the areas a_1, a_2, a_3 ... from the axis OX.

3.2 MOMENT OF INERTIA OF PLANE AREAS

The second moment of area about any fixed axis is the moment of inertia of the area about that axis.

The moment of inertia about any axis in the plane is the sum of the product of each elemental area and square of the perpendicular distance between the element and the axis.

Figure 3.3 shows an irregular plane area. $P(x, y)$ locates an elemental area dA. The moment of inertia of the area about x axis $I_{xx} = \int y^2\,(dA)$ and similarly $I_{yy} = \int x^2\,(dA)$.

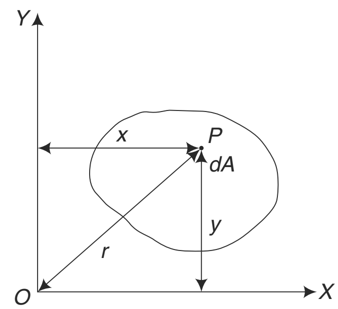


Fig. 3.3 *Perpendicular axis theorem*

3.3 PERPENDICULAR AXIS THEOREM

The perpendicular axis theorem states that the moment of inertia of a plane area about an axis perpendicular to the plane and passing through the intersection of the other two axes xx and yy contained by the plane is equal to the sum of the moment of inertia about xx and yy.

Proof

Referring to Fig. 3.3, consider an elementary area dA, the coordinates of which with respect to x, y and z axes be x, y and r respectively.

Now $\quad I_{xx} = \Sigma y^2\,(dA)$ ...(1)

$\quad I_{yy} = \Sigma x^2\,(dA)$ ...(2)

Similarly $\quad I_{zz} = I_p = \Sigma r^2\,(dA)$ ...(3)

But, $\quad r^2 = x^2 + y^2$

$$I_{zz} = I_p = \Sigma(x^2 + y^2)\,(dA)$$
$$= \Sigma x^2\,(dA) + \Sigma y^2\,(dA)$$
$$= I_{yy} + I_{xx}$$

$$I_p = I_{zz} = I_{xx} + I_{yy}$$

which proves the perpendicular axis theorem. Second moment of area (dA) about the pole 0 is called Polar Moment of Inertia. Since r is the distance of the elemental area dA from the pole, I_p is termed as the polar moment of inertia of the area A with respect to the pole 0.

$$I_p = I_{xx} + I_{yy}$$

3.4 PARALLEL AXIS THEOREM

The parallel axis theorem states that the moment of inertia of a plane area about any axis parallel to the centroidal axis is equal to the moment of inertia about the centroidal axis plus the product of the area and the square of the perpendicular distance between the two parallel axes.

Proof

In Fig. 3.4, the axis CG is the centroidal axis (or neutral axis) and AB is another parallel axis at a distance h from CG.

Consider an elementary area dA at a distance y from the centroidal axis CG.

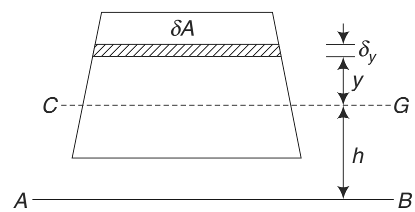


Fig. 3.4 *Parallel axis theorem*

Then $I_{CG} = \Sigma y^2 (dA)$

Also $I_{AB} = \Sigma(h + y)^2 (dA)$

$= \Sigma(h^2 + y^2 + 2hy) (dA)$

$= \Sigma h^2 \, dA + \Sigma y^2 \, dA + \Sigma 2hy \, dA$

But $\Sigma h^2 dA = Ah^2$

where A is the area of the section

$\Sigma y^2 \, dA = I_{CG}$

and $\Sigma y \, dA$ = First moment of area about the centroidal axis = 0.

Hence $I_{AB} = I_{CG} + Ah^2$ which proves the parallel axis theorem.

3.5 RADIUS OF GYRATION OF PLANE AREAS

The radius of gyration of any lamina about a given axis is defined as the distance from the given axis at which all the elemental parts of the lamina would have to be placed so as not to alter the moment of inertia about the given axis.

If the moment of inertia of a plane area about an axis xx is expressed by $I_{xx'}$ then the radius of gyration r_x of the area about the axis is defined by

$$r_x = \sqrt{\frac{I_{xx}}{A}}$$

Similarly,

$$r_y = \sqrt{\frac{I_{yy}}{A}}$$

Illustrative Examples

Example 3.1 Locate the centroid of a triangle of height h and base b.

Solution Let the centroid of the triangle be shown in Fig. 3.5 from its base. y is given by, $\bar{y}$

$$y = \frac{\int y\, dA}{A} \qquad ...(1)$$

$$dA = \int x\, dy \quad \text{(area of the elementary strip)}$$

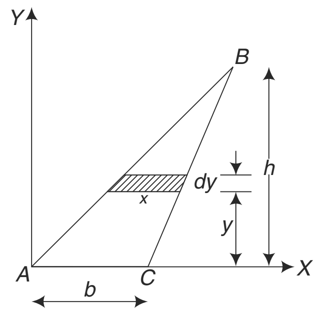


Fig. 3.5 *Centroid of a triangle*

By similar triangles,

$$\frac{x}{b} = \frac{(h-y)}{h}$$

$$x = \frac{b}{h}(h-y) \text{ and } dA = \frac{b}{h}(h-y)\, dy$$

$$\int y(dA) = \frac{b}{h}\int_0^h (h-y)\, y\, dy$$

$$= \frac{b}{h}\left[\frac{hy^2}{2} - \frac{y^3}{3}\right]_0^h = \frac{1}{6}bh^2$$

Substituting in Eq. (1)

$$\bar{y} = \frac{1}{6}bh^2 \div \frac{1}{2}bh$$

$$\bar{y} = \frac{h}{3}$$

Example 3.2 Locate the centroid of a semicircle of diameter d shown in Fig. 3.6.

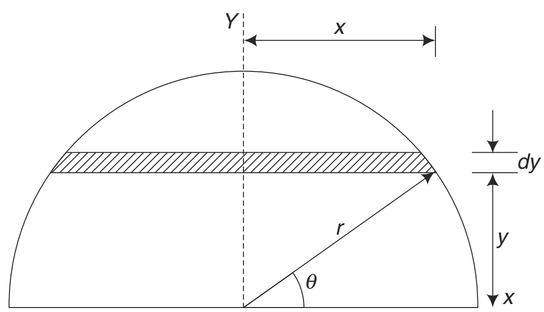


Fig. 3.6 *Centroid of a semicircle*

Solution Consider a small strip of an elemental area of thickness dy.

$$\bar{y} = \int \frac{y\,dA}{A}$$

$$dA = 2x\,dy$$

In polar coordinates, $x = r\cos\theta$; $y = r\sin\theta$; $dy = r\cos\theta\,d\theta$

$$\int_0^{\pi/2} y dA = \int_0^{\pi/2} 2r\sin\theta\,(r\cos\theta)\,r\cos\theta\,d\theta$$

$$= 2r^3 \int_0^{\pi/2} \cos^2\theta \sin\theta\,d\theta$$

$$= 2r^3 \int_0^{\pi/2} \cos^2\theta\,d(-\cos\theta)$$

$$= -2r^3 \int_0^{\pi/2} \cos^2\theta\,d(\cos\theta)$$

$$= -2r^3 \left[\frac{\cos^3\theta}{3}\right]_0^{\pi/2}$$

$$= -\frac{2r^3}{3}(0-1) = \frac{2r^3}{3}$$

$$\bar{y} = \frac{\int y\,dA}{A} = \frac{2r^3}{3} \div \frac{\pi r^2}{2}$$

$$= \frac{4r}{3\pi}$$

Example 3.3 Determine the moment of inertia of a rectangle of width b and depth d as shown in Fig. 3.7.

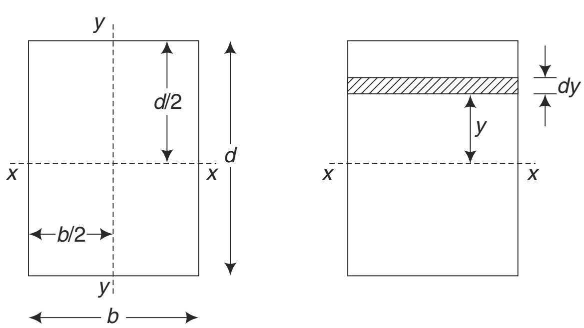


Fig. 3.7 *Moment of inertia of a rectangle*

Solution

$$\bar{x} = b/2$$
$$\bar{y} = d/2$$

M.I. about *xx* axis

Consider an elementary strip of width b and thickness dy located at a distance of y from xx axis.

$$\text{Area of elementary strip} = dA = b\,dy$$

$$\text{M.I. of elementary strip about } xx = dA\,y^2 = b\,dy\,y^2 = b\,y^2\,dy$$

$$\text{M.I. of entire section about } xx = I_{xx} = 2\int_0^{d/2} b\,y^2\,dy = 2b\left[\frac{y^3}{3}\right]_0^{d/2} = \frac{2b}{3}\frac{d^3}{8}$$

$$I_{xx} = \frac{bd^3}{12}$$

Similarly, M.I. of the entire section about $yy = I_{yy} = \dfrac{db^3}{12}$

Example 3.4 Determine the moment of inertia of the hollow rectangular section shown in Fig. 3.8.

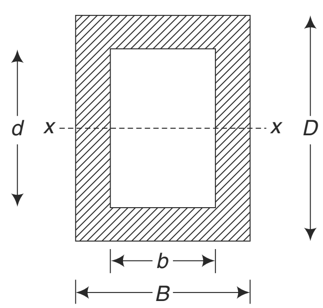


Fig. 3.8 *Moment of inertia of hollow rectangle*

Solution M.I. of the lamina about xx

$$= (\text{M.I. of outer rectangle about } xx) - (\text{M.I. of inner rectangle about } xx)$$

$$= \frac{BD^3}{12} - \frac{bd^3}{12}$$

$$I_{xx} = \frac{1}{12}(BD^3 - bd^3)$$

Similarly, $$I_{yy} = \frac{1}{12}(DB^3 - db^3)$$

Example 3.5 Find the moment of inertia of a circular lamina shown in Fig. 3.9.

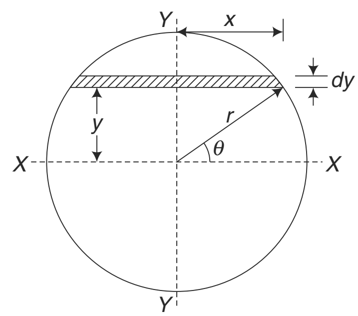


Fig. 3.9 *Moment of inertia of a circular lamina*

Solution Let d = diameter of the lamina

Consider an elementary strip as shown in Fig. 3.9.

Area of elementary strip $= dA$

$$= 2x\,dy$$

In polar coordinates, $x = r\cos\theta$; $y = r\sin\theta$ and $dy = r\cos\theta\,d\theta$

$$I_{xx} = \int dA\,(y)^2$$

$$= \int_{-r}^{r} 2x\,dy\,y^2$$

$$= \int_{-\pi/2}^{\pi/2} 2r\cos\theta\,(r\cos\theta\,d\theta)\,(r\sin\theta)^2$$

$$= 2r^4 \int_{-\pi/2}^{\pi/2} \cos^2\theta\sin^2\theta\,d\theta$$

$$= 2r^4\,(2) \int_{0}^{\pi/2} \cos^2\theta\sin^2\theta\,d\theta$$

$$= 4r^4 \int_0^{\pi/2} \cos^2\theta \sin^2\theta \, d\theta \qquad ...(1)$$

$$\int_0^{\pi/2} \cos^2\theta \sin^2\theta \, d\theta = \int_0^{\pi/2} \frac{1+\cos 2\theta}{2} \frac{1-\cos 2\theta}{2} d\theta$$

$$= \frac{1}{4}\int_0^{\pi/2} (1-\cos^2 2\theta)\, d\theta$$

$$= \frac{1}{4}\int_0^{\pi/2} \left(1 - \frac{1+\cos 4\theta}{2}\right) d\theta$$

$$= \frac{1}{8}\int_0^{\pi/2} (1-\cos 4\theta)\, d\theta$$

$$= \frac{1}{8}\left[\theta - \frac{\sin 4\theta}{4}\right]_0^{\pi/2}$$

$$= \frac{1}{8}\frac{\pi}{2} = \frac{\pi}{16} \qquad ...(2)$$

Substituting (2) in Eq. (1),

$$I_{xx} = 4r^4 \frac{\pi}{16}$$

$$= \frac{\pi r^4}{4} \text{ or } \frac{\pi d^4}{64}$$

Example 3.6 Compute the moment of inertia of a hollow circular lamina shown in Fig. 3.10.

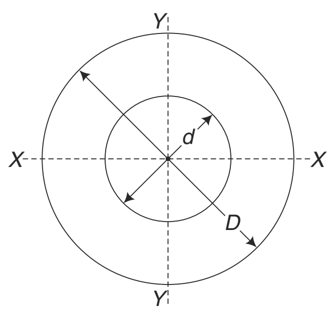


Fig. 3.10 *Moment of inertia of a hollow circle*

Solution For a circular lamina,

$$I_{xx} = \frac{\pi d^4}{64} = I_{yy}$$

For a hollow circular lamina,

$$I_{xx} = I_{yy}$$

$$= \text{M.I. of outer circle} - \text{M.I. of inner circle}$$

$$= \frac{\pi D^4}{64} - \frac{\pi d^4}{64}$$

Example 3.7 Determine the moment of inertia of a semicircle shown in Fig. 3.11.

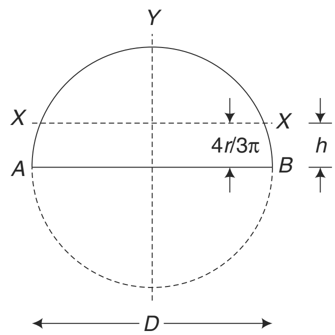


Fig. 3.11 *Moment of inertia of a semicircle*

Solution **Moment of Inertia about the Base**

For a circle, $I_{AB} = \frac{\pi D^4}{64}$

For a semicircle, $I_{AB} = \frac{\pi D^4}{128}$

Moment of Inertia about the Centroidal Axis *xx*

By parallel axis theorem,

$$I_{AB} = I_{xx} + Ah^2$$

Therefore, $I_{xx} = I_{AB} - Ah^2$

$$I_{AB} = \frac{\pi D^4}{128} = \frac{\pi r^4}{8}$$

$$A = \text{Area of semicircle} = \frac{\pi r^2}{2}$$

$$h = \text{Distance between } xx \text{ and } AB = \frac{4r}{3\pi}$$

Hence, $I_{xx} = \frac{\pi r^4}{8} - \frac{\pi r^2}{2}\left[\frac{4r}{3\pi}\right]^2$

$$= \frac{\pi r^4}{8} - \frac{8 r^4}{9 \pi} = 0.11 r^4$$

But, $I_{yy} = \dfrac{\pi r^4}{8}$ or $\dfrac{\pi D^4}{128}$

Example 3.8 Determine the moment of inertia about xx of a symmetrical I-section shown in Fig. 3.12.

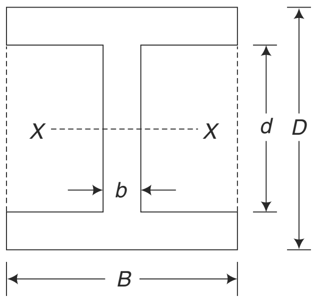


Fig. 3.12 *Moment of inertia of I-section*

Solution Moment of inertia about xx

$$I_{xx} = \text{(M.I. of bigger rectangle)} - \text{(M.I. of hollow rectangular portion)}$$

$$\text{M.I. of bigger rectangle} = \frac{BD^3}{12}$$

$$\text{M.I. of hollow rectangular portion} = \text{width of hollow portion} \times (\text{depth})^3/12$$

$$\text{Width of hollow portion} = B - b$$

$$\text{Depth} = d$$

Hence, $$\text{M.I. of hollow part} = \frac{(B-b)\,d^3}{12}$$

Therefore $$I_{xx} = \frac{BD^3}{12} - \frac{(B-b)\,d^3}{12}$$

Example 3.9 Determine the moment of inertia about xx for the channel section shown in Fig. 3.13.

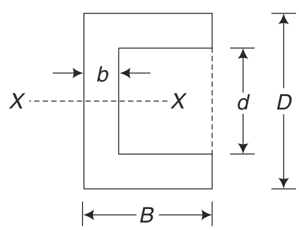


Fig. 3.13 *Moment of inertia of channel section*

Solution I_{xx} = (M.I. of bigger rectangle) – (M.I. of hollow rectangle)

$$\text{M.I. of bigger rectangle} = \frac{BD^3}{12}$$

$$\text{M.I. of hollow rectangle} = \frac{(B-b)\,d^3}{12}$$

Hence,
$$I_{xx} = \frac{BD^3}{12} - \frac{(B-b)\,d^3}{12}$$

Example 3.10 Find the centre of gravity and moment of inertia for the T-section shown in Fig. 3.14.

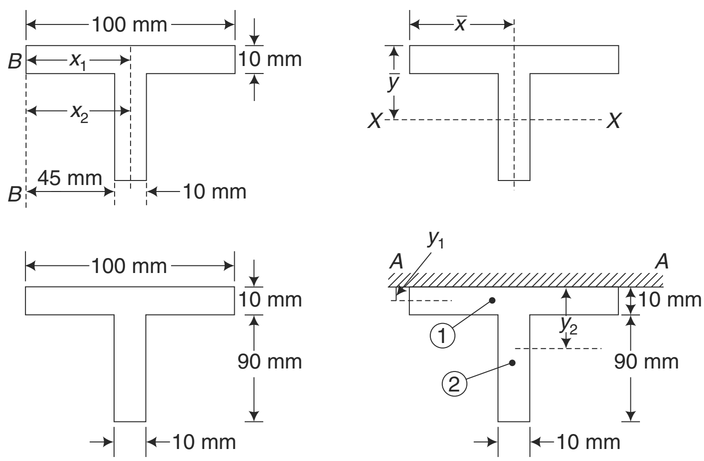


Fig. 3.14 *Centroid and moment of inertia of T-section*

Solution **Centre of gravity**

Let $\overline{X}$ = Distance of c.g. of YY axis, and

$\bar{y}$ = Distance of c.g. of XX axis

The given section is symmetric about YY axis.

Hence, $\overline{X} = 100/2 = 50$ mm

The given T-section is divided into two rectangular elements as shown in Fig. 3.14.

Hence,
$$y = \frac{a_1y_1 + a_2y_2}{a_1 + a_2}$$

a_1 = Area of element (1)

a_2 = Area of element (2)

y_1 = Distance of c.g. of element (1) from reference line

y_2 = Distance of c.g. of element (2) from reference line

It may be noted that, for determining $\bar{y}$, the reference line may be taken at the top or bottom of the given section. For determining $\bar{x}$, the reference line may be taken at the left of right side of the section. Let the reference line *AA* be taken at the top of the section as shown in Fig. 3.14 (for finding $\bar{y}$).

$$a_1 = 100 \times 10 = 1000 \text{ mm}^2$$

$$y_1 = 10/2 = 5 \text{ mm}$$

$$a_2 = 10 \times 90 = 900 \text{ mm}^2$$

$$y_2 = 10 + (90/2) = 55 \text{ mm}$$

Hence
$$\bar{y} = \frac{1000 \times 5 + 900 \times 55}{1000 + 900}$$

$$= 28.68 \text{ mm from } AA$$

Moment of Inertia about *XX* axis,

$$I_{xx} = \Sigma \left[\frac{bd^3}{12} + \text{area (distance)}^2\right]$$

$$= \Sigma \left[\frac{bd^3}{12} + ah^2\right]$$

Since the given T-section is divided into two elements,

$$I_{xx} = \left[\frac{b_1 d_1^3}{12} + a_1 h_1^2\right] + \left[\frac{b_2 d_2^3}{12} + a_2 h_2^2\right]$$

h_1 = Distance between *XX* axis and the c.g. of element (1)

$= \bar{y} - y_1 = 28.68 - 5 = 23.68$ mm

h_2 = Distance between *XX* axis and the c.g. of element (2)

$= \bar{y} - y_2 = 28.68 - 55 = -26.32$ mm

Hence,
$$I_{xx} = \left[\frac{100 \times 10^3}{12} + 1000 \times (23.68)^2\right] + \left[\frac{10 \times 90^3}{12} + 900 \times (-26.32)^2\right]$$

$$= 1.80 \times 10^6 \text{ mm}^4$$

Moment of inertia about *YY* axis,

Due to symmetry, we have $\bar{x} = 50$ mm.

Also,
$$\bar{x} = \frac{a_1 x_1 + a_2 x_2}{a_1 + a_2}$$

Let the reference line *BB* be taken at the left of the section as shown in Fig. 3.14.

$$a_1 = 1000 \text{ mm}^2$$

$$x_1 = 100/2 = 50 \text{ mm}$$

$$a_2 = 900 \text{ mm}^2$$

$$x_2 = 45 + (10/2) = 50 \text{ mm}$$

Hence,

$$\bar{x} = \frac{(1000 \times 50 + 900 \times 50)}{(1000 + 900)}$$

$$= 50 \text{ mm}$$

$$I_{yy} = \Sigma\left[\frac{db^3}{12} + \text{area (distance)}^2\right]$$

$$= \left[\frac{d_1 b_1^3}{12} + a_1 k_1^2\right] + \left[\frac{d_2 b_2^3}{12} + a_2 k_2^2\right]$$

k_1 = distance between YY axis and the c.g. of element (1)

$= \bar{x} - x_1$ and

k_2 = distance between YY axis and the c.g. of element (2)

$= \bar{x} - x_2$

Therefore,

$$k_1 = 50 - 50 = 0$$

$$k_2 = 50 - 50 = 0$$

$$I_{yy} = \left[\frac{d_1 b_1^3}{12}\right] + \left[\frac{d_2 b_2^3}{12}\right] \quad [\because \quad k_1, k_2 = 0]$$

$$= \left[\frac{10 \times 100^3}{12}\right] + \left[\frac{90 \times 10^3}{12}\right]$$

$$I_{yy} = 0.84 \times 10^6 \text{ mm}^4$$

Hence, if a section is symmetric about any axis, and if the axis passes through the centres of all the elements considered, the general equation for moment of inertia about the axis will become,

$$I = \Sigma \frac{bd^3}{12}$$

where b = Dimension of the rectangle parallel to the concerned axis

Example 3.11 Find the polar moment of inertia and radii of gyration for the *T*-section shown in Fig. 3.14 of the previous problem.

Solution

Polar moment of inertia

Polar M.I.

$$I_p = I_{xx} + I_{yy}$$

$$= (1.80 \times 10^6) + (0.84 \times 10^6) = 2.64 \times 10^6 \text{ mm}^4$$

Radii of gyration

$$r_{xx} = \sqrt{\frac{I_{xx}}{A}}$$

$$A = a_1 + a_2 = 1000 + 900 = 1900 \text{ mm}^2$$

$$r_{xx} = \sqrt{\frac{(1.80 \times 10^6)}{1900}} = 30.78 \text{ mm}$$

$$r_{yy} = \sqrt{\frac{I_{yy}}{A}} = \sqrt{\frac{(0.84 \times 10^6)}{1900}} = 21.03 \text{ mm}$$

$$r_{min} = r_{yy} = 21.03 \text{ mm}$$

Example 3.12 Determine the centre of gravity and moment of inertia for the unsymmetrical I-section shown in Fig. 3.15.

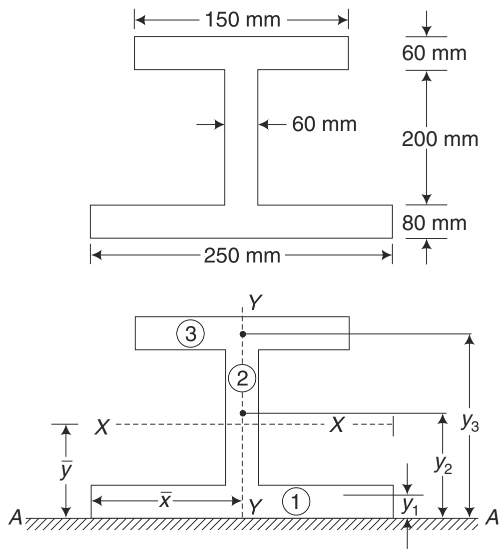


Fig. 3.15 *Centroid and moment of inertia of an unsymmetrical I-section*

Solution

Centre of gravity

The section is symmetric about *YY* axis. Hence, *YY* axis will pass through the centre of section as shown in Fig. 3.15. Only, *XX* axis has to be located.

Hence, $\bar{x} = 250/2 = 125 \text{ mm}$

$$\bar{y} = \left[\frac{a_1y_1 + a_2y_2 + a_3y_3}{a_1 + a_2 + a_3}\right]$$

The reference line *AA* is taken at the bottom of the section.

$$a_1 = 250 \times 80 = 20000 \text{ mm}^2$$

$$y_1 = 80/2 = 40 \text{ mm}$$
$$a_2 = 60 \times 200 = 12000 \text{ mm}^2$$
$$y_2 = 80 + (200/2) = 180 \text{ mm}$$
$$a_3 = 150 \times 60 = 9000 \text{ mm}^2$$
$$y_3 = 80 + 200 + (60/2) = 310 \text{ mm}$$

Hence, $$\bar{y} = \frac{(20000 \times 40) + (12000 \times 180) + (9000 \times 310)}{(20000 + 12000 + 9000)}$$
$$= 140.24 \text{ mm from } AA$$

Moment of inertia about *XX* axis

$$I_{xx} = \Sigma\left[\frac{bd^3}{12} + \text{area (distance)}^2\right]$$
$$= \left[\frac{b_1 d_1^3}{12} + a_1 h_1^2\right] + \left[\frac{b_2 d_2^3}{12} + a_2 h_2^2\right] + \left[\frac{b_3 d_3^3}{12} + a_3 h_3^2\right]$$
$$h_1 = \bar{y} - y_1 = 100.24 \text{ mm}$$
$$h_2 = \bar{y} - y_2 = -\,39.76 \text{ mm}$$
$$h_3 = \bar{y} - y_3 = -\,169.76 \text{ mm}$$

Hence, $$I_{xx} = \left[\frac{250 \times 80^3}{12} + (20000 \times (100.24)^2)\right] + \left[\frac{60 \times 200^3}{12} + (12000 \times (-\,39.76)^2)\right]$$
$$+ \left[\frac{150 \times 60^3}{12} + (9000 \times (-\,169.76)^2)\right]$$
$$= 5.33 \times 10^8 \text{ mm}^4$$

Moment of Inertia about *YY* axis

The section is symmetric about *YY* axis and the *YY* axis passes through centres of all the three elements. Hence, the equation

$$I_{yy} = \Sigma\left[\frac{db^3}{12} + \text{area (distance)}^2\right] \text{ reduces to}$$
$$I_{yy} = \Sigma\left[\frac{db^3}{12}\right]$$
$$= \left[\frac{d_1 b_1^3}{12}\right] + \left[\frac{d_2 b_2^3}{12}\right] + \left[\frac{d_3 b_3^3}{12}\right]$$
$$= \frac{(80 \times 250^3) + (200 \times 60^3) + (60 \times 150^3)}{12}$$
$$= 1.25 \times 10^8 \text{ mm}^4.$$

Example 3.13 Find the centre of gravity and moment of inertia for the unequal angle section shown in Fig. 3.16.

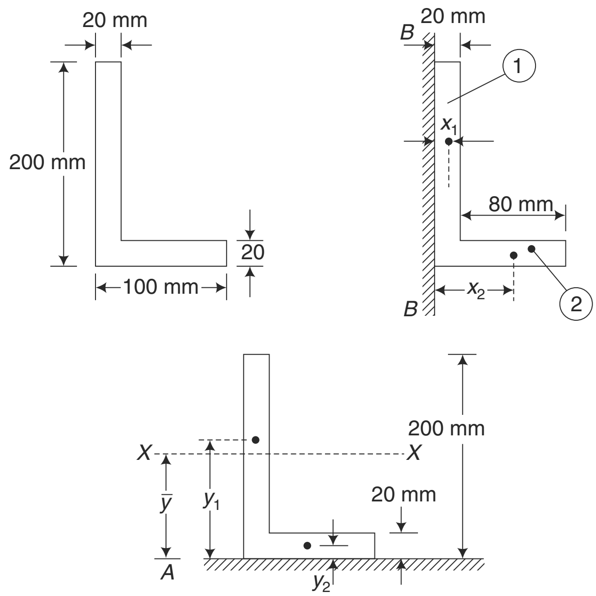


Fig. 3.16 *Centroid and moment of inertia of L-section*

Solution

The section is unsymmetrical about both the axes.

Hence
$$\bar{x} = \left[\frac{a_1x_1 + a_2x_2}{a_1 + a_2}\right] \text{ and}$$

$$\bar{y} = \left[\frac{a_1y_1 + a_2y_2}{a_1 + a_2}\right]$$

To find $\bar{x}$

$$a_1 = 20 \times 200 = 4000 \text{ mm}^2$$
$$x_1 = 20/2 = 10 \text{ mm}$$
$$a_2 = 80 \times 20 = 1600 \text{ mm}^2$$
$$x_2 = 20 + (80/2) = 60 \text{ mm}$$
$$\bar{x} = \frac{(4000 \times 10) + (1600 \times 60)}{(4000 + 1600)}$$
$$= 24.29 \text{ mm from } BB$$

To find $\bar{y}$

$$y_1 = 200/2 = 100 \text{ mm}$$

$$y_2 = 20/2 = 10 \text{ mm}$$

$$\bar{y} = \frac{(4000 \times 100) + (1600 \times 10)}{(4000 + 1600)}$$

$$= 74.29 \text{ mm from } AA$$

Moment of inertia about *XX* axis

$$I_{xx} = \left[\frac{b_1 d_1^3}{12} + a_1 h_1^2\right] + \left[\frac{b_2 d_2^3}{12} + a_2 h_2^2\right]$$

$$h_1 = \bar{y} - y_1 = -25.71 \text{ mm}$$

$$h_2 = \bar{y} - y_2 = 64.29 \text{ mm}$$

Hence,

$$I_{xx} = \left[\frac{20 \times 200^3}{12} + (4000 \times (-23.71)^2)h\right] + \left[\frac{80 \times 20^3}{12} + (1600 \times (64.29)^2)\right]$$

$$= 2.265 \times 10^7 \text{ mm}^4$$

Moment of inertia about *YY* axis

$$I_{yy} = \left[\frac{d_1 b_1^3}{12} + a_1 k_1^2\right] + \left[\frac{d_2 b_2^3}{12} + a_2 k_2^2\right]$$

$$k_1 = \bar{x} - x_1 = 14.29 \text{ mm}$$

$$k_2 = \bar{x} - x_2 = -35.71 \text{ mm}$$

Hence,

$$I_{yy} = \left[\frac{200 \times 20^3}{12} + (4000 \times (14.29)^2)\right] + \left[\frac{20 \times 80^3}{12} + (1600 \times (-35.71)^2)\right]$$

$$= 0.384 \times 10^7 \text{ mm}^4$$

Example 3.14 Find the polar moment of inertia and the radius of gyration for the angle section given in Example 3.13.

Solution **Polar moment of inertia**

$$I_p = I_{xx} + I_{yy}$$

$$I_{xx} = 2.265 \times 10^7 \text{ mm}^4$$

$$I_{yy} = 0.384 \times 10^7 \text{ mm}^4$$

Hence, Polar M.I. $I_p = 2.649 \times 10^7 \text{ mm}^4$

Radius of gyration

$$r_{xx} = \sqrt{\frac{I_{xx}}{A}}$$

$$= \sqrt{\frac{2.265 \times 10^7}{(4000 + 1600)}} = 63.60 \text{ mm}$$

$$r_{yy} = \sqrt{\frac{I_{yy}}{A}}$$

$$= \sqrt{\frac{0.384 \times 10^7}{(4000 + 1600)}} = 26.19 \text{ mm}$$

$$r_{min} = r_{yy} = 26.19 \text{ mm}$$

Example 3.15 Compute the centre of gravity and moment of inertia for the section shown in Fig. 3.17.

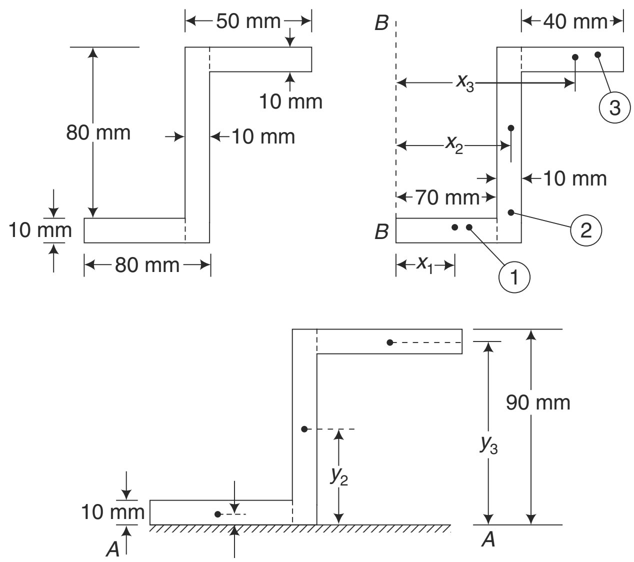


Fig. 3.17 *Centroid and moment of inertia of a Z-section*

Solution

Centre of gravity

$$\bar{x} = \left[\frac{a_1x_1 + a_2x_2 + a_3x_3}{a_1 + a_2 + a_3}\right]$$

$$a_1 = 70 \times 10 = 700 \text{ mm}^2$$

$$x_1 = 70/2 = 35 \text{ mm}$$

$$a_2 = 10 \times 90 = 900 \text{ mm}^2$$

$$x_2 = 70 + (10/2) = 75 \text{ mm}$$

$$a_3 = 40 \times 10 = 400 \text{ mm}^2$$

$$x_3 = 70 + 10 + (40/2) = 100 \text{ mm}$$

Hence, $$\bar{x} = \frac{(700 \times 35) + (900 \times 75) + (400 \times 100)}{(700 + 900 + 400)}$$

$$= 66 \text{ mm from } BB$$

$$\bar{y} = \left[\frac{a_1 y_1 + a_2 y_2 + a_3 y_3}{a_1 + a_2 + a_3}\right]$$

$$y_1 = 10/2 = 5 \text{ mm}$$

$$y_2 = 90/2 = 45 \text{ mm}$$

$$y_3 = 90 - 5 = 85 \text{ mm}$$

Hence, $$\bar{y} = \frac{(700 \times 5) + (900 \times 45) + (400 \times 85)}{(700 + 900 + 400)}$$

$$= 39 \text{ mm from } AA$$

Moment of inertia about *XX* axis

$$I_{xx} = \left[\frac{b_1 d_1^3}{12} + a_1 h_1^2\right] + \left[\frac{b_2 d_2^3}{12} + a_2 h_2^2\right] + \left[\frac{b_3 d_3^3}{12} + a_3 h_3^2\right]$$

$$h_1 = \bar{y} - y_1 = 34 \text{ mm}$$

$$h_2 = \bar{y} - y_2 = -6 \text{ mm}$$

$$h_3 = \bar{y} - y_3 = -46 \text{ mm}$$

Hence, $$I_{xx} = \left[\frac{70 \times 10^3}{12} + 700 \times (34)^2\right] + \left[\frac{10 \times 90^3}{12} + 900 \times (-6)^2\right] + \left[\frac{40 \times 10^3}{12} + 400 \times (-46)^2\right]$$

$$= 2.305 \times 10^6 \text{ mm}^4$$

Moment of inertia about *YY* axis

$$I_{yy} = \left[\frac{d_1 b_1^3}{12} + a_1 k_1^2\right] + \left[\frac{d_2 b_2^3}{12} + a_2 k_2^2\right] + \left[\frac{d_3 b_3^3}{12} + a_3 k_3^2\right]$$

$$k_1 = \bar{x} - x_1 = 31 \text{ mm}$$

$$k_2 = \bar{x} - x_2 = -9 \text{ mm}$$

$$k_3 = \bar{x} - x_3 = -34 \text{ mm}$$

Hence, $$I_{yy} = \left[\frac{10 \times 70^3}{12} + 700 \times (31)^2\right] + \left[\frac{90 \times 10^3}{12} + 900 \times (-9)^2\right] + \left[\frac{10 \times 40^3}{12} + 400 \times (-34)^2\right]$$

$$= 1.555 \times 10^6 \text{ mm}^4$$

Example 3.16 Find the centre of gravity and moment of inertia about XX axis for the rivet section shown in Fig. 3.18.

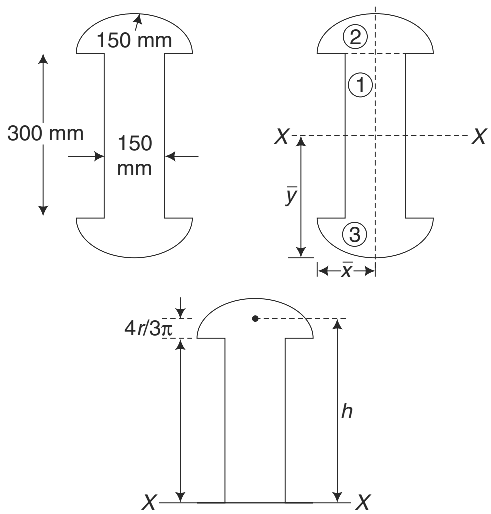


Fig. 3.18 *Centroid and moment of inertia of a rivet*

Solution The section is symmetrical about both the axes.

Hence, $\bar{x} = 300/2 = 150$ mm

$\bar{y} = 600/2 = 300$ mm

Moment of inertia about XX axis

$$I_{xx} = \Sigma\,[I_{self} + \text{area (distance)}^2]$$

For element (1)

$I_{xx} = I_{self}$ since XX axis passes through its centre

$$= \frac{b_1 d_1^3}{12} = \frac{150 \times 300^3}{12} = 3.375 \times 10^8 \text{ mm}^4$$

For elements (2) and (3),

$$I_{xx} = 0.11r^4 + \text{area (distance)}^2$$

$$= 0.11r^4 + a\,h^2$$

$$r = \text{radius} = 150 \text{ mm}$$

$$a = \text{area} = \frac{\pi r^2}{2} = 35342 \text{ mm}^2$$

$$h = \frac{300}{2} + \frac{4 \times r}{3\pi} = 213.66 \text{ mm}$$

Hence, $I_{xx} = (0.11 \times 150^4) + (35342 \times 213.66^2)$
$= 1.67 \times 10^9$ mm^4 (for elements (2) and (3))

Therefore, moment of inertia of the entire section
$= 3.375 \times 10^8 + 2 \times 1.67 \times 10^9$
$= 3.678 \times 10^9$ mm^4

Example 3.17 Find the moment of inertia about *XX* axis for the section shown in Fig. 3.19.

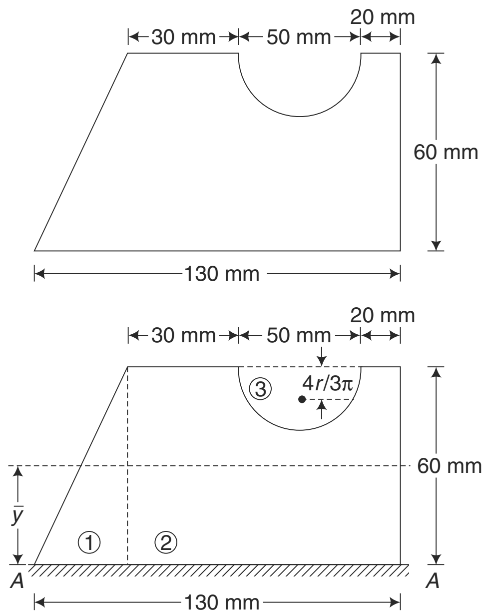


Fig. 3.19

Solution

$$\bar{y} = \left[\frac{a_1 y_1 + a_2 y_2 - a_3 y_3}{a_1 + a_2 - a_3}\right]$$

$a_1 = (1/2) \times 30 \times 60 = 900$ mm^2

$y_1 = (1/3) \times 60 = 20$ mm

$a_2 = 100 \times 60 = 6000$ mm^2

$y_2 = 60/2 = 30$ mm

$$a_3 = \frac{\pi d^2}{8} \; (d = 50 \text{ mm}) = 981.75 \text{ mm}^2$$

$$y_3 = 60 - \frac{4r}{3\pi} = 49.39 \text{ mm}$$

Hence, $\bar{y} = \dfrac{(900 \times 20) + (6000 \times 30) - (981.75 \times 49.39)}{(900 + 6000 - 981.75)}$

$= 23.26$ mm from AA

$$I_{xx} = \left[\frac{b_1 d_1^3}{36} + a_1 h_1^2\right] + \left[\frac{b_2 d_2^3}{12} + a_2 h_2^2\right] - [(0.11 r^4 + a_3 h_3^2)]$$

r = radius = 25 mm

$h_1 = \bar{y} - y_1 = 5.26$ mm

$h_2 = \bar{y} - y_2 = -4.74$ mm

$h_3 = \bar{y} - y_3 = -24.13$ mm

Hence, $$I_{xx} = \left[\frac{30 \times 60^3}{36} + 900 \times (5.26)^2\right] + \left[\frac{100 \times 60^3}{12} + 6000 \times (-4.74)^2\right] - [(0.11 \times 25^4) + 981.75 \times (-24.13)^2]$$

$= 1.525 \times 10^6$ mm^4

Short-Answer Questions

1. Define moment of inertia.
2. Define centroid.

Exercises

1. (a) Define centre of gravity.
   (b) Locate the centroid of the lamina shown in Fig. 3.20.

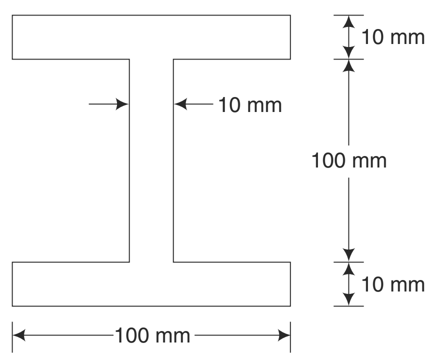


Fig. 3.20

2. (a) Show that the centroid of a uniform lamina is given by

$$\overline{Y} = \Sigma ay / \Sigma a$$

(b) Determine the moment of inertia for the lamina given in problem 1(b).

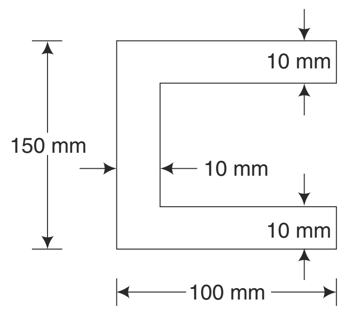


Fig. 3.21

3. (a) Determine the centroid of a trapezium of top width *a* and bottom width *b* and height *h* using first principles.
   (b) Find the centroid and moment of inertia about *XX* for the channel section shown in Fig. 3.21.
4. (a) State and prove the parallel axis theorem.
   (b) Find the moment of inertia about both the axes for an inverted T-beam having the following dimensions:

   Size of web = 20 mm × 100 mm
   Size of flange = 150 mm × 30 mm
5. (a) What do you mean by polar moment of inertia?
   (b) What is radius of gyration? Determine the minimum radius of gyration for a rectangle of size 200 mm × 300 mm.
6. (a) State and prove the perpendicular axis theorem.
   (b) Determine the polar moment of inertia and radii of gyration for the I-section having the following dimensions:

Size of top flange	100 mm × 15 mm
Size of web	20 mm × 120 mm
Size of bottom flange	180 mm × 20 mm

7. Calculate the moment of inertia about both axes for an angle section having the following dimensions:

   Size of vertical leg = 20 mm × 100 mm

   Size of horizontal leg = 100 mm × 10 mm

8. Determine the moment of inertia of the following hollow rectangular section about the horizontal axis passing through the centroid.

   Size of inner rectangle = 300 mm × 600 mm

   Size of outer rectangle = 500 mm × 1000 mm

9. Compute the value of moment of inertia about *XX* axis of a regular hexagon of side 30 mm.

10. Determine the moment of inertia about *YY* axis of the section shown in Fig. 3.22.

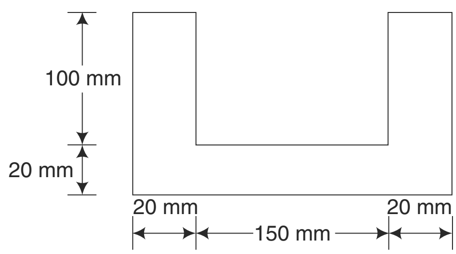


Fig. 3.22

11. For the section given in Problem 10, calculate the polar moment of inertia and minimum radius of gyration.

12. Determine the minimum radius of gyration for the section shown in Fig. 3.23.

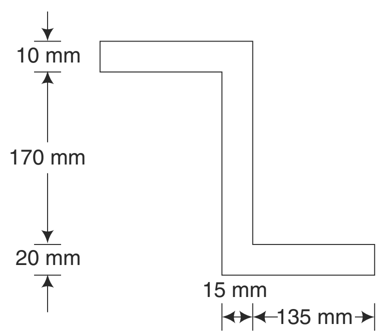


Fig. 3.23

13. Estimate the moment of inertia about XX for the section shown in Fig. 3.24.

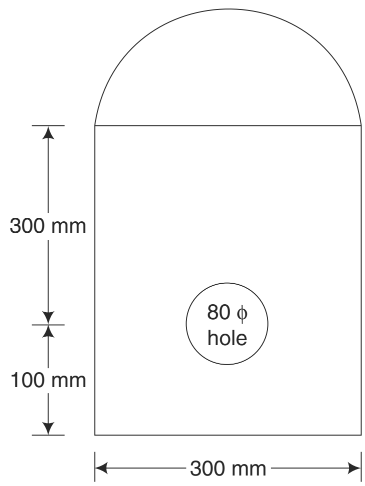


Fig. 3.24

14. Determine the moment of inertia about XX and YY axes for the section shown in Fig. 3.25.

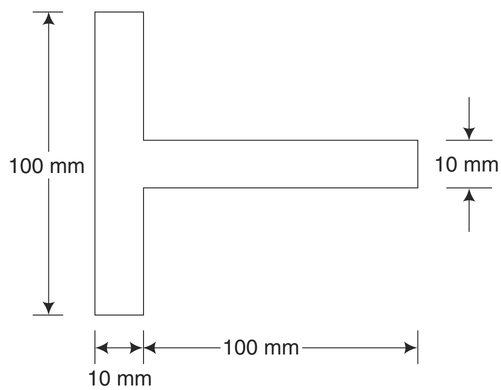


Fig. 3.25

Chapter 4
BUILDINGS

4.1 INTRODUCTION

Building is defined as any structure for whatsoever purpose and of whatsoever materials constructed and every part thereof may or may not be used as human habitation.

4.2 CLASSIFICATION OF BUILDINGS

According to the National Building Code (1970), the buildings are classified based on,

1. Type of occupancy
2. Type of construction

Based on the type of occupancy, buildings are classified as follows:

(i) Residential buildings
(ii) Educational buildings
(iii) Institutional buildings
(iv) Assembly buildings
(v) Business buildings
(vi) Mercantile buildings
(vii) Industrial buildings

(i) Residential Buildings These include any building in which accommodation is provided for normal residential purposes, with or without cooking and dining facilities. For eg. Houses, lodges, apartment houses and dormitories.

(ii) Educational Buildings These include any building used for schools, colleges, etc.

(iii) Institutional Buildings These include any building which is used for treatment purposes. Hospitals, clinics, houses for aged and infants, jails, etc., come under this category.

(iv) Assembly Buildings These include any building where a group of people gather for recreation, social, religious, patriotic and similar purposes. Cinema theatres, gymnasiums, railway stations, stadiums etc., come under this category.

(v) ***Business Buildings*** These include any building which is used for the transaction of business. Offices, bank city halls, courthouses and libraries come under this category.

(vi) ***Mercantile Buildings*** These include any building which is used as a shop, stores or markets for display and sale of merchandise, either wholesale or retail.

(vii) ***Industrial Buildings*** These include any building in which products or materials of all kinds and properties are fabricated, assembled or processed. Laboratories, dry cleaning plants, power plants, refineries and sawmills etc are come under this category.

The second classification is based on the type of construction which is indirectly considered by the fire resistance of the building. Accordingly, there are four types. They are

Type i. That provides 4-hour fire resistance

Type ii. That provides 3-hour fire resistance

Type iii. That provides 2-hour fire resistance

Type iv. That provides 1-hour fire resistance

4.3 COMPONENTS OF BUILDINGS

The Component parts of a building are as follows:

Foundation It is the portion of the building below ground level. This is given for stability of the building and to distribute the load coming from superstructure on a larger area.

Footings These are stepped courses in the foundation having their base laid on concrete course and stepped inward by suitable offsets in stages till the thickness of the main wall is reached.

Basement The store or floor of a building below ground level made generally for storage purposes.

Plinth The portion of a structure between the surface of the surrounding ground and surface of the floor, immediately above the ground.

Damp-proof course A continuous layer of an impervious material to check dampness in the wall. It is generally provided at the plinth level.

Lintel Lintel may be defined as a beam (of generally R.C.C) to support the brick work over-doors and window-openings. Generally, the width of the lintel is that same as that of the brick wall.

Balcony A horizontal projection, including a hand rail or balustract, to serve as passage or sitting out place.

Ghajja A sloping overhanging, horizontal structural usually provided over openings on external walls to provide protection from sun and rain.

Window An opening to the outside, other than a door, which provides all or part of the required natural light or ventilation or both to an interior space.

Door It is an opening to the outside of the building as well as to connect inside rooms of the buildings. The width and height of the opening should be such that two persons walking shoulder to shoulder may conveniently pass through the door.

Porch A roof supported on pillars in front of a verandah or in front of a building to park a car for a short while.

Parapet A short wall provided on top of roof of a building. The main purpose of this wall is to fulfill architectural requirements of the buildings.

Roof It is the cover of the building, to protect it from rain, wind, snow, sunlight, etc.,

Flat roof It is a type of roof, usually made by reinforced cement concrete.

Inclined roof It is also one of the types of roof, usually made by tiles, asbestos sheet, etc.,

Coping A projection on top of a parapet wall provided on the outside or both sides to throw off water in order to prevent rolling, throughout the wall.

Corridor A narrow verandah or a gallery or open communication to different parts of a building.

Exit A passage, channel or means of entrance from any building, storey or floor area to a street or other open space.

Drain A line of pipes including all fittings and equipment such as manholes, inspection chambers, trap and floor traps used for the drainage of a building.

Water Closet A privy arrangement for flushing the toilet pan with water.

4.4 BUILDING BY LAWS

Building permit Every person who intends to erect or re-erect a building or intends to make additions and alterations in an existing building shall apply to the authority in prescribed form with prescribed fees, together with plans in ferro prints and statements in triplicate.

Plans Plans shall consist of the following:

(i) *Site plan* drawn to a scale not less than 8 m = 1 cm showing boundaries of the site, adjacent streets, etc., and the north direction.

(ii) *Building Plans, elevations and sections* drawn to a scale not less than 1 m = 1 cm and all new constructions shall be coloured red. Drainage and sewer lines shall be shown in red dotted lines. Work proposed to be dismantled shall be shown in yellow colour. Location of W.C., sink, drains, etc., shall be shown clearly. Sectional drawings shall show the size of footings, walls roof, slab beams, etc. All plans shall be signed by the owner and by a qualified architect or engineer.

Specifications giving the kind and grade of materials and proportions, etc., shall accompany the application.

The authority shall sanction or refuse the sanction within 45 days. If the authority fails to intimate the applicant of any objection or refusal, the application and plans may be deemed sanctioned and construction may be started.

The duration of sanction will be three years and if the construction has not started or is not in progress, the sanction will become invalid. If the construction has not started within a year of the sanction, renewal of the permit shall be required with a formal application.

Size of plot Minimum area of a plot shall be 170 sq. m or as fixed by the authority.

Covered area The minimum covered area of a building shall be as follows:

Area of plot	Maximum permissible covered area
Up to 200 sq.m	60 per cent of site area on ground and first floor only
201 to 500 sq.m	50 per cent of site area
501 to 1000 sq.m	40 per cent of site area
More than 1000 sq.m	33.33 per cent of site area

In a bazaar or market area, the covered area may be up to the extent of 75 per cent of the area of the site and in an industrial area, the covered area shall not exceed 60 per cent of area of the site.

In central areas of towns, the minimum covered area may be 2/3 the area of the plot.

Open space Open space in the front, rear and sides of the plot shall be left as given below:-

Minimum open space in the front shall be 3 m.

The minimum distance from the centre of the street shall be 4.5 m.

Minimum open space in the sides shall be 1.5 m.

Minimum open space in the rear shall be 4.5 m.

Garage, Servants' Quarters, Bath, Latrine, etc., may be constructed in the back open space with maximum height of 2.8 m from plinth but not exceeding more than half the width of the whole plot.

Open Spaces in Central Area of Towns

In central areas of towns, a minimum front open space or setback of 1.5 m shall be given. When the plot above is two or more streets, 1.5 m setback shall be provided on all the streets. Projects above first-floor level may be permitted over the open space provided height of projections is 6 m from the centre of the road.

The minimum open space in the rear shall be 3 m.

The minimum open space in the side shall be 1.5 m.

Projections Projections of chujja, cornice, sunshades, etc., up to a maximum of 23 cm below a height of 4.3 m from ground level or street level are permissible. Above a height of 4.3 m sunshades may project up to a maximum width of 60 cm. No projection of any sort is permissible on a road less than 9 m in width having no footpaths.

Height of a building The total height of all storeys shall not be more than the width of the front open space plus the width of the road. The maximum height shall be such that no part of the buildings is cut by a plane drawn at 45° angle from the opposite edge of the road. In central areas of towns, a maximum of 63.5° angle may be allowed.

Size of rooms The minimum floor areas of different rooms shall be as given below:

Living rooms = 11 sq.m

Kitchen = 5.6 sq.m

Bath = 1.8 sq.m

Servant's quarters = 9.3 sq.m

Latrine = 1.5 sq.m

Combined bath and WC = 2.8 sq.m

Height of room

Minimum height of main room from floor to ceiling shall be 3.3 m.

Minimum height of kitchen, store, bath, etc., shall be 3 m.

Minimum height of garage, servant's quarters, etc., shall be 2.8 m.

Height of plinth

Minimum height of plinth of main building shall be 30 cm.

Minimum height of plinth of garage, servant's quarters, etc., shall be 15 cm

Ventilation and lighting Every habitable room shall have openings such as windows, fan lights, etc., opening directly to the external air or in open verandah, of total area inclusive of frames not less than 1/8 of the floor area excluding doors. The aggregate area of doors and windows shall not be less than 1/4 of the floor area of the room. Ventilators not less than two in numbers shall be provided within 60 cm from the ceiling, having a minimum total area of 4 per cent of the floor. The minimum size of one ventilator shall be 0.28 sq.m

Bathrooms and water closets shall have windows having an area not less than 10 per cent of the floor area.

Staircase Minimum clear headway in between two flights shall be 2 m, minimum width of a staircase shall be 1 m. Minimum width of tread shall be 25 cm and maximum, rise shall be 19 cm. Opening for light and ventilation shall not be less than 1 sq. m per floor height.

Sanitary Every latrine shall be connected to a sewer line within 30 m of the site. Pucca drains shall be provided leading to the road drains, to drain off the surface water. Bath and WC shall have at least one wall open the external air.

Chulla or cooking hearth shall be provided with flue and chimney for smoke to escape.

Structural safety All structures shall be so designed, built and maintained that the stresses in the materials of construction shall not exceed the safe permissible stresses as laid down by Indian standards.

The live and wind loads shall conform to those specified in Indian Standards.

Foundations The width of the foundation of every building or structure shall be designed and constructed to distribute the load within safe bearing capacity of soil of the locality.

The minimum depth of foundation of main building shall be 1 m. The foundation of garage, kitchen, bathrooms, etc., may have a minimum depth of 75 cm.

The bottom layer of the foundation shall be of lime concrete or 1 : 4 : 8 cement concrete of a minimum thickness of 30 cm.

4.5 ORIENTATION OF BUILDINGS

The placing of the building with respect to the geographical direction (East, West, North and South), the direction of the wind, and the altitude and azimuth of sun is known as the orientation of the building. The building should be placed in such a way that it derives maximum benefit from sun, air and nature and at the same time it is protected from their harmful effects. It may be possible to orient each building in the desired direction to have the maximum benefit of sun, air, and nature, as in towns the orientation in individual buildings is decided on various factors like the position and direction of streets, position of gardens and parks, the shape and size of the plot of land, etc. In such cases, the orientation should be fixed with respect to the frontage of the building only. The proper orientation of each room should be worked out, taking into account its functional requirements as, for example, the garage, the staircase and other general service facilities could be grouped on the western side to protect the living rooms from the hot afternoon sun.

In cities, as the orientation of buildings as per choice is not possible, the buildings should be planned to have the maximum advantage of nature. The rooms should be arranged suitably to have the maximum possible comfort within limits, and verandahs, doors and windows, chujjas, sun shades, sun breakers, etc. should be provided in such a way as to get maximum advantage of the natural wind and sun. Where sufficient light is required as in operation theatres, in hospitals and science laboratories, the rooms should be placed on the north with large openings to get light from the north.

For office buildings, it is desirable to orient a building so as to avoid, exposure of the occupied rooms from eastern and western sun, as otherwise, expensive measures may be necessary for screening the penetration of sunlight, specially from the west.

For the selection of orientation the main factors of considerations are:

(i) the incident of solar intensities depending on the altitude and azimuth of sun, and the altitude of the place

(ii) the direction of the prevailing wind during the different parts of the year

The climatic condition, intensity of sun and direction of wind differ from region to region. It is, therefore, not possible to follow a rigid method with regard to the orientation of buildings. In general, the orientations in the following three different regions may be dealt separately:-

1. Hot and humid region
2. Hot and arid region
3. Hill region

4.5.1 Hot and Humid Region

In this region, the climate is humid, the temperature in summer is moderately high and rainfall is heavy. The prime object for orientation and design of buildings in this region is to provide free air movement through the building and to prevent the temperature of its interiors from rising above the shade temperature. The buildings should face the direction of the prevailing wind to obtain maximum benefit from air movement. A tilt of up to 45° may be allowed, if required, for which the loss in efficiency is only up to 20%. Window sills should be low to ensure maximum ventilation at the normal living level. Walls should be shaded from the sun so as to prevent temperature rise. Protection of openings against rain is also necessary.

Buildings should normally have open planning, as far as possible. They should be of one room thick so as to ensure thorough ventilation.

In Bengal, wind blows generally from north and south, and hence a building facing the south is preferable.

Around Chennai, the general direction of wind and also the monsoon wind is from the east and hence a building may be oriented east and west, but to avoid the afternoon sun, the living rooms may be on the east or south-east of the building.

Cities falling within hot and humid regions of India are Ahmedabad, Mumbai, Mangalore, Travancore, Chennai, Coastal Andhra, Mysore, KolKata and adjoining towns.

4.5.2 Hot and Arid Region

In these regions the climate is extreme, the temperatures range from 45°C maximum to 16°C minimum, or more or less. Cloudless sky, low humidity and high incidence of sun's glare are the main features. The sunny areas are hot and dry in the day-time and cool to cold at night. As far as possible, the buildings should be protected from day-time heat and glare during summer, and at the same time the rate of heat loss at night during winter should be reduced. In these regions, the buildings should be oriented for sun (not for wind as in humid region). The sun's heat is beneficial during the cold season but harmful during the hot season. The sun is in the south during the hottest part of the day and the altitude of the sun is high in summer and low in winter. For comfort during over-heated as well as under-heated periods, orientation and construction of buildings should be such that

(i) There is minimum heat gain in the structure during overheated period.
(ii) Minimum heat flow out of the structure during underheated period.
(iii) Equal heat gain and heat loss in the period when outside temperature is in the comfort zone.

To minimise the heat gain during summer and to take benefit of solar heat in winter, the longer wall should face north and south, and shorter walls east and west, so that least wall area is exposed to the slanting rays of the sun during forenoon and afternoon. i.e., the longer axis of the building should run east-west, so as to avoid excessive heat from west side. Provision of chujjas on the southern walls will give adequate shade to the walls during summer, and provision of windows and openings on the south will allow sun's ray in the rooms during winter. Verandahs are desirable on the south for protection from heat in summer, and also for sitting purpose in the winter to enjoy sun's rays. Openings in the west should be small and should be properly protected. To save the cost of verandah on the west, the afternoon sun may be kept off by providing louvers or tilted vertical sun-breakers. Alternately, a small tilt of the axis of the building may be given away from the west towards the south, i.e. facing near-about north-east. An attempt should be made to get maximum advantage of breeze during rainy season, autumn and spring to ensure comfort and proper ventilation.

Hot and arid regions are Central and North India consisting of Delhi, Amritsar, Gwalior, Indore, Nagpur, Agra, Kanpur, Lucknow, Gaya, Jamshedpur and adjoining areas.

4.5.3 Hilly Regions

In these regions, temperature is usually much low and cold prevails according to the altitude. There is a marked drop in temperature during the night. The buildings in theses regions should be located in the southern slope of hills as they receive maximum sunshine for the greatest duration of time. The openings should be placed as to avoid undesirable cold wind in winter. A massive structure with high heat capacity is useful. The heat it stores during the day is welcome except during very hot days. It is necessary to provide ceilings of good thermal insulation to reduce loss of heat by radiation during night. Where there is heavy snowfall, the roof should be sloping to prevent accumulation of snow.

4.6 VENTILATION

Ventilation consists of the inlet of fresh air and exit of vitiated or stagnant air, and maintaining a movement of air in the rooms and the building. For proper ventilation, windows and ventilators should be provided of requisite numbers, opening directly into external air or into an open verandah. For proper ventilation, windows should have minimum area of 1/8 of the floor area of the room, and the aggregate area of the doors and windows should not be less than 1/4 of the floor area of the room. Windows should be provided at 60 to 90 cm above floor level. In addition to the doors and windows ventilators should be provided having a total area of 4 per cent of floor area. Ventilators serve as good exit for inside air and should be provided as near to the ceilings as possible within 60 cm from the ceiling. The area of each ventilator should not be less than 3 sq.m.

In a living room, at least two windows should be provided, one in each of the opposite walls. If that is not possible there should be at least two windows, one in each of the adjoining walls. Bathrooms, latrines and kitchens should have at least one window of 0.9 × 0.12 m size. Area of windows required for proper ventilation of rooms may be calculated by various formulae:

(i) $A = \sqrt{B} \times L H$

(ii) $A = \dfrac{B \times L \times H}{100}$

(iii) $A = \dfrac{B \times L}{8}$

where, A = total clear opening of window

L = length of room

B = breadth of room

H = height of room

The relation between height (h) and width (w) of a window may be taken as $w = .7h$ though this may vary according to the requirement and aesthetic point of view.

4.7 ACOUSTIC REQUIREMENTS

The environmental definition of sound is noise, i.e., unwanted sound. It takes into account the effect of sound rather than its nature. A particular sound may not be liked by a listener due to its unhealthy or undesirable effect on him or on the environment. Some of the effects of noise are enumerated as follows:

1. Excessive exposure to noise results in loss of hearing.
2. A noisy environment decreases the quality of sound in general, e.g., areas near airports, local railway lines, bus-stands, vegetable markets, hawkers, etc.
3. Interference while giving a lecture or a musical performance is annoying.
4. A noise can distract one from one's task. It causes inefficiency, inattention and intolerability.
5. If external noise is to be reduced, measures have to be adopted. A noisy environment may entail loss of business.

Hence, in the design of houses, halls, auditoria, theatres, cinema houses, libraries, etc., the acoustics designer has a very important role. He considers and takes into account the need of the user versus the type of environment, frequency structure of the noise, duration and consequent reduction required in external noise levels or proposed improvement in internal sound levels. In short, control of sound in an enclosed space is his job. His general aim is to provide the best conditions for production as well as reception of desirable, comfortable and effective sound or music. Exclusion of unwanted and undesirable noise is an important aspect of acoustics.

The general requirement of acoustics are as below:

1. An adequate level of sound evenly distributed in the auditorium or hall
2. A suitable reverberation time (decay of sound) appropriate to the enclosed space and its function
3. Reduction of background and external noise
4. Absence of echoes and other similar acoustic defects

In the design of an auditorium or a big gathering place, such as a church or a temple, the requirements are the following:

1. Good and intelligible sound and its quality reception.
2. Good reception of musical performance covering fullness of tone, definition, blend and balance of sounds. Such a receptive auditorium is called a concert hall, opera house or a recording studio. In India, it is also known as a *natya griha* or *rang mandir*.

3. A multi-purpose auditorium has to be designed for more than one purpose and a correct compromise has to be made in its designing, e.g., church, town hall, school hall, college hall and other such multi-purpose halls including marriage halls and *mangal karyalayas*.

Absorbent materials are used for walls and roofs to reduce the sound energy reflected from the surface and to absorb the same. Sometimes, a false ceiling is provided. The perfect absorber is given an absorption coefficient of 1.0, e.g., an open window.

Absorption of a surface = Area of surface (m^2) × absorption coefficient of that surface.

The unit of absorption is *sabin*.

The strength of sound is measured in *decibels*. A decibel ratio is always made with reference to the standard value for the threshold of hearing. It is a logarithmic ratio of two quantities—ratio of the proposed or existing quantity to a standard quantity.

1 db (decibel) is the smallest change that the human ear can detect. A 10 db (decibels) increase or decrease makes a sound approximately twice as loud or as half as loud. An aircraft or jet liner take off has a sound level of 130 db, while normal conversation is between 50 and 60 db. Threshold of hearing is 0 db corresponding to a sound pressure of 0.00002 Pa. Pascal (Pa) is the SI unit of pressure.

$$1 \text{ Pascal} = 1 \text{ Newton/square metre } (\text{N/m}^2)$$

Thus,

$$0 \text{ db} = 2 \times 10^{-5} \text{ Pa}$$

$$60 \text{ db} = 2 \times 10^{-2} \text{ Pa}$$

$$100 \text{ db} = 2 \text{ Pa}$$

$$120 \text{ db} = 20 \text{ Pa}$$

$$140 \text{ db} = 200 \text{ Pa}$$

The acoustic designer considers all aspects of environmental sound pollution and give guidance for various forms of constructions for adequate sound installation, such as partition walls (composite or otherwise) and their material, types of floor construction and their material, types of windows (single, double) and their material, ceilings, if required, and its type, wall treatment, roof treatment, canvas frames, cushioned furniture, etc.,

4.8 SELECTION OF SITE

With the knowledge of the properties and uses of various construction materials, the next step is to study about the actual construction procedure. The first and foremost job in construction is to select a suitable site for the building. A properly selected site of the building gives enhanced beauty to the building without any extra expenditure.

The following points should be considered while selecting the site for any particular building:

1. Soil at the building site should not be of artificially made-up type. Buildings constructed over such soils normally undergo differential settlement and cracks are quite common in such buildings.

2. The site should not be undulating since this leads to increase in cost for levelling the ground.
3. The site should have its general slope, sloping away from the site in order to enable easy drainage of the building.
4. Civic services, such as main water supply mains, electric lines, telephone lines, drainage sewers, should be near the site so that no additional costs are incurred.
5. The groundwater table in the site should not be high.
6. Type of the building also affects the site selection. For example, industrial buildings should be situated outside the city, residential buildings must be near schools and hospitals, and public buildings should be located in open areas so that all the requirements may be fulfilled.
7. The selected site should be as far as possible large enough to provide sufficient light and air to the building.
8. The building site should not be in a depression since this will cause drainage problems as well as affect the aesthetic appearance.
9. If the site is sloping, it should be rising towards the back. This improves the elevation and also gives the feeling of comfort. On sloping sites, planning with differential floors becomes possible. The garage and the miscellaneous utilities can be accommodated in the basement.
10. The site should be connected with good communication lines such as good system of roads and railways.
11. The site should possess good soil at reasonable depths so that the foundation cost is reduced.
12. The selected site should be adequate to accommodate all the essential accessories required in the building.
13. Residential buildings should not be located near workshops and factories since such locations are subjected to continuous noise.
14. A site along seashore is good from the entertainment point of view but sea breeze being damp affects health. Metallic fittings are liable to corrode here.
15. The topographical features of the site with natural and artificial surroundings affect the selection of site to great extent. For instance, in a region of the city having large buildings, a small residential building may not be aesthetically appealing.
16. For industrial buildings, the site selected should be such that
    (a) all the raw materials required for the industry must be available nearby
    (b) the labourers should be available from the nearby areas
    (c) the site must have enough space for future expansion, of industry, for the construction of residential areas for workers, etc.
    (d) suitable disposal plant to treat the solid or liquid wastes produced by the industry must be available at reasonable distance

17. Climate plays an important role in selecting sites for industrial buildings. For example, a cool and moist weather is more favourable for weaving and textile mills.

4.9 SUBSTRUCTURE

A structure essentially consists of two parts, namely, the *super structure* which is above the plinth level and the *substructure* which is below the plinth level. Substructure is otherwise known as the foundation and this forms the base for any structure. Generally, about 30 per cent of the total construction cost is spent on the foundation. The soil on which the foundation rests is called the *foundation soil*.

4.10 OBJECTIVES OF A FOUNDATION

A foundation is provided for the following purposes:

1. To distribute the total load coming on the structure on a larger area
2. To support the structures
3. To give enough stability to the structures against various disturbing forces, such as wind and rain
4. To prepare a level surface for concreting and masonry work

4.11 SITE INSPECTION

The general inspection of the site serves as a good guide for determining the type of foundation to be adopted for the proposed work. Hence, it is desirable to visit the site of work and inspect the same carefully. The inspection of the site helps in getting the data with respect to the following items:

1. Behaviour of ground due to variations in the depth of water table
2. Disposal of storm water at the site
3. Nature of soil by means of visual examination
4. Movement of ground due to earthquake, landslide, etc.

In order to know the quality and thickness of underground soil, test pits are made up to the foundation level, the soil is excavated and examined. Electrical methods are also adopted to determine the soil quality from the resistance offered by the soil for the passage of current.

4.12 SOILS

4.12.1 General

Soil is a complex material produced by the weathering of solid rock. It is the unaggregated or uncemented deposits of mineral and/or organic particles or fragments covering a large portion of the earth's crust.

For engineering purposes, soil is defined as a natural aggregate of mineral grains, that have the capacity of being separated by means of simple mechanical processes, e.g., by agitation in water. Soil Engineering, Soil Mechanics or Geotechnique is one of the youngest disciplines of civil engineering involving the study of soil, its behaviour and application as an engineering material.

4.12.2 Types of Soils

The various types of soils are as follows:

1. Gravel
2. Sand
3. Silt
4. Clay

1. Gravel Soil particles of which more than 50 per cent have a size larger than 4.75 mm are called gravel. It is cohesionless and consists of unaltered mineral grains, which are angular to well-rounded in shape. Gravel is a very good foundation soil.

2. Sand It consists of cohesionless particles, of which more than 50 per cent have a size smaller than 4.75 mm. Sand particles are mostly unaltered mineral grains. Sand is also a good foundation soil.

3. Silt Silt comprises fine particles of weathered rocks with little or no plasticity. The presence of flake-shaped particles and/or organic and vegetable matters makes the silt plastic. Organic silts are highly compressible and they have a light grey to dark grey colour. Silt is not quite suitable for building foundation.

4. Clay It is composed of microscopic and sub-microscopic particles of weathered rock. Clay becomes plastic in the presence of water. Plastic clay has very low permeability. Clay is not a good foundation soil at places where water is likely to come in contact with the soil.

4.12.3 Soil Classification

The purpose of soil classification is to arrange various types of soils into groups according to their various engineering properties. For civil engineering purposes, soils may be classified by the following systems:

1. Particle size classification
2. IS classification system and unified soil classification
3. Textural classification

1. Particle size classification In this system, soils are classified according to the grain size. To indicate grain sizes, terms such as boulder, cobble, gravel, sand, silt and clay are used. The grain size of the various types of soils is given in Table 4.1.

2. IS classification system and unified soil classification This system is based on both grain size and plasticity properties of the soil and is therefore applicable to any engineering use. In this system of classification, soils are broadly divided into the following three categories.

(i) Coarse-grained soils
(ii) Fine-grained soils
(iii) Highly organic soils

Table 4.1 Grain size of various types of soils

S.No.	*Soil*	*Grain-size*
1.	Boulder	Greater than 300 mm
2.	Cobble	80 mm–300 mm
3.	Gravel	4.75 mm–80 mm
	1. Fine gravel	4.75 mm–20 mm
	2. Coarse gravel	20 mm–80 mm
4.	Sand	0.075 mm–4.75 mm
	1. Fine sand	0.075 mm–0.425 mm
	2. Medium sand	0.425 mm–2.0 mm
	3. Coarse sand	2.0 mm–4.75 mm
5.	Silt	0.002 mm–0.075 mm
6.	Clay	Less than 0.002 mm

(i) Coarse-grained soils In these soils, more than half the total material by mass is larger than 0.075 mm IS sieve size. They are further divided into the following two subdivisions.

(a) Gravel
(b) Sand

(ii) Fine-grained soils In these soils, more than half the material by mass is smaller than 0.075 mm IS sieve size. They are further divided into the following three subdivisions.

(a) Inorganic silts and very fine sands
(b) Inorganic clays
(c) Organic silts and clays and organic matter

(iii) Highly organic soils These soils contain large percentages of fibrous organic matter, such as peat and the particles of decomposed vegetation. In addition, certain soils containing shells, concretions, cinders and other non-soil materials in sufficient quantities are also grouped in this division.

3. Textural classification Classification of composite soils based on the particle size distribution is known as textural classification. This classification is based on the percentages of sand, silt and clay sizes making up the soil. Such a classification is more suitable to describe coarse-grained soils rather than clay soils whose properties are less dependent on the particle size distribution. Probably the best known of these textural classifications is the triangular classification of US Public Roads Administrations shown in Fig. 4.1.

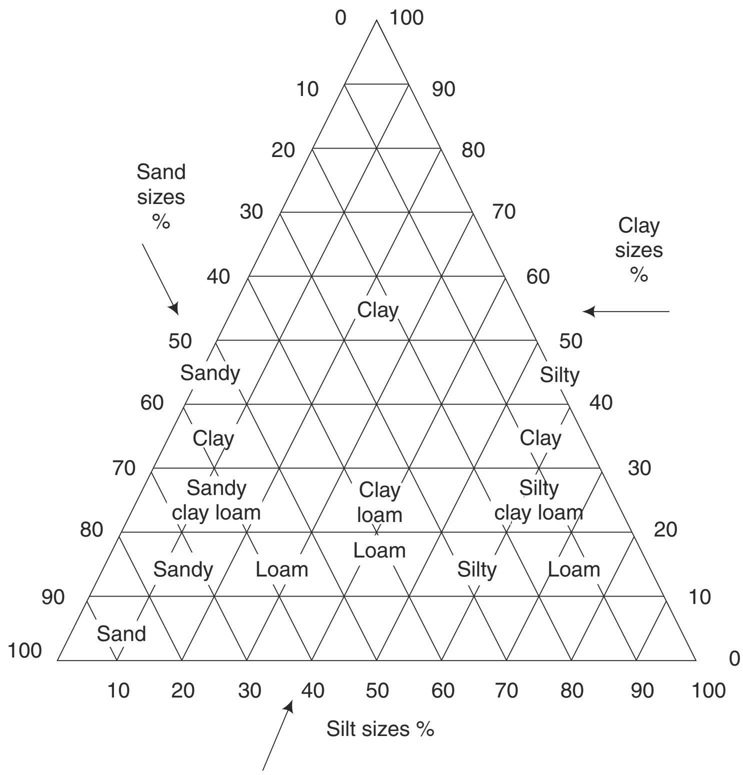


Fig. 4.1 *Textural classification*

In the figure for the given percentages of the three constituents forming a type of soil, lines are drawn parallel to the three sides of the equilateral triangle, as shown by arrows in the chart. For example, if a soil is composed of 20 per cent sand, 20 per cent silt and 60 per cent clay, the three lines drawn accordingly intersect in the zone marked for clay. Hence, such a soil will be termed clay.

4.12.4 Bearing Capacity of Soil

This term is used to indicate the maximum load per unit area which the soil will resist safely without displacement. By dividing the ultimate bearing power of soil by a factor of safety, the safe bearing capacity is obtained.

On completion of a structure, there may be some displacement in the position of the foundation. For ordinary framed structures of concrete, the permissible angular distortion is 1/500 and the desirable value is 1/1000. The maximum differential settlement should not exceed 25 mm in case of foundations on sandy soil and 40 mm in case of foundations on clayey soil.

In case of non-cohesive soils, such as sand and gravel, the allowable bearing capacity should be reduced by 50 per cent, provided that the water table is above or near the bearing surface of the soil. The bearing capacity of reclaimed soils or shrinkable soils can be taken as 50 kN/m^2 in the absence of the site data.

The bearing capacity of the soil can be found by loading the soil, noting the settlement and by dividing the maximum load by the area on which the load is applied. The maximum load is obtained from the graph between the load and settlement.

4.12.5 Methods of Improving Bearing Capacity of Soils

In some cases, the bearing capacity of soil is so low that the dimensions of the footings, work out to be very large and uneconomical. Under such situations, it becomes necessary to improve the bearing capacity of the soils, which can be done by the following methods.

(i) Increasing the depth of foundation

(ii) Compacting the soil. This can be done by using the following methods.
- (a) Running moist soil
- (b) Rubble compaction into the soil
- (c) Flooding the soil
- (d) Vibrating the soil
- (e) Vibroflotation method
- (f) Compaction by pre-loading
- (g) Using sand piles

(iii) Draining the subsoil water

(iv) Confining the soil mass

(v) Grouting with cement

(vi) Chemical treatments like injecting silicates, etc.

4.13 LOADS ON FOUNDATIONS

The type of foundation to be used depends upon the loads borne by it. There are three types of loads borne by the foundation—dead load, live load and wind load.

4.13.1 Dead Load

This is the self-weight of the various components of a building. The provision for the future construction must also be made in the dead-load calculation. In order to calculate the dead load, a knowledge of weight of the common building materials is necessary.

4.13.2 Live Load

This is also known as superimposed load and is the moveable load on the floor. This includes the weight of persons standing on a floor, weight of materials stored temporarily on a floor, weight of snow, etc.

4.13.3 Wind Load

In case of tall buildings, the effect due to wind should be considered. The exposed sides and roofs of such buildings are subjected to wind pressure and its effect is to reduce the pressure on the foundation in the windward side and to increase the pressure in the leeward side.

4.14 ESSENTIAL REQUIREMENTS OF A GOOD FOUNDATION

The following are the essential requirements of a good foundation:

1. The foundation should be so located that it is able to resist any unexpected future influence which may adversely affect its performance.
2. The foundation should be stable or safe against any possible failure.
3. The foundation should not settle or deflect to such an extent that will impair its usefulness.

4.15 TYPES OF FOUNDATION

Foundation may be broadly classified into the following two categories.

1. Shallow foundation
2. Deep foundation

A *shallow foundation* is one in which the depth is equal to or less than its width. When the depth is more than the width, it is termed as a *deep foundation*.

4.15.1 Shallow Foundation

When the depth of the foundation is less than or equal to its width, it is defined as a shallow foundation. The two main types of shallow foundation discussed in this section are the isolated footing and the combined footing.

The various types of shallow foundations are

- Isolated column footing
- Wall footing
- Combined footing
- Cantilever footing
- Continuous footing
- Inverted arch footing
- Grillage foundation
- Raft or Mat foundation
- Stepped Foundation

1. Isolated footing In framed structures where several columns are to be constructed, isolated footings can be adopted. The columns involved can be provided with masonry or concrete footing. If masonry footing is provided, steps are given and the foundation area is thus increased so that the stresses developed at the base are within the limit. Concrete can be moulded to any shape and hence a concrete footing may be a sloping one to provide sufficient spread. In case of masonry footing, the projection of each step must be 1/2 brick thick and each step is made of 1 or 2 bricks put together. Masonry footing and RCC footing are shown in Fig. 4.2. Isolated footing is provided under a column to transfer the load safely to the soil bed. If the column is loaded lightly, a spread is given under the base of the column. This spread is known as footing. For heavily loaded column, the total width of the footing may be very high. This is attained in three or four steps and is called *stepped footing*. If the total width of the footing is attained by gradually increasing the width towards the bottom, then it is called *sloped footing*.

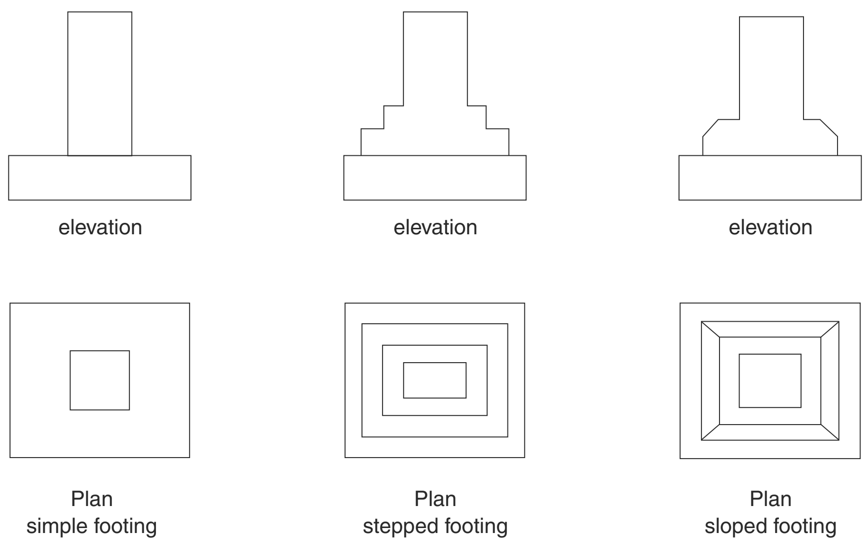


Fig. 4.2 *Isolated or Column footing*

2. Wall footing

If the footing is provided throughout the length of the wall in the case of load-bearing walls, then it is called wall footing. Wall footings can be either simple or stepped.

Depth of footing The minimum depth of footing is given by the Rankine's formula as,

$$D = P/W\left(\frac{1 - \sin\varphi^{2}}{1 + \sin\varphi}\right)$$

where,

D = minimum depth of footing

P = safe bearing capacity of soil in kg/m^2

W = unit weight of soil in kg/m^3

φ = angle of repose of soil in degrees

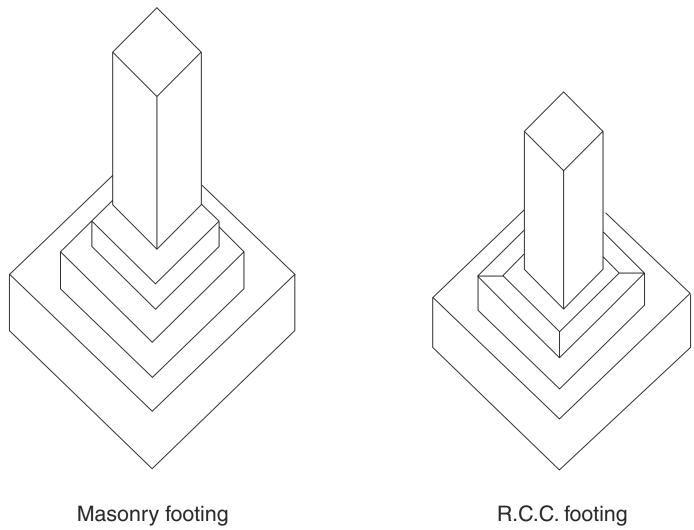


Fig. 4.3 *Textural classification*

The minimum depth of footing for the load bearing wall is limited to 90 cm for the stability.

Width of footing It is obtained by dividing the load including dead load, live load and wind load etc. by the allowable bearing capacity of the soil.

$$B = T/P$$

where,

B = Width of footing in metre
T = Total load per metre run in kg
P = Safe bearing capacity of the soil in kg/m^2

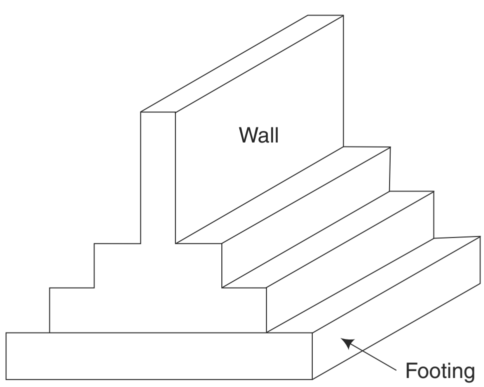


Fig. 4.4 *Wall footing*

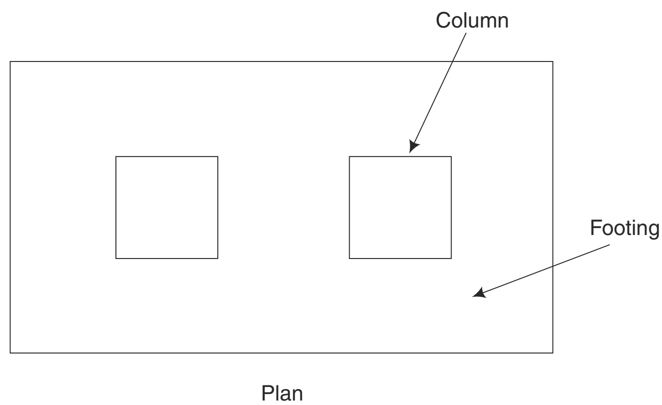


Fig. 4.5 *Combined footing*

3. Combined footing This type of footing is adopted when the space between two columns is so small that the foundation for individual columns will overlap. Combined footings are proportioned in such a way that the centre of gravity of the loads coincides with the centre of gravity of the foundation. Hence these footings have either a trapezoidal or a rectangular shape. The plan of a combined footing is shown in Fig. 4.5.

If a footing is constructed for two or more columns, it is called combined footing. The shape of the combined footing is proportional in such a way that the centre of gravity of the resultant area is in the same vertical line as the centre of gravity of the loads. Generally, the shape of the footing is rectangular or trapezoidal as shown in Fig. 4.6.

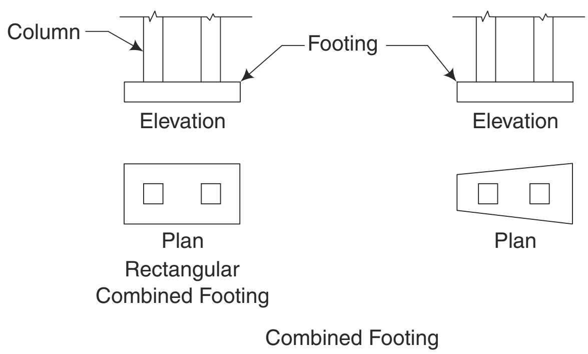


Fig. 4.6 *Combined footing*

4. Strip footing Strip footing is one of the different types of shallow foundation. This is used where soil of good bearing capacity is available at a depth of less than 3 m from the ground level. Since the footing is provided throughout the length of the wall in case of load bearing walls, it is also called as wall footing. Strip footings are classified as follows:

(a) Simple footing Simple footings are provided in case of walls of very light structures like residential buildings. In simple footing, cement or lime concrete is used in foundation. The projection beyond the face of the wall (offset) of the concrete base is 15 cm on either side as shown in Fig. 4.7.

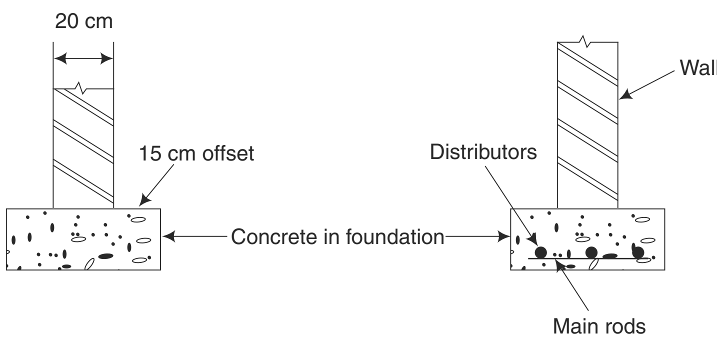


Fig. 4.7 *Simple footing*

(b) Stepped footing Stepped footings are provided where the ground has a slope, otherwise it becomes uneconomical to provide foundations at the same level. It consists of two or more footings of brick or stone masonry and a concrete bed below the ground level as shown in Fig. 4.8. The overlap between two layers of foundation concrete slab is equal to the depth of concrete slab or two times the height of the step, whichever is more. The depth of concrete bed is generally kept in even number of masonry courses.

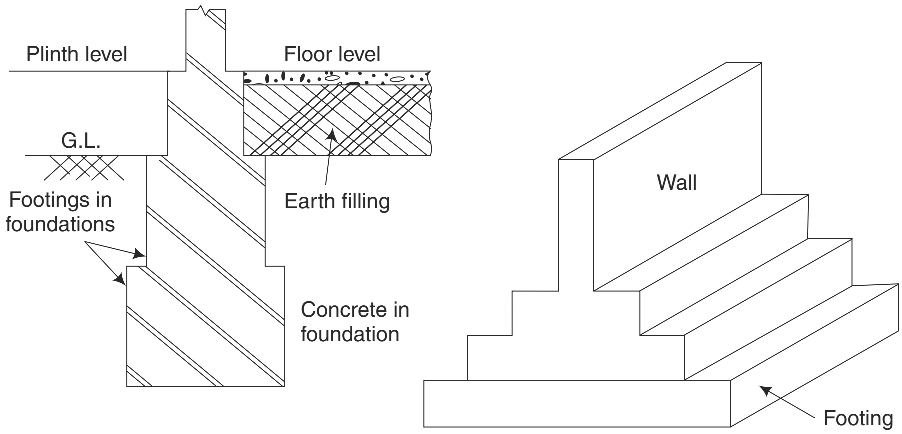


Fig. 4.8 *Stepped footing*

Width of footing It is obtained by dividing the total load including dead loads, live loads and wind loads, etc. by the allowable bearing capacity of the soil.

$$\text{Width of footing} = \frac{\text{Total load per metre run in } N}{\text{Safe bearing capacity of the soil in N/m}^2}$$

(c) Depth of footing The minimum depth of the footing is given by the Rankine's formula as given below.

$$D = \frac{P}{W}\left(\frac{1 - \sin\phi}{1 + \sin\phi}\right)^2$$

where

D = Minimum depth of footing

P = Safe bearing capacity of the soil

W = Unit weight of the soil in N/m^3

ϕ = Angle of repose of the soil in degrees

The minimum depth of footing for the load bearing wall is limited to 900 mm for the stability criteria.

5. Cantilever Footing

Cantilever footing consists of an eccentric footing for the exterior column and a concentric footing for the interior column and they are connected by a strap or a cantilever beam. Such footings are used when it is not possible to place a footing directly below a column because of limitations of boundary or eccentric loading conditions. The load from the exterior column is balanced by a load of the interior column acting about a fulcrum.

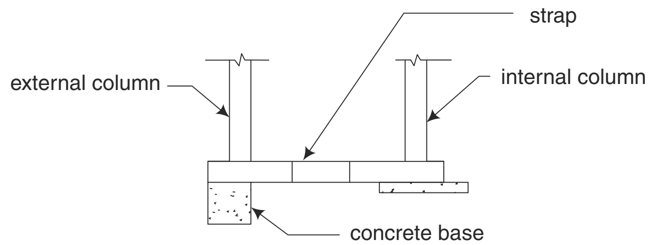


Fig. 4.9 *Cantilever footing*

6. Continuous Footing

In this type of footing, a single continuous RC slab is provided as foundation for three or more columns in a row. This type of footing is more suitable to prevent the differential settlement in the structure and for the safety against earthquake.

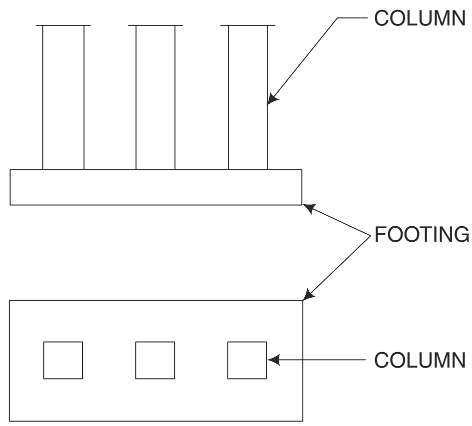


Fig. 4.10 *Continuous footing*

7. Inverted Arch Footing

In this type of footing, inverted arches are constructed between two walls at the base. It is suitable for soils of low bearing capacity and when the depth of the foundation is to be kept less. The end columns must be strong enough to resist the outward pressure caused by such action. This type of foundation is suitable for bridges, sensors, tanks, etc.

8. Grillage Foundations

Grillage foundation is used to transfer the heavy structural loads from steel columns to a soil having low bearing capacity. It is constructed by rolled steel joists (RSJ) which are placed in single or double tier. In double-tier grillage, the top tier is placed at right angles to the bottom tier. The distance between the flanges of RSJ should be equal to 1.5 to 2.0 times the width of the flange or 30 cm whichever is smaller. The steel joists of the grillage are kept in position by pipe separators and nuts. The whole arrangement of the rolled steel joists is completely embedded in concrete. The concrete filling is not supposed to take any load but it keeps the steel joists in position and prevents them from corrosion. The bed of concrete should have a minimum depth of 15 cm. A grillage foundation may be constructed for a single column or for more than one column.

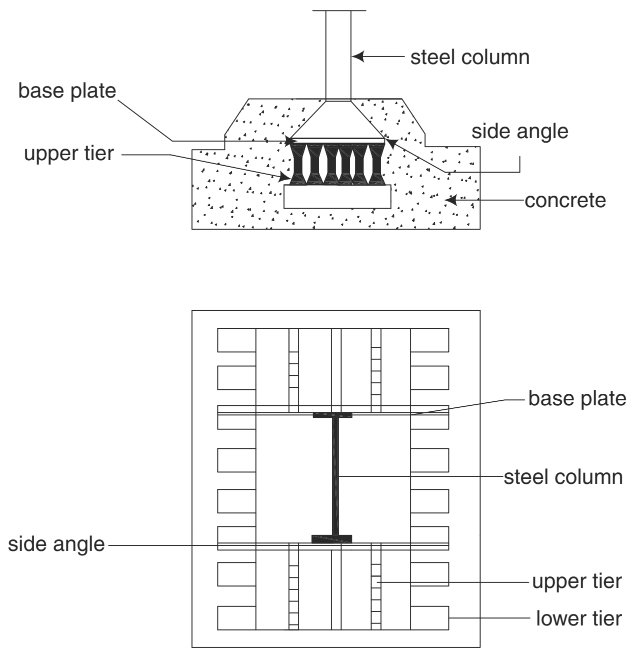


Fig. 4.11 *Grillage foundation*

9. Raft Foundation or Mat Foundation

When the load of the structure is very heavy and the bearing capacity of the soil is very low then raft foundation is adopted. In this type of foundation, the load is transmitted to the soil by means of a continuous slab that covers the entire area of the bottom of a structure similar to a floor. Due to low bearing capacity, large isolated footings are necessary to support the structure. If the sum of the base areas of the footings required to support a structure exceeds about half the total building area then it is preferable to combine the footings into a single raft. In such case, raft foundation exerts the minimum contact pressure and also counteracts the effect of hydrostatic uplift.

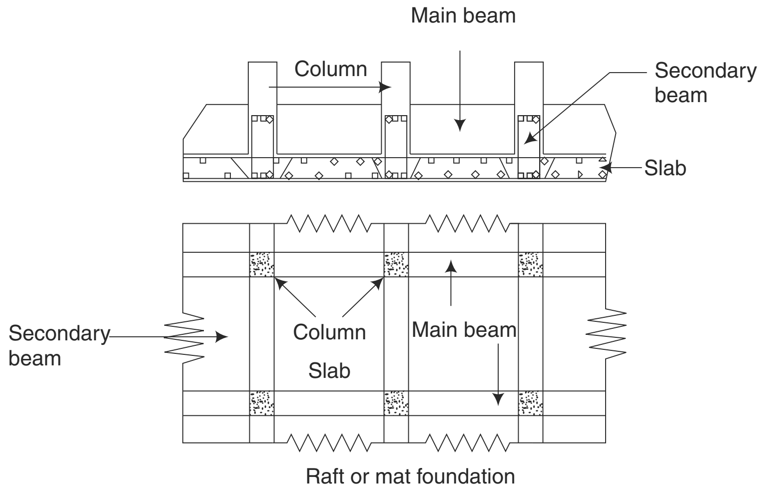


Fig. 4.12 *Raft foundation*

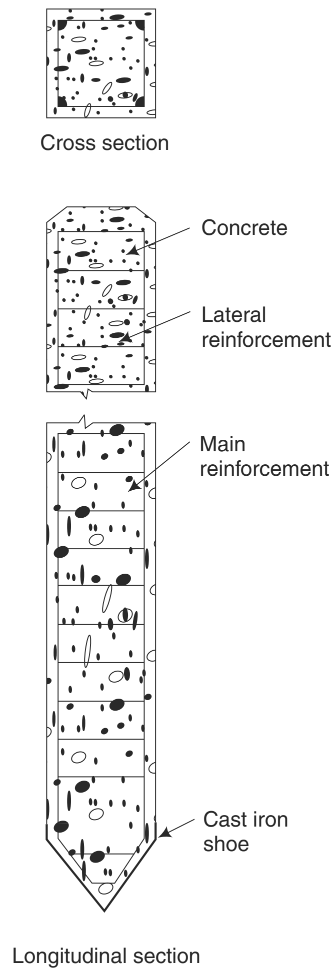


Fig. 4.13 *Under-reamed pile*

10. Deep Foundation

Deep foundation consists of pile and pier foundations. Pier foundations are rarely used for buildings. This consists in carrying down through the soil a huge masonry cylinder which may be supported on solid rock.

4.15.2 Different Types of Foundations

1. Pile foundation Pile is an element of construction used as foundation. It may be driven in the ground vertically or with some inclination to transfer the load safely. Loads are supported in two ways, i.e. either by the effect of friction between the soil and the pile skin or by resting the pile on a very hard stratum. The former is called the friction pile and the latter one is the load bearing pile.

Friction piles may be made of cast iron, cement, concrete, timber, steel, wrought iron and composite materials. Load bearing piles are steel sheet piles, concrete piles and timber piles. Piles may be cast-in-situ or precast. They may be cased or uncased.

2. Under-reamed piles Structures built on expansive soils often crack due to the differential movement caused by the alternate swelling and shrinking of soil. Under-reamed piles provide a satisfactory solution to the above problem. Figure 4.13 shows the details of an under-reamed pile.

The principle of this type of foundation is to transfer the load to a hard strata which has sufficient bearing capacity to take the load.

Single and double under-reamed piles may also be provided for foundations of structures in poor soils overlying firm soil strata. In such soils if double under-reamed piles are provided, both the under-reams shall rest within the firm soil strata.

3. Timber pile In this type, trunks of trees are used as piles. The wood should be free from any defect. These piles may be circular or square. The dimension varies from 30 cm to 50 cm. The length of a timber pile should not exceed 20 times its top width to avoid bulking. At the bottom of the pile, an iron shoe is provided and at the top a steel plate is fixed.

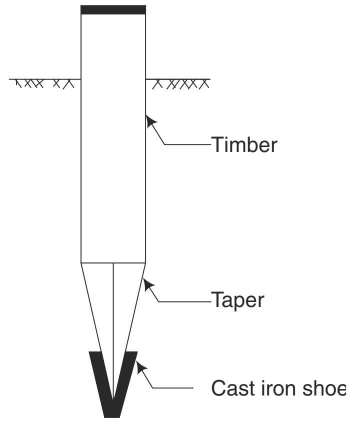


Fig. 4.14 *Timber pile*

4. Composite piles These piles are made up of two portions of different materials driven one above the other.

Common types of composite piles in use are

1. Timber and concrete
2. Steel and concrete

In the timber and concrete composite pile, the timber portion is used below the lowest level of the ground water table, and the concrete piles, usually cast-in-situ, is formed above it. This combination gives the twin advantage of durability of concrete piles and the cheapness of timber piles. In steel and concrete composite piles a steel pile, or H pile is attached to the lower end of concrete pile.

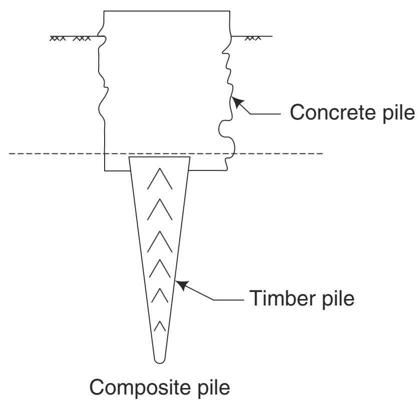


Fig. 4.15 *Composite pile*

5. Steel pile Steel piles are made in three forms: rolled steel H-section piles, box piles and tube piles. There can be no restriction on length due to high strength. However, steel piles may be affected by corrosive agents like salt, moisture, acid or oxygen. To prevent the steel pile from corrosion, its thickness may be increased or encased in concrete or chemical coating with paint is applied.

See Fig. 4.16. In this, H-Section pile having wide flanges is used. The pile projects slightly above the ground level and foundations as a column. Due to its small cross section, it can be driven into the soil easily.

A box pile is rectangular or octagonal. It is filled with concrete. When an H-Section pile is difficult to be driven, a box pile is preferred.

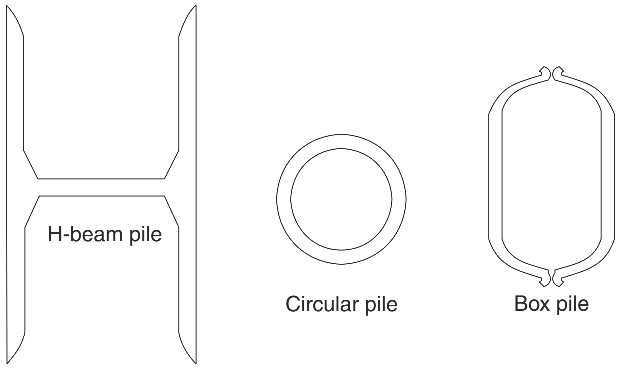


Fig. 4.16 *Steel piles*

4.16 CAISSON FOUNDATION OR WELL FOUNDATION

This is generally used for making foundations under water, such as ducks, bridges, etc. It is not a solid structure like a pier but is hollow inside, resembling a well. The load is transferred through the surrounding wall around called staining. The well is constructed and brought to the site. Then it is gradually driven down by digging the soil from inside. The bottom is plugged with concrete and the hollow portion is filled with sand. The whole well is then covered with a well cap above which the super structure is constructed.

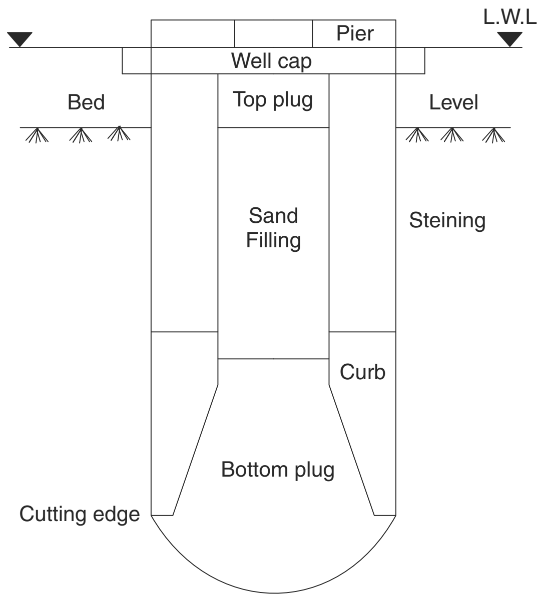


Fig. 4.17 *Well foundation*

A well foundation has the following advantages:

1. It can go to a large depth.
2. Its cost of construction is low.

The typical section of a well foundation consists of cutting edge, well curb, bottom plug, staining, top plug and well cap, etc., as shown in Fig. 4.17.

There are different types of shapes of wells in plan such as,

1. Circular
2. Twin circular
3. Double D
4. Dumb well

5. Twin hexagonal
6. Twin octagonal
7. Rectangular

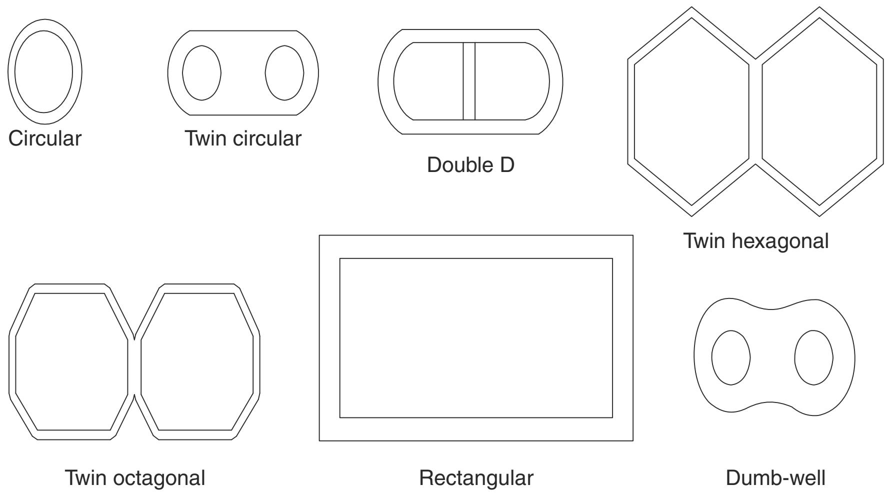


Fig. 4.18 *Shapes of wells in foundation*

4.17 FAILURE OF FOUNDATIONS AND REMEDIAL MEASURES

1. Unequal Settlement of Subsoil

Due to unequal distribution of load on the foundations, varying bearing capacity of the soil, eccentricity of the load, etc., unequal settlement occurs. In order to prevent this, the foundations should rest on rock or hard moorum. Also, it should be seen that the allowable bearing pressure of the soil is not exceeded and proper attention should be given to the eccentricity of the load.

2. Unequal Settlement of Masonry

Mortar joints may shrink and compress, which may lead to unequal settlement of the masonry. In order to avoid this settlement, the mortar to be used in the masonry should be stiff, the masonry should be raised evenly and should be watered properly.

3. Withdrawal of Moisture from the Sub-Soil

This occurs at places where there is considerable variation in the height of the water table. The precaution needed to avoid this type of failure is to drive piles up to the hard-rock level.

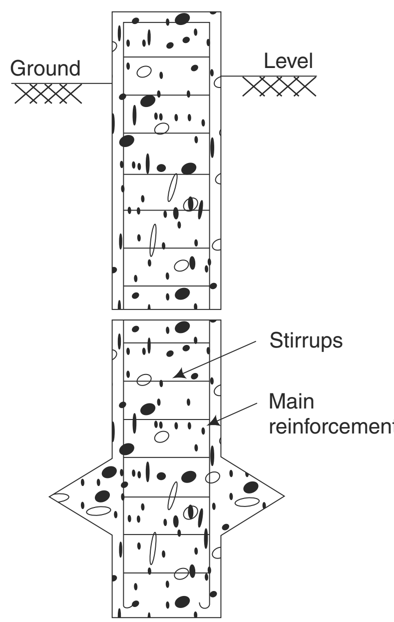


Fig. 4.19 *Under-reamed pile*

4. Lateral Pressure on the Superstructure

The thrust of a pitched roof or wind action on the superstructure causes the wall to overturn. The remedial measure is to provide a foundation of a suitable width.

5. Horizontal Movement of Earth

Very soft soil is liable to give way under the action of load. In such cases it is desirable to construct retaining walls or to drive sheet piles to prevent sliding of earth.

4.18 FOUNDATIONS FOR MACHINERY

The design of a machine foundation is more complex than that of a foundation which supports only static loads. In machine foundations, the designer must consider the dynamic forces caused due to the operation of machine, in addition to static loads. These dynamic forces are in turn transmitted to the foundation supporting the machine. The designer should therefore be well conversant with the method of load transmission from the machine, as well as with the problems concerning the dynamic behaviour of the foundation and the soil underneath the foundation.

4.18.1 General Requirements of Machine Foundations

The following requirements should be satisfied based on design considerations:

1. The foundation should be able to carry all the imposed loads without causing shear or crushing failure.
2. The settlements should be within the permissible limits.
3. The combined centre of gravity of machine and foundation should be in the same vertical line as the centre of gravity of the base plane.
4. No resonance should occur. Hence the natural frequency of foundation–soil system should be either too large or too small compared to the operating frequency of the machines. For low speed machines, the natural frequency should be high and vice-versa.
5. The amplitudes under service conditions should be within permissible limits.
6. All rotating and reciprocating parts of a machine should be well-balanced so as to minimise the unbalanced forces or moments.
7. Wherever possible, the foundation should be planned so as to permit a subsequent alteration of natural frequency by changing the base area or the mass of the foundation as necessary.

From the practical point of view, the following requirements should be fulfilled:

1. The groundwater table should be as low as possible and groundwater level should be deeper by at least 1/4 the width of foundation below the base plane. This limits the vibration propagation.
2. Machine foundations should be separated from adjacent building components by means of expansion joints.

3. Any steam or hot-air pipes embedded in the foundation must be properly isolated.
4. The foundation must be protected from machine oil by an acid-resisting coating or a suitable chemical treatment.
5. Machine foundations should be taken to a level lower than the level of the foundations of adjoining buildings.

4.18.2 Types of Machine Foundations

Machine foundations can be classified into three categories:

1. Block foundation usually adopted for reciprocating machines and light rotary machines.
2. Block and trough foundation for impact machines, such as drop and forge hammers.
3. Frame foundation generally adopted for heavy rotary machines, such as turbo generators.

4.18.3 Foundations for Impact Type Machines

Three types of foundations for the drop or forge hammers are shown in Fig. 4.20. As shown in the figure, the frame supports the tup which is a weighted block striking the material being forged on the anvil. The anvil in effect is a base block for a hammer on which material is forged into shape by repeated striking of the tup. The anvil rests

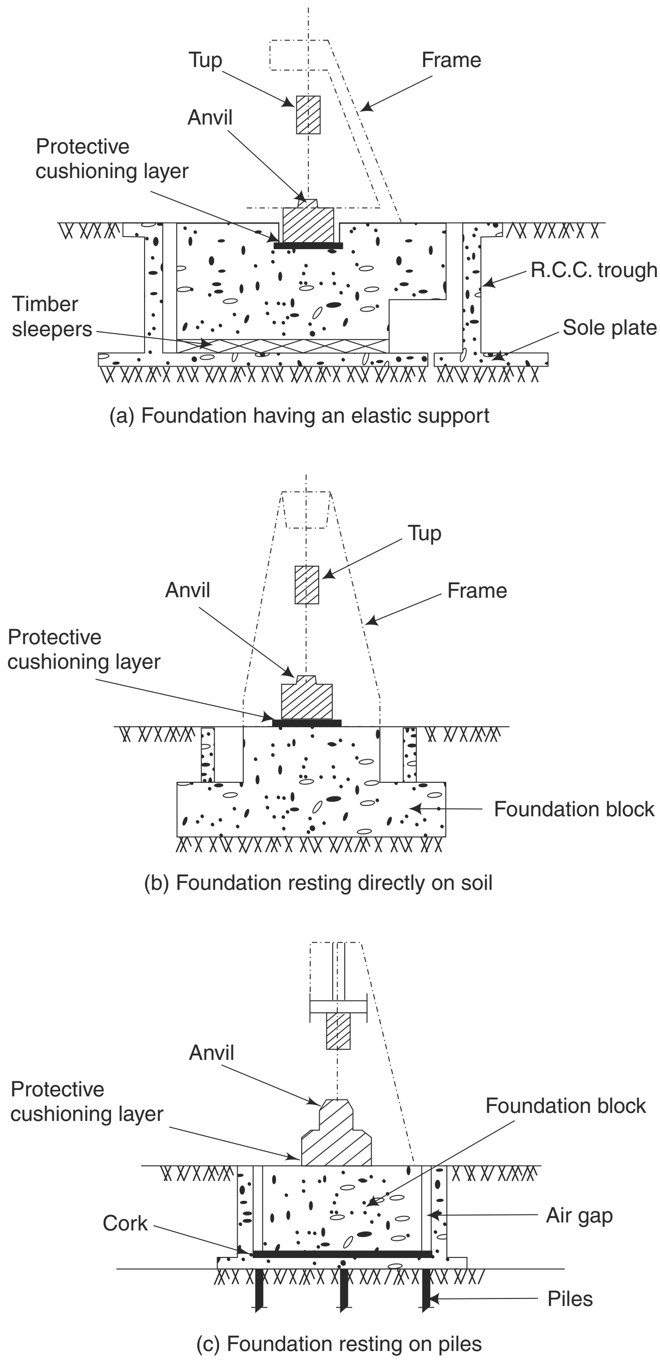


Fig. 4.20 *Foundations for hammers*

on a foundation block, which is a mass of reinforced concrete. The foundation block may rest directly on the ground as in Fig. 4.20(b), or on a resilient mounting such as timber sleepers, springs, cork layer, or any soft insert as shown in Fig. 4.20(a). The RCC trough containing the foundation block may rest on a sole plate or may be carried on piles as in Fig. 4.20(c). An elastic cushioning of suitable material and thickness is provided between the anvil and the foundation block in order to prevent bouncing of the anvil and creation of large impact stresses and consequent damage to the top surface of the concrete in the foundation block. This is shown as protective cushioning layer in Fig. 4.20(c).

4.18.4 Foundation for Heavy Rotary Type Machines

The design of a foundation for heavy rotary type machines, such as steam turbo generators, involves vibration considerations which are generally complicated. Special features relating to the design of such foundations should be advised by the manufacturers. These machines are generally supported on frame foundations as shown in Fig. 4.21.

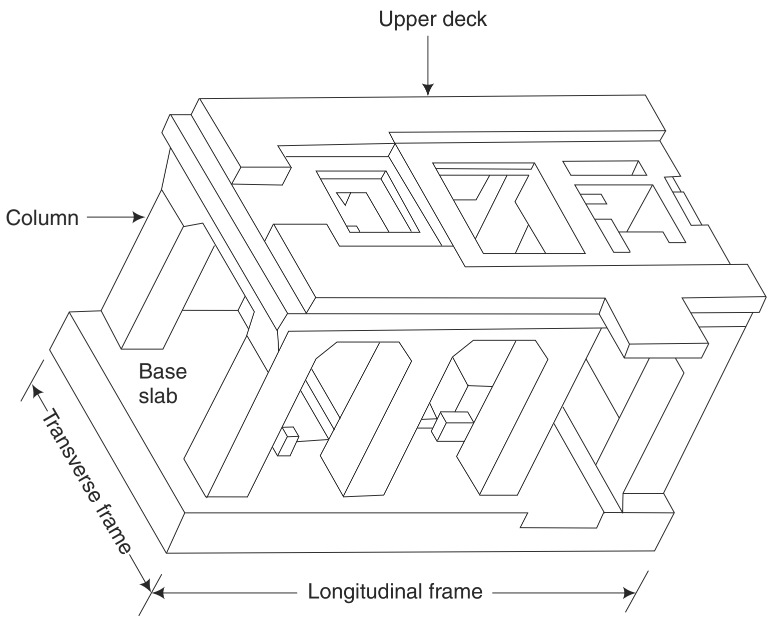


Fig. 4.21 *Typical frame foundation for turbo generators*

A heavy base slab is advantageous in the damping of the vibrations. The effective thickness of the base slab is kept at least 1/10 of its length, or the minimum width of the column. The weight of the base should not be less than the total weight of the machine plus the weight of the foundation without the base slab.

The soil stress should be restricted to 50–70 per cent of the allowable stress under static load. Wider contact of foundation with the soil is preferable. It is suggested that the foundation at contact with the machine base should be at least 150 mm larger than the base all around. The depth of foundation is 0.75 m in the ground even for inconsequential machines and more for larger machines.

For reciprocating machines, rigid block types are generally used. It is advisable to make the entire block in one operation without a construction joint. It is advisable to provide a nominal reinforcement of about 0.2 per cent of the cross-sectional area in the axes of displacement.

Machine foundations should normally be isolated from the neighbouring structure by an air gap or with soft inserts.

4.19 FOUNDATIONS FOR SPECIAL STRUCTURES

By special structures we mean unconventional or rarely occurring structures such as buildings. There are a number of such special structures, which may be above or below ground, on-shore or off-shore, civil or defence, and commercial or industrial. The foundations for some special structures is discussed in the following sections.

4.19.1 Foundations for Water Tanks and Silos

Overhead structures like water tanks, grain silos, etc., which are supported on columns can be considered as an example of special structures. The columns of these structures can be founded on soil by means of footings, rafts (or mats) of the beam and slab type or flat slab type, piles or piers, with cap, depending upon the load and soil conditions (Fig. 4.22). When footings are used, strap beams may be provided to connect the columns at their base and to overcome the effects of differential settlements. Under conditions of heavy loads, weak soil and closely spaced columns, individual footings if overlap have to be ruled out and a raft becomes a necessity. Even when the footings do not overlap, but cover more than half the base area, a raft proves to be a more economical system than that of individual footings.

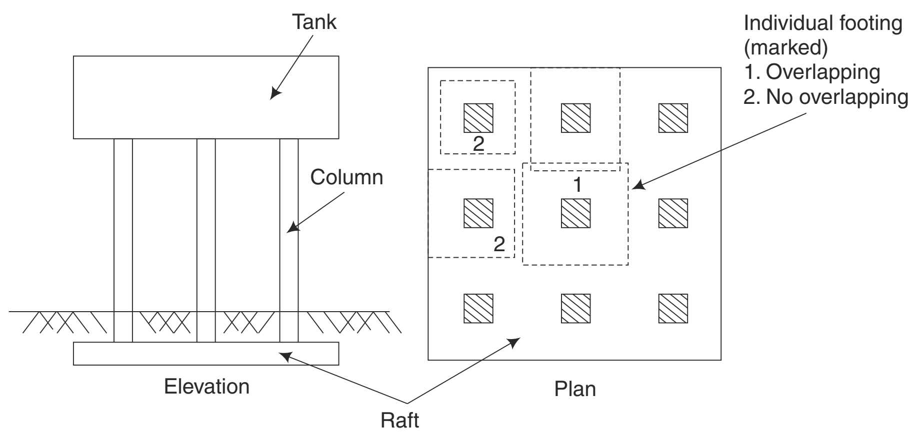


Fig. 4.22 *Raft foundation for overhead water tanks*

When the columns form a circular row, a circular or annular raft is very often used as the foundation on to which the load is transmitted as a circular line load through a ring beam, which supports the columns. Figure 4.23 shows such a foundation.

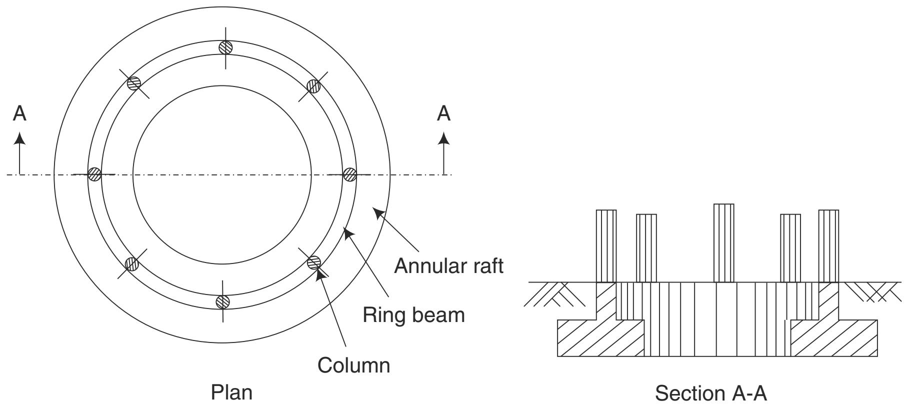


Fig. 4.23 *Annular raft foundation*

4.19.2 Foundations for Chimneys and Cooling Towers

Tall cylindrical structures such as chimneys are normally founded on circular rafts, when the soil conditions are favourable. For facilitating construction, these circular rafts are normally detailed octagonally. Figure 4.24 shows this type of foundation.

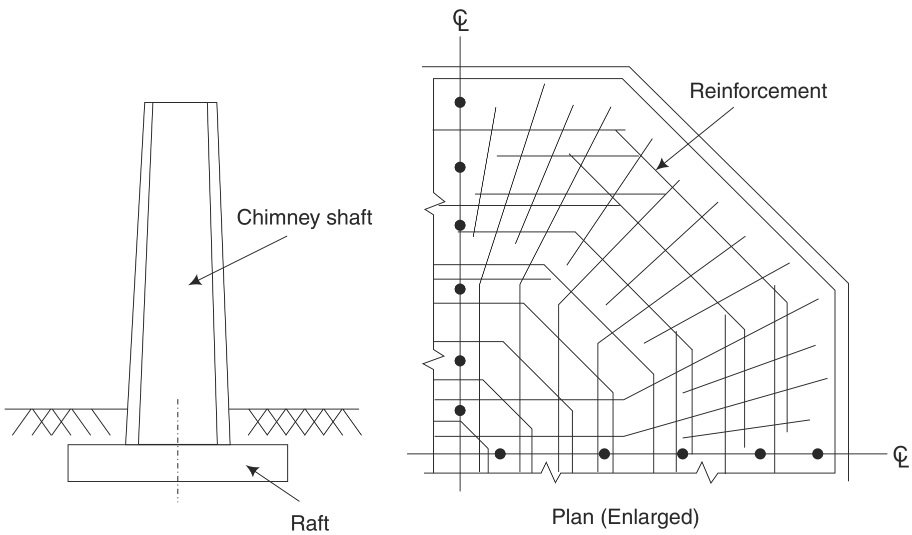


Fig. 4.24 *Octagonal raft for chimney*

Cooling towers, are normally in the form of a hyperboloid of revolution and are usually found in thermal power stations. Figure 4.25 shows such a foundation. An annular raft may prove to be a convenient foundation for such towers on good soil. Deep foundations, if needed, could be of piles or caisson.

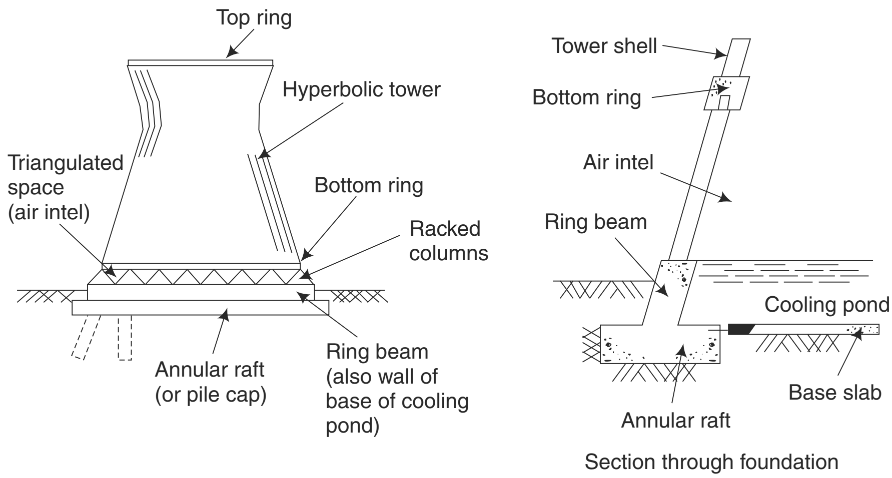


Fig. 4.25 *Foundations for cooling towers*

4.19.3 Foundations for Telecommunication Towers

Tall reinforced concrete telecommunication towers for television, radio, telephone (microwave), etc. are normally founded on an annular raft through a conical substructure. In addition to the flexural effect due to soil reaction, the foundation ring is also subjected to hoop tension due to the horizontal component of the inclined thrust from the cone. To resist this, prestressing is sometimes resorted to. The tallest of these structures is the Moscow TV Tower at Ostankino shown in Fig. 4.26. This structure has a total height of 533 m and a weight of 550 MN. It has a ring foundation (decagonal, prestressed) with an outside diameter of 74 m and a thickness of 9.5 m. It is founded at a depth of 4.5 m below the ground level, to a mean soil pressure of 274 kN/m^2. The foundation soil is compressible to a depth of 35 m, which has incompressible rock underneath.

Even though reinforced concrete telecommunication towers are very popular in Europe, particularly in West Germany, but similar towers in India are practically made of steel and are mostly founded on piles.

4.19.4 Foundations for Transmission Line Towers

All tall tower-shaped structures are subjected to large horizontal forces due to wind. These horizontal forces transmit both horizontal loads and moments at the foundation level. (In a general case, even twisting moments can be transmitted.) When the vertical

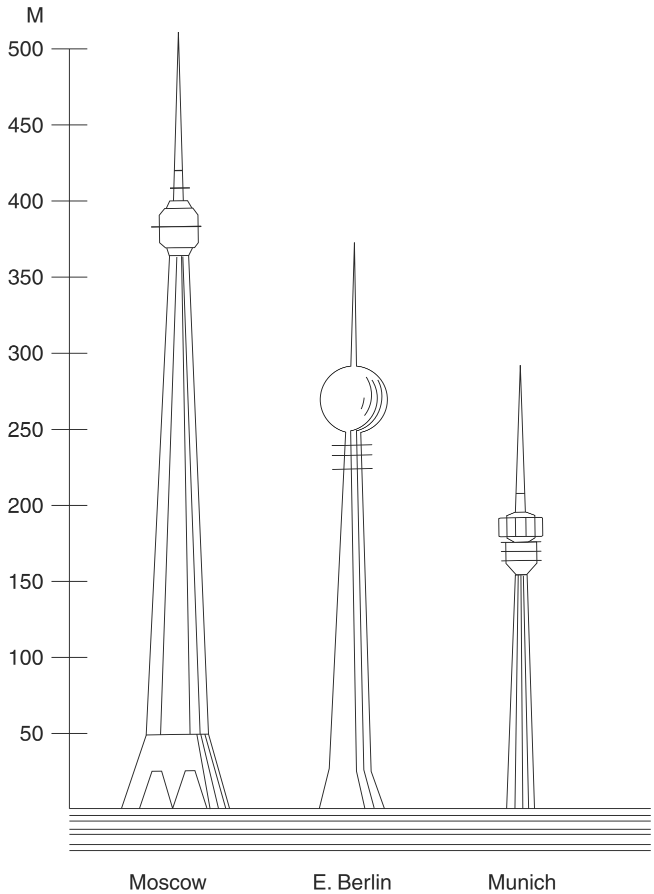


Fig. 4.26 *Conical substructure for telecommunication towers*

loads are comparatively smaller, these moments can produce a resultant tension in the foundation elements such as footings and piles. Wind may not always act and in a general case, it may act in any direction. Hence, the soil and structural aspects of the design of the concerned foundation element should cater simultaneously to the maximum values of compression, tension and horizontal forces, which may also act in either direction as explained in Fig. 4.27.

Some typical foundations for transmission line towers are illustrated in Fig. 4.28. For small towers the foundation can be in the form of blocks into which the tower legs are properly anchored. Individual reinforced concrete footings or combined footings may have to be used for higher loads.

Under-reamed piles which are normally used as foundations in expansive soil can be effectively used as foundations for the legs of transmission line towers even in ordinary soil. They can be used either as a single pile or in a group, depending upon the load and

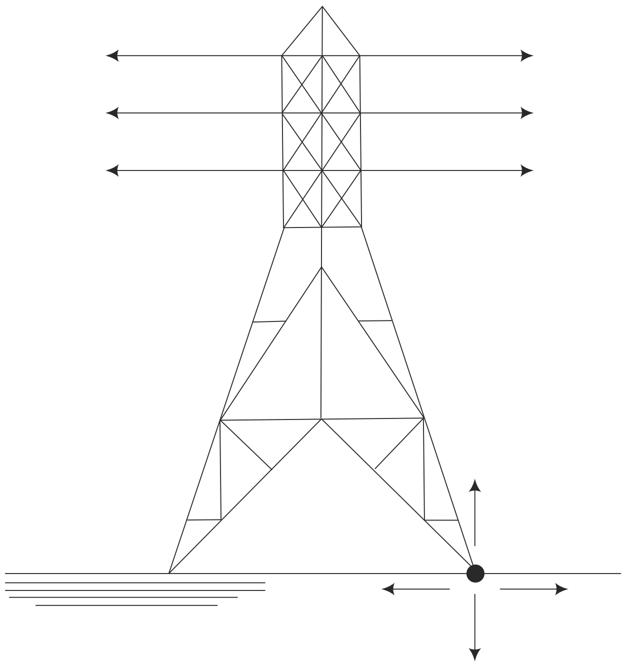


Fig. 4.27 *Transmission line tower: Forces on foundation*

the capacity of the individual pile. The function of these piles in expansive soils is to transmit the loads to the stable zone which lies under the zone susceptible to swelling and shrinkage due to moisture variation. When the loads are compressive, the under-ream or the bulb serves to increase the bearing area, while under tension it serves as an anchor for the pile in the stable zone. This dual function explains the effectiveness of under-reamed piles as potential foundations for transmission line towers.

Following are the different foundations for transmission line towers as shown in Fig. 4.28.

(a) Block foundation
(b) Piled foundation with capping block
(c) Pillar foundations
(d) Augered belled foundation
(e) Footing
(f) Anchored leg
(g) Grillage foundation
(h) Combined footing (elevation)
(i) Beam and slab raft (plan)
(j) Under-reamed piled foundations
(k) Screw pile foundation

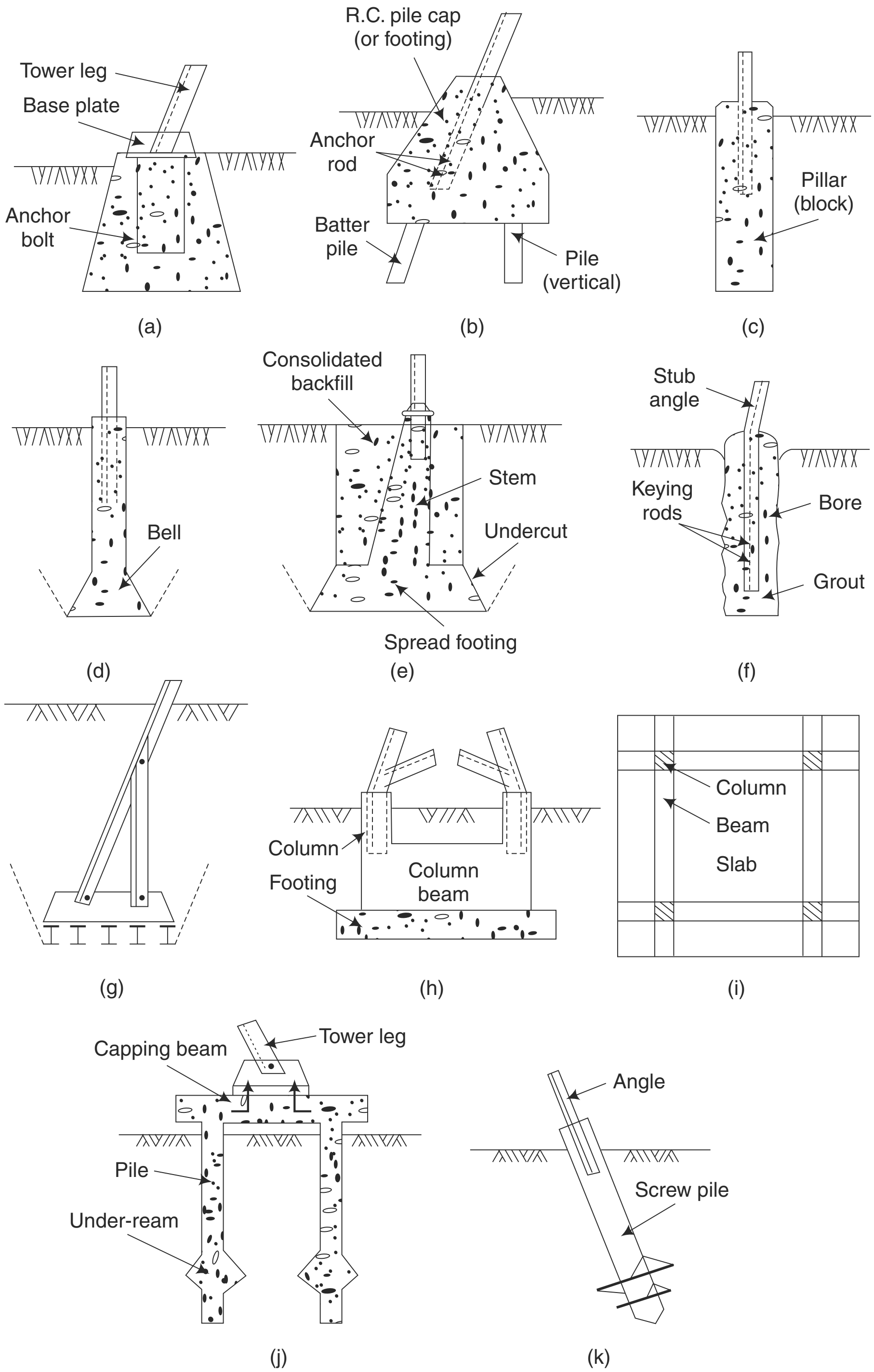


Fig. 4.28 *Foundations for transmission line towers*

4.19.5 Foundations for Guyed Structures

Guyed steel masts and towers are often used to carry radio antennas and for similar telecommunication purposes. The guy wires serve to absorb all horizontal forces. This helps to reduce the structural sections of the mast towards the lower part which would have otherwise been heavy due to the high moments from the horizontal forces, besides arresting the sway of the mast which is not desirable from the functional point of view. Not only masts, but stacks are also sometimes guyed. A minimum of three guy wires (120° apart) are needed in all cases. If necessary, guy wires can be taken from more than one location on the mast. While the mast itself may be supported on a plain circular footing or a conical shell rooting (upright or inverted) the guy wires should be terminated at suitable anchors (Fig. 4.29). These anchors may take the form of block footings, piles or piers depending upon the capacity required. The anchors are used to resist the vertical and horizontal components of the inclined tension in the guy wires. The magnitude of the vertical component of the tension can be brought down by keeping the angle of the wire (from the horizontal) as low as practicable, but this would be at the expense of extra length and increased horizontal force.

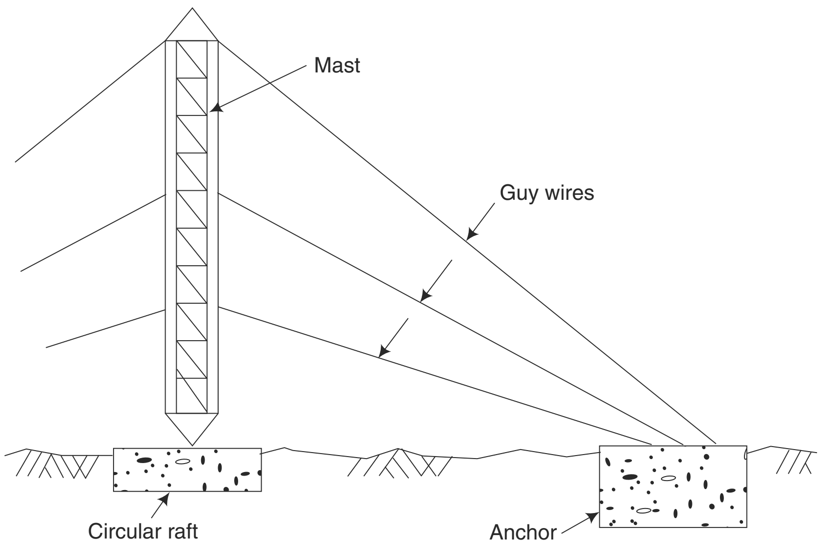


Fig. 4.29 *Guyed mast*

4.19.6 Foundations for Industrial Structures

Industrial structures, particularly those found in chemical and processing industries, pose a number of problems not normally encountered in case of ordinary residential and commercial structures. These are mainly in the form of forces which include not only wind forces, fluid thrust, etc. but even forces created by thermal expansion and contraction. Structures in this group include process towers and stacks supported on octagonal footings or pile groups, drum exchangers, pipe lines and bents which may be above ground, on ground or below ground. Figure 4.30 shows such a type of foundation.

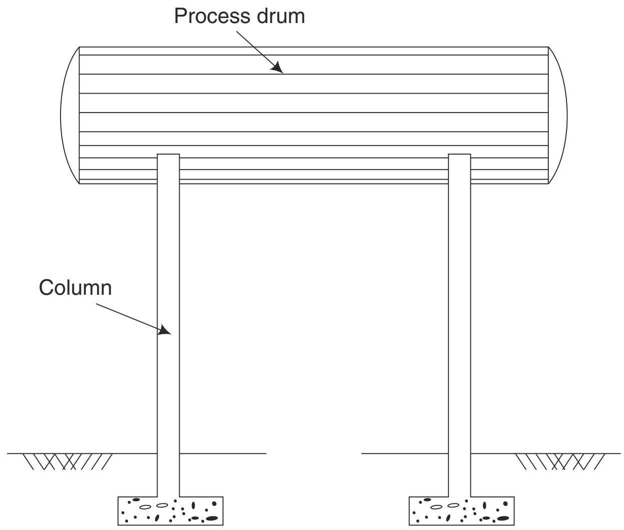


Fig. 4.30 *Foundation for an industrial process drum*

4.19.7 Foundations for Ground Storage Tanks

Cylindrical ground storage tanks of substantial dimensions for fluids, are used in petroleum refineries, chemical plants and many other manufacturing industries, for storing both raw materials and finished products. These tanks are made of thin steel plates welded together. They are basically of two types, i.e. with floating roof and with fixed roof.

These storage tanks present special foundation problems, as they are often required to be founded on soft coastal and estuarine soils. The tanks are relatively very light compared to the material (fluid) stored in them. Since the bottom plates are sufficiently flexible, they are able to transmit their liquid load on to the soil without much structural interaction. Since the bulb of pressure can extend to considerable depths depending upon the diameter of the tank, settlements of the order of a metre are common in the case of larger tanks. Oil companies, however, are wary of adopting pile foundations in such soils, as the cost of the foundation can exceed by several times the cost of the tank itself. Hence, attempts are normally directed to make the foundation as cheap as possible and consistent with performance. Among the several types of foundations available, those with oiled sand pad, crushed rock or concrete ring wall, interlocking sheet pile ring wall and piled foundations with crushed rock pile cap are suitable types for soils in the order of their decreasing quality. Some of these types are illustrated in Fig. 4.31. The advantage of providing thicker foundation bases lies in dispersing the load mostly through the base, thereby reducing the bearing pressure on the soil below.

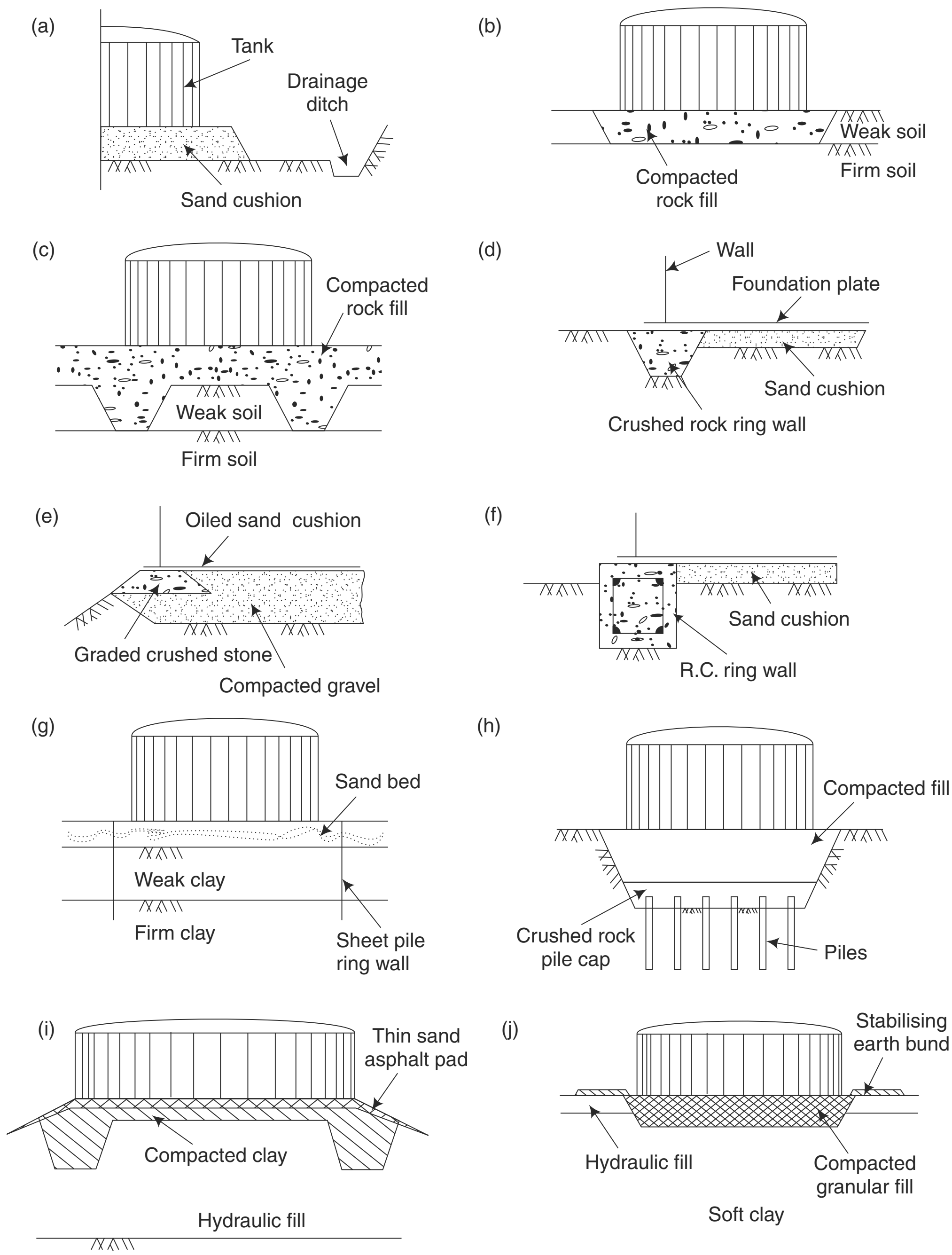


Fig. 4.31 *Ground storage tank foundations*

An ingenious foundation incorporating a thin reinforced concrete dome as an economic alternative to pile foundation is illustrated in Fig. 4.32.

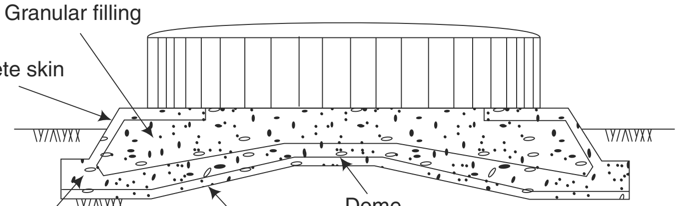


Fig. 4.32 *Durley dome foundation for oil storage tanks*

Short-Answer Questions

1. A column transmits a load of 2800 kN. The safe bearing capacity of the soil is 400 kN/sq.m. What are the dimensions of the foundation required?
2. Which materials are usually used for friction piles?
3. Name the foundation that may be adopted for expansive soils.
4. Distinguish between shallow foundation and deep foundation.
5. What are the points to be considered while selecting the site for any particular building?
6. List the types of machine foundations.
7. Define safe bearing capacity.
8. What are the essential requirements of a good foundation?
9. What are the different loads acting on the foundation of a building?
10. Under what circumstances is a combined footing preferred to an isolated one?
11. Explain the following types of foundations with neat sketches.
    (a) Isolated footing
    (b) Combined footing
    (c) Under-reamed pile foundation
12. What are the usual causes of failure of foundations?
13. Write short notes on IS classification system for soil.
14. Under what circumstances stepped footings are provided?
15. What is simple footing?
16. How will you calculate the width and depth of a shallow foundation?
17. What do you mean by special structures?
18. Give some examples of special structures.
19. Under what conditions does raft foundation become necessary?

20. What are the functions of guy wires in masts and towers?
21. In what ways do under-reamed piles serve as potential foundations for transmission line towers?

Exercises

1. List the objectives of a foundation.
2. Explain under what conditions can an isolated footing be adopted.
3. What is a deep foundation?
4. Explain under what circumstances a pile foundation is adopted.
5. What are the basic needs of a foundation for a machine?
6. Explain with neat sketches the block foundation used for impact-type machines.
7. Explain the classification of soils in detail.
8. Describe briefly the methods for improving the bearing capacity of the soil.
9. Describe briefly strip footing with a neat sketch.
10. Explain with neat sketches, the raft foundation for water tanks.
11. Briefly explain the foundations for
    (i) Chimneys and cooling towers
    (ii) Telecommunication towers
12. Explain in detail some typical foundations for transmission line towers with neat sketches.
13. Give a detailed account on foundations for
    (i) Guyed structures
    (ii) Industrial structures
14. With neat sketches, explain the various types of foundations for ground storage tanks.

Chapter 5
SUPERSTRUCTURE

5.1 INTRODUCTION

The superstructure consists mainly of walls, doors, windows and lintels. The purpose of the superstructure is to provide the necessary utility of the building, structural safety, fire safety, sanitation and ventilation.

The art of construction in stone or in brick is called masonry. The former is called stone masonry while the latter is called brick masonry.

5.2 BRICK MASONRY

5.2.1 Technical Terms

Some of the common terms used in the brick masonry are illustrated in this section in Fig. 5.1(a) and Fig. 5.1(b).

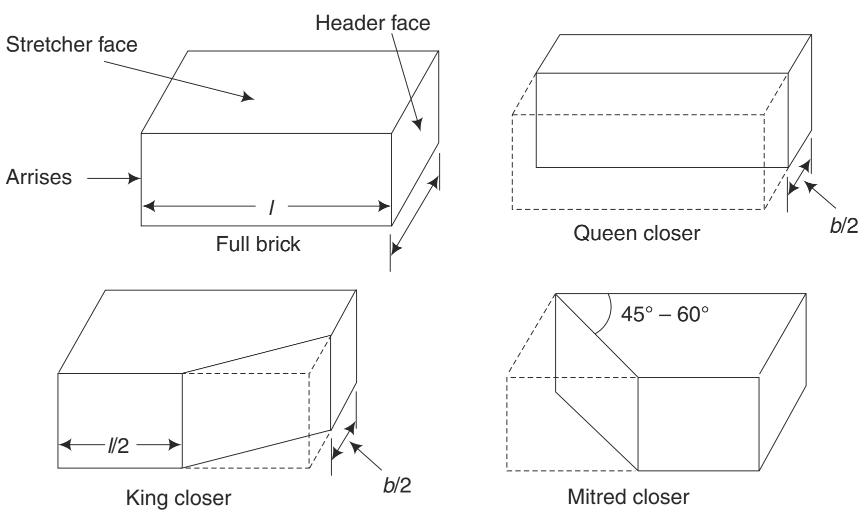


Fig. 5.1 (contd.)

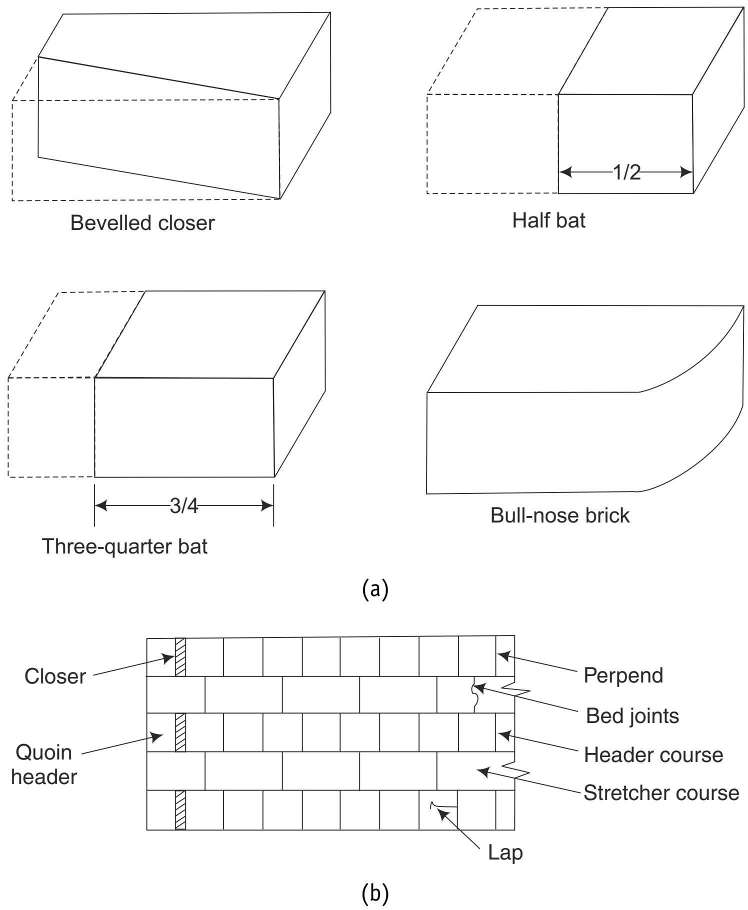


Fig. 5.1 *Components of brick masonry*

Arrises The edges formed by the intersection of plane surfaces of a brick are called arrises.

Stretcher This is a brick laid with its length parallel to the face or direction of a wall. A layer of bricks containing stretchers is called a stretcher course.

Header This is a brick laid with its breadth or width parallel to the face or direction of a wall. A course (layer of bricks) containing headers is a header course.

Bed joint The horizontal layer of mortar upon which bricks are laid is called a bed joint.

Perpends The vertical joints either in the length or in the cross directions are known as perpends. For a good bond, the perpends in alternate layers should be one above the other.

Lap The horizontal distance between the vertical joints in two successive courses is termed as lap.

Closer A piece of brick that is used to close up the bond at the end of brick courses is known as a closer. It helps preventing the vertical joints of successive courses coming one over the other. The types of closer are the following:

1. Queen closer This is obtained by cutting the brick longitudinally into two equal parts. This is generally placed near the quoin header to obtain necessary lap.

2. King closer This is obtained by cutting a triangular portion of the brick such that half a header and half a stretcher are obtained on the adjoining cut faces. A king closer is used near door and window openings to get satisfactory arrangement of mortar joints.

3. Bevelled closer This is obtained by cutting a triangular portion of half the width but of full length of the brick. This is used for splayed brick work.

4. Mitred closer This is obtained by cutting a triangular portion of the brick through its width and making an angle of 45–60° with the length of the brick. It is used at corners, junctions, etc.

Bat This is a piece of brick cut parallel to its width so as to form half or three quarter of a brick known as half bat or three-quarter bat.

Bullnose A brick moulded with a rounded angle is termed as a bullnose and it is used for a rounded quoin.

Cownose A brick moulded with a double bullnose on end is termed as a cow nose.

Squint quoin A brick which is cut or moulded in such a way that an angle other than right angle is formed in the plan is known as squint quoin.

5.2.2 Bonds in Brick Work

A bond is an arrangement of layers of bricks by which no continuous vertical joints are formed. Bricks can be arranged in various forms. The following are the types of bonds in brick work:

1. Stretcher bond All the bricks are arranged in stretcher courses. The stretcher bond is useful for one-brick partition walls as there are no headers in such walls. As the internal bond is not proper, this is not used for walls of thickness greater than one brick. A stretcher bond is shown in Fig. 5.2.

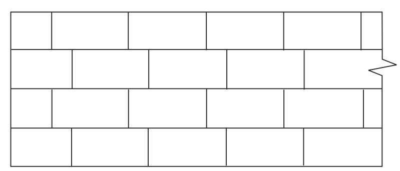


Fig. 5.2 *Stretcher bond*

2. Header bond In this type, all the bricks are arranged in header courses. It is used for curved surfaces since the length will be less. If a stretcher bond is used in a curved surface, it will project beyond the face of the wall. Figure 5.3 shows a header bond.

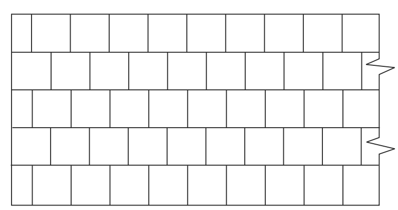


Fig. 5.3 *Header bond*

3. English bond

(a) One-brick wall

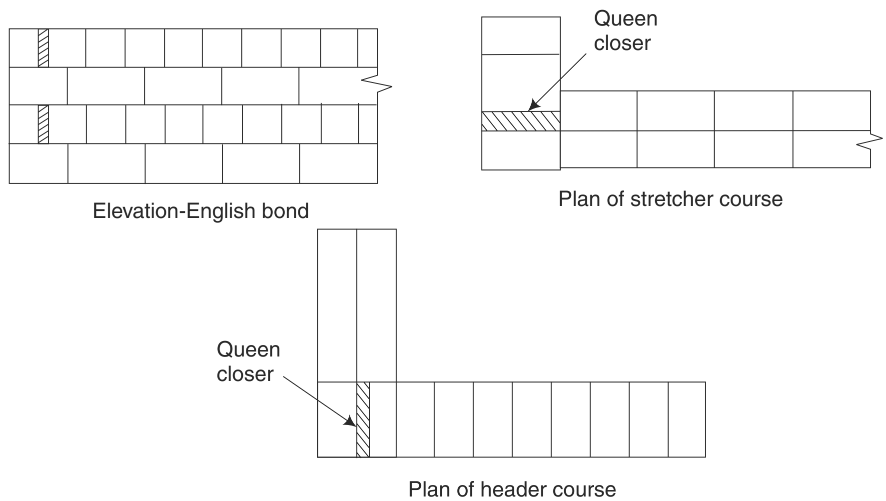


Fig. 5.4 *English bond (one brick wall)*

English bond is the most commonly used type of bond. It is the strongest type of bond. It is used for all wall thicknesses.

(a) *Alternate Courses* English bond consists of headers and stretchers in alternate courses in elevation.

(b) *Queen Closer* A queen closer is placed next to the quoin header, in each header course to the full thickness of the wall. This is done to break the continuity of the vertical joints in the successive courses. Thus, a lap joint is provided to create the bond.

(c) *Alternative Header* Each alternative header lies centrally over a stretcher of the stretcher course.

(d) *Wall Thickness in Even Number of Half-Bricks* If the wall thickness is an even number of half-bricks, the same course will show either headers or stretchers on both the face and back. That is, the appearance on both face and back are the same.

(e) *Wall Thickness in Odd Number of Half-Bricks* If the wall thickness is an odd number of half-bricks, the same course will show headers of the face and stretchers on the back or stretchers on the face and headers on the back of the wall.

(f) *Continuous Vertical Joints* Continuous vertical joints should not be allowed except at the stopped end.

(g) *Wall Thickness of Two Bricks or More* For walls of thickness of two bricks or more, the interior or hearting of these thicker walls should be filled with headers only.

(h) *Thinner Header Course* There are more vertical joints in the header course than in stretcher course. Hence, the joints in the header course should be thinner than in the stretcher course.

(b) One-and-a-half brick wall In English bond, stretcher and header courses are laid alternately in the facing of the wall. In this, the queen closer is placed next to the quoin header to break the continuity of the vertical joints. Each alternate header is centrally placed over a stretcher. If the thickness of the wall is an even number of half brick, the wall presents the same appearance on both the faces, otherwise the same course will present stretchers on one face and header on the other (Fig. 5.5).

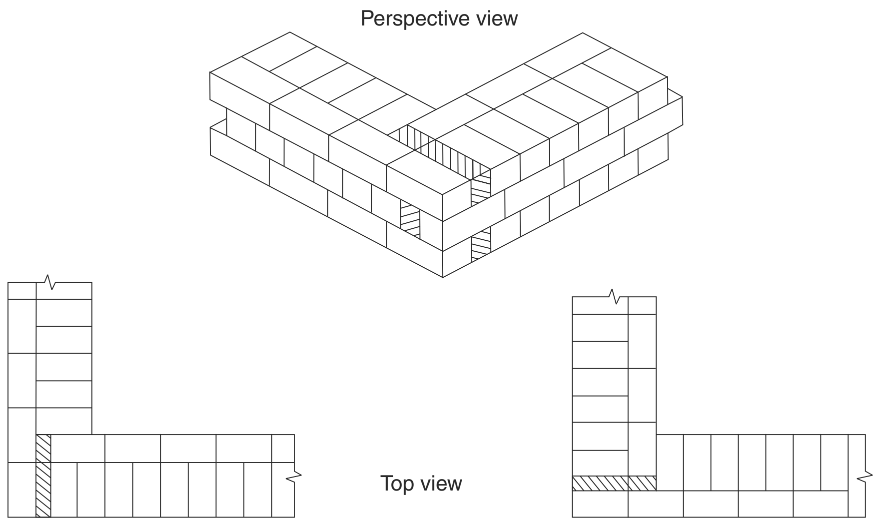


Fig. 5.5 *One-and-a-half brick wall in English bond*

4. Flemish bond In this type of bond, the headers are distributed evenly as shown in Fig. 5.6 and hence creates a better appearance.

The peculiarities of a Flemish bond are as follows:

(a) In every course headers and stretchers are placed alternately.
(b) The queen closer is put next to the queen header in alternate courses to develop the lap.
(c) Every header is centrally supported over a stretcher below it.
(d) The Flemish bond may be either a double Flemish bond or a single Flemish bond.

In a double Flemish bond, headers and stretchers are placed alternately in front as well as in rear elevations. For this type of bond, if the wall thickness is equal to an odd multiple of half bricks, then half bats and three quarter bats have to be used. For walls of thickness equal to even number of half bricks, no bats will be required. A stretcher or a header in the front elevation will appear as a stretcher or header in the rear elevation also. This has a better appearance than the English bond but not so strong as the English bond.

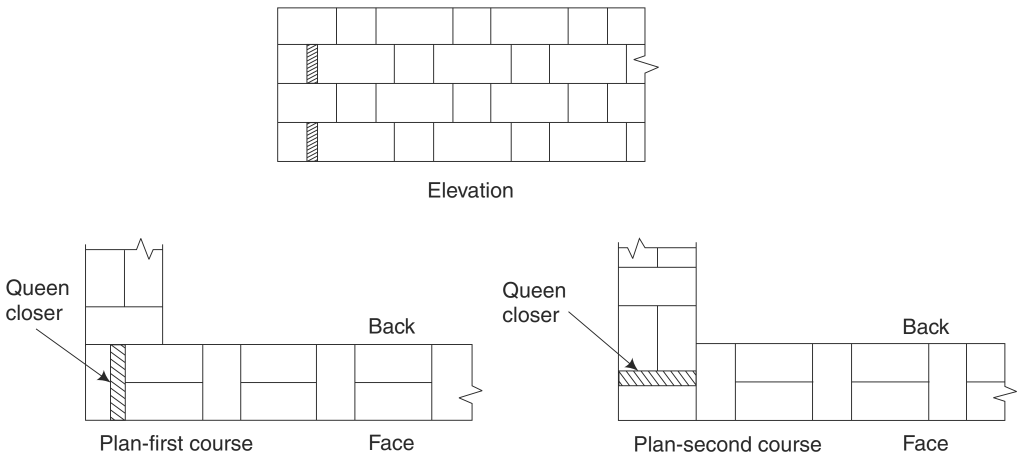


Fig. 5.6 *Flemish bond—one–brick thick wall*

A single Flemish bond consists of a Flemish bond in the front and an English bond in the rear along with the filling. This type of bond is used when expensive bricks are used for the front and requires a minimum wall thickness of 1/2 bricks.

(e) As in the English bond, the bricks in the same course do not break the joints with each other and the joints are straight.

(f) In this bond, short continuous vertical joints are formed.

(g) Brick bats are to be used for walls having a thickness equal to uneven multiple of half bricks.

Comparison of English Bond and Flemish Bond

Sl.No	*Aspects*	*English Bond*	*Flemish Bond*
1.	Strength and wall thickness	Strength is more, for walls of thickness 1½ bricks or more	Strength is more, for walls of 1 brick thickness; for thicker wall, strength is less
2.	Appearance	Appearance on the facing is not pleasing	Appearance on the facing is more pleasing and uniform
3.	Stretchers and headers	Alternate courses of stretchers and headers	Alternate arrangement of a stretchers and a header in each course
4.	Cost	More costly, as less number of brick bats are used	Less costly since a large number of bats are used
5.	Breaking of joint	Maintaining of correct breaking of joint is difficult	Maintaining of correct breaking of joint is easy
6.	Labour	Skilled labour is not required; hence, it is easy and fast to construct.	More skilled and experienced labour is required
7.	Mortar	Less mortar is used	More mortar is required

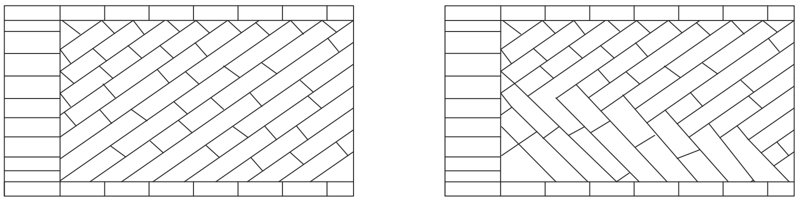
5. Raking Bonds

In this type of bond, the bonding bricks are kept at an inclination to the direction of the wall. The raking course is generally provided between the two stretcher courses. This bond is used in thick walls.

Raking bonds are two types:

(a) Diagonal bond

(b) Herringbone bond



Diagonal bond   Herringbone bond

Fig. 5.7

Raking bonds are used for thick walls. These are of the following two types:

(a) Diagonal bond

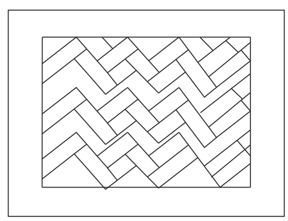
See Fig. 5.7. In this bond, bricks are laid diagonally. Internal placing of bricks is made in one direction only at certain angle of inclination, after face bricks are laid. The angle selected is to ensure minimum breaking of bricks.

(b) Herringbone bond

In this bond, the bricks are laid at an angle of 450 from the centre in both the directions.

6. Zig-Zag Bond

See Fig. 5.8. In the bond, the bricks are laid zig-zag. This method is used for paving or making ornamental finish in the brick floor.



Zigzag bond

Fig. 5.8

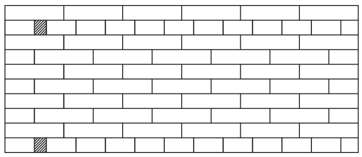
Bricks cut to triangular shapes and of suitable size are packed in the small triangular spaces at the ends.

Garden Wall Bond This type of bond is used for the construction of garden walls, boundary walls, compound walls, where the thickness of the wall is one brick and the height does not exceed two metres.

Garden wall bonds are two types:

(i) Garden wall English Bond In this bond, the header course is provided only after three to five stretcher courses.

(ii) Garden wall Flemish bond In this bond, each course contains one header after three to five stretchers continuously placed throughout the length of the course.



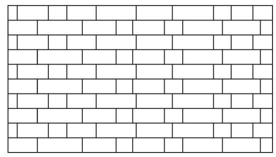


Fig. 5.9 *Garden-wall bond*

5.2.3 Dimensions of a Brick Masonry Wall

In order to make a brick masonry wall safe, its thickness must be sufficient enough to withstand the loads coming on it. The loads acting on a wall are dead loads, live loads, and wind loads. The vertical loads may be concentric or eccentric.

The tendency of the wall to overturn due to the effect of wind pressure depends on the overall height of the wall. The distance between the top of floor concrete and the highest part of the wall is the overall height. The height of a floor is also important while designing a wall. For domestic buildings, the floor height may be 3–4 m.

The length of the wall is fixed on the basis of its tendency to buckle laterally. Its thickness also depends on the strength of bricks as well as the strength of cement mortar.

5.2.4 Points to be Observed while Supervising the Construction of Brick Work

1. The bricks to be used should conform with the requirements of the specification of the work.
2. The bricks should be saturated with water so as to prevent absorption of moisture from the mortar.
3. Bricks should be laid with the frog located uppermost and the mortar should completely cover the bed.
4. Brick work should be carried out in a proper bond.
5. The mortar to be used should be of good quality.
6. The brick work should be raised uniformly.
7. In brick work, brick bats should not be used except as closers. All brick bats of size less than half brick should be rejected.
8. Single scaffolding should be adopted to carry out brick work at higher levels.
9. The vertical faces should be checked with a plumb bob and the inclined faces should be checked with the templates.
10. After construction, brick work should be well watered for a period of about two to three weeks if lime mortar is used and for about one to two weeks if cement mortar is used.

5.2.5 Cracks in a Brick Masonry Wall

In most of the structures cracks appear in a brick masonry wall due to the following reasons:

1. Combining the brick work with other materials having greater deflections and strains.
2. Effect of deflection and shrinkage of the concrete slabs resting on walls.
3. Development of internal forces due to moisture absorption, temperature variations, etc.

The measures to prevent cracking in masonry walls are given below:

1. The foundation supporting masonry walls should be designed with sufficient stiffness.
2. The provision of horizontal and vertical expansion joints in the walls helps in reducing the occurrence of cracks.
3. The usage of concrete with low shrinkage characteristics also prevents cracking.
4. It is preferable to have short spans for the floor slabs.

5.3 STONE MASONRY

Stone is a natural choice for masonry, where it is available in plenty. Its durability has been demonstrated in our temples and massive structures. Coal tar, paraffin, linseed oil or solution of alum and soap are the preservatives used to prevent the stone from the effects of rain water, wind, etc.

Stone masonry is the construction carried out using stones with mortar. But, because of high cost of transportation, painful and costly work of dressing and the need for experienced labour, stone masonry is presently not popular. Further, stone-masonry walls occupy more space compared to brick-masonry walls.

Types of Stones

Types of stones used in stone masonry are

- Dense stones like granites and quartzite
- Fire-resistant stones and sandstones
- Soft stones like limestone, marble and slate used for carvings, arches, etc.

Uses of Stone Masonry

- Foundation, floor, walls, lintels, columns, roofs, etc.
- Walls, roofs, lintels for temples, monuments, etc.
- For facing works in brick masonry to give massive appearance

5.3.1 Dressing of Stones

After quarrying, stones are to be dressed for surface finish. Dressing of stones is the art of cutting the stones to the shape required for use in the structures. It is done at the quarry itself. Quarry dressing has the following advantages in comparison to sit dressing:

- Cheap labour is available at the quarry site.
- Freshly quarried stones contain some moisture called quarry sap. Hence, they are comparatively soft and can be easily dressed.
- It is possible to sort out the stones at the quarry for different works. Irregular and rough portions of the stones can be removed then and there in the quarry. Thus, the weights of the stones as well as transportation of stones are reduced.

Tools used for dressing of stones

Hammers Mason hammer, scrabbling hammer, mash hammer, Waller's hammer, spalling hammer, fare hammer

Chisels Crow chisel, soft stone chisel, draught chisel, plain chisel, splitting chisel, punch chisel and point chisel

Axes

Punching machine

Types of dressing Stones for different types of stone masonry are dressed as follows:

1. Hammer Dressing

For rubble masonry, stones are roughly dressed with hammers. The surface thus obtained is called hammer-dressed. The stones are made roughly square or rectangular or polygonal using a Waller's hammer. The exposed face of the stone may be roughly shaped by using a mash hammer. The lower and upper surfaces of the stones are almost dressed flat.

2. Chisel Dressing

For good Ashlar masonry, the faces of stones are finely dressed by means of chisels. A draught chisel is sunk round the margin of the stone. Its front face is dressed to rock face. Sometimes, to make the entire face truly smooth, chisel draughts are sunk diagonally on the stone face and the intermediate portions are brought down to a level with the help of dressing tools. At length, the chisel marks are removed by rubbing the surface with a stone slab and fine sand.

3. Axed Finish

Axed Finish is employed in hard stones like granites. An axe is used for the dressing operation.

4. Polished Finish

Granite, marble and trap take a good polish. This is achieved manually or by the aid of polishing machines.

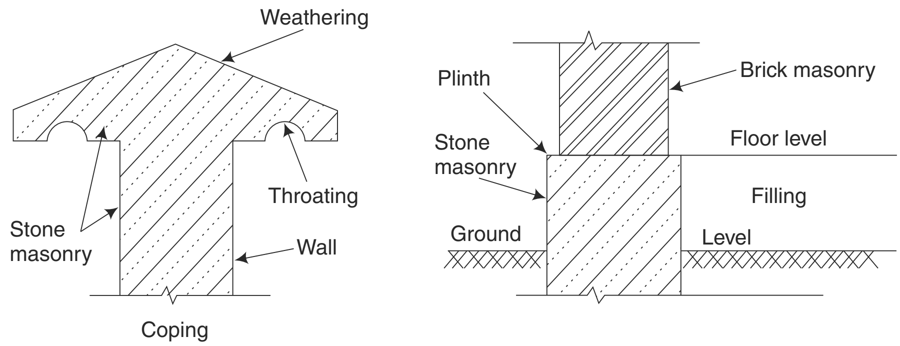


Fig. 5.10 *Technical terms in stone masonry*

5.3.2 Technical Terms

The technical terms in stone masonry are illustrated in Fig. 5.10.

Natural bed The surface on which the materials were originally deposited in the formation of rock is known as natural bed. Rocks, from which stones for masonry are obtained, have distinct planes of division along which stone can easily be split. These planes are the natural beds of the stone.

Plinth Plinth is the projecting course at the ground-floor level. It is used to indicate the height of ground-floor level from ground level. The plinth course protects the interior of a building from rain water, frost, etc.

Course Course is a layer of stones (or bricks). The thickness of a course is equal to the thickness of a stone (or brick) plus the thickness of one mortar joint.

String course String course is a continuous horizontal course of masonry, provided at every floor level. This course remains projecting from the face of the wall. It is intended to improve the elevation of the structure.

Lacing course Lacing course is a horizontal course provided to strengthen a wall of regular small stones.

Quoins Quoins is the external corners or angle of a wall surface. The stone or brick used to form the quoin is known as quoin stone or quoin brick.

Spalls Spalls are stone chips broken off from large-sized stones during dressing and shaping.

Bed joint It is the horizontal joint between two consecutive courses of stone masonry.

Corbel Corbel is a stone piece provided in a wall. It projects partly outside. The projecting stone surface acts as bearing for the structural member such as beam, roof truss, wall plates, etc., resting on it.

Pin header Pin header is a long stone provided vertically in the stone masonry. It ensures a bond between successive courses.

Cornice Cornice is a moulded course of stone masonry. It is placed at the top of a wall or ceiling near the top of the building.

Sill Sill is the bottom surface of a door or a window opening.

Coping Coping is a course of stone, concrete or brick placed on the exposed top of parapet wall or compound wall. It protects the wall from seepage of rainwater through joints at the topmost course of the wall. A coping is suitable weathered and throated.

Throating Throating is a small groove cut on the underside of a still, coping, cornice or sunshade. It is provided to discharge rainwater without trickling down to the walls.

Weathering Weathering is a slope provided to the top surface of stones used for coping, cornice and still to drain off the water immediately.

Through stone or bond stones In stone masonry, some long stones at regular intervals are placed through the full thickness of a wall to develop bond. Such stones are known as through stones or bond stones.

Jambs Jambs are the vertical sides of the openings of masonry for doors, windows, etc Jambs may be plain or splayed or may be provided with the recess to receive the frames of doors and windows.

Reveals Reveals are the exposed vertical surfaces left on the sides of an opening after the door or window frame is fitted in position.

Hearting Hearting is a filled-up core of a rubble wall.

Lintels or heads Lintels are the horizontal stones provided at the top of the openings for doors, windows, etc.

Cramp Cramp is a metal connection used in stone masonry construction.

5.3.3 Classification of Stone Masonry

Stone masonry is classified based on the thickness of joints, continuity of courses and finish of face. The two broad classifications are given below:

1. Rubble Masonry
- (i) Random rubble masonry un-coursed and coursed
- (ii) Squared rubble masonry un-coursed and coursed
- (iii) Polygonal rubble masonry

2. Ashlar Masonry
- (i) Ashlar fine masonry
- (ii) Ashlar rough–tooled masonry
- (iii) Ashlar rock or quarry faced masonry
- (iv) Ashlar chamfered masonry
- (v) Ashlar facing masonry

1. Rubble Masonry

A rubble stone masonry wall is made up of irregular sizes and shapes. The stones obtained from the quarry are broken into small sizes and are directly used in the construction work.

In some cases, these stones may be shaped to suit the requirement, with the help of hammers just by removing excess projections. These stones have rounded natural face or angular faces or angular broken pieces.

Rubble masonry is further classified into three types. They are explained below.

(i) Random Rubble Masonry Random rubble masonry uses stones of irregular shapes. The stones are arranged in a random fashion. The joints are pointes to achieve a good appearance. The efficiency of this type depends on the workmanship of the stone mason.

Random rubble masonry may be either uncoursed or coursed as explained below.

(a) Uncoursed Random Rubble Masonry See Fig. 5.11(a). It is the cheapest type of stone masonry. Stone blocks are not dressed, but used in the masonry as obtained from the quarry. They are of varying sizes and placed in irregular pattern.

The vertical joints are not constructed in plumb. So, no regular courses are achieved. Larger stones are used at the bed level and in the corners. However, at 30 cm to 60 cm height intervals, the stones may be leveled.

Spaces between larger stones are filled with spalls (small stones of irregular sizes) and packed in mortar. Bond stones are used at random intervals. The appearance is not very pleasing.

Uses It is used for compound walls, godowns and walls of unimportant structures.

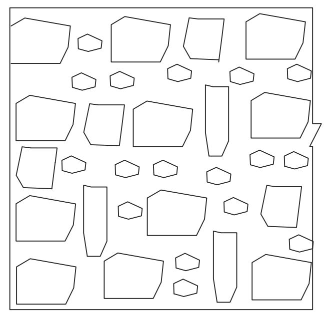


Fig. 5.11(a) *Uncoursed random rubble masonry*

(b) Coursed Random Rubble Masonry See Fig. 5.11(b). In Coursed Random Rubble Masonry, stones of 5 to 20 cm size are used. Stones are hammer dressed.

Stones of equal height are used in every course of the stone masonry. Thus, masonry work is carried out in courses.

The stones are arranged such that the vertical joints of two adjacent courses do not coincide. Through Stones are used at every 2 meter distance in each course to form bond.

Uses This type of masonry is used for residential buildings, industrial buildings, compound walls, warehouses, etc.

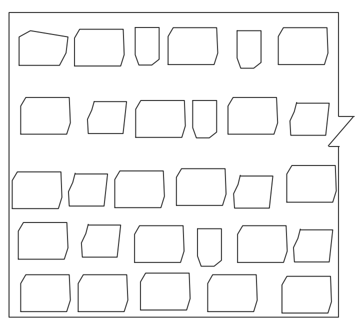


Fig. 5.11(b) *Coursed random rubble masonry*

(ii) Squared Rubble Masonry In squared rubble masonry, the stones are roughly squared with straight edges and sides with hammer blows.

(a) Un-coursed Square Rubble Masonry See Fig. 5.11(c). In this type, the stones are of varying sizes of different heights, but with straight edges and sides. They are laid in irregular pattern. Hence, no regular courses are achieved.

A uniform joint is made in the facing of the masonry for better appearance.

(b) Coursed squared Rubble Masonry See Fig. 5.11(d). This type of masonry also uses the same stones as used for uncoursed squared rubble. But, the work is carried out and leveled in courses of different heights.

Each course may consist of quoins, jamb and bonders.

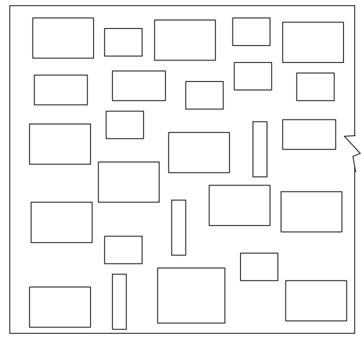


Fig. 5.11(c) *Un-coursed squared rubble masonry*

(iii) Polygonal Rubble Masonry In this type, the stones are hammer finished on the face of the wall to an irregular polygonal shape. These stones are bedded in position to show the face joints, running irregularly in all the directions.

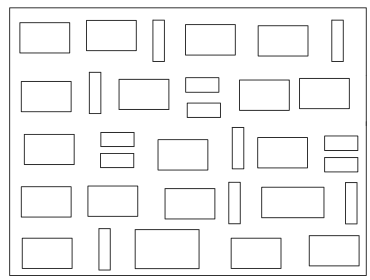


Fig. 5.11(d) *Coursed squared rubble masonry*

2. Ashlar Masonry

In Ashlar Masonry, no irregular stones are used. The entire construction is done using square or rectangular dressed stone blocks of required dimensions. The beds, sides and faces of the stones used in this masonry are all dressed finely with chisel.

The height of stones varies from 25 to 30 cm. This masonry is laid in courses with thin end joints. It is the highest grade of masonry and costly. By arranging stones in various patterns, different types of appearance can be obtained. The backing of ashlar masonry may be built with stone rubble or brick masonry.

(i) Ashlar Fine Masonry See Fig. 5.12. This type of ashlar masonry is very costly. In this masonry, all the stone blocks used should be finely chisel dressed on all the beds, sides and faces.

Height of each course is generally not less than 30 cm. Thickness of mortar joint should never be more than 3 mm. The face stones are laid as headers and stretchers alternatively. For walls having thickness less than

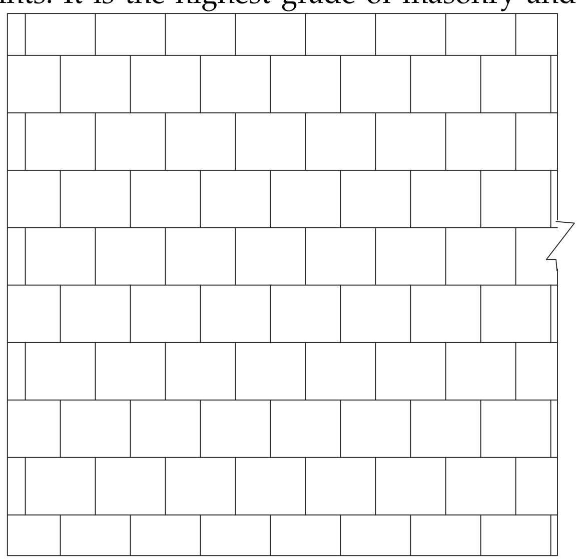


Fig. 5.12 *Ashlar fine masonry*

75 cm. Through stones should be used at suitable intervals at each course for proper bond. This type of masonry gives perfect smooth appearance.

(ii) Ashlar Rough – Tooled Masonry In this type of masonry, the beds and sides of each stone block are finely chisel dressed just in the same manner as for ashlar fine. But, the exposed face is dressed by rough tooling.

A strip about 25 mm wide and made by means of chisel is provided around the perimeter of the rough dressed face of each stone. The thickness of mortar should not be more than 6 mm.

(iii) Ashlar Rock or Quarry Faced Masonry In this type, a strip of 25 m wide, made by means of a chisel is provided around the perimeter of the exposed face of each stone as in the case of rough-tooled masonry.

However, the remaining portion of the face of the stone is left in the same form as received from the quarry. It is not dressed. It is kept as such so as to give rock or quarry facing. Each stone block is maintained to its size with perfect straight sides, faces and beds and truly rectangular in shape. The thickness of mortar joint may be up to 10 m.

(iv) Ashlar Chamfered Masonry This is a special form of rock-faced ashlar masonry. In this masonry, a strip provided around the perimeter of the exposed face is chamfered or beveled at an angle of 45° using the chisel to a depth of 25 m. Due to this, a groove is formed in between the adjacent blocks of stone.

Around this chamfered strip, another strip of 10 mm to 12 mm wide is dressed with the help of chisel. The space inside this strip is kept rock-faced, except the large projections that are removed by a hammer.

(v) Ashlar Facing Masonry See Fig. 5.13. This masonry may be called as a combination of ashlar masonry and rubble masonry. In this type of masonry, only face work is provided with rough tooled or hammer dressed stones. Backing of the wall may be made in rubble masonry or brick masonry or concrete.

The beds and sides except exposed face are dressed perfectly fine and square. Thickness of joint does not exceed 6 mm.

Uses This type of construction is used for heaving engineering works such as retaining walls, sea walls, etc.

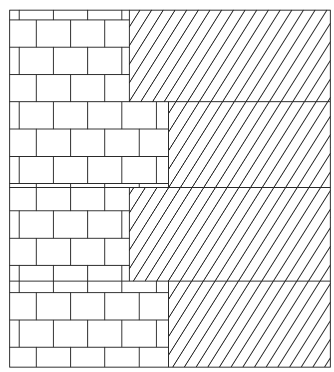


Fig. 5.13 *Ashlar facing masonry*

(vi) Ashlar Block-in-Course Masonry This type of masonry is an intermediate approach between the ashlar masonry and rubble masonry. It is constructed of large stone blocks. The faces of each stone block are hammer dressed. This masonry has regular courses. It is actually coursed rubble masonry of superior variety. The height of the blocks is kept the same in any course, though it is not necessary to keep uniform height for all the courses.

5.3.4 Points to be Observed while Supervising the Construction of Stone Masonry

1. The stones to be used should conform with the requirements of work.
2. The stones should be well watered so that absorption of water from mortar is prevented.
3. Stones are laid on their natural bed.
4. Stone work should be carried out in proper bond with sufficient number of through stones.
5. The mortar should be of good quality.
6. Stone work should be raised uniformly. If a cross wall is to be constructed later, steps should be provided in the wall.
7. Double scaffolding should be used to carry out stone work at a higher level.
8. The vertical faces must be checked with a plumb and inclined surfaces with wooden templates.
9. The stone work should be cured for 2–3 weeks if laid in lime mortar and for 1–2 weeks if cement mortar is used.

5.3.5 Principles of Stone Masonry Constructions

1. ***Quality*** Stones of stone masonry should be hard, strong, tough and durable.
2. ***Dressing*** Proper dressing of stones have to be done according to the type of masonry.
3. ***Natural Bed*** All the stones should be laid on the natural bed only.
4. ***Mortar*** Cement mortar or sometimes rich lime mortar in suitable proportion is used.
5. ***Pressure Acting on the Stone*** Stones in the stone masonry are laid such that the pressure acting on the stones is perpendicular to the natural bed of the stones.
6. ***Tensile load*** Stone masonry work should not be designed to take any tensile load.
7. ***Watering*** Stones should be watered before use to prevent water absorption from mortar.
8. ***Course of stones*** Different courses of stones laid perpendicular to the line of action of pressure on the stones.
9. ***Through Stones*** Through stones should be used sufficiently such that they cover about 15 to 25% of the area in elevation. This is to ensure proper bonding.
10. ***Surface of Stone Masonry*** Surfaces of stone masonry should always be kept wet while the work is in progress and also till the mortar has set.
11. ***Vertical Joints*** Extreme care has to be taken by providing proper bond to prevent formation of vertical joints. Vertical joints should be staggered.
12. ***Lap between Bond Stones*** Bond stones running to full thickness of walls should be used at regular intervals. For thicker walls, the minimum overlap between the bond stones should be 15 cm.

13. ***Facing of Stone Masonry*** Small stone pieces are used for facing of stone masonry.
14. ***Hearting*** Hearting of masonry should be properly packed with stone chips and mortar.
15. ***Verticality*** Verticality of faces of stone masonry walls are checked with a plumb Rule.
16. ***Inclined Surfaces*** Inclined surfaces should be checked with wooden templates.
17. ***Unequal Settlement*** Stone wall should be raised uniformly throughout its length. It will avoid possible unequal settlement.
18. ***Future Work*** If a cross wall is to be built later, steps should be provided in the wall.
19. ***Voids in Masonry*** Voids in stone masonry should not be dry-packed or filled with small size aggregates. Instead, they should be well-packed with large aggregate and mortar.
20. ***Stepped Raking*** Unfinished end of stone masonry should be raked back. This stepped raking develops proper bond between the old and the new works.
21. ***Curing*** After the construction is over, the whole masonry work should be kept cured for two to four weeks.
22. ***Double Scaffolding*** Double scaffolding should be used to carry out stone work at a higher level of the structure.

Table 5.1 Comparison of brick masonry with stone masonry

Sl.No	*Aspects*	*Brick Masonry*	*Stone Masonry*
1.	Availability	Bricks are manufactured using clay	Stones are available in nature and obtained from quarries.
2.	Handling	Handling is easy	Handling is difficult
3.	Labour	Semi-skilled labour is needed	Skilled labour is necessary
4.	Strength	Reasonably good compressive strength	Very high compressive strength
5.	Durability	Reasonably durable and moderate long life	Highly durable and long lasting
6.	Maintaining the Bond	Made to regular size and shape. Due to this, proper bond can be maintained.	Stones require dressing for maintaining the bond.
7.	Quantity of Mortar required	Less	More
8.	Plastering	Plastering is needed	Plastering is not done.
9.	Moisture Absorption	Absorbs moisture from atmosphere	Stones are watertight
10.	Mortar Joint	Thin and uniform	Thick
11.	Wall Thickness	Thinner walls can be constructed	Difficult to construct walls of thickness less than 30 cm
12.	Openings and Connections	Construction of openings and connections are easy	Dressing of stones is required to achieve this

Contd.

Contd.

13.	Cost of Construction	Less	High
14.	Maintenance Cost	More	Less
15.	Architectural Treatment	Less Suited	Amenable to architectural treatment
16.	Fire Resistance	Highly Fire Resistant	Reasonably resistant to fire
17.	Dead Load	Dead load of walls is less	Dead load is more
18.	Special Lifting Devices	Not Needed	Needed
19.	Appearance	Elegant appearance. Used in residential, commercial buildings, etc.	Massive appearance, hence used for monumental works, temples, bridges, etc.

5.4 RCC STRUCTURAL MEMBERS

Nowadays, plain and RCC structural member like foundation, beams, columns, lintels, roofs, etc. are abundantly used in the construction of all types of buildings. This type of construction has withstood the test time. Its advantages are manifold. It is highly durable, strong, economical, quickness in construction, improved appearance, etc. Different types of finishes can be given to concrete.

5.4.1 Beams

Beams are horizontal members of a structure, carrying transverse loads. Beams carry the floor slab or the roof slab. They transfer all the loads (the dead load and live loads) including its self weight to the vertical members of the structures. The vertical members may be columns or walls supporting the beams. Ultimately, the loads from the columns or walls are transmitted to the foundation. From the foundation, the loads are safely transmitted to the sub-soil.

The RCC beam is subjected to bending moments and shear. Due to the vertical external load, bending compresses the top fibres of the beams and elongates the bottom fibres. The strength of an RCC beam depends on the composite action of concrete and steel. Since concrete is strong in compression and weak in tension, reinforcing main steel bars are embedded in the tension zone to give the required tensile strength. Concrete takes all the compressive stresses and main steel bars take all the tensile stresses.

In addition to the main reinforcement, vertical shear bars called stirrups are provided to withstand shearing forces.

Beams may be termed simple beams when the end connections do not carry any end moments due to any continuity developed by the connection. A beam is continuous when it extends across more than two supports and is called a fixed beam if the ends are rigidly attached to other members so that a moment can be carried across the connection. Beams may be classified as follows.

Girders Main load carrying members into which floor beams or joists frame.

Joists Members used to carry roofing and floors of buildings.

Lintels Beam members used to carry wall loads over wall openings.

Spandrels Exterior beams at the floor level used to carry part of the floor load and the load due to exterior walls.

Stringers Members used in bridges parallel to the traffic to carry the deck slab and commonly frames into transverse members.

1. Floor Beams

These are the secondary members of a floor system in a building and the main members in bridge construction into which stringers frame. In most cases for maximising economy, a rolled steel shape is used so that the bending is about the strong axis. Beams can be of steel, concrete, timber or stone; generally, steel and concrete are used.

In case of the reinforced concrete beam, due to the vertical external load, bending compresses the top fibres of the beam and elongates the bottom fibres. Concrete being weak in tension needs to be strengthened to take up the tension induced in the bottom fibres. Hence steel rods are added to concrete at places where tension is induced thereby making the beam strong in compression as well as in tension.

Beam loading will consist of both dead and live loads. Where the span is small and the external load is light, the beam weight may be quite small. When heavy beams are used for large spans, their self-weight may be significant. In any case, the designed section should always be checked for adequacy for the applied loads, and the self-weight of the beam.

2. Types of Beams

Depending on the support, a beam may be of any one of the following types:

1. Simply supported beam
2. Fixed beam
3. Cantilever beam
4. Continuous beam
5. Overhanging beam

(i) Simply Supported Beam A beam supported freely at the two ends on walls or columns is called a simply supported beam. It is important to note that in actual practice, no beam rests freely on the supports (walls or columns) without fixing on the supports. Hence, no beam is practically simply supported. End connections (supports) do not carry any end moments due to the non-continuity developed by the connections of beam and supports.

(ii) Fixed Beam In a fixed beam, both the ends of the beams are rigidly fixed or embedded into the supports (walls or columns). Main reinforcement bars and shear bars (stirrups) are placed as in the case of simply supported beams.

Here, bending is constrained at the supports. A moment can be carried across the end connections.

(iii) Cantilever beam When a beam is fixed in a wall or column at one end and the other end is free, it is called a cantilever beam. This type of beam has tension zone in the top side and a compression zone in the bottom side.

Uses Cantilever beams are used to support slabs projecting outside the wall or column. Examples are portico, balcony, etc.

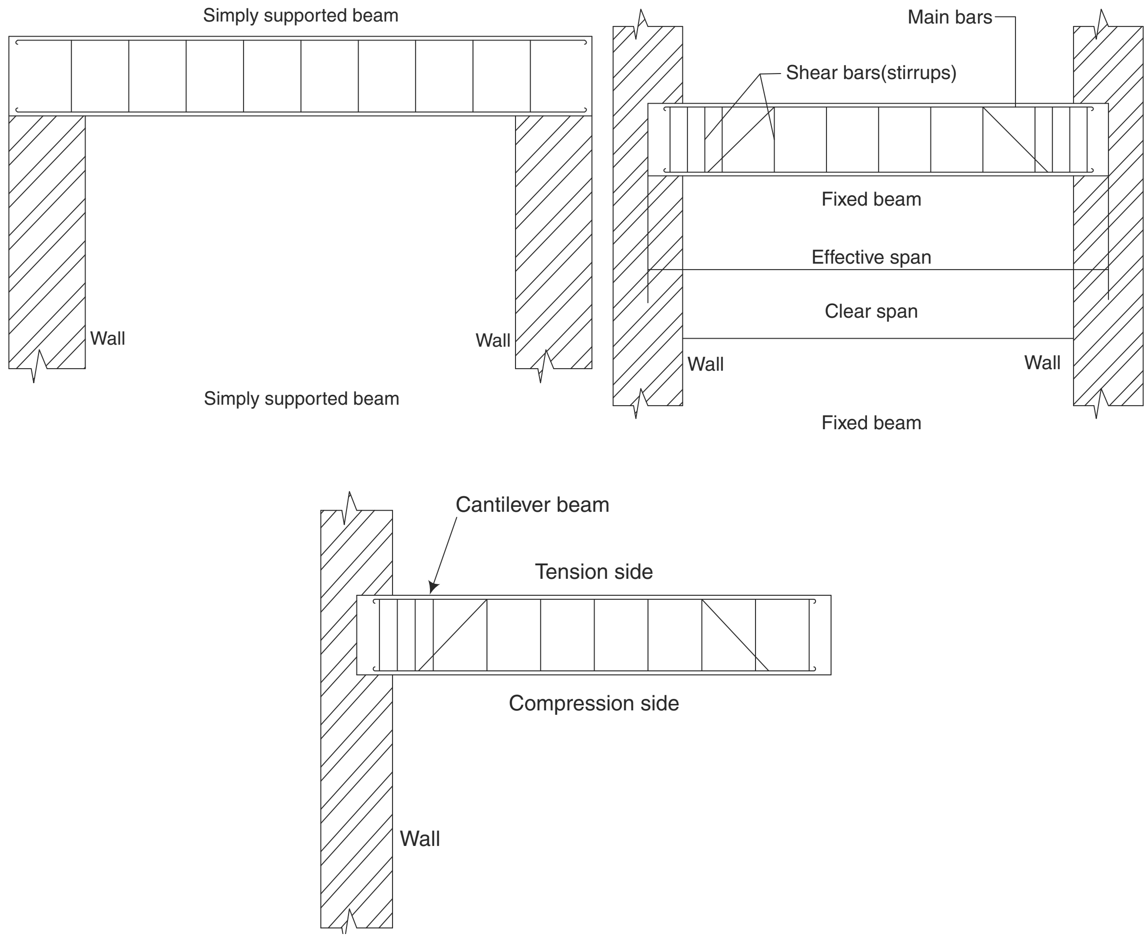


Fig. 5.14 *Cantilever beam*

(iv) Continuous Beams

A beam is said to be continuous beam when it is supported on more than two supports. This beam is more economical for any span lengths.

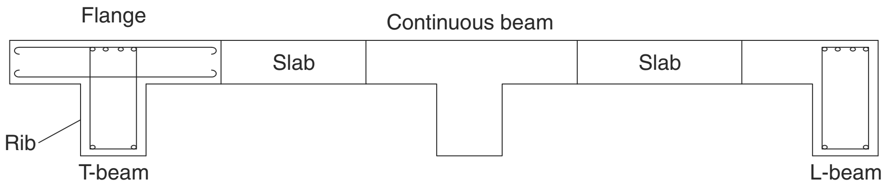


Fig. 5.15 *Cantilever beam*

T-Beam As the name suggests, the section of this beam is in the shape of 'T'. The design concept of a T-beam is the monolithic action of the slab with the flange and rib portions of the beams. A T-beam is developed when a slab is cast monolithically with the beam and the slab extends on both the sides of the beams.

L-Beam An L-beam is developed when a slab extends on one side of the beam only and is monolithic. L-beams are used at the end walls of a room.

(v) Overhanging Beam

In an overhanging beam, its end extends beyond the wall or column support. The overhanging of the beam is the unsupported portion of the beam. It may be on side or both the sides of the support.

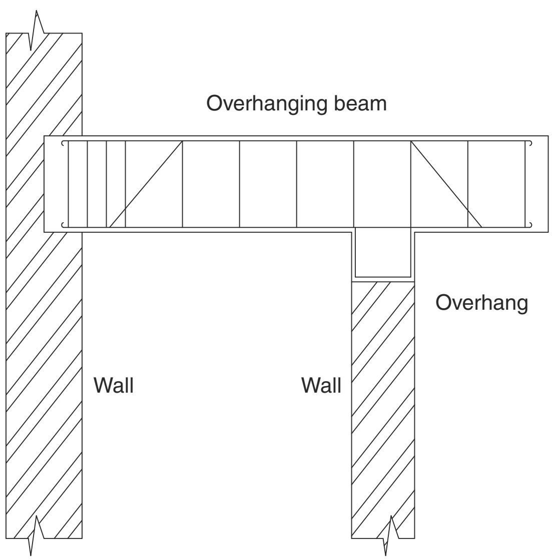


Fig. 5.16 *Overhanging beam*

Depending on the reinforcement, a beam may be classified as follows:

(i) Singly reinforcement beam

If the main reinforcement of steel bars are provided only on one side of the beam, it is known as singly reinforcement beam.

(ii) Doubly reinforcement beam

If the main reinforcement of steel bars is provided both at top and bottom (tension and compression zones) of the beam, it is known as a doubly reinforced beam. See Fig. 5.17(b).

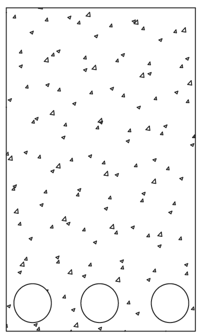


Fig. 5.17(a) *Singly reinforced beam*

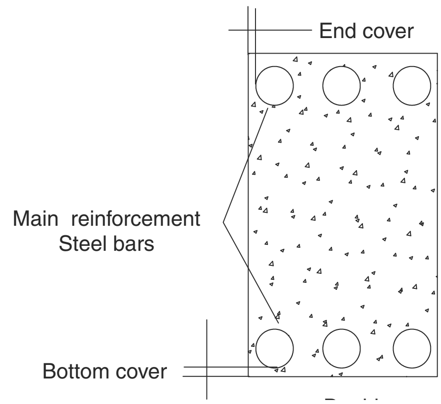


Fig. 5.17(b) *Double reinforced beam*

Concrete covers Main bars are placed uniformly along the perimeter of the column leaving required covers. Concrete cover is the distance between the outer surface of the member and the nearest point of reinforcement.

Bottom cover and End cover The minimum bottom cover to be provided in the beam is 25 mm or the diameter of the bar, whichever is more. The end cover is 25 mm or twice the diameter of the bar, whichever is more.

Types of Loading on Beams

See Fig. 5.18(i), (ii), (iii) and (iv).

Loading on a beam may be different types. They are

(i) Concentrated loads
(ii) Uniformly distributed loads
(iii) Uniformly varying loads
(iv) Arbitrary loading

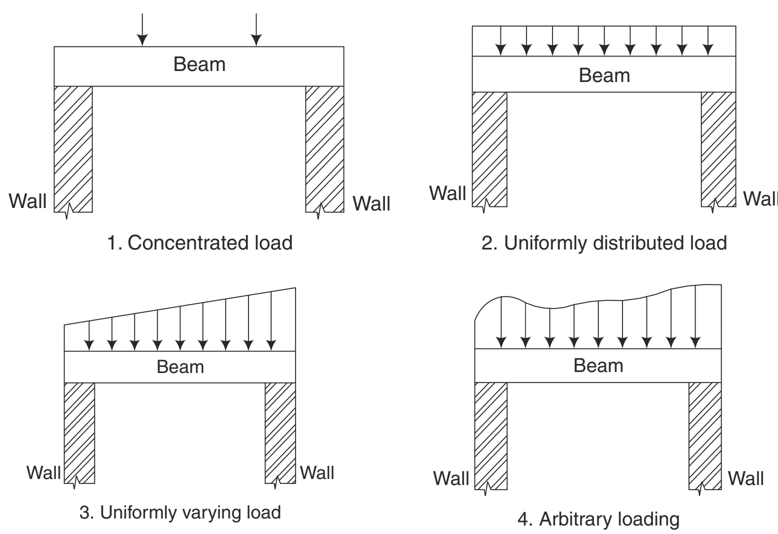


Fig. 5.18 *Types of loading on beam*

Steel Beams

Steel beams are generally rolled steel I-sections. I-sections with cover plates may be used when a large modulus of section is required. An I-section may be split and rejoined by welding and used for beams with large spans and light loads. Such a beam is more resistant to bending as the modulus of the section is increased.

An I-section along with a channel section is used when the beam is subjected to lateral loads at the compression flange level of the section.

5.5 COLUMNS

A column is a vertical structural member. It transmits the load coming from the slab (ceiling/roof) and beam, including its self-weight to the foundation of the building. Columns may be subjected to a pure compressive load (axial compression) or a combination of compressive load and bending moment. A structural member subjected to an axial compressive load is known as strut.

Compression member in a truss may be known as chord members or web members, depending on their truss location. Columns may also be called by various other names, such as braces or struts.

5.5.1 Classification of Columns Based on Dimensions

Failure depends on the length of the member compared to its cross-sectional dimensions. Based on their length, the columns can be classified as long or short.

$$\text{If } \frac{l_{\text{eff}}}{a} \leq 12, \quad \text{it is a short column, and}$$

$$\text{If } \frac{l_{\text{eff}}}{a} > 12, \quad \text{it is designated as a long column}$$

where

l_{eff} is the effective length of column which depends on the conditions of the end support, and

a is the least lateral dimension of the column or diameter of column in case of circular columns.

A short column is one in which the ultimate load at a given eccentricity is governed only by the strength of materials and the dimensions of the cross-section. A slender or long column is one in which the ultimate load is also influenced by slenderness, which produces additional bending because of transverse deformations. Thus we see, for short columns, the failure load is characterised by yielding and for long columns by buckling or instability. Members with lengths that fall between short and long columns are called intermediate columns. These fail by both yielding and buckling.

5.5.2 Classification Based on Materials of Construction and Shape

1. RCC Columns

If the effective length of a compression member is equal to or less than thrice the least lateral dimension, the member is made of plain cement concrete. If the effective length of a compression member is more than thrice the least lateral dimension, the member should be reinforced.

Reinforced concrete columns are of square, rectangular or circular cross sections. The load carrying capacity of the column depends on the strength of concrete and steel. If the percentage of steel used is less in a column, the steel will reach its yield strength prior to concrete. The column will not fail since it can take more load at this stage. Due to this increase in load, steel will yield and the concrete will reach its full strength. Hence, the strength of the entire material is utilised. On the other hand, if the percentage of steel used is large, then concrete fails first and the failure will be spontaneous.

Uses RCC columns are used in multi-storeyed buildings and heavily loaded structures. RCC columns are very widely used now-a-days.

2. Steel Columns or Stanchions

Steel columns are also known as stanchions. These are widely used in industrial structures. Steel columns are fabricated using rolled steel joists, channels, angles and plates.

A steel column is a vertical compression member. It supports or girders in a building. A girder is a main load carrying member into which floor beams or joists are connected. Joists are beam members, which are used to carry floors and roofs of buildings of light loads supported on long columns.

The shape of the cross section of the steel section and the sectional area should be designed carefully to avoid buckling. The important property required for a compression member is a high value of moment of inertia. I-sections, tubular sections and two equal-angle steel sections may be used for light loads. Single-angle sections should be avoided for steel columns.

5.5.3 Built-Up Sections for Steel Columns

When two or three steel sections of rolled sheets and plates are connected to form a column, it is known as a built-up column or box column. See Fig 5.19(a). Built-up sections are compression structural members with wide flanges. Hence, these are used for heavy loads. The type of built-up section to be used depends on the type of structure and the end connections of the columns.

Steel compression members are pipes of circular, square or rectangular cross-sections and sections such as angles, channels, T or I-sections. These may also be built up of rolled sheets and plates. The kind of compression member to be used depends on the end connections and type of structure.

Built-up sections for commonly used compression members are shown in Fig. 5.18(a). The pipe or round tubing shown in Fig. 5.19(b) may be used for columns in one-storey warehouses, super markets and residential basements and garages. Wide-flange shapes are commonly used as building columns. Single channels can be used as compression members if intermediate bracing is provided in the weak direction. Angle and T-sections are used mainly as bracing members and compression members in trusses.

Columns can also be made of timber and masonry, which are not often used.

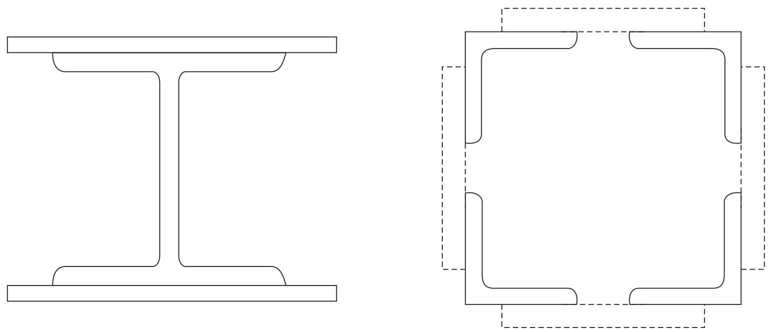


Fig. 5.19(a) *Built-up sections for columns*

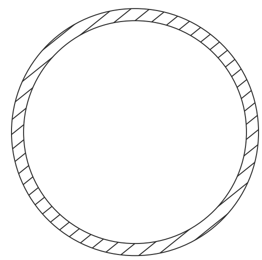


Fig. 5.19(b) *Column pipe*

5.6 LINTELS

A lintel is a horizontal member which is placed across an opening to support the portion of the structure above it. The function of a lintel is same as that of a beam. Lintels may be of wood, steel, brick, stone and reinforced cement concrete. Each type is briefly explained in this section.

1. Wood Lintel A single piece of timber can be used as a lintel or three pieces bolted together along the thickness of the wall can be adopted. A bearing of 150–200 mm should be provided on the wall and it should be placed on mortar. The width is equal to the thickness of opening and depth should be about 1/12 to 1/8 of the span with a minimum of 80 mm.

Wood lintels are liable to be destroyed by fire and decay. They are comparatively weak. Wood lintels help in securing heads of frames of timber doors and windows.

2. Stone Lintel Slabs of stones are placed across the openings. If stones are used as lintels, relieving arches are to be provided since stones have low tensile resistance. The depth of stone lintel should be at least one mm per one cm length of the opening.

3. Brick Lintel A temporary wood support known as turning piece is used to construct a brick lintel. The depth of the lintel must be some multiple of brick courses. Brick lintel is weak and hence used up to 1 m span with light loading.

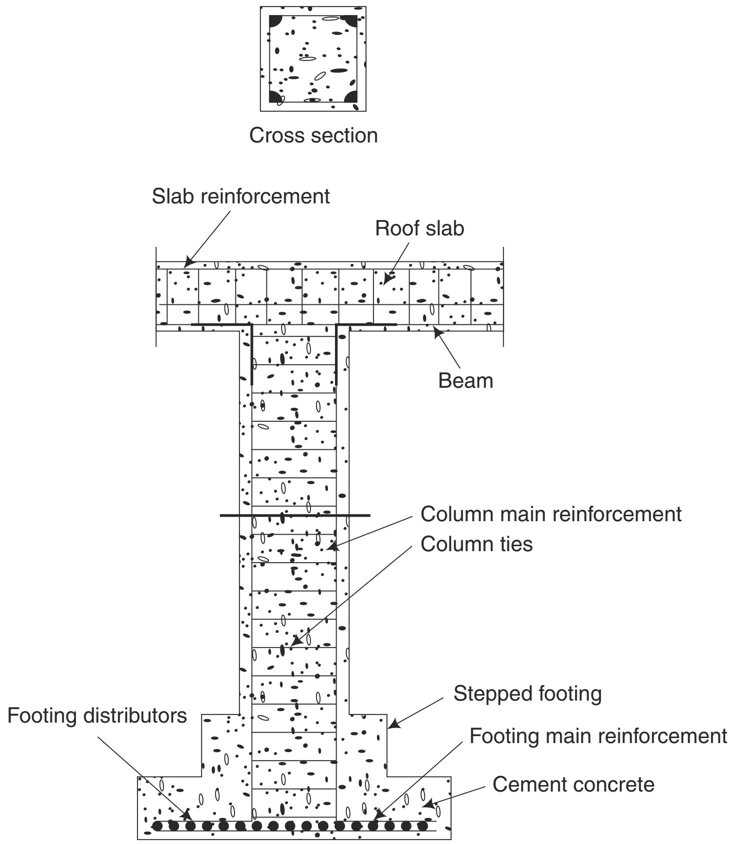


Fig. 5.19(c) *Reinforced concrete column (Longitudinal section)*

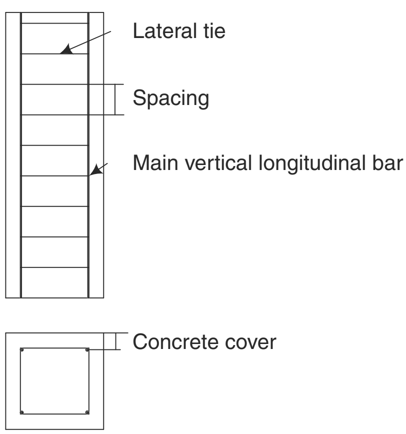


Fig. 5.19(d) *Square RCC column (Square Tie)*

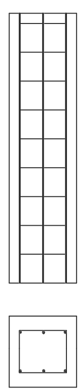


Fig. 5.19(e) *Rectangular column (Rectangular Tie)*

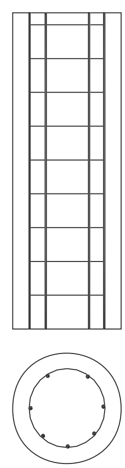


Fig. 5.19(f) *Circular column (Circular Tie)*

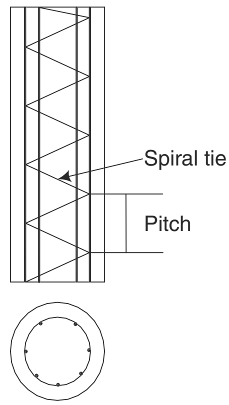


Fig. 5.19(g) *Circular column(Spiral Tie)*

4. Steel Lintel This lintel consists of steel angles or rolled steel joists. The former is used for small spans and the latter for large spans. Tube separators are provided to keep the joists in position. Joists are embedded in concrete to protect steel from corrosion and fire.

5. Reinforced Cement Concrete Lintel RCC has replaced practically all other materials for lintel. RCC lintels are fire-proof, durable, strong and easy to construct. The usual concrete mix used for lintel is 1:2:4. Plain concrete lintels can be used up to a span of 800 mm. The amount of reinforcement depends upon the span.

RCC lintels can be precast or cast-in-situ. Precast RCC lintels are convenient for spans up to 2 m. Also, they increase the speed of construction and allow sufficient time for curing before fixing. The top of the lintel should be properly marked with tar or paint so that the lintel can be placed correctly. For cast-in-situ RCC lintels, centering is prepared, reinforcement is placed and concreting is done. Sunshades can be easily projected from the lintels.

Where appearance is not important, the surface of RCC lintel is left exposed. Figure 5.20 shows a lintel over a wall. Flexible DPC must be provided and the toe of the lintel should be strong enough to bear the load of wall above it.

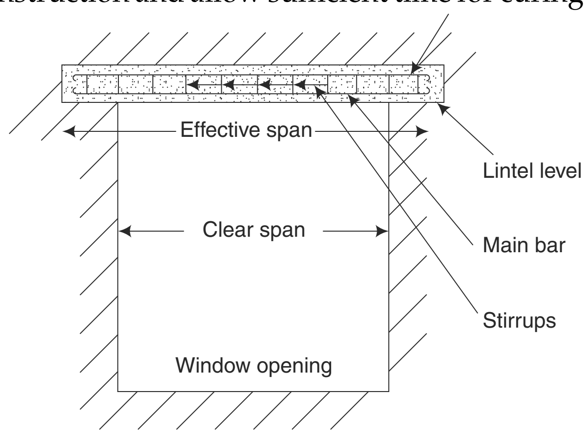


Fig. 5.20 *Reinforced concrete lintel*

5.7 ROOFING

A roof is the uppermost part of a building which is supported on structural members and covered with roofing materials to give protection to the building against rain, wind, heat, snow, etc.

A good roof is just as essential as a safe foundation. A roof must be designed and constructed to meet the requirements of different climates and the covering materials available. A roof should be durable and stable, strong enough to take the loads coming on it, be well drained and waterproof.

5.7.1 Types of Roofs

The roofs are classified according to shape, span and structural design principles as follows:

1. Flat roofs	(a) RCC roof	(b) Madras terrace roof	
2. Sloping or pitched roof	(a) Single roof	(b) Double roof	(c) Trussed roof
3. Curved roofs	(a) Shell roof	(b) Dome roof	

5.7.2 Flat Roofs

Flat roofs are used in buildings of any shape. They are economical too. They are suitable for buildings in plains or in hot regions, where rainfall is moderate and where there is no snowfall.

Flat roofs are two types, namely, RCC roofs and Madras terrace roof.

RCC Roofs

An RCC roof is commonly and most widely used. In this roof, concrete with steel reinforcement bars is used to form a flat roof.

An RCC roof consists of an RCC slab, built monolithically with the supporting columns. The slab is reinforced in both the principal directions. Load is carried by the slab, which is directly supported by the columns.

The thickness of the roof slab depends on the span and loading conditions. (An RCC beam may also be provided to support the slab. The thickness of the roof slab, beam and reinforcement are designed based on the roof and the loading conditions.) The roof-slab thickness may be 80 to 150 mm.

Columns are provided with enlarged heads known as column heads. To support heavy loads, the thickness of the slab over the columns may be increased. The thickened part of the slab is called a drop panel.

Damp-proof Course

It prevents entry of moisture (dampness) due to a leaking roof. Weathering course or weathering-proof course is provided on the top of an RCC roof to prevent the roof from the weathering agencies like sun, rain, wind, and snow. Also, it minimises the heat radiation into the room below the roof.

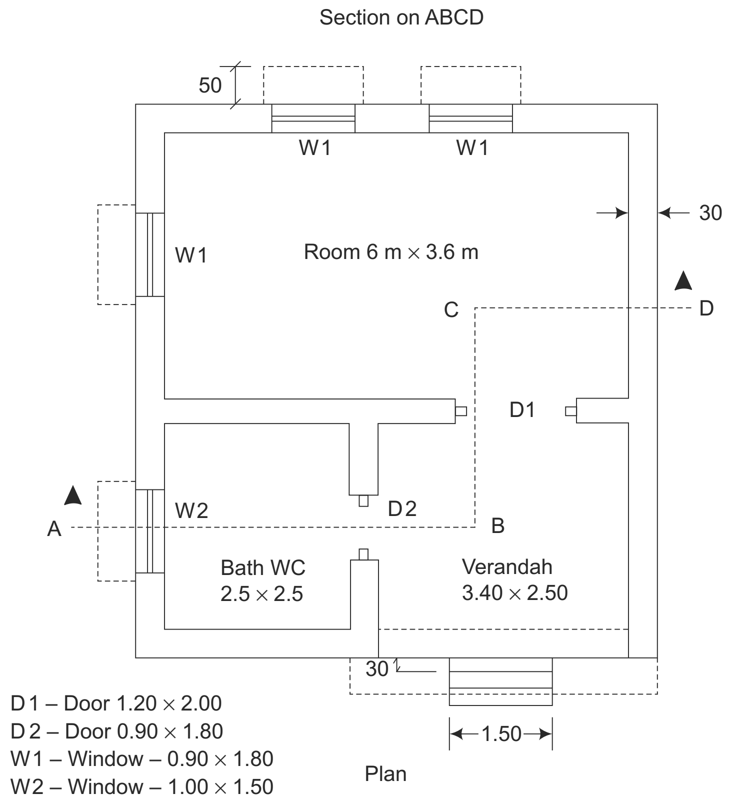


Fig. 5.21 *A section of an RCC roof*

Surki concrete (broken brick aggregate and lime) is laid on the roof and completed well. The thickness of the weathering course is 75 mm. It is given with a slope of 10 (1 in 50 slope), directed towards the rainwater drain pipes.

After curing for 6 days, two courses of flat tiles or one course of pressed tiles may be laid in a cement mortar ratio of 1:3 mixed with crude oil.

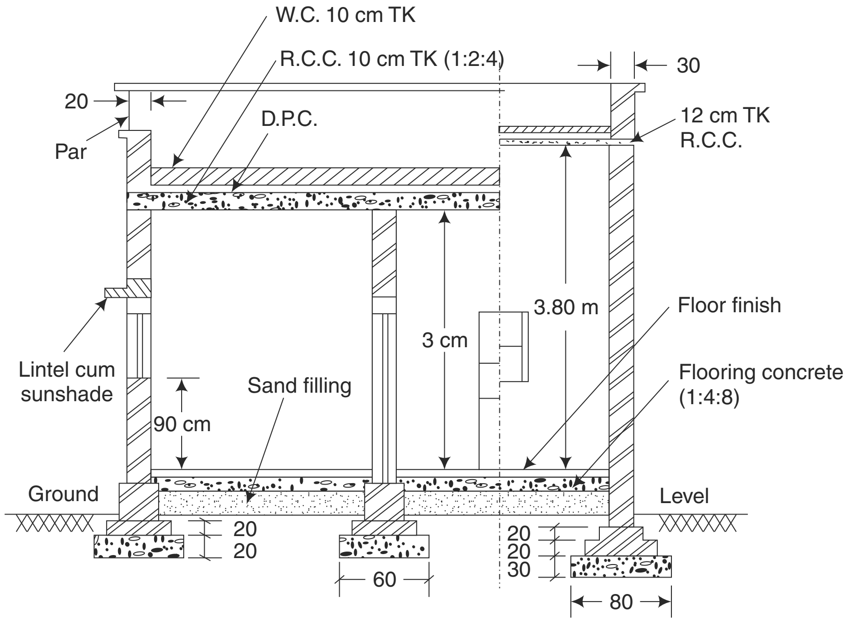
Construction of Flat RCC Roof Details

Centering Centering sheets or planks are arranged horizontally at the top levels of wall over the wooden are steel supports.

Grid of steel bar Main reinforcement mild steel bars of diameter 9 m to 18 mm are tied in the form of grid of the centering sheets as per design.

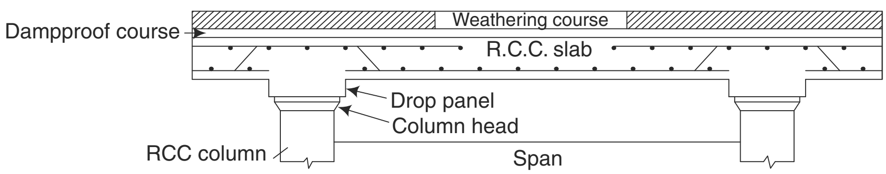
Cover RCC slab bends downwards, causing tension at the bottom fibres. Hence, steel bars are placed at the bottom of slab, keeping a minimum clear cover of 15 mm between the bars and centering sheets.

Mixing cement concrete Cement concrete of 1 : 2 : 4 mix is mixed thoroughly with sufficient quantity of water manually or in concrete mixer and placed on the centering sheets.



(a)

Fig. 5.22(a) *RCC roof on the wall*



(b)

Fig. 5.22(b) *RCC roof on columns*

Compaction of the concrete The concrete is compacted well manually or by using mechanical vibrator to the required thickness and the top surface is levelled.

Slope of the roof Surface of the roof at the top of the building is given a gentle slope up to 10° for draining- off rain water easily and rapidly.

Curing Curing is carried out for one or two weeks to facilitate continued hydration of cement.

Long spans and T-beam slab For long spans a 'T' beam is developed by casting the roof slab monolithically with the beam and the slab.

5.7.3 Steel Roof Trusses — Sloping Roof

Truss is a pin-jointed frame made of axially loaded members. Steel trusses are used for pitched roofs especially in industrial buildings. Steel trusses are normally adopted for spans greater than 12 m. Concrete trusses are rarely adopted since these are weak in tension. Steel trusses are less massive when compared to concrete but need frequent maintenance as they are liable to be rusted. They must be painted with anti-corrosive paints. Steel trusses are adopted in bridges also. There are various types of trusses out of which the common types are shown in Fig. 5.23.

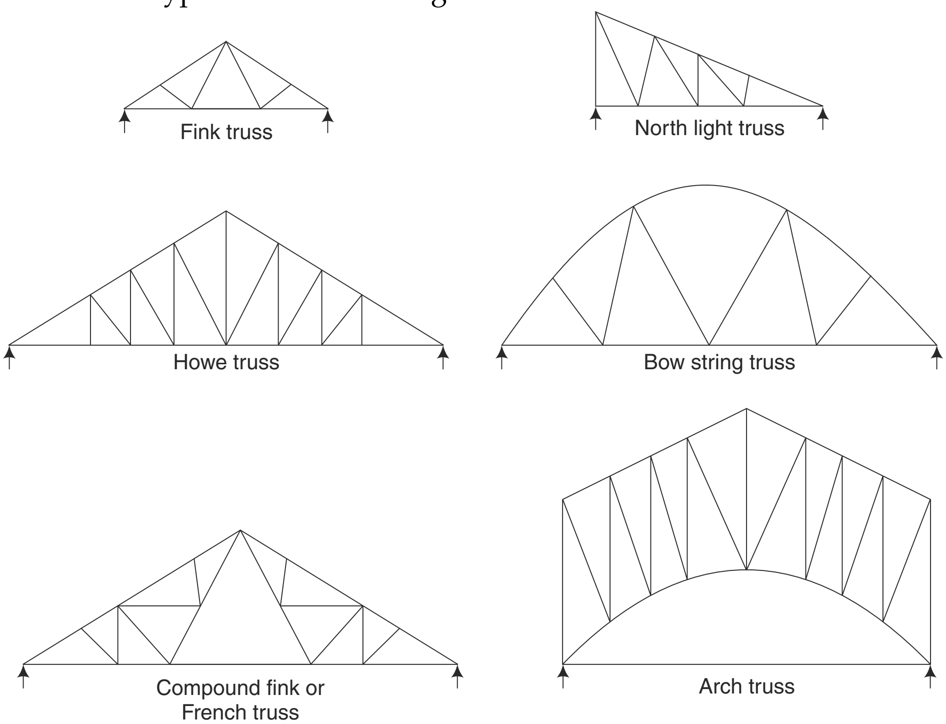


Fig. 5.23 *Various forms of trusses*

A sloping roof has a top sloping surface known as a pitched roof. Sloping roof or pitched roof is commonly used at places of coastal regions of heavy rainfall and snow fall. These are comparatively light in weight. Shapes of sloping roofs depend on the area to be covered, material used, light and ventilation needed, etc.

1. Terminology

(i) Span Span is the distance between the supports of a roof or truss.

(ii) Pitch Pitch is the inclination of the sides of a roof to the horizontal.

(iii) Rafter Rafter is an inclined wooden member running from the ridge to eave.

(iv) Wall plate Wall plate is placed at the top of the walls to support the rafter.

(v) Eave board It is fixed along the eave joining the pair of rafters.

(vi) Ridge piece Ridge piece is a horizontal member, running along the length of the roof.

(vii) Battens Battens are small sections of the timber fixed to the rafters for placing the roofing material on the sloping roof.

(viii) Purlins Purlins are horizontal members kept over the tie beam to support the rafters.

(ix) Truss Truss is a framework of triangles, used to carry the load of the roof-covering materials and other members of the roof.

2. Sloping Roofs are Classified as

- Single roof
- Double or Purlin roof
- Trussed roof

(i) Single Roof

Single roofs consist of only common rafters, supporting the roofing material. Rafters are supported at the wall plates and rigid pieces. Single roofs are used for spans up to 5 m, so that no intermediate support is required for the rafters.

The varieties of single roofs are (a) lean-to-roof, (b) coupled roof, (c) coupled close roof, and (d) collar roof.

(a) Lean-To-Roof

See Fig. 5.24. A lean-to-roof is the simplest type of sloping roof. It is used for verandahs, car sheds, out-houses, etc., attached to the main buildings. This roof projects from the main wall of the building. Its span is limited to 2.5 m only.

Common rafters are provided at an angle of about 30° to the horizontal. These are kept at uniform intervals along the length of the roof. These are secured on the wall plates at both the ends. The upper wall plate rests on stone or steel corbel on the main wall.

Battens (wooden) are fixed to the rafter. Roof coverings are fixed to the battens as shown. Roof coverings may be AC sheets or tiles.

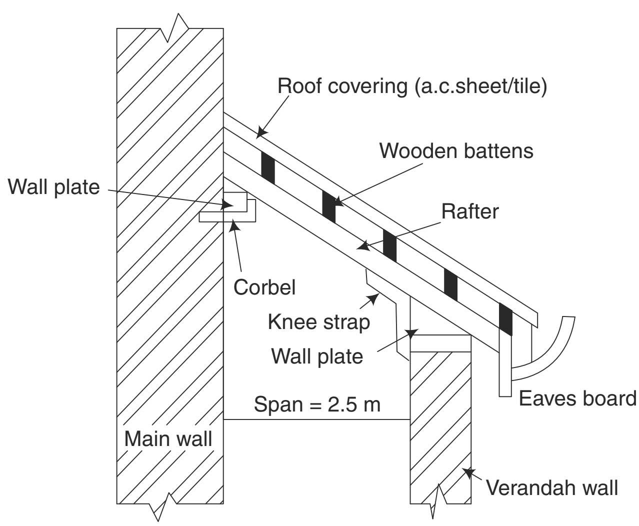


Fig. 5.24 *Lean-to roof*

(b) Coupled roof

See Fig. 5.25. In a coupled roof, a pair or coupled of rafters slope upwards from the walls. The rafters are kept at uniform intervals along the length of the roof. The rafters are connected at the upper end to a longitudinal beam called the ridge piece. The ridge piece is running along the length of the roof.

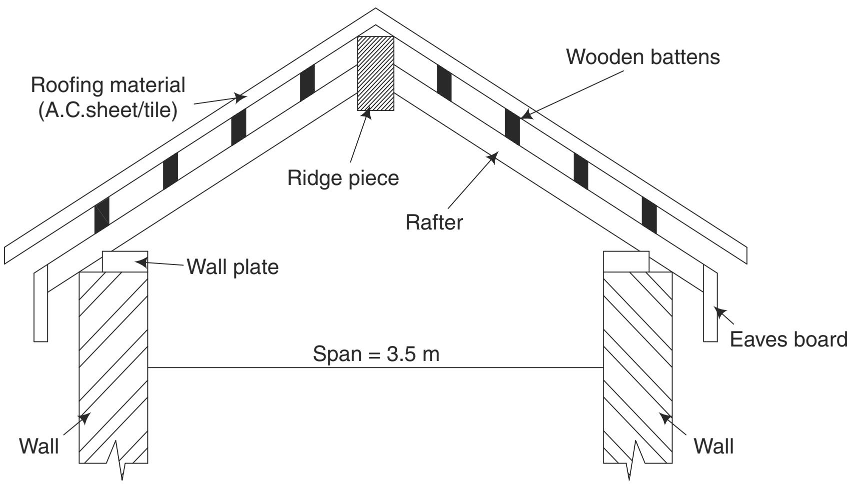


Fig. 5.25 *Coupled roof*

The rafters are nailed to wall plates at the lower ends. The wall plates are fixed on the supporting walls. The roofing materials such as AC sheets or Tiles are supported on battens, which are fixed to the rafters. Coupled roof is suitable for spans up to 3.5 m. It is not favoured, as the rafters have a tendency to spread out at the lower ends and thrust out of the wall.

(c) Coupled close roof

See Fig. 5.26. This is similar to the coupled roof except that, the lower ends of the rafters are connected to a tie beam at the bottom. There is a tie beam for each pair of rafters.

When the length of the rafters becomes larger, the rafters will have a tendency to spread out and thrust out of the walls. The tendency of spreading out of rafters can be arrested with the tie beam. Such a roof is called a coupled close roof. A coupled close roof is suitable for spans up to 5.5 metres.

(d) Collar beam roof

See Fig. 5.27. This is similar to the coupled close roof. The only difference is that the tie beam is fixed at a height of 1/2 to 1/3 of the vertical height between the wall and the ridge piece. This raised beam is called a collar beam.

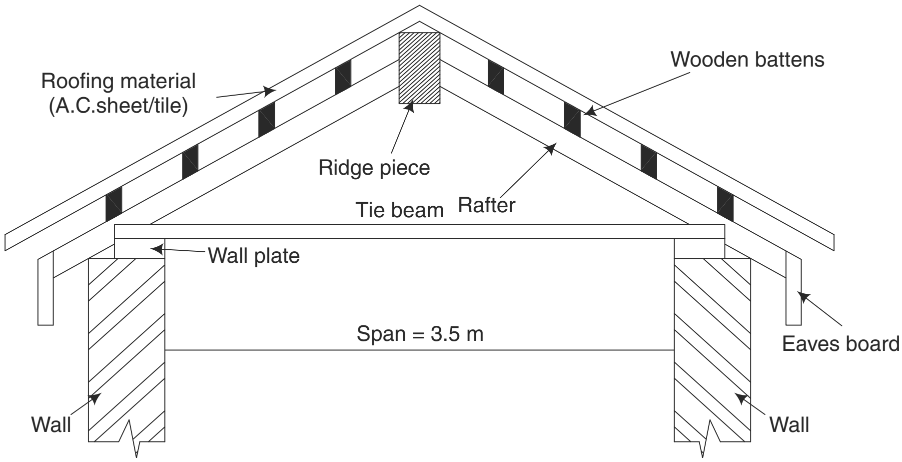


Fig. 5.26 *Coupled close roof*

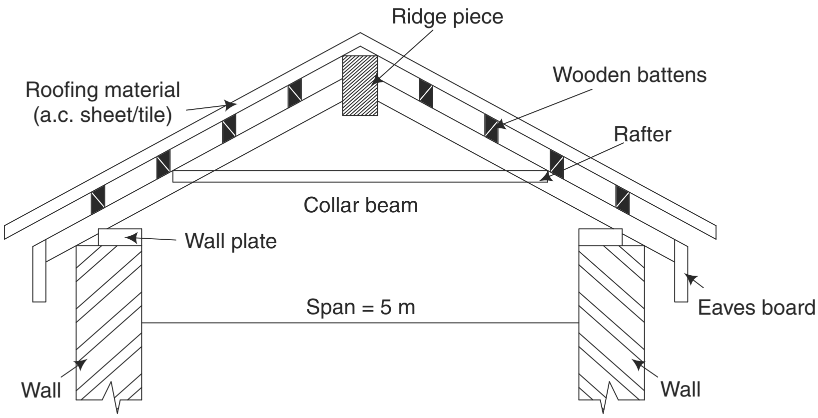


Fig. 5.27 *Coupled tie roof*

The tie beam is raised to prevent the coupled close roof from bending due to increase in span or increase in load. This roof is suitable for spans of up to 5 metres.

(ii) Double or purlin roof

See Fig. 5.28. In this type, additional members called purlins are provided at intermediate points. Purlins support the common rafters. The size of rafters can be reduced by the use of purlins. Purlins rest on the collar beam.

This roof is suitable for spans of up to 3.5 metres. Each rafter is supported at four points, namely, (i) at the bottom on the wall, (ii) at the top by the ridge piece, (iii) at the centre by the collar beam, and (iv) at the intermediate supports by purlins.

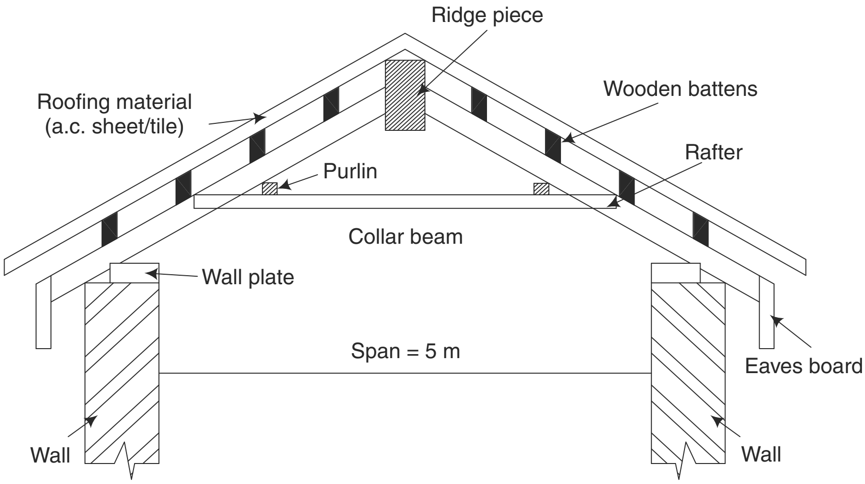


Fig. 5.28 *Double or purlin roof*

(iii) Trussed roofs

A number of straight members connected in the shape of triangle and forming a frame is known as *truss*. Trusses are wooden-framed structures, provided where there are no inside walls to support the purlins.

Trusses are provided at regular intervals of about 3 metres along the room length. The spacing of trusses depends upon the load on the roof, position of cross walls, span and material of the truss.

Ends of purlins are supported by the trusses. The purlins provide intermediate support to the common rafters, which in turn support the roof coverings. Trussed roofs are used for spans exceeding 5 metres.

5.7.4 Definitions

(i) **Ties** Tension carrying members in the truss are called ties.
(ii) **Struts** Compression members in the truss are called struts.
(iii) **Span** The distance between the supporting ends of a truss is called its span.
(iv) **Rise** The rise of the truss is the vertical distance between the apex and the line joining the supports.
(v) **Pitch** The ratio of the rise to the span is called the pitch.
(vi) **Purlins** Purlins provide intermediate support to the common rafters.

The common types of trussed roofs are

(a) King-post truss
(b) Queen-post truss
(c) Steel-roof truss

(a) King-post truss

See Fig. 5.29. A king-post truss is a timber truss. It consists of a king post at the centre, two inclined struts, two inclined principal rafters and a tie beam at the bottom. The vertical central post which connects the ridge piece with the tie beam is known as the king-post truss.

The truss rests on a bed block of stone or concrete at either end. The bed blocks rest on walls. The roofing material is supported on common rafters. The common rafters are supported on wooden purlins provided at suitable intervals. Purlins are supported by the principal rafters. The king post connects the ridge piece and the middle of the tie beam.

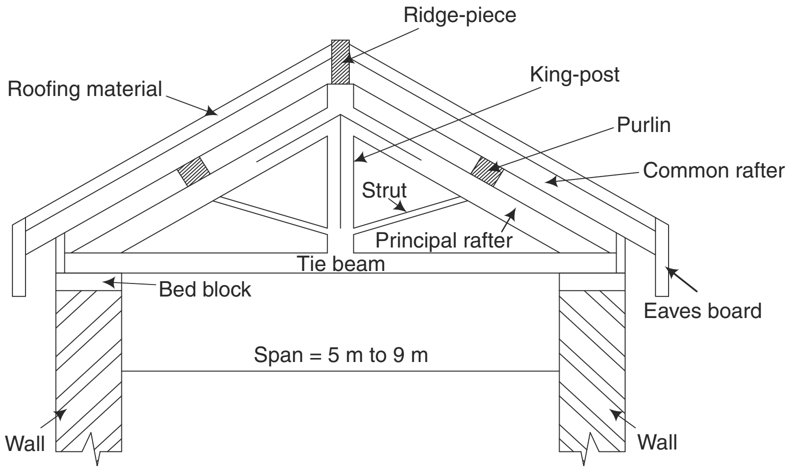


Fig. 5.29 *King-post truss*

The struts are connected to the king post at the bottom and the principal rafters at the top. Struts prevent the principal rafters from bending at the centre. The roofing material is fixed to the common rafters. These are used for spans in the range of 5–9 metres. It is usually built of wood completely or of wood combined with steel. Steel rods are used as tension members.

(b) Queen-post truss

A queen-post truss is used for spans from 9 – 12 metres. It is also a timber truss. It consists of two queen posts instead of one as in king-post truss.

(c) Steel-roof truss

Timber trusses become very heavy and costly, when the span exceeds 10 metres. Mild steel is readily available in rolled sections of standard shapes and sizes, namely, angles, channel sections, T-sections, I-sections, etc. Steel-roof trusses are mostly fabricated from angle sections. The reason is that they can resist both tension and compression effectively.

Steel-roof trusses are frames formed by a number of straight members, made of steel angles. These members are connected in the shape of triangles. The members are jointed together by welding or riveting. External loads act at these joints of the members. The shape and positioning of members in a steel truss are designed such that the members are subjected to either tension or compression. The compression members are called struts and should be short to avoid buckling. The tension members are known as ties. Trusses do not have any bending stresses in them.

The principal rafter and the main ties are generally made of two angle sections placed side by side. The struts and ties are generally made of single angle section.

Advantages of steel-roof trusses

1. Steel trusses are more rigid and stronger than wooden trusses.
2. Members of the steel trusses are equally strong in both tension and compression.
3. They can be used over any span length ranging from 5.5 metres to very large spans up to 30 metres.
4. They are easy to fabricate from rolled steel sections, which are readily available in the required dimensions.
5. They are more economical compared to timber trusses.
6. Steel trusses are permanent structures with durability of a very long life.
7. Steel trusses are more resistant to environmental/atmospheric agencies.
8. They are fire resistant unlike timber.
9. They are termite-proof unlike timber.
10. They can be easily installed.

Disadvantages of steel-roof trusses

Steel-roof trusses are likely to get rusted. They must be painted with anti-corrosive paints. Hence, steel trusses need periodical maintenance.

Uses

1. In construction of buildings of large spans such as educational institutions, industries, auditoriums, theatres, godowns, warehouses, garages, etc., including bridges.
2. No intermediate columns in the above type of buildings and availability of a clear and un-obstructed working space.
3. Places of heavy rainfall or snowfall.

Types of steel-roof trusses

The type, size, and relative positions of members of a steel-roof truss are based on the span, roof slope, load coming over the roof, roof covering material and centre to centre of the truss.

1. King post steel truss See Fig. 5.30. The relative positions of the members of the truss, namely, main tie, rafters and struts are shown. The steel truss shown in Fig. (1) can be used for spans up to 5.5 metres. The steel truss shown in Fig. (2) can be used for spans up to 6 metres.
2. Simple fink steel truss See Fig. 5.31. Fink-type truss is found to be very satisfactory for ordinary buildings. These trusses are used for spans up to 8 metres.

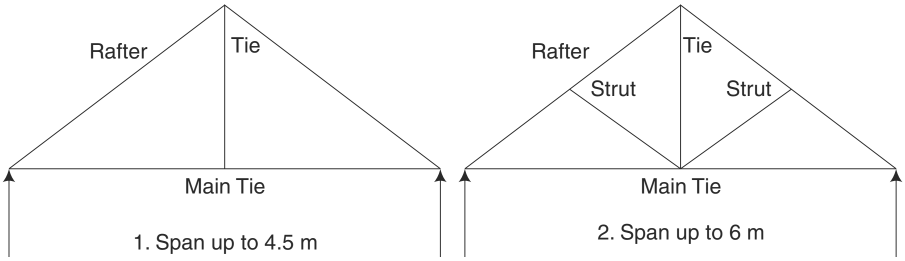


Fig. 5.30 *King-post steel truss*

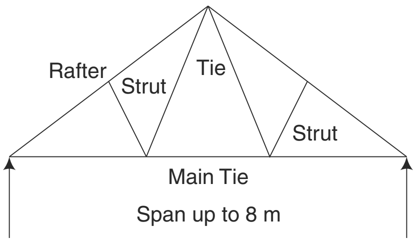


Fig. 5.31 *Compound fink steel truss*

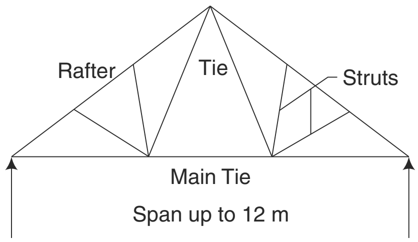


Fig. 5.32 *Compound Howe's steel truss*

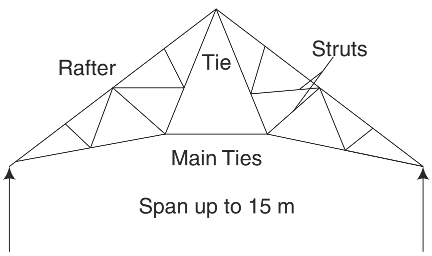


Fig. 5.33 *Compound fink steel truss*

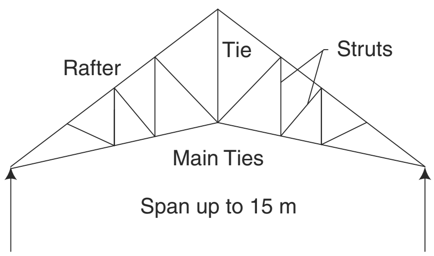


Fig. 5.34 *Compound Howe's steel truss*

3. Simple Howe's steel truss These trusses are used for spans of up to 12 metres.
4. Compound fink steel truss or French truss These trusses are used for spans up to 15 metres. This type truss is also known as French truss.
5. Compound Howe's steel truss See Fig. 5.35. These trusses are also used for spans up to 15 metres. In this truss, the diagonals are in compression and the verticals are in tension under dead load.
6. North light steel truss See Fig. 5.36. These trusses are used for spans up to 15 metres. This type of truss is used for industrial buildings to obtain adequate natural lighting for a wide building.

   In this, the steep sides of the truss are glazed. The glazed panel is faced towards north to avoid direct sunlight and direct glaring of the sun. This type of truss is also known as saw tooth.
7. Bowstring steel truss These trusses are used for spans of up to 30 metres.

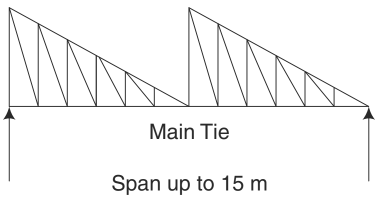


Fig. 5.35 *North light steel truss*

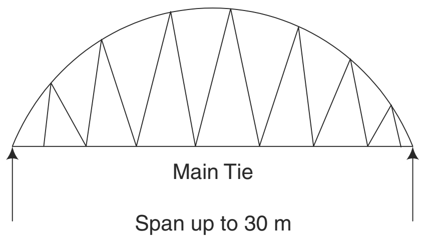


Fig. 5.36 *Bowstring steel truss*

5.7.5 Roof Coverings for Pitched Roofs

The selection of proper roof covering depends on the climate of the locality, nature of the building, cost of the roof coverings and resistance to fire and heat. Some of the commonly used roof coverings are discussed below:

Thatch Thatch is very light and is the cheapest form of roof covering. It is combustible, absorbs moisture and is liable to decay. Thatch is used in rural areas at a pitch of 45° to have proper drainage.

Half-round tiles These are used for cheap buildings. If tiles are laid in two layers, it is known as double tiled roof. An overlap of at least 80 mm should be provided for these tiles. These are brittle and hence require frequent replacement.

Shingles Wood shingles are obtained from timber with length varying from 300–380 mm and width of 60–250 mm. They are laid in the same manner as tiles and are useful in hilly areas where wood is cheap.

Patent tiles Mangalore tiles are one of the patent tiles. They are red in colour and special tiles are available for ridge. It is found that about 15 tiles are required to cover 1 m^2 of roof area.

Trafford asbestos cement tiles These are made up of cement and asbestos. They possess less corrugations and are laid with laps of 150 mm at the ends and 100 mm at the sides.

Eternit slates These are fire resistant, light and cool. They are not easily affected by weather. About 8 slates are required for covering 1 m^2 of roof area. Eternit slates are available in grey, black and red colours.

Corrugated galvanised iron sheets These are used as roof covering for factories, sheds, cheap buildings, etc. They may be covered with country tiles so as to keep the interior side of the building cool. Sheets are laid with the corrugations running down the slope of the roof. Laps of 15 cm are to be provided at the ends. These sheets are light in weight and are easy to fix.

Asbestos – cement corrugated sheets These sheets can be cut, nailed, sawn or screwed and they are light, non-absorptive, strong and tough. These sheets can withstand extreme variation of temperature.

Ruberoid This is a light, flexible and waterproof material. This is not affected by atmospheric agents and white ants. These are available in red and grey colours. Its weight varies from 10–20 N/m^2 and it is available in rolls.

5.7.6 Weatherproof Course

Weatherproof course is also known as weathering course. Weathering course is a layer provided on the top of RCC or Madras terrace roof to protect the roof from the weathering agencies like rain, wind, sun and snow. Weathering course prevents entry of rain water into the roof slab or terrace. It also arrests the penetration of heat into the room below the roof.

Weathering course consists of lime concrete with broken brick aggregate and two courses of flat tiles set in cement mortar 1 : 3 mixed with crude oil. Lime concrete has a proportion of 1 : 2.5 (lime:broken brick aggregate). Lime concrete is laid to a thickness of 100 mm and compacted to a thickness of 75 mm. A minimum slope of 1 in 50 is given to the lime concrete layer towards the rainwater drainage pipes.

After the concrete is cured, by sprinkling water for six days, two courses of flat tiles are laid in cement mortar 1 : 3 with crude oil.

Methods* of *Weather Proofing in RCC Slab Roofs

1. In the case of RCC slab roofs, to prevent the entry of rain water, a 10 cm thick brick-bats lime concrete (1 : 2 : 4) or brick-bats cement concrete (1 : 8 : 14) terracing is provided over the roof slab as shown in Fig. 5.37.

   Over this concrete terracing, a suitable flooring such as CC tiles, terrazo, China mosaic, Indian patent stone, etc. is laid. This technique of weather-proofing is illustrated in Fig. 5.37. A good fall or slope to the surface from 1 in 20 to 1 in 40, depending upon the intensity of rainfall should be given.
2. An alternative technique of weather-proofing the RCC flat roofs is by using plastic transparent films, as shown in Fig. 5.38. These films of alkathene or Polythene are available in thicknesses from 100 to 700 gauge in rolls of 1.8 m width.
3. Another technique of weather-proofing the flat roofs, made of wooden battens, RCC joists or Jack arches, etc. is illustrated in Fig. 5.39. The details of different layers, connecting the clay tiles, cement plaster, tar-felt mudplasters with clayey earth in between bitumen coats, are explained in Fig. 5.39.

5.8 FLOORING

Floors are the horizontal elements of a building structure which divide the building into different levels for the purpose of creating more accommodation within a limited space. The floor consists of the following two components:

1. ***A subfloor (or base course)*** The purpose of this component is to impart strength and stability to support floor covering and all other superimposed loads.

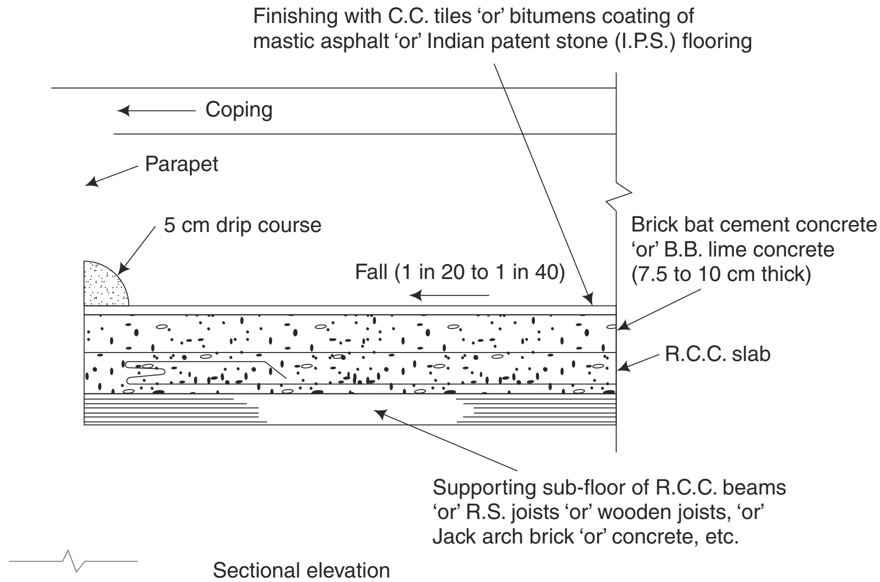


Fig. 5.37 *Weather-proofing using C.C. tiles*

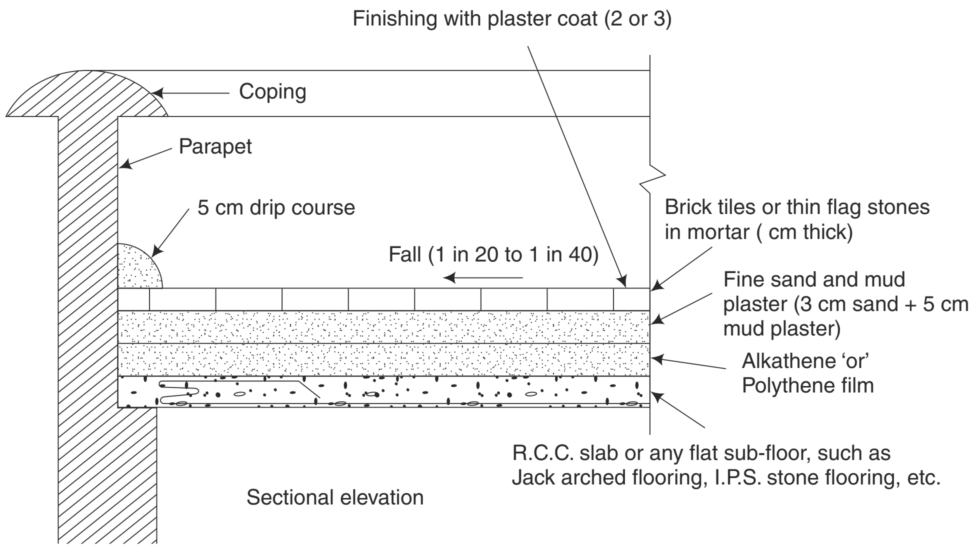


Fig. 5.38 *Weather-proofing using plastic transparent films*

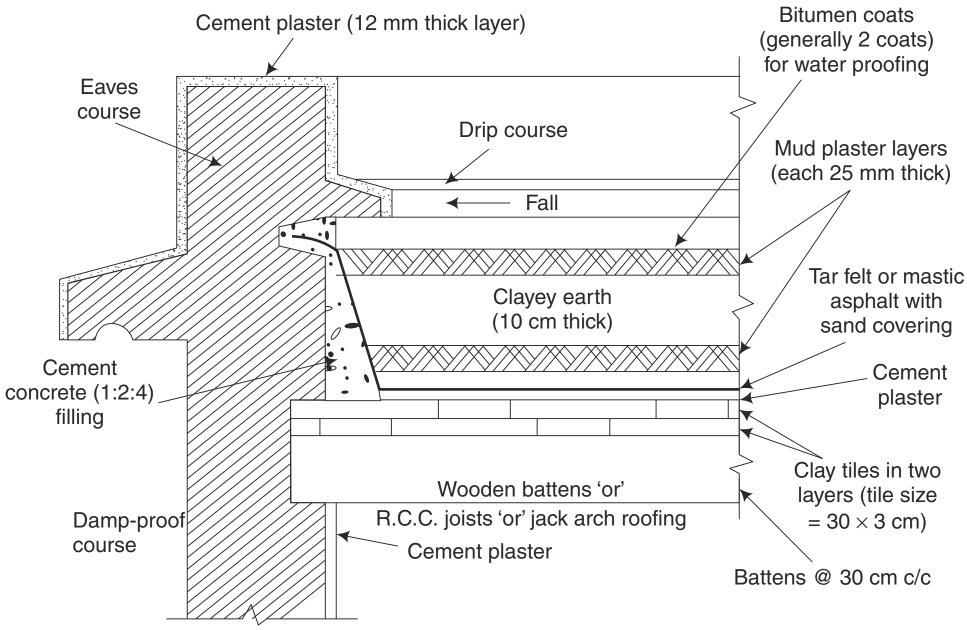


Fig. 5.39 *Weatherproofing using clay tiles, tar felt, etc.*

2. ***Floor covering (or flooring)*** This is the covering over the subfloor and is meant to provide a hard, clean, smooth, impervious, durable and attractive surface to the floor.

A floor may be defined as a building component that divides a building in different levels, for the purpose of creating accommodations within a restricted space, at levels one above the other.

The bottom-most floor of a building is called the ground floor and the other floors above it are termed the upper floors or first floor, second floor, etc. If the floor is below the natural ground level, it is called a basement floor.

5.8.1 Selection of Floorings

Each type of flooring has its own merits and there is not even a single type which can be suitably provided under all circumstances. However, the selection of flooring can be made considering the following factors:

1. Initial cost
2. Appearance
3. Cleanliness
4. Durability
5. Damp resistance
6. Sound insulation
7. Thermal insulation
8. Smoothness
9. Hardness
10. Comfortability
11. Fire resistance
12. Maintenance

5.8.2 Materials Usually Employed for Flooring

The flooring is laid over the base floor. The different materials used for flooring are:

1. Mud and moorum
2. Stones
3. Bricks
4. Wood or timber
5. Concrete
6. Mosaic
7. Terrazo
8. Asphalt
9. Plastic or PVC
10. Tiles
11. Rubber
12. Linoleum
13. Granolithic
14. Cork
15. Magnesite
16. Glass
17. Marble

5.8.3 Requirements or Qualities of a Good Floor

1. It should give a hard and smooth surface.
2. It should have adequate strength and stability.
3. It should be damp-resistant.
4. It should have good thermal insulation capacity.
5. It should be durable and easy to maintain.
6. It should be fire-resistant.
7. It should have an aesthetic look.

5.8.4 Components of a Floor

Structurally, a floor may consist of two main components:

1. Sub-floor or base course
2. Floor covering

The sub-floor or base floor provides proper support to floor covering. The floor covering provides a smooth, clean, impervious and durable surface.

5.8.5 Types of Flooring

The various types of commonly used ground floor finishes are as follows:

1. Mud and moorum flooring
2. Brick flooring
3. Stone flooring
4. Concrete flooring
5. Granolithic flooring
6. Terrazzo flooring
7. Mosaic flooring

8. Marble flooring
9. Wood or timber flooring
10. Asphalt flooring
11. Industrial flooring
12. Granite flooring

1. Mud and Moorum Flooring

Mud Flooring

Method of construction The floor bed should be well prepared and a 250 mm thick layer of selected moist earth is evenly spread out and is rammed well so as to get a consolidated thickness of 150 mm. No water is used during the process of ramming. In order to prevent formation of cracks after drying, chopped straw in small quantity is mixed with the moist earth before ramming. Upon this bed, a thin coat of cement, cowdung plaster (1 cement: 4 cowdung) is applied evenly and wiped clean by hand.

Moorum Flooring

Method of construction In this type of floor, a hard bed is prepared by laying a 25-cm thick layer of hand packed rubble boulders and then wetted and rammed hard. Upon this hard bed, a 15-cm thick layer of moorum (disintegrated rock) with coarse pieces at the bottom and finer at the top is laid. Over this layer of moorum another 25-mm thick layer of powdered moorum is spread. Water should then be sprinkled on the entire surface and rammed well. Finally, over the dry hard surface a thin coat of cement plaster (1 cement : 4 cowdung) is applied evenly and wiped cleanly by hand.

Suitability Mud floors are generally used for unimportant buildings particularly in villages.

Advantages They are cheap, hard, fairly impervious and easy in construction and maintenance.

2. Brick Flooring

Method of construction In this flooring the subgrade is compacted properly to the desired level. 10–15 cm thick layer of lean cement concrete (1 : 8 : 16) or lime concrete is laid over the prepared subgrade. This forms the base course, over which bricks are laid in desired pattern on 12 mm thick mortar bed in such a way that all the joints are filled with mortar.

Suitability Brick floors are suitable for warehouses, stones and godowns or in places where bricks are available economically.

Advantages This floor is cheap, non-slippery, durable, sufficiently hard and easily repairable.

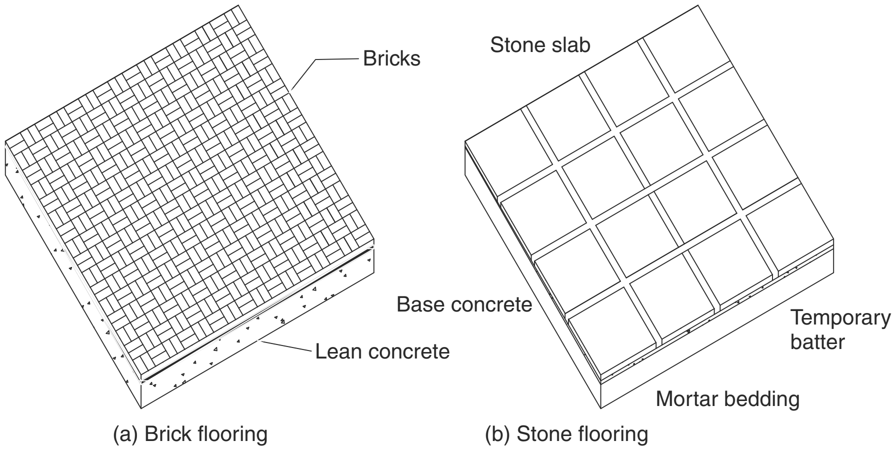


Fig. 5.40 *Brick and stone flooring*

3. Stone Flooring

Method of construction The subgrade is prepared by laying a 100 mm to 150 mm thick layer of cement or lime concrete over a bed of well consolidated earth. The stone slabs may be square or rectangular, usually 300 mm × 300 mm, 450 mm × 450 mm, 600 mm × 600 mm or 450 mm × 600 mm size. The thickness of stone varies from 20 mm to 40 mm. The selected stone should be hard, durable, good quality and of uniform thickness and the surface. The stones should be finely chisel dressed on surface and should have their edges true and parallel from side top side. When the stone slabs are properly set, mortar in the joints is raked out to a depth of 20 mm and flush pointed with cement mortar 1:3.

Suitability This type of flooring is suitable for godowns, sheds, stores, bus shelter, schools, hospitals, etc.

Advantages Where stones are available in plenty, this floor is economical. It is hard, durable, easy to construct and has good resistance to wear and tear.

4. Cement Concrete Flooring

Method of Construction This flooring is commonly used for residential, commercial and even industrial buildings.

The floor consists of two components:

(i) Base concrete The base course is laid over well-compacted soil, compacted properly and leveled to a rough surface. The base course consists of 7.5 cm to 10 cm thick cement concrete (1:3:6 to 1:5:10). The top surface of the concrete base is roughly finished to develop good bond between the base and topping.

(ii) Wearing surface After the base concrete has hardened, its surface is brushed with stiff broom and cleaned thoroughly. The entire surface is divided into square of rectangular panels not exceeding 2.5 m in length. Cement concrete 1:2:4 of thickness 25 mm to 40 mm is then laid in alternate panels. The top surface is beaten and made in a uniform line and level, and finally it is smoothened by trowelling. The surface is kept under curing for 10 days.

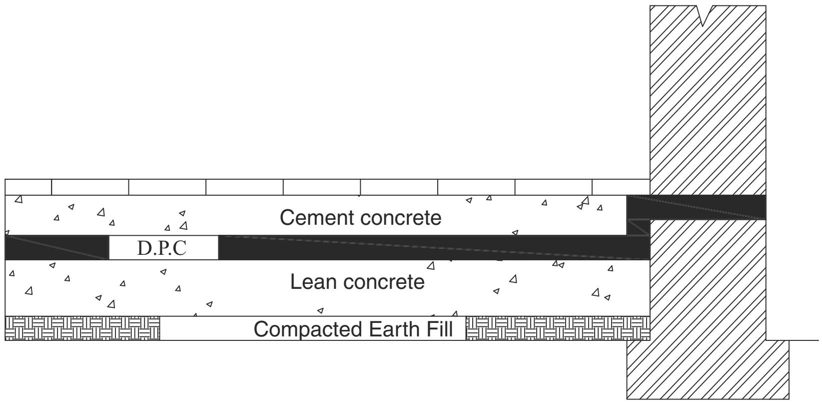


Fig. 5.41 *Cement concrete flooring*

Suitability It is suitable for residential, commercial, industrial and public buildings of all types.

Advantages It is cheap and durable, easy to maintain and it is fire resistant.

5. Granolithic flooring

Method of Construction In this flooring the sub-base preparation and concrete base laying is done in a similar manner, as explained for cement concrete flooring. A finishing layer is given above is made of very rich concrete mix with hard stone chips, called granolithic finish. To improve wearing qualities, sand may be replaced by crushed granite powder. The surface may be finished smooth with a steel trowel. The floor area may be divided into panels of size 600 mm × 600 mm or 600 mm × 450 mm using threads, if desired.

Suitability This type of flooring is mostly suitable for industrial floors.

Advantages It is durable, cheap, resistant to abrasion and does not wear easily.

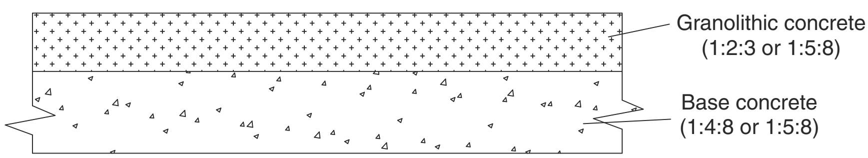


Fig. 5.42 *Granolithic flooring*

6. Terrazzo flooring

Method of construction In this flooring the sub-base preparation and concrete base laying is done in a similar manner, as explained for cement concrete flooring. The top layer may have about 40 mm thickness, consisting of (i) 34 mm thick cement concrete layer (1 : 2 : 4) laid over the base concrete, and (ii) about 6 mm thick terrazzo topping. Terrazzo is a specially prepared concrete surface consisting of white cement with marble chips of different colours in 1:2 proportion, laid in a thin layer over a concrete base course. Even though this flooring is expensive, it is decorative and has good wearing properties.

Suitability This type of flooring is suitable for hospitals, public buildings, living room and bathrooms of residential buildings, etc.

Advantages It provides an attractive, clean and durable surface.

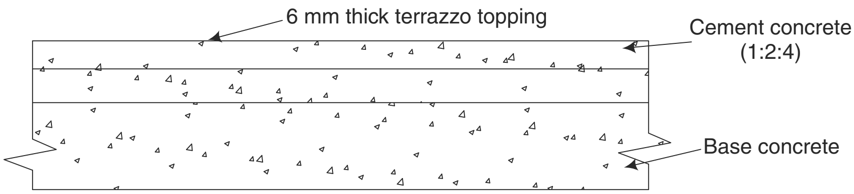


Fig. 5.43 *Terrazzo flooring*

Disadvantages It is more expensive.

7. Mosaic flooring

Method of Construction Mosaic flooring is made of small pieces of broken tiles of glazed china, cement, or of marble, arranged in different patterns. These pieces are cut to desired shapes and sizes. This floor is normally laid over a hard bed of cement concrete. The top surface of the concrete base is cleaned and wetted. On a small portion of the floor, a layer of rich cement, mortar 1:3 is evenly spread in a thickness of nearly 1 cm and mosaic tiles are laid with hand and set properly in desired pattern. Dry cement either ordinary or coloured is sprinkled and pressed in the joints. The process is continued for the whole floor. The joints of the tiles are then rubbed with a corborundum stone. After the tiles are set, the surface is completely polished with a mosaic-polishing machine.

Suitability This type of flooring is suitable for use in operation theatres, bathrooms, public buildings, etc.

8. Marble flooring

Method of Construction This flooring is laid over the prepared subgrade which is cleaned, wetted and mopped properly. A layer of cement mortar of 1:4 is spread in an average thickness of about 20 mm. Marble slabs are laid in this bedding mortar, pressed and leveled. The marble slabs may be rectangular or square in shape and their thickness varies from 20 to 40 mm. The joints between two slabs must be very thin. The cement that oozes out of the joints is cleaned. The paved area is cured for a minimum of seven days.

Suitability It is suitable for places of worship and for public buildings which require rich appearance, kitchens, bathrooms, operation theatres and hospitals. etc.

Advantages It is attractive and easily maintained.

Disadvantages It requires high initial cost.

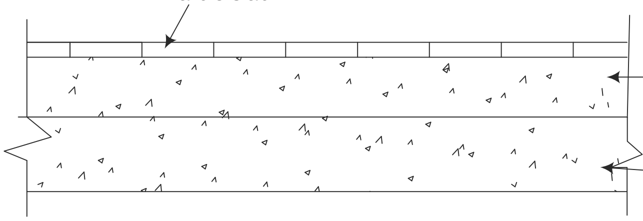


Fig. 5.44 *Marble flooring*

9. Wood or Timber Flooring

Method of construction Timber flooring is used for dancing halls, auditoriums, etc. There are two types of timber floors:

(i) Suspended type

(ii) Solid type

(i) Suspended-type timber flooring Where the problem of dampness is acute, the timber flooring is provided above the ground level. In such a case, sleeper walls are constructed at centre to centre distance of 1.2 to 1.8 m. Wall plates are provided along the sleeper walls. The bridging joists of timber are nailed to the wall plates at their ends. They are placed at a centre to centre distance of about 30 cm. Finally, the floor boards are provided on the bridging joists to finish up the floor.

(ii) Solid-type timber flooring Where the problem of dampness is not acute, timber floors may be supported on the ground all along. In this type of flooring base concrete is first laid in 15 cm to 20 cm thickness. Over it a layer of mastic asphalt is applied. Wooden block flooring is then laid over it. In order to fix the wooden floor on concrete slabs, longitudinal nailing strips, with beveled sections, are embedded in concrete at suitable intervals.

Suitability It is suitable for dancing halls, auditoriums, carpentry halls, in hilly areas, where timber is available cheaply and in areas where temperature is very low.

Advantages It provides a non-slippery platform and is easy to repair.

Disadvantages This flooring is not commonly used for residential buildings due to its cost. Dampness prevention should be carried out before its construction.

10. Asphalt flooring

Method of Construction Mastic is melted and clean sand is mixed with it and laid in one or two layers on the base of the concrete with a trowel. A uniform level surface can be obtained by quick trowel line before the mastic loses its plasticity and before it gets hardened.

Suitability It is suitable for use under a wide range of service conditions from light domestic buildings to heavy duty commercial and industrial buildings, storage houses, foot paths, etc.

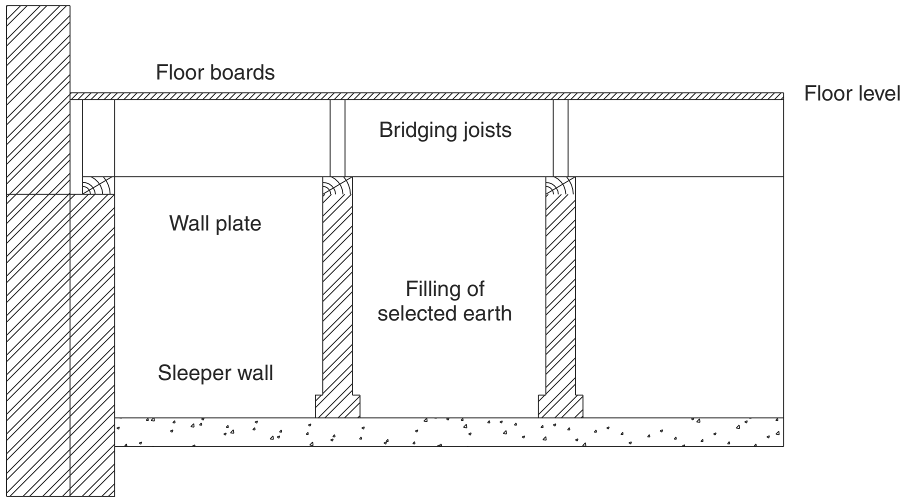


Fig. 5.45 *Suspended type timber floor*

Advantages Mastic asphalt flooring is dustless, jointless and impervious. The flooring is easily cleaned and resistant to acids.

Asphalt floorings are of the following types.

(i) Asphalt mastic flooring
(ii) Asphalt tiles flooring
(iii) Asphaltic terrazzo flooring
(iv) Acidproof mastic flooring

1. Asphalt mastic flooring Asphalt mastic is a mixture of sand (or grit) and asphalt in the ratio of 2:1. It is mixed hot and then is laid in continuous sheets. It can also be applied cold, by mixing with mineral oil and asbestos. The thickness of the asphalt mastic may be 2.5 cm for ordinary construction. It is laid on cement concrete base and is spread by means of trowel to get a levelled surface. On the top of the surface, a thin layer of sand is spread, which is then rubbed with a trowel. The joints of mastic asphalt laid on successive days are properly lapped.

2. Asphalt tiles flooring These are prepared from asphalt, asbestos fibres, inert materials and mineral pigments, by pressing the mix in different sizes ($20cm^2$–$45cm^2$), with thickness varying from 3 –6 cm. Those tiles are either directly cemented to concrete base or are fixed on wooden floors by using an intervening layer of mastic asphalt or asphalt saturated felt. Asphaltic tiles are cheap, resilient, soundproof, non-absorbent and moisture proof.

3. Asphaltic terrazo flooring This is prepared like mastic asphalt, except that marble chips are used in the place of sand/grit. Asphalt may be either in black or other suitable colours and is laid in hot condition.

4. Acidproof mastic flooring Acidproof blocks of asphalt are available, which are manufactured from moulding acidproof asphalt and inert crushed rock aggregate under high pressure. Asphalt blocks are first laid on concrete base and then acidproof asphalt is uniformly spread over the surface of the blocks. Fine sand is spread over the liquid asphalt before it hardens.

11. Industrial Flooring

In most of the industries, cement concrete flooring is commonly adopted since it is moderately cheap, easy to construct and quite durable. The floor consists of the following two components:

(a) *Base concrete*

(b) *Wearing surface*

The two components of the floor can be constructed either monolithically (i.e. laying the wearing surface immediately after the base concrete is laid) or non-monolithically. The method of laying cement concrete flooring on ground floor of an industry can be broadly divided into the following three steps:

(a) Preparation of sub-base

(b) Laying of the base concrete

(c) Laying the wearing surface

1. Preparation of sub-base The earth filling in plinth is consolidated thoroughly so as to ensure that no loose pockets are left in the whole area. Then a 10–15 cm thick layer of clean coarse sand is spread over the whole area. The sand layer is consolidated and dressed to the required level and slope.

2. Laying of base concrete The base course may be 7.5–10 cm thick, either in lean cement concrete (1:3:6 to 1:5:10) or lime concrete containing 40 per cent mortar of 1:2 lime-sand (or 1 lime : 1 surkhi : 1 sand) and 60 per cent coarse aggregate of 40 mm nominal size. The base course is laid over well-compacted soil, compacted properly and levelled to rough surface. It should be properly cured.

3. Laying the wearing surface The wearing surface is laid in square or rectangular panels, by using either glass or plain asbestos strips or by using wooden battens set on mortar bed. The panels may be 1 × 1 m, 2 × 2 m, 1 × 2 m in size. The wearing surface consists of 1:2:4 cement concrete, laid to the thickness of 4 cm. Before laying the concrete in the panel, a coat of neat cement slurry is applied to ensure proper bond of topping with the base course.

Advantages

(a) It possesses good wearing properties.

(b) It is easy to construct and maintain.

(c) It is non-absorbent, smooth and pleasing in appearance.

(d) It is durable and hence it is commonly used in factories and industries.

(e) It is economical.

Disadvantages

(a) It cannot be satisfactorily repaired by patch work.

(b) Defects in carelessly made floor cannot be rectified and as such, it requires proper attention while laying.

12. Granite flooring

Granite flooring is a superior type of flooring commonly used in residential buildings, shopping complex, hospitals, offices, etc. where extra cleanliness is an essential requirement. Granite stone is available in the form of 8 mm and 12 mm thick tiles and 20 mm thick slab. These tiles and slabs are available in any shape and size. Before laying the tiles, neat cement slurry is spread over the bedding mortar and the tiles are laid flat over it. Then they are pressed gently into the bedding mortar with the help of wooden mallet, till a levelled surface is obtained. Also, a thin paste of cement is applied on the bottom of the tiles before laying. After a day, the joints between adjacent tiles are cleaned of loose mortar, etc. to a depth of 5 mm. This is done by using wire brush and then the joints are grouted with cement slurry of the same colour shade as that of the tiles. The flooring is then cured for seven days.

5.9 DAMP-PROOFING

Damp-proofing is the method adopted to prevent the entry of dampness into a building, so as to keep them dry, habitable and safe. The provision of damp-proofing courses prevents the entry of moisture from walls, floors and basement of a building.

1. Causes of dampness There are various causes which are responsible for the entry of dampness in a structure. They are listed below.

(i) Entry of moisture from the ground Building materials used in the foundation may absorb moisture from the pervious soil by capillary action. This will lead to the entry of dampness to the floor and walls.

(ii) Entry of rain water The unprotected exposed surfaces and leaking roofs become sources of entry of rain water into a structure thereby leading to dampness.

(iii) Exposed tops of walls Dampness may enter through the exposed tops of parapet walls and compound walls. This may lead to serious consequences.

(iv) Deposition of atmospheric moisture on walls, floors and ceilings When warm humid air is cooled, condensation of water vapour takes place. This is the main source which causes dampness in walls, floors and ceilings. This is evident mainly in badly designed kitchens.

(v) Location Dampness will enter into the structure which is located on a site that cannot be easily drained.

(vi) Orientation of walls The walls obtaining less sunshine and heavy showers of rain are liable to become damp.

(vii) Workmanship The dampness is also caused due to bad workmanship in construction such as defective rainwater pipe connections, defective joints in the roofs, improper connections of walls, etc.

2. Effects of dampness Following are the effects of dampness in a structure:

1. A damp building creates unhealthy conditions for those who occupy it.
2. Corrosion of the metals used in building construction is evident.
3. Formation of unsightly patches on the wall surfaces and ceilings.
4. Formation of dry-rot leading to the decay of timber in a damp atmosphere.
5. Deterioration of electrical fittings.
6. Floor covering materials are seriously damaged.
7. Acceleration of the growth of termites.
8. Softening and crumbling of the plaster.

3. Requirement of an ideal material for damp-proofing

1. The damp-proof course should remain effective during the life of the building. Hence, the material should be durable.
2. It should remain steady and should not allow any movement in itself.
3. It should be impervious.
4. The material should safely resist the load coming on it.
5. It should be strong enough to undergo some structural movement without fracture.

4. Materials used for damp-proofing

(i) Hot bitumen It is flexible and should be applied with a minimum thickness of 3 mm.

(ii) Mastic asphalt It is a semi-rigid material and it forms an excellent impervious layer. It is very durable but can withstand only slight distortion.

(iii) Bituminous felts It is also flexible and it is available in rolls of normal width. This can accommodate slight movements. It is liable to squeeze out under pressure.

(iv) Metal sheets of lead, copper and aluminium Metal sheets can also be used as damp-proofing material. These metal sheets are flexible and do not squeeze out under pressure. The surface of lead coming in contact with lime and cement will be corroded and hence it should be protected with bitumen. Aluminium sheets should also be protected with bitumen but copper does not require any protective coating.

5. Methods of damp-proofing

1. If the level of the ground floor is in level with the ground surface or just above it, the damp-proofing course is provided as shown in Fig. 5.46.

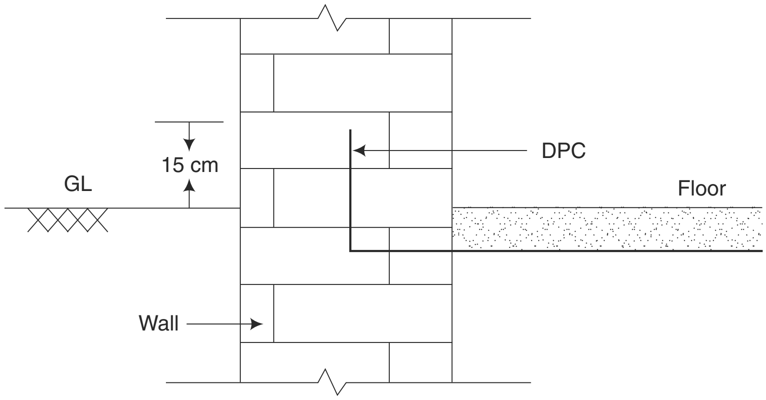


Fig. 5.46 *Damp-proofing for ground floor in level with ground surface*

2. If two ground floors are at different levels, DPC is provided as shown in Fig. 5.47.

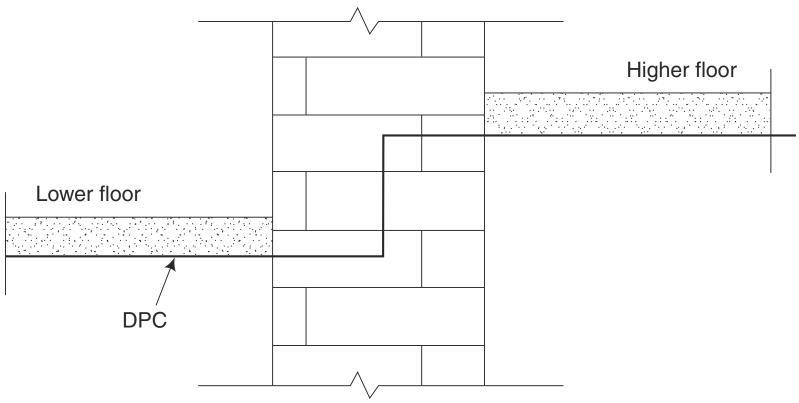


Fig. 5.47 *Damp-proofing for floors at different levels*

3. In case of basements, the damp-proofing course should be properly provided. The usual practice is to provide asphalt tanking as shown in Fig. 5.48.
4. In case of sloping ground, the damp-proofing course should be steeped such that it remains at a minimum vertical distance of 15 cm above-ground as shown in Fig. 5.49.

5.10 PLASTERING

Plastering is the process of covering rough walls and uneven surfaces in the construction of houses and other structures with a plastic material called plaster or mortar.

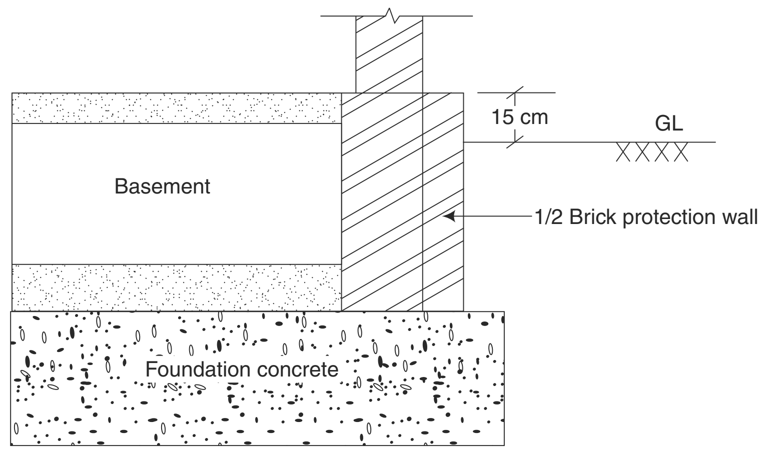


Fig. 5.48 *Damp-proofing for basements*

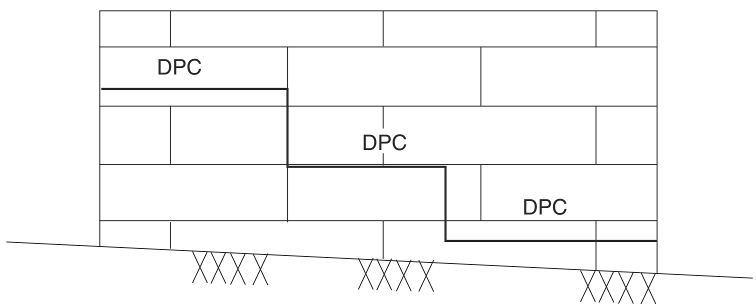


Fig. 5.49 *Damp-roofing for sloping ground*

5.10.1 Objectives of Plastering

1. To provide an even, smooth, regular, clean and durable finished surface and hence to improve the appearance.
2. To protect the surfaces from the effects of atmospheric agencies.
3. To conceal the defective workmanship.
4. To cover up the use of inferior quality and porous materials and the joints formed in masonry work.
5. To provide a satisfactory base for whitewashing, colour washing, painting or distempering.
6. In the case of internal plastering, the object is to protect the surfaces against dust and vermin nuisance.

5.10.2 Types of Plasters

1. Lime plaster Lime plaster is an intimate mixture of equal proportions of lime and sand, ground in a mortar mill to form a paste of required consistency. Sand to be used in the mortar should not pass through a 100-mesh sieve for more than five per cent or a 50 mesh sieve for more than 20 per cent. Water and sand used should be clean and free from all deleterious materials.

Fat lime or poor lime is used in lime plaster. To improve the strength of lime mortar, small quantity of cement is added. This mortar is mainly used for external work.

2. Cement plaster Cement plaster is an intimate mixture of Portland cement and sand with required amount of water to make a plastic mass. The proportion of cement and sand depends upon the nature of work. The ingredients are first mixed in a dry state and water is added to make a paste. This plaster should be used within 30 minutes since cement starts setting after 30 minutes.

3. Mud plaster Mud plaster is prepared with equal volumes of clay or brick earth and of chopped straw, hay, loose soil or cowdung and hemp. The ingredients are mixed and left for seven days with large quantity of water. Then, it is again mixed till it reaches the required consistency before using. Mud plaster made of sand and clay can also be used.

4. Waterproof plaster This plaster consists of one part of cement, two parts of sand and pulverised alum at the rate of 12 kg/m^3 of sand. In order to make this to be waterproof, soap water containing about 75 gm soap/litre of water is added.

5.10.3 Requirements of a Good Plaster

1. It should provide a smooth, non-absorbent and washable surface.
2. It should not shrink while drying which results in cracking of the surface.
3. It should adhere firmly to the surface and resist the effects of atmospheric agencies.
4. It should offer good insulation against sound and high resistance against fire.
5. It should provide to a decorative appearance the surface and should be durable.

5.10.4 Methods of Plastering

Plaster may be applied in one, two or three coats. In the cheapest construction, one coat of plaster is used. In ordinary works, two coats are adopted and in superior jobs, three coats are applied.

1. Plastering in two coats The procedure for carrying out the plastering in cement in two coats is as follows:

1. The mortar joints are raked out to a depth of 20 mm and the surface is cleaned and well watered.
2. If the surface to be plastered is very rough, a preliminary coat is applied.

3. The first coat of plaster is now applied with a thickness of 9 mm to 10 mm for brick masonry. To maintain uniform thickness, screeds are formed on the wall surface by fixing dots. Fixing a dot is just placing small quantity of plaster making a square of 150 mm × 150 mm. Another dot is placed vertically below this and a vertical strip of plaster connecting these two dots is provided. This is a screed. Screeds are placed at a distance of 2 m and plaster is applied between them.
4. The second coat is applied after about 6 hours and the thickness of second coat is about 3 mm to 12 mm. It is finished as per the requirements.
5. The completed work is allowed to set for 24 hours and it is well watered for at least one week.

2. Plastering in three coats The procedure for plastering in three coats is the same as the above except that the number of coats is three. It is done as detailed in Table 5.2.

Table 5.2 Plastering in three coats

Coat	*Name of coat*	*Thickness*	*Remarks*
First coat	Rendering coat	9 mm to 10 mm	Left for a period of 3 to 4 days to harden. Surface is kept rough.
Second coat	Floating coat	6 mm to 9 mm	The purpose is to prepare an even surface.
Third coat	Setting or finishing coat	3 mm	This is similar to the second coat of two-coat plaster.

Plaster in three coats with lime mortar is done as explained in Table 5.3.

Table 5.3 Plaster in three coats with lime mortar

Coat	*Name of coat*	*Thickness*	*Remarks*
First coat	Rendering coat	12 mm	Left for a period of 2 days to set and not to dry.
Second coat	Floating coat	6 mm to 9 mm	Applied with trowels and rubbed with straight edge. Water is sprinkled and the surface is rubbed with floats to make it an even surface.
Third coat	Setting or finishing	3 mm	Applied after 5 days. Neeru or agol coat is used to prepare a smooth surface. After giving a set of 24 hours, the work is well watered for a fortnight.

5.10.5 Defects in Plastering

1. Small patches swell out beyond the plane and this is particularly seen inside the building. This is known as blistering of plastered surface.
2. Cracks are formed on the surface which may be visible or invisible. The development of fine hair cracks is known as crazing.
3. Soluble salts are present in plaster materials as well as in building materials. When newly constructed wall dries out, soluble salts appear as a white crystalline

substance. This is referred to as efflorescence and this effects the adhesion of paint with wall surface.

4. The formation of a very small loose mass on the plastered surface is known as flaking and it is due to the failure of bond between coats of plaster.
5. The plaster from some portion of the surface comes off and a patch is formed. This is known as peeling and is also due to failure of bond in coats of plaster.
6. Sometimes, the plaster may contain particles which expand on setting. A conical hole is formed on the surface which is known as blow or pop.
7. Rust stains are seen on the plastered surface, especially when plaster is applied on metal lath.
8. The excessive dampness at certain points on the surface makes that portion soft. The reasons are, due to the presence of thinners in the finishing coat, presence of deliquescent salts, excessive suction of the undercoat, etc.
9. Uneven surface is due to poor workmanship.

5.10.6 Remedies for Minimising the Defects in Plastering Work

1. Workmanship should be the best in brick work and plastering work.
2. Bond of brickwork should be proper.
3. Efflorescence is removed by rubbing brushes on the surface. A solution of 1 part of HCl acid or H_2SO_4 acid and 5 parts of clean water is prepared and applied on the affected area. The surface is then cleaned with water. The surface is kept under observation for few days. If efflorescence appears again, it is removed and painting can be done only when it ceases.
4. Bricks of superior class should be used.
5. The surface to be plastered should be well watered so that it may not absorb water from the plaster.
6. Excessive trowelling should be avoided.
7. Damp-proof courses should be provided at convenient places in the building.
8. Fresh plastered surfaces should be protected from superfluous quantity of water and excessive heat.

5.11 VALUATION

Value means worth of an asset. Valuation implies the act of estimating the price for an asset, based on its present condition.

In general, all properties are classified broadly into two categories: immovable property and movable property.

Immovable property includes land, buildings, mines, trees, quarries, etc. Movable property includes things which can be moved from place to place, e.g., coal, oil, building materials such as steel, cement, jelly and sand. Movable properties are otherwise called chattels.

The value of a property is based on principles of economics. There are many factors influencing the value of a property and they will vary from place to place and type of property. So valuation needs a thorough understanding regarding the property, as it is a money matter.

5.11.1 Objectives of Valuation

The purpose of valuation is to arrive at a fair and reasonable price for any existing property.

The following are main objectives of valuation of a property:

1. Buying and selling of the properties Whenever one wants to buy or sell a property, one must be aware of the value prevailing in the market at that time.

2. Taxation Tax schedule is prepared based on valuation only. Government taxes such as estate duty, wealth-tax, capital gain tax and gift tax are calculated based on valuation only.

3. Security of loans When loans are to be granted against a property, the valuation of the property has to be carried out.

4. Rent determination In order to determine the probable amount of rent from a property such as a house, valuation is essential.

5. Compulsory acquisition Sometimes a property may be acquired by law and, in that case, the owner of the property has to be paid a suitable compensation. The above is possible through valuation.

6. Speculation Sometimes a person may purchase a property, with a view to develop it in future. To gauge the potential of a property, valuation is necessary.

7. Private development Valuation becomes essential for a property to be purchased by a person with a view to improve it for personal use.

8. Betterment charges When the property comes under some town-planning scheme of the area, its value will increase and consequently, the owner has to pay additional tax known as betterment charges. So, it becomes necessary for the owner to know the value of his property before and after the town-planning scheme execution.

9. Court fees, registration charges When a case has to be filed with respect to a real estate, valuation becomes necessary, to affix the stamp of suitable amount. Similarly for transferring a property, the registration charges are fixed based on the value of property only.

10. Insurance For the purpose of insuring a property, valuation is necessary.

11. Reinstatement The process of reinstating a property needs its current value.

5.11.2 Valuation of a Building

The value of a building depends on the type of the building, its structure, the quality of materials used in the construction, and so on. The value of the building also depends on the place of location, the height of the building, the height of plinth, the thickness of wall, the type of floor, roof, doors and windows, etc. The value also depends on the demand which varies from time to time.

While valuing a building, the age of the building should be obtained from the past records.

The following methods are used for the valuation of a building:

1. Rental method of valuation In this method, net income by way of rent is determined by deducting the outgoings from the gross rent.

$$\text{Net income} = \text{Gross rent} - \text{Outgoings}$$

Then a suitable interest is assumed and year's purchase is calculated. Now, the value of the building is obtained as the product of net income and year's purchase.

2. Direct comparison with capitalised value This method may be adopted if the rental value of a building is not available but the sale price of a similar property is available. The value of the concerned property is fixed in comparison with the value of similar property in the locality.

3. Valuation based on profit This method is suitable for public buildings such as hotels, cinema theatres, auditoriums and music halls for which the value depends on the profit. For the above cases, the value is obtained by multiplying the net profit with the year's purchase.

$$\text{Net profit} = \text{Gross income} - \text{Outgoings}$$

4. Valuation based on cost In this approach, the actual cost of the constructed property is found after allowing for necessary depreciation and the resulting figure is taken as the value of the property.

5. Development method of valuation In this method, the anticipated value of a property is obtained by multiplying the net income with the year's purchase. The property mentioned above includes those which are not at present in good condition, needing additions, alterations, improvements, etc. In such a case, the value can be obtained upon anticipating the future net income from it.

6. Depreciation method of valuation It is worth to discuss the above method in detail. Depreciation refers to gradual loss of the value of a property due to wear and tear, excess usage, improper handling, age, etc. Depreciation technique involves collecting or providing an amount equal to the loss due to depreciation every year, separately from the profit. So that, when the property is sold at the end (scrap value) it can be replaced by a new one with the scrap value and the total depreciation amount.

As far as a building is concerned, depreciation method of valuation based on plinth area is a well known one.

7. Area-based valuations

(a) Plinth-area estimate This estimate is prepared on the basis of plinth area of the building. The plinth area rate is obtained from the cost of similar building having similar specifications, height and construction in the locality.

Plinth area is the built-up covered area of a building measured at floor level of any storey. It is calculated by taking the external dimensions of the building at the floor level excluding plinth offsets. Courtyard, open areas, balconies and cantilever projections are not included in the plinth area.

The following shall be included in the plinth area:

(i) All floors, area of walls at the floor level excluding plinth offsets, if any

(ii) Internal shafts for sanitary installations provided if these do not exceed 2 sq.m. in area, air condition ducts, lifts, etc.

(iii) The area of *barsati* and the area of *mumty* at terrace level

(iv) Area of porches other than cantilevers

The following shall not be included in the plinth area:

(i) Area of loft

(ii) Internal sanitary shafts provided if these areas more than 2 sq.m. in area

(iii) Unenclosed balconies

(iv) Towers, turrets, domes, etc., projecting above the terrace level, not forming a storey at the terrace level

(v) Architectural bands, cornices, etc.

(vi) Sunshades, vertical sun breakers or box louvers projecting out.

Approximate cost of the building may be found using the formula:

Approximate cost of the building

= Total plinth area × Plinth area rate of the building in the locality

Approximate area for different types of buildings are given in Table 5.4.

Table 5.4 Approximate area of different types of building

Type of building	*Floor area per head*	*Area occupied by wall*
Residential	2.5 to 3.0 sq.m.	15 to 20% of plinth area
School	1.0 to 2.0 sq.m.	15 to 20% of plinth area
Hotel	7.0 to 10.0 sq.m.	15 to 20% of plinth area
Hospital	8.0 to 10.0 sq.m.	15 to 20% of plinth area
Factory	2.5 to 3.0 sq.m.	10% of plinth area
Office	2.5 to 3.0 sq.m.	10% of plinth area

(b) Carpet-area estimate Carpet area of the building is the useful area or the livable or lettable area. The carpet area of the building shall be the floor area excluding the following:

(i) Sanitary accommodation
(ii) Verandah
(iii) Corridors and passages
(iv) Kitchen and pantries
(v) Stores in domestic building
(vi) Entrance hall
(vii) Staircases and mumties
(viii) Shafts for lifts
(ix) Barsaties
(x) Garages
(xi) Canteens
(xii) Air-conditioning ducts and rooms

The floor area can be determined by deducting the area occupied by the walls from the plinth area.

The carpet area of an office building may be 60–70 per cent of the plinth area and that of a residential building may be 50–60 per cent of the plinth area.

Illustrative Examples

Example 5.1 Determine the value of a building if the plinth area is 160 sq.m. using the straight line method of depreciation.

Rate of plinth area = Rs 1000/sq.m.
Rate of depreciation = 1.25% per year
Period of consideration 10 years.

Solution Present value of the building = 1000 × 160 = Rs 1,60,000

Depreciation at the rate of 1.25% for 10 years

$$= 1{,}60{,}000 \times \left(\frac{1.25}{100}\right) \times 10 = \text{Rs } 20{,}000$$

Value of the building after allowing the depreciation

$$= \text{Rs } 1{,}60{,}000 - 20{,}000 = \text{Rs } 1{,}40{,}000$$

Example 5.2 Calculate the value of a building if the carpet area of the building is 98 sq. m. Rate of plinth area is Rs 1550/sq.m. and rate of depreciation is 1.2% per annum. The present age of the building is 13 years. Take the carpet area as 70% of the plinth area.

Solution Carpet area of the building = 98 sq.m.

$$\text{Carpet area} = \left(\frac{70}{100}\right) \times \text{Plinth area}$$

$$98 = \left(\frac{70}{100}\right) \times \text{Plinth area}$$

$$\text{Plinth area} = 98 \times \left(\frac{100}{70}\right) = 140 \text{ sq.m.}$$

$$\text{Valuation before depreciation} = \text{Rs } 1550 \times 140 = 2{,}17{,}000$$

$$\text{Depreciation for 13 years} = \text{Rs } 2{,}17{,}000 \times \left(\frac{1.2}{100}\right) \times 13 = 33.852$$

$$\text{Value of the building after depreciation} = \text{Rs } 2{,}17{,}000 - 33{,}852 = \text{Rs. } 1{,}83{,}148$$

Example 5.3 Calculate the approximate cost of the residential building having a carpet area of 2000 sq.m. Plinth area rate is Rs. 1000/sq.m.

Solution Carpet area = 50 to 60% of plinth area

Assuming carpet area as 50% of plinth area

$$\text{Plinth area} = \left(\frac{100}{50}\right) \times \text{Carpet area}$$

$$\text{Plinth area} = 2 \times 2000 = 4000 \text{ sq.m}$$

$$\begin{aligned}\text{Approximate cost of the building} &= \text{Plinth area rate} \times \text{Plinth area}\\ &= \text{Rs. } 1000 \times 4000 = \text{Rs. } 40{,}00{,}000\end{aligned}$$

Example 5.4 Calculate the plinth area, carpet area and floor area for the plan of the building given in Fig. 5.22.

Solution

$$\begin{aligned}\text{Plinth area} &= 6.6 \times 6.9 = 45.54 \text{ sq.m.}\\ \text{Floor area} &= \text{Plinth area} - \text{area occupied by walls}\\ \text{Area occupied by walls} &= (2 \times 5.2 \times 0.3) + (2 \times 6 \times 0.3) + (2 \times 2.7 \times 0.2)\\ &\quad + (1 \times 2.7 \times 0.3) + (1 \times 2.5 \times 0.2) \text{ sq.m.}\\ &= 2.52 + 3.60 + 1.08 + 0.81 + 0.50 \text{ sq.m.}\\ &= 8.51 \text{ sq.m}\\ \text{Floor area} &= 45.54 - 8.51 \text{ sq.m} = 37.03 \text{ sq.m}\\ \text{Carpet area} &= \text{Floor area} - \text{non-usable area}\\ \text{Floor area of verandah} &= 3.4 \times 2.5 = 8.5 \text{ sq.m}\\ \text{Floor area of Bath and W.C.} &= 2.5 \times 2.5 = 6.25 \text{ sq.m}\\ \text{Carpet area} &= 37.03 - (8.50 + 6.25) = 22.28 \text{ sq.m}\end{aligned}$$

Example 5.5 The actual expenditure incurred in the construction of a single storey residential building of plinth area 72 m^2 is found to be Rs 1,02,600 in which 60% is towards the cost of the materials and the remaining is towards the cost of the labour. It is now proposed to construct a similar building of the same height and specifications with the plinth area of 94 m^2 at a place where the cost of materials is 10% more and the cost of the labour is 20% less. Estimate approximately the cost of the proposed building.

Solution Total cost of the existing building = Rs 1,02,600

Plinth area of existing building = 72 m^2

Plinth area rate = 1,02,600/72 = Rs 1,425 per m^2

Cost of materials = 0.6 × 1425 = Rs. 855 per m^2

Cost of labour = 0.4 × 1425 = Rs. 570 per m^2

Increase in cost of materials = 10%

Decrease in cost of labour = 20%

Plinth area rate for the proposed building = (1.1 × 855) + (0.8 × 570)

= Rs 1396.50 per m^2

Plinth area of the proposed building = 94 m^2

Approximate cost = 94 × 1396.50 = Rs 1,31,271

The approximate cost of the proposed building is Rs. 1,31,271.

Example 5.6 The particulars regarding a two-storeyed building are given below:

Plinth area of ground (first) floor = 82 m^2

Plinth area of second floor = 68 m^2

Expenditure for the construction of ground floor = Rs 1,10,700

Expenditure for the construction of second floor = Rs 80,240

Estimate the probable cost of a similar building proposed to be constructed in the same locality with plinth areas of 96 m^2 in ground floor and 80 m^2 in second floor.

Solution Plinth area rate for ground floor = 1,10,700/82 = Rs 1,350 per m^2

Plinth area rate for second floor = 80,240/68 = Rs 1,180 per m^2

Probable cost for the proposed building = (96 × 1350) + (80 × 1180) = Rs 2,24,000

The probable cost of the proposed building is Rs 2.24 lakhs.

Example 5.7 Find the value of a 60-year old building of 110 m^2 plinth area if the life of the building is 100 years. The plinth area rate of the building is Rs 2,400/m^2 and the cost of land is Rs 3,00,000.

Solution

Depreciated value of the building

$$D = P \frac{\{100 - S\}^n}{100}$$

P = Cost of the building at present market value

= Plinth area × unit plinth are a rate

= 110 × 2400

= Rs. 2,64,000

S = 1 for building having a life of 100 years

n = The number of years of the building

= 60 years

$$D = 264000 \frac{\{100 - 1\}^{60}}{100}$$

Depreciated value of the building = Rs. 1,44,449.35

Cost of land = Rs. 3,00,000

Total cost of the building including land = Rs. 4,44,449.35

Example 5.8 A building with plinth area of 100 m^2 was constructed over a plot area of 200 m^2, 10 years ago. Plinth area rate at the time of construction was Rs, 900 per m^2. Find the value of the building, taking the life of the building as 50 years. Cost of land is Rs 300 per m^2.

Solution

P = Cost of the building at present market value.

= Plinth area × unit plinth area rate

= 100 × 900

= Rs. 90,000

n = The number of years of the building

= 10 years

S = 2 for building having life of 50 years

$$D = P \frac{\{100 - S\}^{n}}{100}$$

$$= 90000 \frac{\{100 - 2\}^{10}}{100}$$

Depreciated value of the building = Rs. 73536.55

Cost of land = Rs. 300 × 200

= Rs. 60,000

Total cost of the building including land = Rs. 1,33,536.55

Example 5.9 A building is situated by the side of a main road of Chennai on a land of 600 m^2. The built up portion in 30 m × 15 m. The building is of first-class type and provides water supply, sanitary and electric fittings and the age of the building is 40 years. The plinth area rate of the building is Rs 20000 per m^2 and the cost of land is Rs 1200 per m^2. The life of the building is 100 years. Find the valuation of the property.

Solution

Depreciated value of the building

$$D = P \frac{\{100 - S\}^{n}}{100}$$

Plinth area of the building = $30 \times 15 = 450$ m^2

P = Cost of the building at present market value

= Plinth area × unit plinth area rate

= 450 × 20000

= Rs. 90,00,000

S = 1 for building having life of 100 years

n = The number of years of the building

= 40 years

$$D = 90,00,000 \frac{\{100-1\}^{40}}{100}$$

Depreciated value of the building = Rs. 60,207,45.83

Cost of land = Rs. 1200 × 600

= Rs. 7,20,000

Total cost of the building including land = Rs. 67,40,745.83

Example 5.10 A residential building constructed 10 years ago is situated on a plot whose total area is 360 m^2. The plinth area of the building 200 m^2. the present value cost of construction of the building is Rs. 1,10,000. The cost of land is Rs 70 m^2. The rate of depreciation for the value of the building is 1%. Calculate the total value of the property.

Solution

Present cost of the building = Rs 1,10,000

Depreciation rate = 1 per annum

Age of building = 10 years

Depreciated value of the building

$$D = \frac{P\{100-S\}^n}{100}$$

$$= 1,10,000 \frac{\{100-1\}^{10}}{100}$$

Depreciated value of the building = Rs. 99,482

Amount of depreciation = Rs 1,10,000 – 99,482

= Rs 10,518

Minimum depreciation at 10% = Rs 11,000

Depreciated cost of building = Rs 1,10,000 – 11,000

= Rs. 99,000

Cost of land = 70 × 360

= Rs. 25,200

Total value of property = Rs 1,24,250

Example 5.11 A building with a ground floor of 110 m^2 and first floor of 80 m^2 is constructed over a plot measuring 12 × 15 m. the plinth area rate is Rs 2,000 per m^2 for ground floor and Rs 1750 per m^2 for first floor. In the ground floor there is a courtyard of 14 m^2. Find (i) the plinth area of the building, and (ii) approximate value of the building.

Solution

(i) Plinth area of the building = Plinth area of the ground floor + Plinth area of the first floor.

Plinth area of the ground floor = Built up area – area of courtyard

= 110 – 14

= 96 m^2

Plinth area of the building = 96 + 80

= 176 m^2

(ii) Approximate value of the building = {Plinth area of ground floor × Plinth area rate for ground floor} + {Plinth area of first floor × Plinth area rate for first floor}

= {96 × 2000 + 80 × 1750}

= Rs. 3,32,000

Example 5.12 Find the approximate cost of a building with a carpet area of 100 m^2. The plinth are rate is Rs 2400 per m^2. Take the carpet area to be 80% of the plinth area.

Solution

Carpet area = 100 m^2

Plinth area rate = Rs 2400 per m^2

Carpet area = 80% of plinth area of the building

$$100 = \frac{80}{100} \times \text{Plinth area}$$

Plinth area = 125 m^2

Approximate cost of the building = Plinth area × Plinth area rate per m^2

= 125 × 2400

= Rs. 3,00,000

Short-Answer Questions

1. What is meant by bonding of bricks?
2. Classify stone masonry based on its construction.
3. Give a list of types of bonds in brick work.
4. What is meant by valuation?

5. What are the factors affecting the value of a building?
6. What are the types of plasters?
7. What are the advantages of granolithic flooring?
8. What is carpet area?
9. How are properties classified for the purpose of valuation?
10. What are the factors to be considered while selecting a suitable roofing material?
11. What is a truss?
12. What is meant by built-up column?
13. What are the components in the superstructure of a building?
14. Explain the following terms with neat sketches:
    (a) Arrises
    (b) Stretcher
    (c) Header
    (d) Bed joint
    (e) Perpends
    (f) Lap
    (g) Queen closer
    (h) King closer
    (i) Bevelled closer
    (j) Mitred closer
    (k) Bat
    (l) Bull nose
    (m) Cow nose
    (n) Squint quoin
15. Explain with neat sketch the stretcher bond for one-brick thick wall.
16. Explain with neat sketch the header bond for one-brick thick wall.
17. What are the causes of cracks in a brick masonry wall?
18. Write down the remedial measures to prevent cracks in brick masonry wall.
19. Explain the following terms in stone masonry.
    (a) Natural bed
    (b) Sill
    (c) Corbel
    (d) Cornice
    (e) Coping
    (f) Weathering
    (g) Throating
    (h) Plinth
    (i) String course
    (j) Lacing course
    (k) Spalls
    (l) Quoins
    (m) Through stone
    (n) Jambs
    (o) Heads
    (p) Buttress
    (q) Plaster
20. Distinguish between spandrils and stringers.
21. How does a one-and-a-half brick English bond wall look?
22. What is the necessity for providing weatherproof course?
23. Write a short note on any one technique of weather-proofing in RCC slab roofs.
24. Where is stone flooring provided and why?
25. What are the components of industrial flooring?

26. How can the method of laying cement concrete flooring be broadly divided?
27. What are the advantages of cement concrete flooring?
28. What are the disadvantages of industrial flooring?
29. What are the types of asphalt flooring?
30. What is damp-proofing?
31. Mention the causes of dampness.
32. What are the effects of dampness?
33. List out the requirements of an ideal material for damp-proofing.
34. Which materials are used for damp-proofing?

Exercises

1. What is a queen closer and where is it used?
2. Explain the different types of brick masonry normally adopted.
3. Draw a neat sketch of a one-brick thick English bond and explain its features.
4. What are the characteristics of a Flemish bond? Give a neat sketch.
5. What are the factors which decide the thickness of the wall?
6. What are the points to be observed while supervising the brick work?
7. What are the causes for cracks in a masonry wall?
8. Explain the various kinds of rubble masonry with necessary sketches.
9. Explain ashlar masonry with a neat sketch.
10. What are the points to be observed while supervising the stone work?
11. Compare brick masonry with stone masonry.
12. Write short notes on the following:
    (a) Beams
    (b) Columns
    (c) Lintels
13. Explain the purpose of lintel and their types.
14. What are roofs? Explain briefly a reinforced cement concrete roof.
15. For an industrial building, what type of roof can be adopted?
16. Explain the various roof coverings normally adopted.
17. What are the advantages and disadvantages of flat roofs?
18. What is a floor? What are the materials normally used for the construction of a floor?
19. Explain the construction of the following type of floors:
    (a) Cement concrete flooring
    (b) Mosaic flooring

(c) Terrazzo flooring
(d) Tiled flooring

20. What are the objectives of plastering?
21. Explain the method for the preparation of different types of mortar for plastering.
22. What are the requirements of a good plaster?
23. Explain the two-coat plastering method.
24. What is the difference between the three-coat and two-coat methods of plastering?
25. What are the defects in plastering? How can these be rectified?
26. For what purposes is valuation necessary?
27. Explain the various methods adopted to find the value of a building.
28. How can the value of an open area be determined?
29. What is the depreciation method of valuation?
30. How will you calculate the plinth area of a building?
31. What is a plinth-area estimate?
32. Explain the method of valuation by carpet area.
33. Calculate the value of a building if the carpet area of the building is 80 sq.m, rate of plinth area is Rs 1650 per sq.m, and rate of depreciation is 1.5 per cent per annum. The present age of the building is 10 years. Assume that the carpet area is 80 per cent of the plinth area.
34. Find the value of a building if the total area is 250 sq.m and the plinth area is about 85 per cent of the total area. Use the straight line method of depreciation.

    Rate of plinth area = Rs 1500 per sq.m
    Rate of depreciation = 1.5 per cent per year
    Period of consideration = 20 years

35. Write short notes on one-and-a-half brick thick English bond.
36. Explain the purpose of weatherproof course.
37. Explain the construction of the following types of flooring.
    (a) Stone flooring
    (b) Industrial flooring
    (c) Asphalt flooring
    (d) Granite flooring
38. What are the causes and effects of dampness in a structure?
39. What is damp-proofing? What are the materials used for it?
40. Describe the various methods of damp-proofing.

Chapter 6
DAMS

6.1 INTRODUCTION

A dam can be defined as an impervious barrier or an obstruction constructed across a natural stream or a river to hold up water on one side of it, up to a certain level. As shown in Fig. 6.1, the side on which water is getting stored is called *upstream side* and the other side is called the *downstream side*. The stored water on the upstream side constitutes the reservoir.

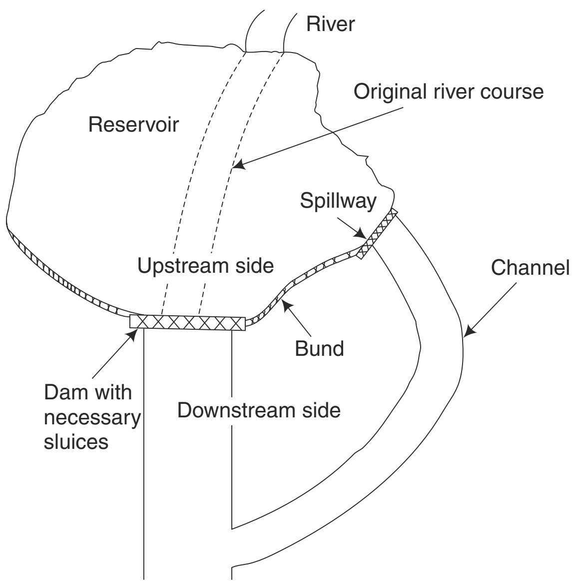


Fig. 6.1 *General layout of a dam*

6.2 PURPOSE OF DAMS

The construction of a dam across a river results in the ponding of water on its upstream side and this serves many useful purposes for mankind. They are as follows:

1. The stored water in the dam can be conveniently used for irrigation purposes.
2. The reservoir forms a very good source for water supply in areas where groundwater source is inadequate.
3. If sufficient head of water is stored, then that can be used for power generation (hydel power).
4. In case of heavy floods, if water is left unobstructed, the result will be very hazardous involving irrecoverable loss of lives of human beings, animals, etc., and loss of property. A dam across the river can act as a good flood-control measure by only letting out the excess quantity of water.
5. A dam with its green surroundings forms an excellent place for recreation purposes such as boating, swimming and water skiing.
6. The reservoir forms a good place for the breeding of fish, which is a considerable wealth from dam. Fish are bred by the pisciculture department.
7. Besides the above-mentioned purposes, a dam serves many miscellaneous purposes, such as adding beauty to the place where it is located and making it a place of tourism importance. The atmospheric heat around the reservoir and its surroundings is controlled well due to the large exposed area of water in the reservoir.

6.3 COMPONENTS OF A RESERVOIR

1. A dam across a river/valley forms a pool of water on the upstream side with necessary sluices to let out water.
2. Irrigation canals taking off from one/either side of the dam with necessary outlets to control the flow in the canal.
3. Spillway to let out the excess water from the dam which otherwise may result in breach of the dam itself due to overstorage of water. Therefore, the spillway acts as a safety valve of the dam.
4. A good earthen bond in case of a totally artificially made reservoir.
5. Ancillary works like fish ladder, log chutes, etc.

6.4 SELECTION OF SITE

The selection of a suitable site for a concrete dam depends on many factors, which are detailed below.

Availability and Characteristics of Materials for Construction It is necessary for economic consideration that the materials required for the dam should be available in close vicinity to the site. For a concrete dam, if natural material or good rock for making the aggregates is available, it is desirable. If limestone is available nearby, it may be possible to replace Portland cement partially or wholly.

Availability of Suitable Site for Construction Facilities The dam site should offer a suitable place for location of colonies, etc. It is necessary to connect the dam site to the nearest rail head by a good road and also if economically feasible, by railway to transport construction machinery, hydromechanical equipment and subsequently for development.

Availability of Utility Services It is economical if the site has, in its near vicinity, an access road, electric line, and water supply, etc.

Climate Very cold and heavy rainfall will impede the progress of construction activities.

Diversion During Construction Sometimes river diversion problems play an important role in the selection of a dam site. This factor may affect the design of the dam and also the construction schedule.

Foundation The site should preferably have good sound rock for foundation. For a concrete or masonry dam, solid rock at the surface or within a reasonable depth below it, is essential. For arch dams, strong abutments are essential.

Flood Control Aspect The dam site should be above the area to be protected.

Hydrology It is an important factor. Good water availability with minimum fluctuations is a desirable feature.

Irrigation Command The dam site should be above the area to be irrigated.

Locality Healthy surroundings free from mosquitoes are preferable.

Sediment Load An assurance that the dam would not silt soon is a desirable factor. The sediment load in the stream should be as little as possible.

Spillway Site In the case of a masonry dam, it is not essential that a good site for spillway be available. If available, it will be advantageous.

Submergence The value of the property and land submerged by the proposed dam should be low in comparison to the benefits expected from the dam. For example, the height of Rihand dam in Uttar Pradesh (India) could not be raised as the neighbouring Singarelli coal mines are under danger of being submerged.

Topography and Storage Capacity For the economic feasibility of a storage project it is necessary that the length of the barrier or dam should be as small as possible and for a given height, it should store a good volume of water. Hence the river valley at the dam site should be as narrow as possible and should open out upstream to provide a reservoir as shown in Fig. 6.1.

6.5 CLASSIFICATION OF DAMS

Dams are broadly classified into two categories—*rigid dams* and *non-rigid dams*.

6.5.1 Rigid Dams and their Types

As the name implies, these dams are constructed using rigid construction materials, such as stone or brick or reinforced cement concrete or plain cement concrete. The basic cross-sectional profile of a rigid dam is triangular as shown in Fig. 6.2. Various types of rigid dams are discussed below.

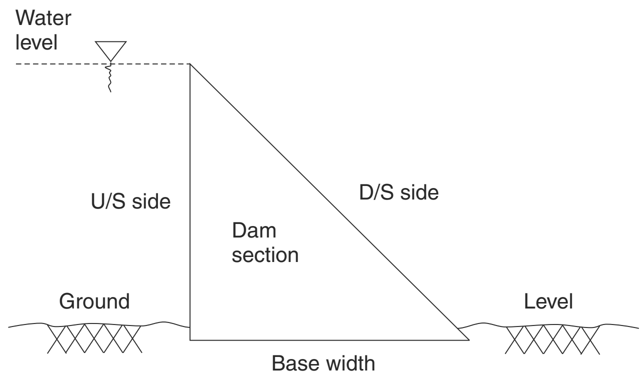


Fig. 6.2 *Basic profile of a dam*

1. Solid gravity dams A gravity dam can be defined as a structure which is designed in such a way that its own weight resists the external forces. This type of dam is more durable and has maximum rigidity. It requires less maintenance when compared to other types. This type can be constructed of masonry or concrete. Nowadays, concrete gravity dams are prevalent.

The dam section is massive as the self-weight is the only force which is going to resist all other disturbing forces acting on the dam. Therefore, it needs a good foundation soil, preferably a rocky strata.

In practice, a triangular basic profile cannot be adopted and instead this profile is modified to accommodate the operating platform for the shutters and roadway at the top. So a practical profile will be a trapezoidal one with a sufficient free board as shown in Fig. 6.3.

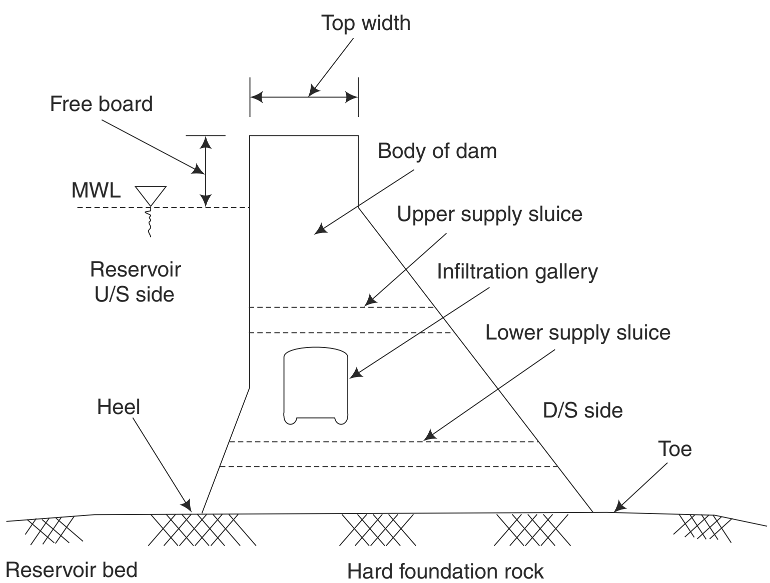


Fig. 6.3 *Cross-section of a gravity dam*

The water stored on the upstream side exerts a major disturbing force on the dam. In addition to this, water may seep through the body of the dam and below the foundation of the dam. This will cause uplift of the dam which also affects the stability of the dam. There are also wave pressure, ice pressure, pressure due to earthquake forces, etc., affecting the stability of the dam. Of the above, pressure due to earthquake is significant and this has been the major cause for serious cracks in several dams.

To relieve the uplift pressure in the dam, infiltration gallery is provided within the dam section. This will collect the seeping water and will convey it to greater depth so as not to affect the stability of the dam.

The provision of supply sluice controlled by shutters enables the release of required quantity of water to the downstream side.

A gravity dam may fail due to overturning, sliding, and crushing at the toe. Generally, a gravity dam will be designed with a higher factor of safety and check will be made for the above possible failures.

2. Arch dams An arch dam is curved in plan with its convex face holding the water as shown in Fig. 6.4(a). This structure is less massive when compared to the gravity dam. The force exerted by the stored water on the upstream side will be transferred to the abutments by the arch action.

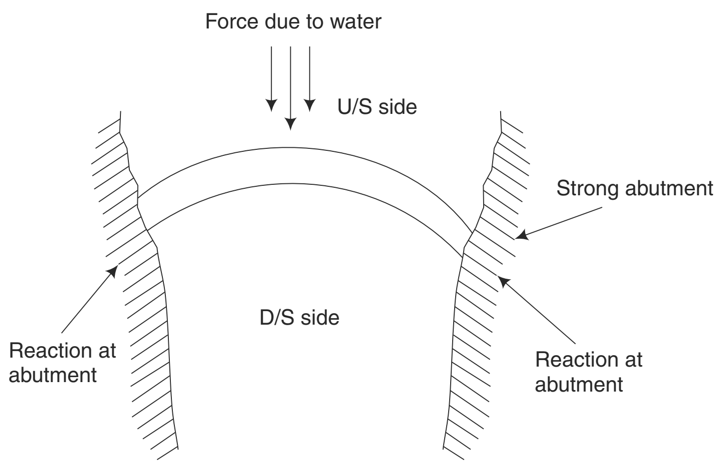


Fig. 6.4(a) *Arch dam*

This dam is suitable for narrow valleys but the major requirement is sound abutments. In this case, uplift on the base of the dam has no problem because only abutments are going to bear maximum force. An arch dam will be economical only if the length of the dam is less than its height. Therefore, this is preferable for very great heights.

According to the method of construction, arch dams are classified into the following types.

(a) Constant-radius arch dam as shown in Fig. 6.4(b).

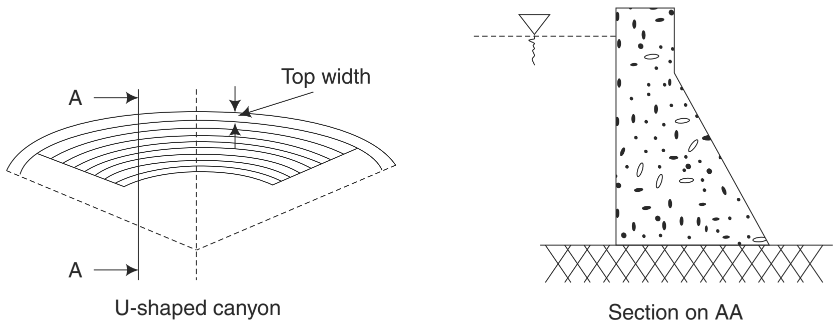


Fig. 6.4(b) *Constant-radius arch dam*

(b) Constant-angle arch dam as shown in Fig. 6.4(c).

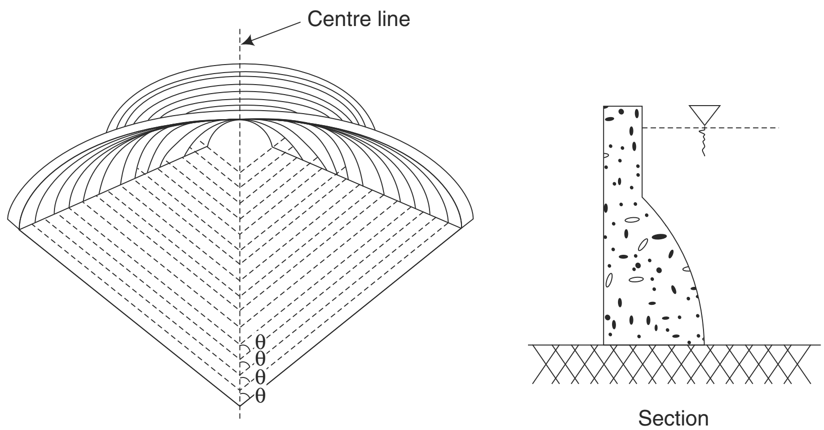


Fig. 6.4(c) *Constant-angle arch dam*

(c) Variable-radius and variable-angle arch dam as shown in Fig. 6.4(d).

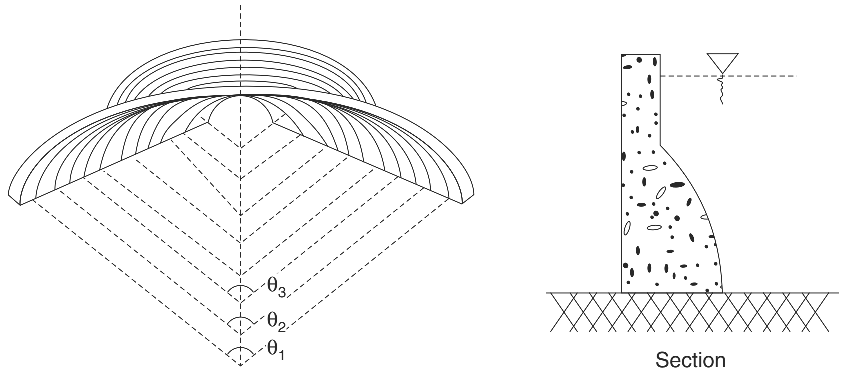


Fig. 6.4(d) *Variable-angle and variable-radius arch dam*

3. Buttress dams A buttress dam has relatively thin sections when compared to a gravity dam. Generally, it consists of a sloping section, buttresses and a base slab.

The sloping membrane (face slab) first takes the water load and transfers it to the buttresses which are at specific intervals. The buttresses in turn transfer the load to the base slab which forms the foundation part of the dam.

The important types are the flat slab type/ambursen type and the multiple arch type.

In the first case, between two buttresses, RCC slabs (reinforced cement concrete) will be available as detailed in Fig. 6.5. In the case of an arch buttress dam, the arch action of the slab permits wider spacing of buttresses. Lateral beams called braces or struts will be provided between buttresses along the length of the dam which provide additional strength to the buttresses.

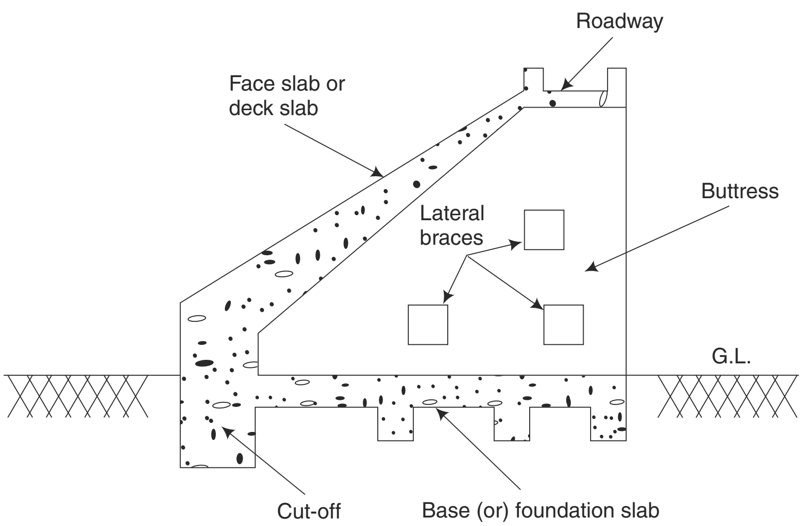


Fig. 6.5 *Section of an RCC buttress dam*

The height of buttress dams can be conveniently increased by mere extension of buttresses and face slabs. Buttress dams are less massive and can be constructed where the foundation soil is relatively weak. Enormous space available between buttresses can be advantageously used for installing water-treatment plants and powerhouses.

4. Timber and steel dams Timber dams (shown in Fig. 6.6) and steel dams (shown in Fig. 6.7) are special types which are not generally used for bigger dam sections.

A timber dam is generally adopted for temporary requirements to enclose certain work sites or to divert the flow to enable the construction of the main dam. After the main structure is built, generally the timber dam will be dismantled. The height of the dam may be up to 9 metres. Timber dams are rarely made watertight. Steel dams are not common in use. But it is possible to construct the dam with steel up to a height of 15–18 m. The construction of a steel dam may be done similar to the timber dams.

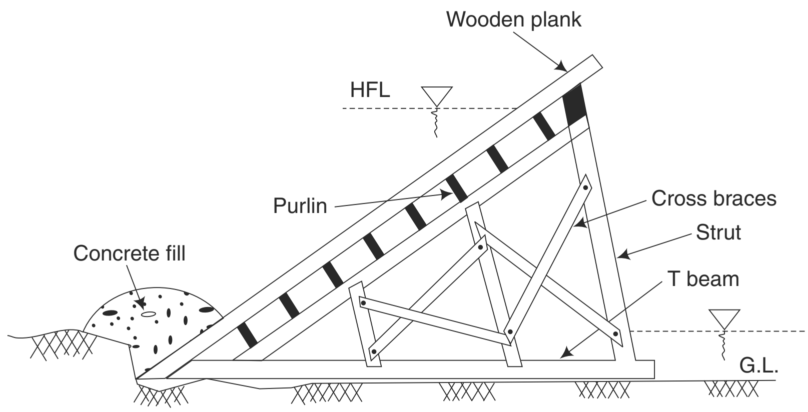


Fig. 6.6 *Buttress-type timber dam*

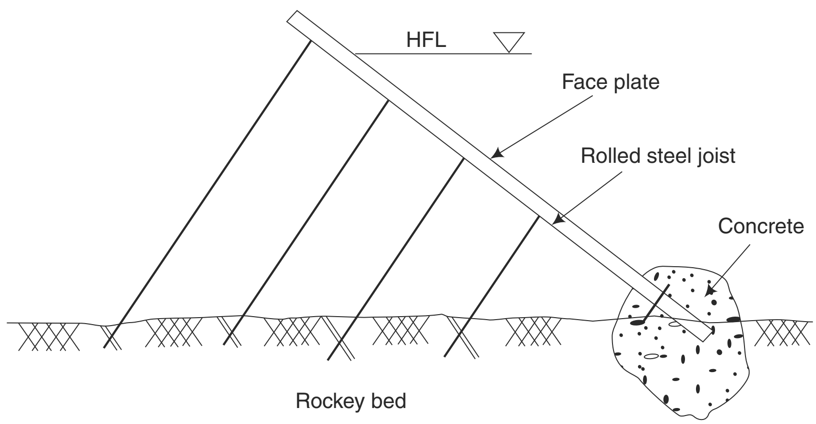


Fig. 6.7 *Section of a steel dam*

6.5.2 Non-rigid Dams and their Types

Non-rigid dams have a trapezoidal basic profile. Earth dams and rock-fill dams which fall under this category are discussed in this section.

1. Earth dams Earth dams are made of soil with minimum processing using primitive equipment. These are built in areas where the foundation is not strong enough to bear the weight of a gravity dam. As the construction material of this dam is ordinary soil which is cheaply available, the cost of construction will be less than that of a rigid dam. These can be constructed in places of low or moderate rainfall which necessitate only moderate heights for the dam.

The three different types of earth dams are described here.

(a) Homogeneous embankment type When only one type of material is economically or locally available, such homogeneous embankments are possible. This is the simplest type of an earth dam consisting of a single material throughout the structure.

A purely homogeneous type poses the problem of seepage which is not desirable from the stability point of view. Sometimes stones will be pitched over the upstream face of the dam to safeguard the dam against wave action and to improve the stability as shown in Fig. 6.8.

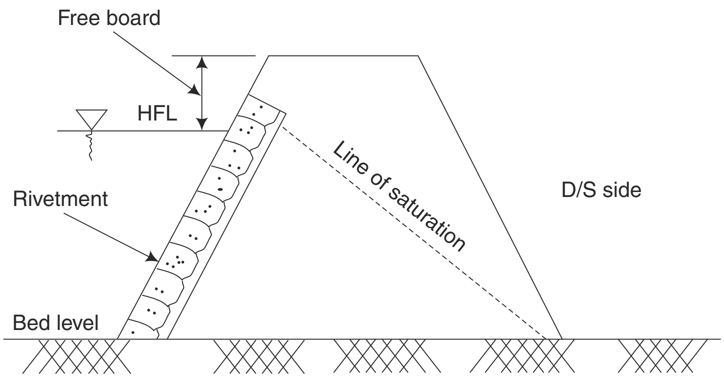


Fig. 6.8 *Homogeneous earth dam*

(b) Zoned embankment type The section of a zoned embankment earth dam will have an inner zone made of impervious soil and an outer zone made of pervious soil as detailed in Fig. 6.9. Normally, inner zone will be of clay or silt or a mixture of both and the outer zone is of locally available soil. The presence of inner impervious zone provides added strength and reduces seepage of water through the dam section. This type can be adopted for dams of greater heights. A suitable filter medium in the form of transition filter combined with toe filter is provided. The provision of above filters will ensure proper collection of the water seeping through the dam section and conveyance of the collected water to the downstream side safely adds to the stability of the dam.

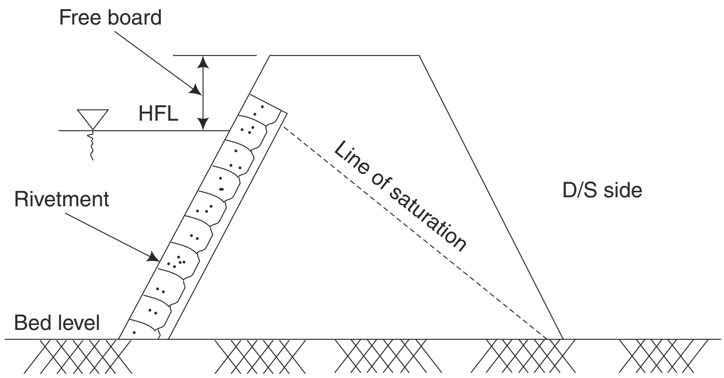


Fig. 6.9 *Zoned embankment type*

(c) Diaphragm-type embankments These have a thin impervious core, which is surrounded by earth as shown in Fig. 6.10. The thin core is called the diaphragm and is usually made of impervious soils or concrete or steel or timber. The diaphragm must be tied to the bed rock or to a very impervious foundation material.

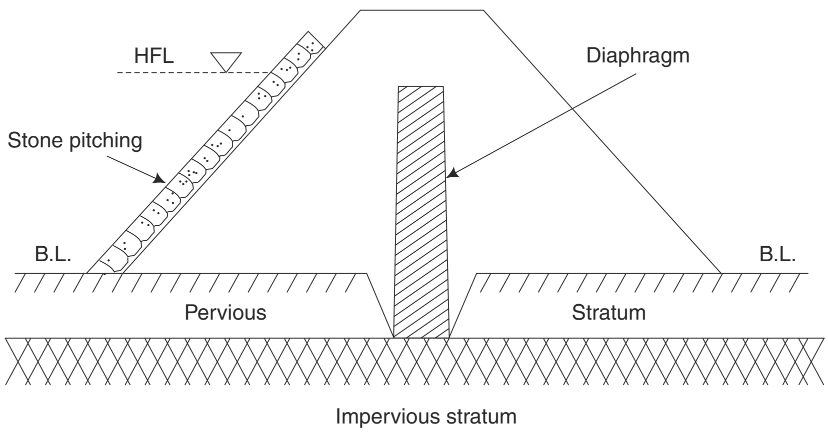


Fig. 6.10 *Diaphragm-type embankment*

2. Rock-fill dams Rock-fill dams are made of loose rocks and boulders piled in the river bed. A slab of reinforced concrete is often laid on the upstream face to make it water tight. These are more stable than earthen dams and less stable than gravity dams. The dam section generally consists of dry rubble stone masonry on the upstream side and loose rock-fill on the downstream side as shown in Fig. 6.11.

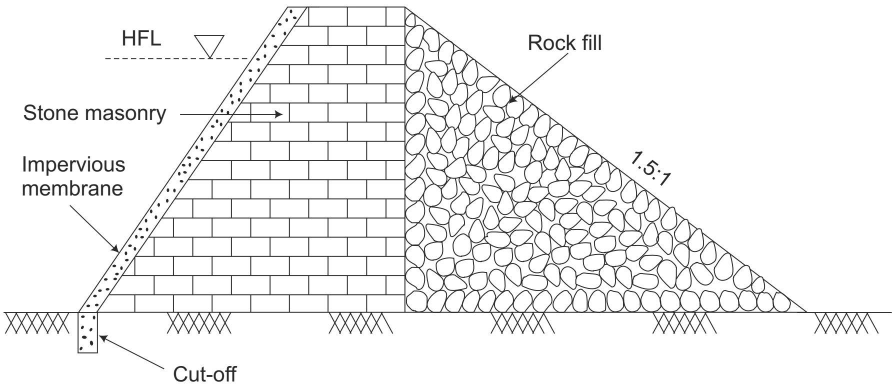


Fig. 6.11 *Section of a rock-fill earth dam*

Rock-fill dams are subjected to more settlement problems which may even result in the cracking of the reinforced concrete membrane on the upstream side. It has better resistance towards earthquakes because of its flexible nature. The structural design of this type of dam is bit complicated when compared to other types.

6.5.3 Gravity Dam

Advantages

1. **Maximum Rigidity** A gravity dam has maximum rigidity, due to its heavy and solid self-weight. Hence, it is also named solid gravity dam.
2. **Durability** It is highly durable and requires minimum maintenance.
3. **Height of the Dam** It can be constructed of any height, provided a suitable foundation is available to withstand the loads on it.
4. **Stability** It is relatively stronger and more stable than earth dams.
5. **Use** A gravity dam is most suited at sites with narrow gorges or valleys and steep side slopes. It is adopted for use as an overflow dam.
6. **No Sudden Failure** Failure of the gravity dam, if any, may not suddenly occur.

Disadvantages

1. **Rock Foundation** A gravity dam can be constructed only on sound rock foundations.
2. **Causes of Failure** A gravity dam may fail due to overturning or sliding or crushing, due to the heavy self-weight of the dam and the forces acting on it.
3. **Raising the Height** Unless specific provision is made in the initial design itself, it will be very difficult to raise the height of the dam subsequently.

4. **Initial Cost** Initial cost is higher than that of earth dams.
5. **Skilled Labour** Skilled labour is required for its construction.

Advantages of Arch Dam

1. The arch dam is suitable for narrow valleys or gorges.
2. The arch dam requires less construction materials and is hence less massive. Saving in the quantity of concrete is around 50% compared to gravity dam. This is because of its better structural effectiveness.
3. When the height of the dam is more than its length, an arch dam is economical. Therefore, this dam is preferable for very great heights.

Advantages of R.C.C. Buttress Dam

1. *Stability* Weight of water on the inclined face slab helps to maintain the stability of the dam. Because of this, the requirement of quantity of concrete becomes less. Thus, the dead weight of the dam is reduced.
2. *Weak soil* As the dead weight of the dam is less, it may be constructed in weak soil, where hard or rocky stratum is not available.
3. *Height of the dam* The height of a buttress dam can be easily increased by simply extending the buttress and the face slabs.
4. *Lateral beams (braces)* The braces add to the strength of the buttress.
5. *Space between Buttress* The space available between the buttress is very large. It may be used for housing water–treatment plants and power houses.

Advantages of Embankment Earth Dams

1. Embankment earth dams are suited to a wide variety of foundation conditions.
2. They are suitable for both steep gorges and wide valleys.
3. Local materials can be made use of.
4. Reduced cost of construction.
5. About 80% of the total number of dams in the world are earth dams.

6.6 GEOLOGICAL EFFECTS

In the construction of dams, geology plays a vital role in site selection. The first consideration in all sites for a dam is the suitability of the rock in foundations. The main geological considerations in the selection of dam sites are as follows.

(i) The underlying rocks must be strong enough to withstand the weight of the dam and the resultant thrust.

(ii) The rocks should be sufficiently impervious to prevent seepage of water beneath the sole of the dam.

(iii) The rocks should be free from fissures, joints and faults so that there is no leakage of water.

Sites which have an impervious band of strong massive rocks, free from joints throughout the length of the dam, are considered to be the best site for a dam. Granite which is free from joints and fissures would make an excellent foundation for any dam.

When a river breaks across a ridge by cutting a deep gorge at right angles to the strike off the bedded or foliated rocks, an ideal dam site may be found in the gorge.

In case of loose, unconsolidated strata like sand and loam where there is considerable loss by percolation or leakage, high dams cannot be efficiently constructed. In such areas, it is possible to construct low-pressure dams if they have sufficiently wide foundations without openings or crevices.

Across the fault plane it is not advisable to construct any dam. Rocks having small fissures and joints can be sealed with concreting material but still it is not reliable during earthquakes.

Massive solid rocks such as granite, quartzite, limestone and sandstone make excellent sites for the foundation of dams, if they are free from open joints and fissures. Decomposed rocks such as dolerite and laterite should be avoided, as there is a possibility of percolation of water.

Short-Answer Questions

1. Distinguish rigid dams from non-rigid dams.
2. What are the components of a reservoir?
3. Give a general layout of a dam.
4. What is the purpose of providing a spillway in a dam?
5. What is the function of an infiltration gallery in a dam?
6. What are the common modes of failure of a gravity dam?
7. List out the classification of dams.
8. Why is a gravity dam so called?
9. Why are the lateral braces provided in the buttress dams?
10. What do you mean by filters in a non-rigid dam? What is the purpose of these filters?
11. Write short notes on geological effects on dams.

Exercises

1. What is a dam and what are the components of a reservoir?
2. What are the factors based on which the site for a dam is selected? Explain them briefly.
3. What is the basic profile of a dam? How is the practical profile determined from the basic profile?

4. Draw a neat sketch of the cross-section of a dam and give the forces acting on it.
5. Explain the different types of arch dams.
6. Explain with sketches the various types of earthen dams.
7. What are the purposes of a dam?

Chapter 7
BRIDGES

7.1 INTRODUCTION

A bridge is a structure providing passage over an obstacle such as a valley, road, railway, canal, river, without closing the way beneath. The required passage may be for road, railway, canal, pipeline, cycle track or pedestrians.

The branch of civil engineering which deals with the design, planning construction and maintenance of bridges is known as bridge engineering.

7.2 NECESSITY OF BRIDGES

Bridges are vital for the development of a country since these enable transporting materials from one area to the other which may be separated by streams and rivers, thereby maintaining uniform flow of essential goods for development. In times of war, materials are swiftly transported for the defence needs of the country by railroad bridges. Bridges link the whole country with road and railway communication maintaining a uniform flow of people, goods and other essential commodities. The necessity of bridges may therefore be summarised as follows:

1. Bridges enable the free flow of traffic during monsoons and other periods of inclement weather.
2. Bridges provide additional communication facilities.
3. The development of the backward districts which may be rich agriculturally critically depends on the existence of bridges.
4. Bridges provide more socio-economic benefits to the people.
5. Bridges also enable movement of troops and military vehicles during hostilities.

7.3 SITE INVESTIGATION

Before a bridge is constructed, a suitable site is selected based on certain factors which have bearing on the economy and stability of the bridge. Reconnaissance is therefore made and the following data are recorded to determine the feasibility of bridge construction:

Considered while selecting the site for a bridge are the following:

1. The bridge should cross the river at right angles to the direction of flow of stream or river water so as to minimise the length of the bridge.
2. The banks on either sides of the river should have firm soil and be straight and well-defined. This will increase the stability of the bridge and reduce the possibility of the erosion of the banks. Also, the soil need not be stabilised or given any other treatment which will increase the cost.
3. The selected site should be at a place where the river is narrow and the flow is streamlined without serious whirls and cross currents. Small width reduces the length of the bridge which means less cost of construction and maintenance. If the flow of water is uniform and parallel, it is a reliable guard against scour.
4. Precautions should be taken to see that the selected site should be far away from where the river is likely to change the course. If the bridge has been constructed and the river has changed its course, the bridge will be rendered useless.
5. Hard inerodable strata or rock should be available close to the river-bed level.
6. There should not be any sharp curves in road approaches.

7.4 PRELIMINARY DATA TO BE COLLECTED

The engineer in-charge of the investigation for a bridge should collect the following information before the construction of a bridge is undertaken:

1. Volume and Nature of Traffic Not only the present volume and nature of traffic but also the future volume which is expected in the next ten years should be collected. The size and the type of the bridge required depend on this data.

2. Velocity of the Stream and High Flood Level (HFL) Attained The discharge of water passing through the bridge depends on the velocity of water. It will help in designing the proper size of the waterway and pier thickness. The velocity of the stream during high flood and also during normal flow can be determined with the help of the current meter or velocity rods. The High Flood Level (HFL) will enable a bridge engineer to determine the height of free board which is the height of the road way above the HFL. It is necessary to prevent the washing away of the bridge during heavy floods.

3. Catchment Area It is an area of that portion of watershed from which water flows and feeds the river. This is necessary to calculate the discharge of the stream.

4. Strength and Nature of Soil and Extent and Type of Vegetation The depth of foundation for the piers and abutments depends on the strength of soil. This is determined by carrying out borings at several places and testing the soil samples. Extent and type of vegetation along with climatic conditions are also noted.

5. Frequency of Flood Occurrence and Rainfall Details The determination of flood frequency is an important factor as most of the bridges are designed for a flood frequency of 50 years. Amount of rainfall and the HFL are also noted for future design.

6. Scour Depth Determination Eroding of the bed of river due to heavy discharge and the velocity of water known as scour has a great bearing on the design of the depth of foundation of piers and abutments. Hence, the extent to which the bed of the river may scour below the HFL is determined according to which the design is made.

In addition to the above, the following data should also be collected.

1. Name of the river, road and location of the probable bridge sites
2. Location of the nearest Great Trigonometric Survey (GTS) benchmark with its Reduced Level (RL)
3. Navigational requirements, if any, for the river
4. Availability, quality and location of the nearest quarries for stones, for masonry and for concrete aggregates
5. Nearest place of availability of cement, steel and timber
6. Means of transport for materials
7. Availability of electric power
8. Availability of skilled and unskilled labour
9. Facilities required for housing labour during construction
10. Liability of the site to earthquake disturbances

7.5 COMPONENTS OF A BRIDGE

Figure 7.1(a) shows the elevation while Fig. 7.1(b) presents the plan of a bridge. Broadly, a bridge can be divided into two major parts: superstructure and substructure. The *superstructure* of a bridge is analogous to a single-storey building roof and *substructure* to that of the walls, columns and foundations supporting it.

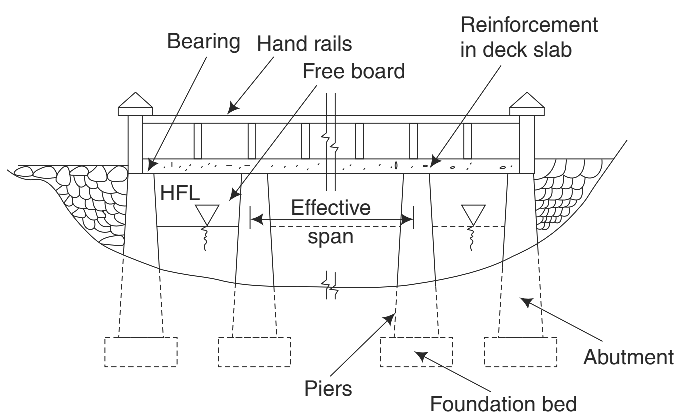


Fig. 7.1(a) *Elevation of a bridge*

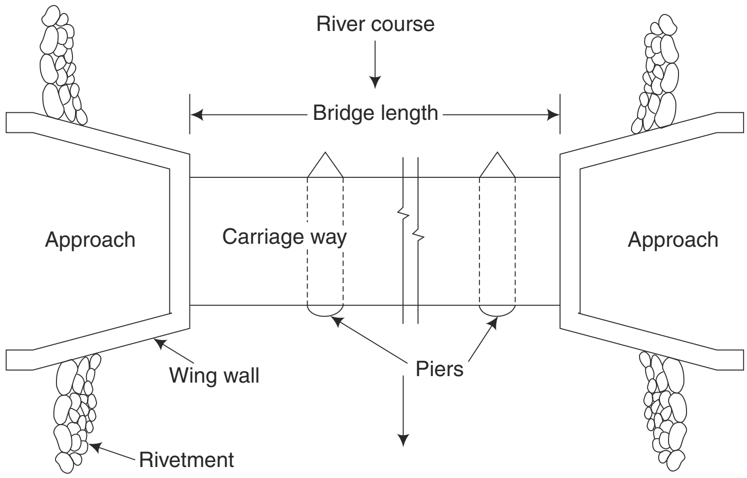


Fig. 7.1(b) *Plan*

Superstructure consists of structural members carrying a communication route. Thus, handrails, guardstones and flooring supported by any structural system, such as beams, girders, arches and cables, above the level of bearings form the superstructure.

Substructure is a supporting system for the superstructure. It consists of piers, abutments, wingwalls and foundations for the piers and abutments.

The other main parts of a bridge structure are the approaches, bearings and river training works, such as the aprons, and the rivetment for slopes at abutments, etc. Some of the important components of a bridge are explained in this section.

Piers These are provided in between the two extreme supports of the bridge (abutments) and in the bed of the river to reduce the span and share the total load coming over the bridge. Piers are provided with foundation which is taken below the bed of the river where hard soil is available.

Abutments The end supports of a bridge superstructure are called abutments. It may be of brick masonry, stone masonry, RCC or precast concrete block. It serves both as a pier and as a retaining wall. The height of abutment is equal to that of the piers. The functions of an abutment are the following:

1. To transmit the load from the bridge superstructure to the foundations
2. To give final formation level to the bridge superstructure
3. To retain earth work of embankment of the approaches

Wing Walls The walls constructed at both ends of the abutments to retain the earth filling of bridge approaches are called wing walls. Normally, the wing walls have steadily decreasing cross-section. The design of wing walls is independent. Generally, the water face of these walls is kept vertical.

Foundations The lowest artificially built parts of piers, abutments, etc., which are in direct contact with the subsoil supporting the structure are called foundations.

The factors which affect the selection of foundation include the type of soil, the nature of soil, the type of the bridge, the velocity of water and the superimposed load on the bridge.

Well foundation is the most commonly adopted bridge foundation in India. The foundation may consist of a single large diameter well or a group of smaller wells of circular or other shapes.

Approaches These are the lengths of communication route at both ends of the bridge. Approaches may be in embankment or in cutting depending upon the design of the bridge. It is recommended (as per Indian Road Congress) that the approaches must be straight for a minimum length of 16 m on either side of the bridge. Its function is to carry the communication route up to the floor level of the bridge.

Hand Rails and Guard Stones Hand rails are provided on both sides of a bridge to prevent any vehicle from falling into the stream. Footpaths are also provided for pedestrians to walk along without interfering with the heavy vehicular traffic.

In order to prevent a vehicle from striking the parapet wall or the hand rails, guard stones painted white are provided along the edge of the footpaths at the ends of the road surface. Guard stones are also provided along both sides of the approach roads in filling to prevent the vehicles from toppling over the sides of the embankments.

Bearings for the Girders The longitudinal girders have to rest over the piers which bear the thrust of the load coming over them. In order that the girder ends should rest on proper seats, the same are provided with bearing blocks made of cement concrete, so that the load may be uniformly distributed over the structure on which they rest. Due to the expansion and contraction of the longitudinal girders during severe heat and cold, rollers are provided on the abutment ends to allow the movements without causing the girder to buckle.

7.6 TECHNICAL TERMS

1. ***Span*** It is the centre to centre distance between two supports.
2. ***Culvert*** It is a small bridge having maximum span of 6 m.
3. ***Vent way*** It is a culvert having a length less than 1 m.
4. ***High Flood Level (HFL)*** It is the level of the highest flood ever recorded in a river or stream.
5. ***Ordinary Flood Level (OFL)*** It is the flood level which generally occurs every year.
6. ***Low Water Level (LWL)*** It is the minimum water level in the dry weather.
7. ***Waterway*** The area of opening which allows maximum flood discharge to pass under the bridge without increasing the velocity to a dangerous limit is called waterway.

8. ***Afflux*** Due to construction of the bridge, there is a contraction in waterway. This results in rise of water level above its normal level while passing under the bridge. This rise is known as afflux.
9. ***Free board*** The difference between the HFL and the level of the crown of the road at its lowest point is called free board.
10. ***Head room*** It is the vertical distance between the highest point of a vehicle or vessel and the lowest point of any protruding member of a bridge.
11. ***Length of the bridge*** The length of a bridge structure will be taken as the overall length measured along the centre line of the bridge from the end to the bridge deck.
12. ***Viaduct*** It is a continuous structure which carries a road or railway like a bridge, over a dry valley composed of series of spans over trestled bents instead of solid piers.
13. ***Causeway*** It is a *pucca* submersible bridge which allows floods to pass over it. It is provided on less important routes in order to reduce the construction cost of cross-drainage structures. It may have vents for low water flow.

7.7 CLASSIFICATION OF BRIDGES

7.7.1 According to the Expected Utility of Service

The bridges are classified as temporary and permanent bridges.

1. Temporary bridges The bridges which are constructed and maintained at low cost and have short span of life are called temporary low cost bridges, e.g., timber bridges. Temporary bridges are constructed in the following cases:

(i) During construction of dams
(ii) During construction of permanent bridges
(iii) For crossing river during *melas*
(iv) During repair work of permanent bridges
(v) During survey work for projects
(vi) For transporting timber from one bank to the other in forests.

These bridges are dismantled when the object of their construction is fulfilled.

2. Permanent bridges These are bridges which are constructed and maintained at high cost and have a long span of life.

These bridges are built to last for centuries, e.g., steel bridges and RCC bridges.

7.7.2 According to the Position of the Floor of the Bridge

Relative to formation level and highest flood discharge, the bridges are classified as deck bridges, through bridges and semi-through bridges.

1. Deck bridges When the platform of a bridge, carrying the communication route is supported at the top of the superstructure, i.e., when the superstructure of a bridge is accommodated between the high flood level and the formation level then the bridge is known as the deck bridge which is shown in Fig. 7.2.

2. Through bridge When the platform of a bridge, carrying the communication route is suspended at the bottom of the superstructure, i.e., when the superstructure of a bridge projects completely above the formation level then the bridge is known as through-type bridge (shown in Fig. 7.3).

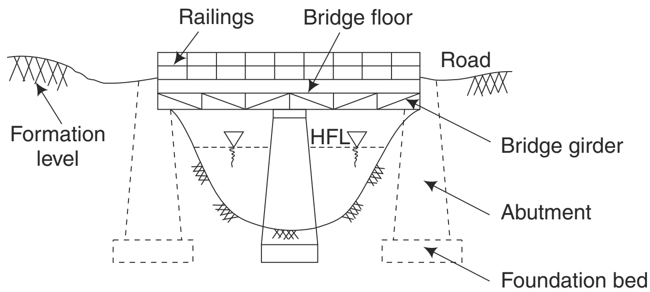


Fig. 7.2 *Deck bridge*

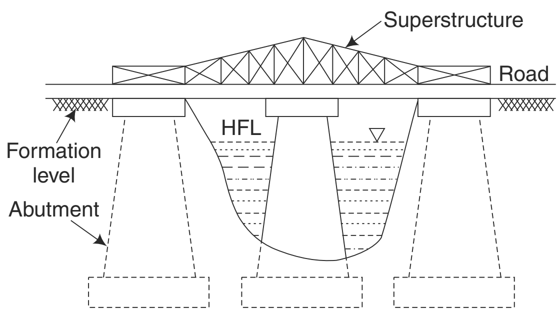


Fig. 7.3 *Through bridge*

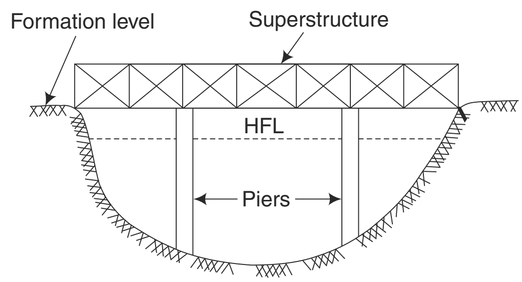


Fig. 7.4 *Semi-through bridge*

3. Semi-through Bridge When the superstructure of a bridge projects partly above and partly below the formation level, it is known as semi-through bridge or pony bridge and is thus an intermediate type between deck and through types. Figure 7.4 shows a semi-through bridge.

7.7.3 According to the Inclination of Bridge

With respect to the axis of water (i.e. direction of flow of water), the bridges are classified as straight bridges and skew bridges.

1. Straight bridge The bridge which is at right angles to the axis of flow of water is called straight bridge. This type of crossing is also known as *square crossing*.

2. Skew bridge The bridge which is constructed at some angle other than 90° to the flow of water is known as a skew bridge. It is better to always avoid a skew bridge because it has the following disadvantages:

(a) The foundations are likely to be scoured.

(b) Construction of skew arches is difficult.
(c) Maintenance is costly and difficult.
(d) The piers have to resist additional water pressure, as whirls are produced. Hence, special care must be taken to ensure that the pier is parallel to the current.

7.7.4 According to the Position of High Flood Level

1. Submersible or low-level bridge It is the bridge which allows the highest flood to pass over its superstructure. These bridges are generally constructed on unimportant routes and when sufficient funds are not available. In this case, storm water runs only for a short period of the year. The stream remains dry for the rest of the year or normal flow runs under the bridge.

2. Non-submersible or high-level bridge It is a bridge which does not allow the high flood water to pass over the floor carrying the communication route.

This type of bridge is of permanent nature. It is constructed on important highways and to carry an unobstructed traffic throughout the year. Moreover, sufficient funds should be available for its construction.

7.7.5 According to the Type of Superstructure

1. Arch bridges
2. Girder bridges
3. Truss bridges
4. Suspension bridges

7.7.6 According to the Method of Providing Clearance in Navigation Channels

1. Movable bridges
2. Transporter bridges

7.7.7 According to the Span

1. Culvert (span less than 6 m)
2. Minor bridges (span between 8–30 m)
3. Major bridges (span above 30 m)
4. Long-span bridges (span above 120 m)

7.7.8 According to the Loadings

Road bridges and culverts have been classified by Indian Road Congress (IRC) into Class AA, Class A and Class B bridges according to the loadings they are designed to carry.

7.7.9 According to the Level of Crossing of Highways and Railways

1. Overbridge The bridge constructed to allow a highway to pass over another communication route (railway) is called an overbridge.

2. Underbridge The bridge constructed to allow a road to pass under another communication route is known as an underbridge.

7.7.10 According to their Function

According to their function or purpose, bridges are classified as

1. Foot bridge
2. Highway bridge
3. Railway bridge
4. Viaduct bridge
5. Aqueduct bridge

7.7.11 According to Materials

1. Timber bridge
2. Masonry bridge
3. Steel bridge
4. RCC bridge
5. Prestressed concrete bridge

7.7.12 According to the Interspan Relationship

1. Simple bridge
2. Continuous bridge
3. Cantilever bridge

Arch Bridge

Arch bridges are often used because of their pleasing appearance. These are more graceful and suited for deep gorges with rocky abutments. Arch bridges can be economically adopted up to a span of 250 m. In this type of bridge, the roadway is constructed on an arch which rests on piers and abutments as shown in Fig. 7.5. An example of an arch bridge is the rainbow bridge across the Niagara river over a span of 290 m.

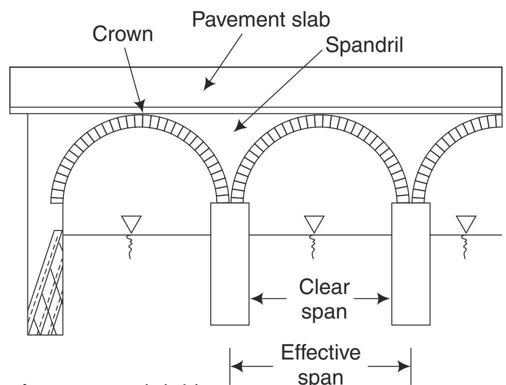


Fig. 7.5 *Arch bridge*

The advantages of an arch bridge are:

1. There will be no bending anywhere in the arch
2. Vibrations due to impact forces are minimum
3. Pleasing appearance

Slab Bridge

This is the simplest type of RCC bridge and easiest to construct. Slab bridges are generally found to be economical for a span of up to 9 m. The thickness of the slabs is quite considerable but uniform, thereby requiring simple shuttering. Though the amount of concrete and steel required are more, the construction is much simpler and placement of material is easy. Figure 7.6 shows a slab bridge.

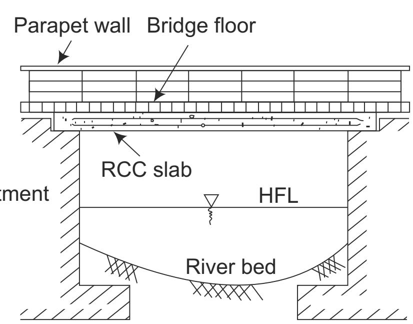


Fig. 7.6 *RCC slab bridge*

T-Beam and Slab Bridge

This consists of T-beams supported over piers and abutments as shown in Fig. 7.7. The deck slab is supported over the T-beams. This type of bridge is suitable for spans between 9–20 m. A T-beam bridge is cheaper and requires less quantity of materials. For example, the longest RCC T-beam bridge in India is the Advai Bridge in Goa with a pier spacing of 35 m.

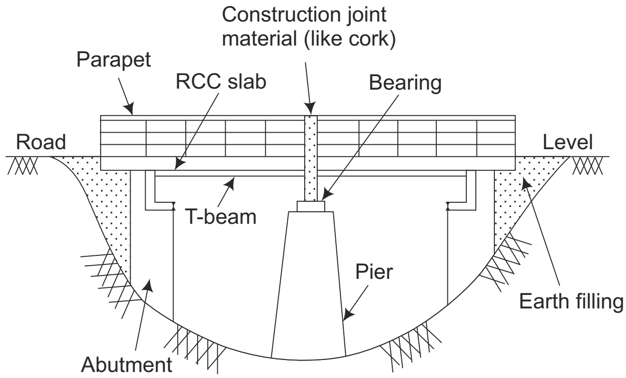


Fig. 7.7 *RCC T-beam and slab bridge*

Bow-String Girder Bridge

Bow-string girder bridges are economical when sufficient head room is needed under a bridge. The main components here are an arch resembling the bow and a tie beam resembling the string of the bow. As the major portion of the load will be borne by the beam, the thrust on the abutments from the arch will be limited. Hence, the abutments need not be too heavy. The roadway is actually suspended from the arch rib by means of vertical suspenders as presented in Fig. 7.8. These bridges can be adopted for spans of 30–45 m.

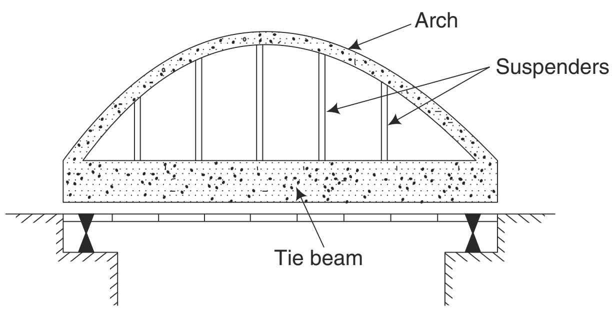


Fig. 7.8 *RCC bow string girder bridge*

Suspension Bridge

Superstructure of a suspension bridge consists of two sets of cables over the towers, carrying the bridge floor by means of suspenders as shown in Fig. 7.9. This bridge is best suited for light traffic for large spans exceeding 600 m. These bridges are flexible and hence the vertical oscillations will be more than the other bridges. The entire load will be borne by the cables which are anchored to the ground.

Steel Bridges

Steel bridges are commonly used for supporting highways, water, oil or gas pipes, a railway track, etc. They can be classified as follows:

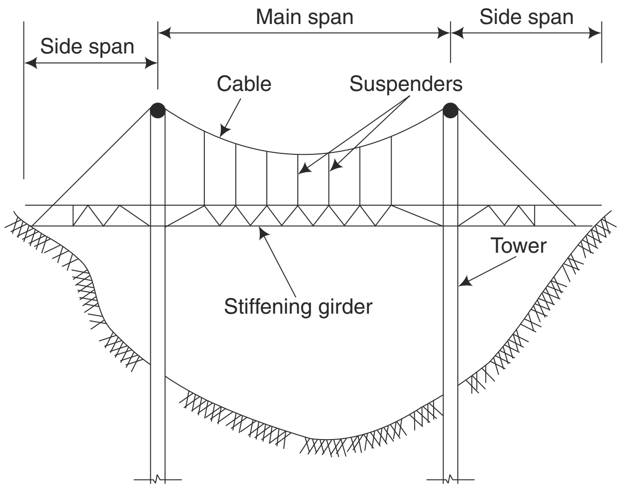


Fig. 7.9 *Stiffened suspension bridge*

1. Steel truss bridges
2. Steel rigid frame bridges
3. Plate girder bridges
4. Steel arch bridges
5. Steel bow string girder bridges
6. Movable bridges

Steel Truss Bridges

Steel truss bridges are provided for long railway bridges, as they are less affected by wind pressure. It is easy to erect steel truss bridge since its component members are relatively light in weight. The primary forces in its members are axial forces. Steel truss bridges which are commonly used are the following and are shown in Fig. 7.10, respectively.

1. N-truss bridge
2. K-truss bridge
3. Warren truss bridge
4. Pratt truss bridge
5. Curved chord Pratt bridge

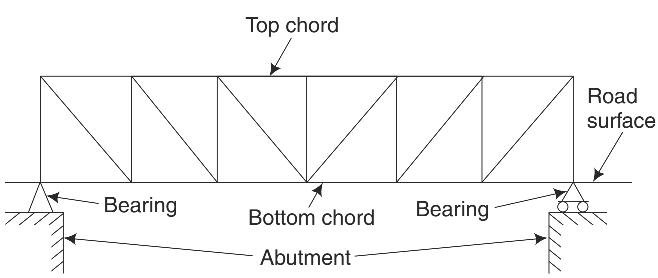


Fig. 7.10(a) *N-truss bridge*

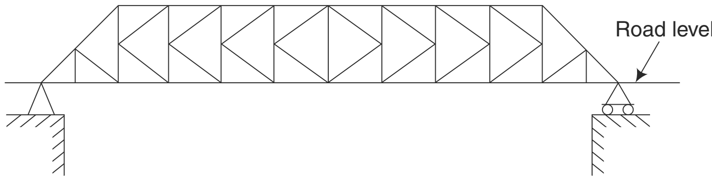


Fig. 7.10(b) *K-truss bridge*

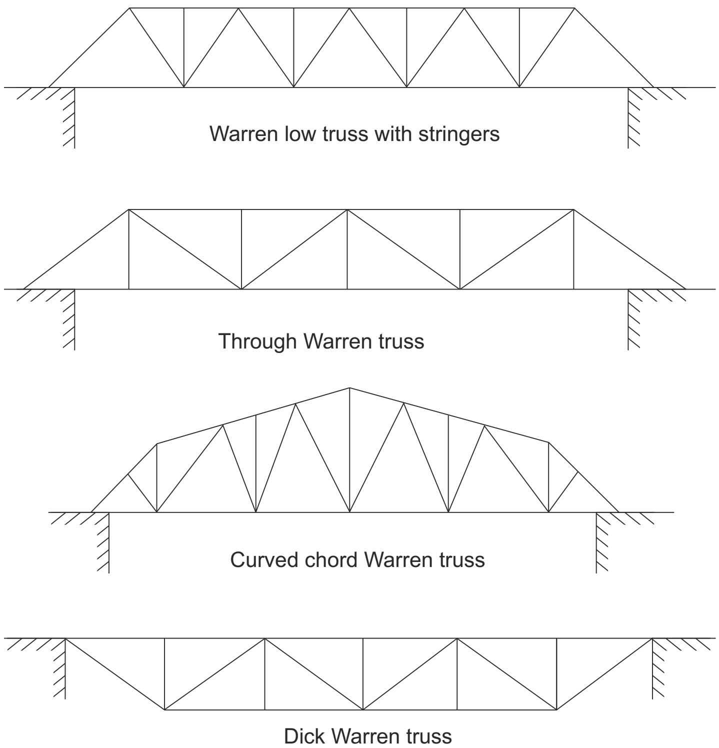


Fig. 7.10(c) *Warren bridge*

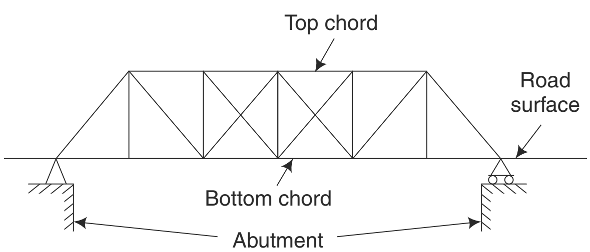


Fig. 7.10(d) *Pratt truss bridge*

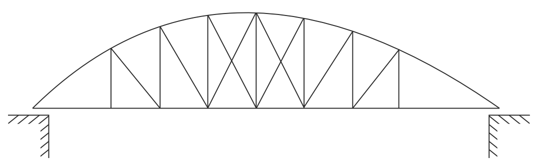


Fig. 7.10(e) *Curved chord Pratt bridge*

Steel Rigid-Frame Bridge

These type of bridges carry the roadway at the top of the portal frames. No bearing and fixtures are required in such bridges. These bridges have more clearance below them and heavy abutments are not required. The structure of such a bridge is shown in Fig. 7.11.

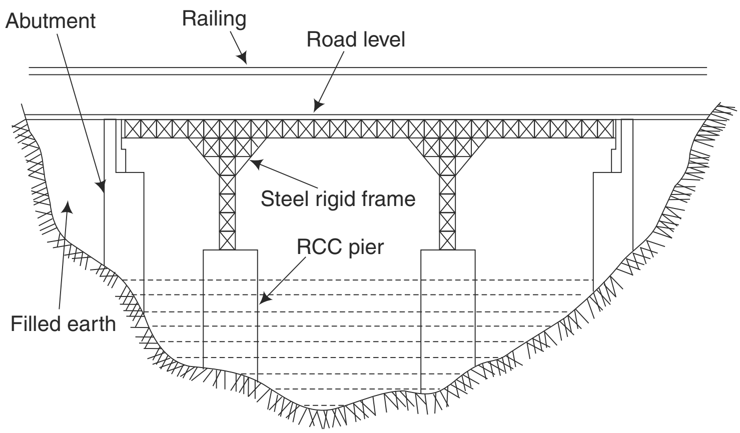


Fig. 7.11 *Steel rigid-frame bridge*

Plate-Girder Bridges

A plate-girder bridge is used to carry heavier loads over longer spans. Hence, they are mainly used for railway bridges. These are used for spans of up to 20 m. In order to increase the lateral stability, box girders which consist of four plates connected by angles are used.

Steel Arch Bridges

Steel arch bridges are constructed where it is not possible to construct an intermediate pier. It can be used for a very long span, i.e., of up to 150 m. Steel arches may either be of the spandrel-braced or trussed-arch type, as shown in Fig. 7.12.

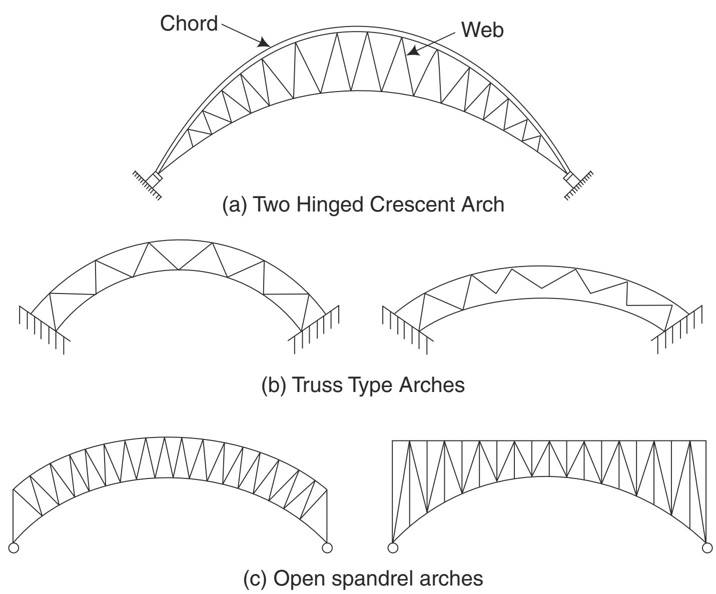


Fig. 7.12 *Different types of steel-arches bridges*

Steel Bow-String Girder Bridges

In steel bow-string girder bridges, in order to bear horizontal thrust, a steel tie is provided which joins the two ends of an arch. In these bridges, suspenders are provided from the arch-ribs to carry the roadway as shown in Fig. 7.13.

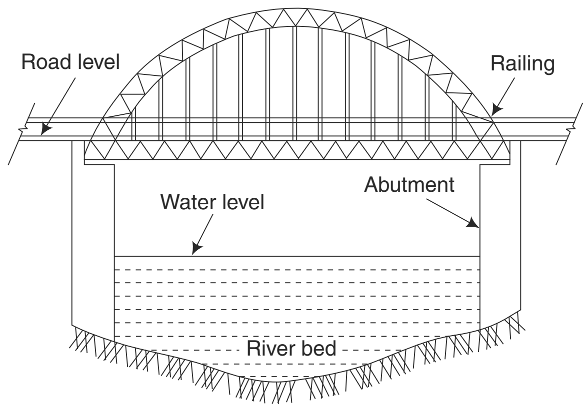


Fig. 7.13 *Steel bow-string girder bridge*

Movable Bridges

Movable bridges are constructed in order to provide a headway or opening for navigation ships. The design of the bridge superstructure is done in such a way that it can be moved so as to allow necessary width and clearance for the passing of ships. The following are the common types of movable bridges:

1. Vertical lift bridge
2. Bascule bridge
3. Swing bridge

1. Vertical Lift Bridge In such bridges, the trusses supporting the roadway are vertically lifted up by means of cables operated by electric motors or hydraulic machines.

2. Bascule Bridge Bascule type bridge is one in which the bridge can be opened vertically upwards. The bridge may be of single bascule or double bascule. The railway bridge connecting the Mandapam and Rameswaram island, is of double bascule type.

3. Swing Bridge In the case of swing bridges, the trusses carrying the roadways revolve about a vertical axis whenever required.

7.8 CULVERTS

A culvert is a drain or water course totally enclosed and usually carried under a road or railway track. The following are the common types of culverts.

(a) Box culvert
(b) Pipe culvert
(c) Arch culvert

7.8.1 Box Culvert

A box culvert consists of one or more square or rectangular openings made of RCC or masonry but RCC box culverts are used widely. Box culverts are used for spans less than 4 m. An RCC box culvert is a cheaper alternative for a pipe culvert. The abutments, top and bottom slabs are all cast monolithically. A box culvert is shown in Fig. 7.14.

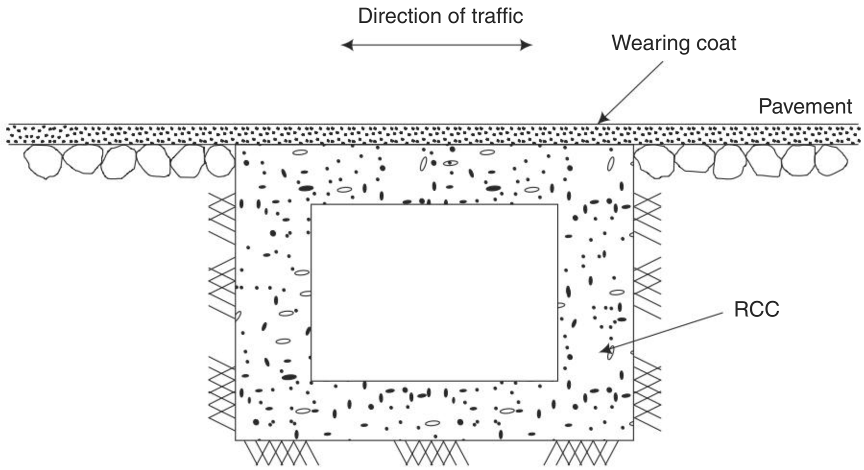


Fig. 7.14 *Box culvert*

7.8.2 Pipe Culvert

Pipe culverts are most economical for small drainage crossings. These culverts are generally constructed for diameters less than 1.8 m. The pipes may be of cast iron or RCC. If the soil is of low bearing capacity, the pipes should be bedded in a layer of concrete. If the discharge of water is more, more than one pipe can be used. Figure 7.15 illustrates a pipe culvert.

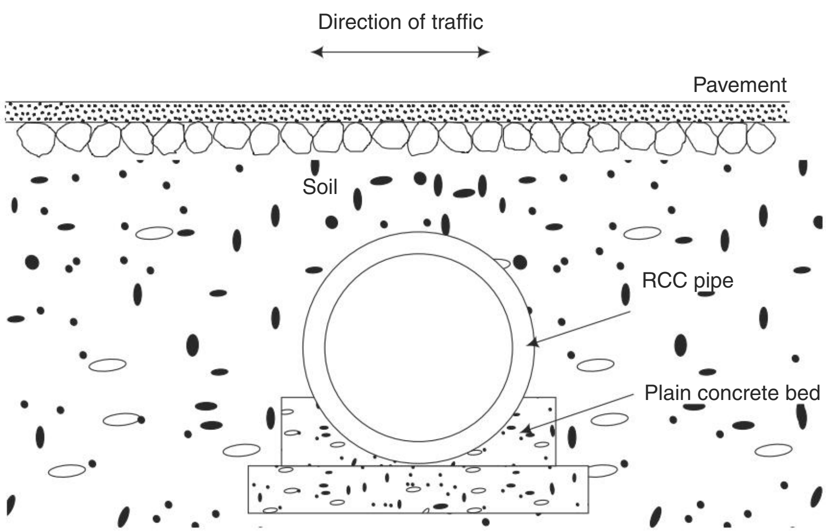


Fig. 7.15 *Pipe culvert*

7.8.3 Arch Culvert

Arch culverts are constructed on brick or stone masonry or concrete walls having short spans of 2–3 m. Depending upon the loading, span and type of construction, the thickness of an arch may be of 20–50 cm. Above the crown of an arch, an earth cushion of at least 45 cm should be provided as shown in Fig. 7.16.

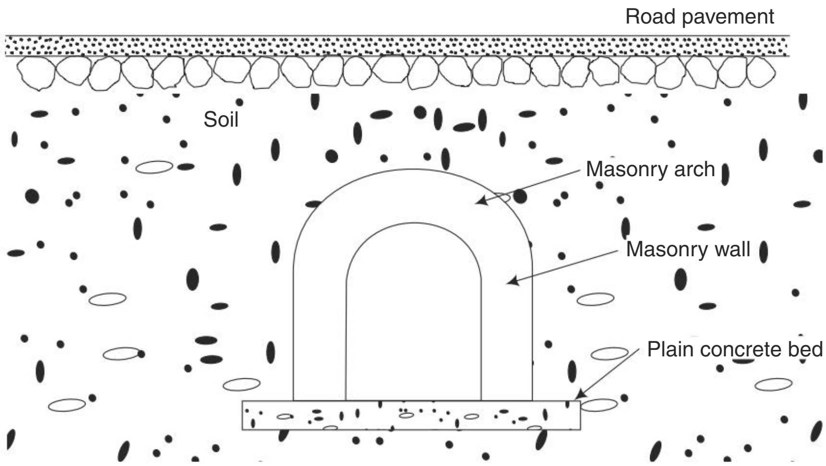


Fig. 7.16 *Arch culvert*

7.9 CAUSEWAYS

Causeways are constructed when they are preferred to a regular bridge under the following circumstances.

(i) The river carries very little water and the water is spread over a wide area. Also, when there is no water in the river during a substantial part of the year.

(ii) There is high flood discharge only occasionally and that too for a short period of time.

(iii) Funds, materials and facilities are not available for the construction of a regular bridge.

(iv) Traffic which uses crossing is light and insignificant.

Causeways are divided into the following three classes.

(a) Flush causeways

(b) Causeways with vents

(c) High level causeways (also called as submersible bridges)

7.9.1 Flush Causeways

A flush causeway is a low level causeway. In this type, the pavement for the traffic may be at the bed level of the stream itself. There is no vent or opening underneath. For the construction of the pavement, a cement concrete slab of 10 cm thickness may be laid over 25 cm thick random rubble course in lime mortar.

7.9.2 Causeways with Vents

In this type of causeway, water flows through a number of box-type or circular openings or vents. The level of the road is fixed in a way such that it can be used even during the rainy seasons. During high floods, the road will submerge.

7.9.3 High-Level Causeways

These are bridge structures constructed with vents. They will submerge only during occasional high floods. IRC code of practice recommends this type of bridge for places where the flood level above the road surface is not more than three days at a time or six times in a year. The total interruption to the traffic being restricted to 15 days in a year. This type of structure is particularly suitable when the river width is small, normal flow is continuous and the difference between the highest flood level and ordinary flood level is so large that the construction of a regular bridge is uneconomical. Since this structure is similar to a bridge and is submerged during high floods, it is called a *submersible bridge*. The longitudinal section of a high-level causeway is shown in Fig. 7.17.

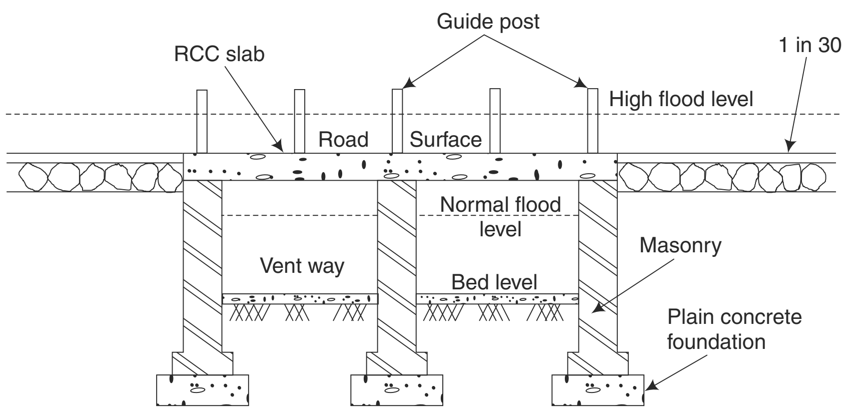


Fig. 7.17 *A high-level causeway*

Short-Answer Questions

1. What is the difference between a pier an abutment?
2. Differentiate between deck bridge and through bridge.
3. What is a slab bridge?
4. How are bridges classified according to the span?
5. What is meant by an overbridge?
6. How are bridges classified according to the loading?

7. What is the function of the following in bridges:
   (a) Wing wall (b) Bearings
8. What are viaducts?
9. Mention the commonly used steel truss bridges which are commonly used.
10. Why are heavy abutments not required in steel rigid-frame bridge?
11. What is the reason for using plate-girder bridges for railways?
12. What are the types of steel arches?
13. What is the function of suspenders and steel tie, in the steel bow-string girder bridges?
14. What are the common types of movable bridges?
15. How are culverts classified on the basis of shape?
16. Under what circumstances are causeways constructed?
17. List out the types of causeways.

Chapter 8
TALL STRUCTURES

8.1 INTRODUCTION

There have been immense developments in the field of civil engineering in our country and they kept pace with rapid advances made in technology. One of the spectacular advances made in the field of civil engineering is the design and construction of tall structures. A tall structure is defined as one in which the structural system is modified to make it sufficiently economical to resist lateral forces due to wind or earthquakes within the prescribed criteria for strength, drift and the comfort of the occupants. However, high rise structures are not new for the traditional Indian architecture. Many historical monuments and temples are the living evidence of such structural marvels.

8.2 NEED FOR TALL STRUCTURES

The factors, which lead to the development of tall structures are given below.

(i) Scarcity of land
(ii) Paucity of funds
(iii) Architectural requirements
(iv) Spiralling rise in the cost of land
(v) Increasing population
(vi) Technological developments

With the increasing trend in urbanisation, construction of tall buildings is taking place on a large scale. There are several factors which limit the height of tall buildings. In certain cities, the building codes and municipal by-laws prescribe the maximum height up to which the buildings may be constructed. At certain places the foundation conditions may not be satisfactory to support multi-storied buildings. The cost of elevators, plumbing, heating and air-conditioning, glazing interior walls increase with the increase in the height of the tall buildings.

8.3 MATERIAL USED IN CONSTRUCTION OF TALL STRUCTURES

Construction in India is labour intensive and reinforced concrete construction is done extensively. Steel is expensive as compared to concrete, the cost ratio ranging from 60 to 90, whereas the corresponding strength ratio is from 15 to 20. Practically, all tall buildings constructed in any part of the country are of reinforced concrete using high yield strength deformed bars. The strength of concrete used varies from M15 to M25 and the strength of reinforcement bars is 415 N/mm^2. Except for the columns, in the lower floors of the tall buildings, the percentage of reinforcement used in most of the elements of the buildings is less than two per cent. The percentage of reinforcement in beams and slabs is around one per cent.

8.4 PRACTICAL APPLICATIONS

In practice, tall structures are constructed in the following forms.

1. Multi-storey framed structures shown in Fig. 8.1 are usually adopted for the construction of offices, residential complex, etc. which require a small size of costly land and provide required floor area. The ability of a multi-storey building to resist the wind and other lateral forces depends upon the rigidity of connections between the beams and columns.

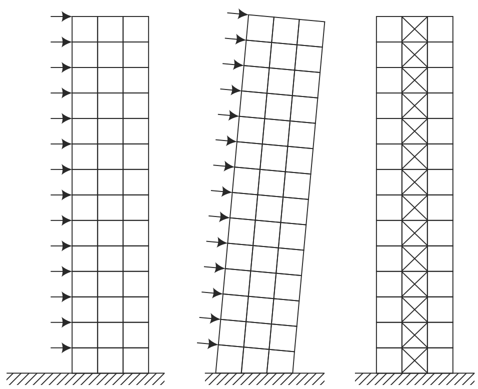


Fig. 8.1 *Multi-storey framed structure*

2. Chimneys shown in Fig. 8.2 are tall slender structures by which waste gases are discharged at a sufficiently high elevation so that after dilution due to atmospheric turbulence, their concentration and their entrained solid particulate is within acceptable limits on reaching the ground. Basically chimneys is a wind structure in which wind loads play a dominant role.

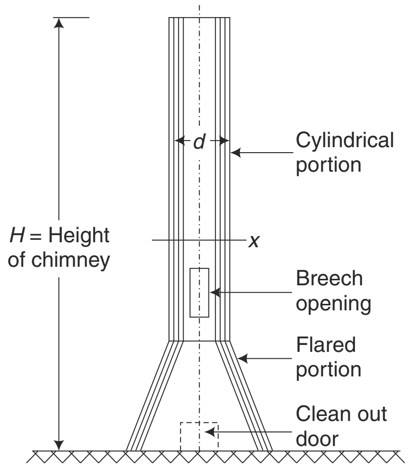


Fig. 8.2 *Chimney*

3. Silos are shown in Fig. 8.3. They are defined as large size containers which are used to store grains, cement, coal, etc. In general, the shapes of silos are of circular cross-section.

4. Elevated water tanks shown in Fig. 8.4 are used for storage and supply of water to citizens of a town or city. These tanks are placed on towers or staging to provide necessary pressure head.

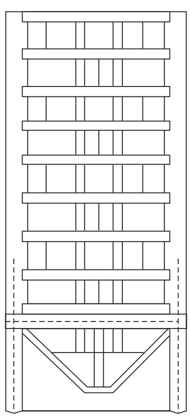


Fig. 8.3 *Silos*

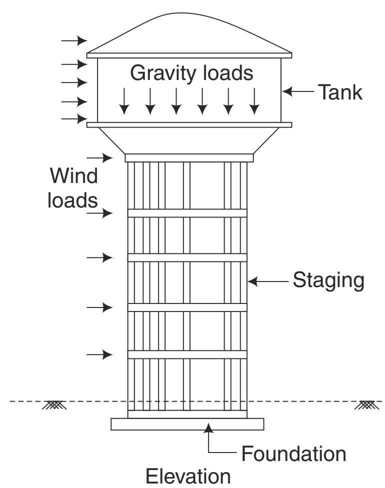


Fig. 8.4 *Elevated water tank*

5. Towers Tall structures with relatively small cross-section and with a large ratio between the height and the maximum width are known as *towers* or *masts*. The water towers, radio and television towers, transmission line towers are few examples of structures belonging to the tower family. Transmission line are used to support transmission cables transmitting voltage exceeding 132 kV over long distances. Figure 8.5 depicts a typical tower.

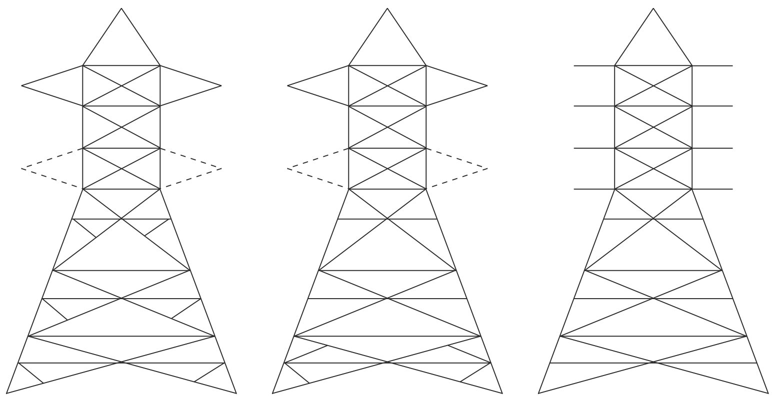


Fig. 8.5 *Towers*

8.5 BASIC DESIGN FEATURES

Following are the various criteria that should be considered in the design of tall structures.

1. Loads
2. Strength
3. Stability
4. Durability
5. Stiffness and drift
6. Foundation settlement and soil structures interaction
7. Creep, shrinkage and temperature effects.
8. Fire
9. Human comfort criteria

1. Load In tall structures the vertical load, i.e. dead and live loads do not pose much problems in the design, as they are mostly deterministic. But the lateral forces due to wind or earthquake are a matter of great concern. These lateral forces can produce critical stresses in the structures, set-up undesirable vibrations or cause excessive lateral sway of the structure and require special considerations in the design of tall structures.

Developments in the design of multi-storey frames have emphasised the importance of limiting the side sway and the action of lateral loads. Provision of shear wall frames rather than traditional rigid frames minimise the lateral sway of the structure. A well-designed shear wall provides structural safety and also gives a good measure of protection to the non-structural items like false ceilings, wall panels, etc. from damages due to seismic disturbances.

2. Strength In tall structures, the primary design requirement is that it should have adequate strength to resist and to remain stable under the worst probable load actions that may occur during the lifetime of the structure including the period of construction. Additional stresses caused by restrained differential movement due to creep, shrinkage or temperature must be included in the design.

3. Stability Tall structures should possess inherent base stability against the combination of vertical and lateral forces. Hence these structures were constructed satisfying the simple rule of resultant force passing within the middle third of the base thereby making the resulting base stresses compressive at all times. It is necessary to make a check on the most fundamental condition of equilibrium, to establish that the applied lateral forces will not cause the entire structure to topple as a rigid body about one edge of the base. Also the resisting moment of the dead weight of the structure must be greater than the overturning moment for stability by providing suitable factor of safety.

4. Durability Structure constructed with proper materials and construction technique will be much stronger and durable as compared to general construction of smaller buildings by common man who constructs the buildings through untrained and general artisans. The life of such buildings in R.C.C. framing can easily be 100 years or more. They will also require lesser maintenance as compared to temporary building like slums, etc. However, the span of reinforced concrete depends on following factors apart from quality of material and construction.

(i) Chemical influences causing corrosion effects
(ii) Permeability or porosity of concrete
(iii) Shrinkage
(iv) Concrete cover to steel
(v) Curing of concrete
(vi) Thermal influences
(vii) Acoustic pressure and others
(viii) Freezing and thawing effect (for cold areas), etc.

5. Stiffness and drift limitations In the design of tall structure provision of adequate stiffness, particularly lateral stiffness is a major consideration to prevent any possible progressive failure. One simple parameter that affords an estimate of the lateral stiffness of a structure is the drift index. Drift index is defined as ratio of the maximum deflection at the top of the building to the total height. Hence the establishment of a drift index limit is a major design decision and it depends on various factors like the building usage, the form of construction, the materials employed, the wind loads considered and in particular, past experience of similar buildings that have performed satisfactorily. However for conventional structures, the preferred acceptable range is approximately 1/650 to 1/350 and sufficient stiffness must be provided to ensure that the top deflection does not exceed this value extreme load conditions.

6. Foundation settlement and soil-structure interaction Gravity and lateral forces on the building will be transmitted to the earth through the foundation system and as the principles of foundation design are not affected by the quality of tallness of the superstructure, conventional approaches will suffice. The concern of the structural designer is then with the influence of any foundation deformation on the building, structural behaviour and on the soil-structure interactive forces. In tall buildings the loads transmitted by the columns can be very heavy because of its height. When the hard strata is located at a greater depth, foundations may be carried down to the stiff load bearing layers by use of piles, caissons or deep basements. Problems are not generally encountered with such conditions since large variations in column loading and spacing can be accommodated with a negligible differential settlement. In areas where soil conditions are poor, loading on foundation elements must be limited to prevent shearing failures or excessive differential settlements. Relief may be obtained by excavating a weight of soil equal to a significant portion of the gross building weight. Particular attention must be given to the design of foundation system for resisting moments and shear, especially if the pre-compression due to the dead weight of the building is not sufficient to overcome the highest tensile stresses caused by wind moments leading to uplift on the foundation.

Soil-structure interaction involves both static and dynamic behaviour. Severe permanent structural damage may be caused by earthquakes. This is when large deformations occur due to the soil being compacted by the ground vibration which under certain conditions may result in the development of excess hydrostatic pressure sufficient to produce liquefaction of the soil. These types of soil instability may be prevented or reduced in intensity by appropriate soil investigation and foundation design. On the other hand dynamic response of buildings to ground vibrations which is also affected by soil conditions cannot be avoided and must be considered in the design.

7. Creep, shrinkage and temperature effects In tall concrete structures the cumulative vertical moments due to creep and shrinkage may be sufficiently large to cause distress in non-structural elements and to induce significant structural actions in the horizontal elements especially in the upper region of the structure. The differential movements due to creep and shrinkage must be considered structurally and accommodated as far as possible in the architectural details at the design stages.

In buildings with partially or fully exposed exterior columns, significant temperature changes may occur between exterior and interior columns and any restraint to their relative deformations will induce stresses in the members concerned. The analysis of such actions requires the knowledge of the differential temperature that are likely to occur between the building and its exterior and the temperature gradient through the members. This will allow an evaluation of free thermal length changes that would occur if no restraint existed and hence using a standard elastic analysis, the resulting thermal stresses and deformation may be determined.

8. Fire Since fire appears to be by far the most common extreme situation that will cause damage in structures, it must be a primary consideration in the design process. The characteristic feature of a fire, such as the temperature and duration, can be estimated from a knowledge of the important parameters involved, particularly the quantity and nature of combustible material present, the possibility and extent of ventilation and the geometric and thermal properties of the fire compartment involved. The mechanical properties of the structural materials, particularly the elastic modulus or stiffness and strength, may deteriorate rapidly as the temperature rises and the resistance to loads is greatly reduced.

The critical temperature at which large deflections or collapse occurs will thus depend on the materials used, the nature of the structure and the loading conditions.

9. Human comfort criteria If a tall flexible structure is subjected to lateral or torsional deflections under the action of fluctuating wind loads, the resulting oscillatory movements can induce a wide range of responses in the building's occupants, ranging from mild discomfort to acute nausea. Motions that have psychological effects on the occupants may thus result in an otherwise acceptable structure becoming an undesirable or even unrentable building.

It is generally agreed that acceleration is a predominant parameter in determining human response to vibration, but other factors such as period, amplitude, body orientation, visual and acoustic cues and even past experience can be influential. Threshold curves are available that give various limits for human behaviour ranging from motion perception through work difficulty to ambulatory limits, in terms of acceleration and period. A dynamic analysis is then required to allow the predicted response of the building to be compared with the threshold limits.

Short-Answer Questions

1. Define tall structures.
2. Define creep and shrinkage.

Exercises

1. Explain the basic design features of tall structures in detail.

Chapter 9
SURVEYING

9.1 INTRODUCTION

Surveying is the art of determining the relative positions of distinctive features on the earth's surface. This is achieved by the measurement of distances, directions and elevations.

In general, surveying is limited to operations concerned with the representation of ground features in plan. A branch of surveying which deals with the measurement of the relative heights of the features is known as levelling.

9.2 IMPORTANCE OF SURVEYING

The knowledge of surveying is advantageous in many phases of engineering. Every engineering project such as water supply and irrigation schemes, rail roads and transmission lines, mines, bridges and buildings, etc. require surveys. Before plans and estimates are prepared, boundaries should be determined and the topography of the site should be ascertained. After the plans are made, the structures must be stated out on the ground. As the work progresses, lines and grades must be given.

9.3 OBJECTIVES OF SURVEYING

The main object of any survey is the preparation of a plan or a map showing all the features of the area under consideration. A plan may be defined as a projection of the ground and the features upon it on a horizontal plane. So, a plan is the representation to some scale of the area and the objects contained in it. The representation is called a map if the scale adopted is small, while it is called a plan if the scale is large. For example, a map of India, a plan of a building.

9.4 TYPES OF SURVEYING

The surveying may be primarily divided into two types: plane surveying and geodetic surveying.

9.4.1 Plane Surveying

The surveying in which earth surface is assumed as a plane and the curvature of the earth is ignored is known as *plane surveying*. As the plane survey extends only over small areas, the line connecting two points on the earth is considered as a straight line and the angle between any two lines is considered as plane angle.

Surveys covering an area up to 260 km^2 may be treated as plane surveys. Such plane surveys are carried out for engineering projects and for geographical, geological, navigational and military purposes.

Plane surveys are used for the layout of highways, railways, canals, construction of bridges, dams, buildings, etc. The scope and use of plane surveying is wide. In order to have proper, economical and accurate planning of projects plane surveys are basically needed.

9.4.2 Geodetic Surveying

The surface of the earth is not plane but spheroidal. Therefore, the line connecting any two points on the earth's surface is not a straight line but a curve.

The surveying in which curvature of the earth is taken into account for all measurements is known as *geodetic surveying*.

The result obtained from the above surveying will possess a high degree of accuracy as it considers the effect of curvature of the earth also. This surveying extends over large areas and so any line connecting two points on the earth's surface is considered as an arc. The angle between any two such arcs is treated as a spherical angle. To undertake this method of surveying, a thorough knowledge in spherical trigonometry is required.

Geodetic surveys need sophisticated instruments and accurate methods of observations. In order to eliminate the errors in observations due to atmospheric refraction, angular observations are generally taken only in nights and arc lamps are used as signals on survey stations.

In India, geodetic surveys are carried out by the Department of the Survey of India under the direction of the Surveyor General of India.

9.5 CLASSIFICATION OF SURVEYS

Depending on the use and the purpose of the finished work, surveys are classified under the following heads:

9.5.1 Classification Based Upon the Nature of the Field

(a) Land surveying

- **(i) Topographical surveys** To locate horizontal and vertical points by linear and angular measurements. For determining the natural features of a country such as streams, lakes, forests etc., and artificial features such as roads, railways, canals, towns and villages, etc.

   (ii) Cadastral surveys Cadastral surveys are made incident to the fixing of property lines, the calculation of land area, or the transfer of land property from one owner to another. It is also done to fix the boundaries of municipalities and of state and federal jurisdictions.

   (iii) City surveying City surveying is done in connection with the construction of streets, water supply systems, sewers and other works.

(b) *Marine (or) hydrographic surveys* It deals with the bodies of water for purpose of navigation, water supply, harbour works or for the determination of mean sea level. The work consists in measurement of discharge of streams, making topography survey of shores and banks, taking and locating soundings to determine the depth of water and observing the fluctuations of the ocean tide.

(c) *Astronomical survey* It offers the surveyor means of determining the absolute locations of any point or the absolute location and direction of any line on the surface of the earth. This consists of observation of heavenly bodies such as sun or any fixed star.

9.5.2 Classification Based Upon the Objective of Survey

(a) *Engineering surveys* These are carried out for the determination of quantities which will be useful for the designing of engineering works.

(b) *Military or defence surveys* These are carried out for the preparation of maps of important military areas.

(c) *Geological surveys* These are carried out to ascertain the composition of the earth's crust.

(d) *Mine surveys* These are conducted for exploring the mineral wealth below the earth surface.

(e) *Archaeological surveys* These are executed to prepare maps of ancient cultures.

9.5.3 Classification Based Upon Methods Employed

(a) Triangulation surveys

(b) Traverse surveys

The framework in traverse survey consists of series of connected lines. The lengths and directions of these lines are measured with a chain or tape and with an angular measurement respectively.

A traverse is divided into two categories: *closed traverse normal open traverse.* A description of the two types of traverse is provided in this section.

1. Closed Traverse A traverse is said to be closed if a complete circuit is made, i.e. the origin and end point are one and the same thereby the circuit forms a closed polygon. This is particularly suitable for locating a building, boundaries of lakes, wooded lands, etc. A closed traverse is shown in Fig. 9.1.

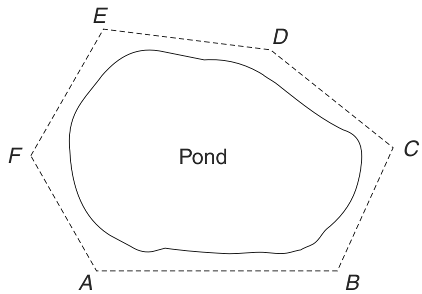


Fig. 9.1 *Closed traverse*

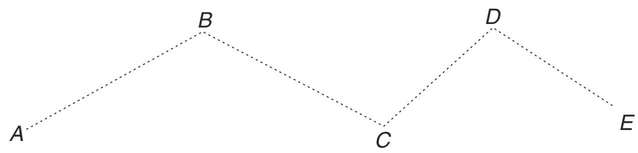


Fig. 9.2 *Open traverse*

2. Open Traverse A traverse is said to be open if it does not form a closed polygon. It consists of a series of survey lines extending in one general direction but never returning to the starting point as shown in Fig. 9.2.

9.5.4 Classification Based Upon the Instruments Used

(a) Chain surveying
(b) Compass surveying
(c) Plane table surveying
(d) Theodolite surveying
(e) Tacheometric surveying
(f) Aerial surveying
(g) Photographic surveying

9.6 PRINCIPLES OF SURVEYING

The two main principles of surveying are (i) working from the whole to the part, and (ii) fixing new points by at least two independent processes.

1. Working from the whole to the part Whether it is a plane surveyor or a geodetic survey, the main principle adopted is to work from the whole to the part. In the case of surveying of extensive areas, such as a town or a big estate, the survey is started by establishing a system of control points with high precision. The line joining these points will form the boundary lines of the area, otherwise, this is the main skeleton of the survey. The above control points may be established by triangulation or by running a traverse surrounding the area. The main triangles and traverses are then broken into smaller ones and measured using less laborious methods. The main reason to work from the whole to the part is to avoid the accumulation of errors and to control any localised errors. If, on the other hand, the survey is carried out from the part to the whole, the errors will be magnified in each and every step and will become uncontrollable at the end. The above principle is also fit to levelling also.

2. Fixing new points by at least two independent processes The use of two independent processes to fix a new point, helps in taking one set of measurements from one process and the same may be checked by another set of measurements. The above is explained by the following two techniques as indicated in Fig. 9.3(a) and Fig. 9.3(b).

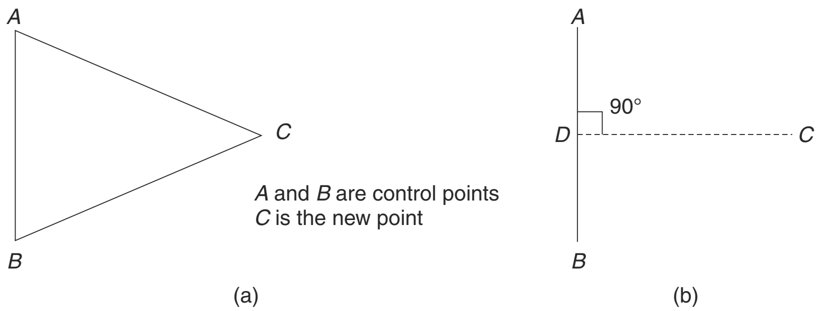


Fig. 9.3 *Fixing of points*

Let *A* and *B* the two given control points established by triangulation. Then, to fix the position of the point *C*,

(a) the distance *AC* and *BC* may be measured and the position of *C* may be fixed by drawing the arcs; or

(b) by dropping a perpendicular from *C* to the base line *AB*. Here, the distance *CD* and 90° angle of intersection are the two different measurements made to locate *C*.

9.7 MEASUREMENT OF DISTANCES

The two main methods of determining the distances between two points on the surface of the earth are the direct method and the computative method. In the case of the direct method, distances are measured using tapes, chains, etc. In the latter case, distances are obtained by calculation using tacheometry, triangulation, etc.

9.7.1 Different Methods of Direct Measurements

Following are the methods of measuring the distances directly:

(a) pacing

(b) measurement with passometer

(c) measurement with pedometer

(d) measurement by odometer and speedometer

(e) chaining

Pacing

Measurements of distances by pacing are chiefly confined to the preliminary surveys and explorations where a surveyor is called upon to make a rough survey as quickly as possible. This method consists of counting the number of paces between the two points of a line. A length of pace more nearly to that of ones natural step is preferable.

Passometer

It is an instrument, shaped like a watch and is carried in pocket or attached to one leg. The mechanism of the instrument is operated by motion of the body and it automatically registers the number of paces. Then it can be multiplied by the average length of the pace to get the distance.

Pedometer

It is similar to the passometer except that it is adjusted to the length of the pace of the person carrying it. It registers the total distance covered by any number of paces.

Odometer and Speedometer

Odometer is an instrument for registering the number of revolutions of a wheel. The odometer is fitted to a wheel which is rolled along the line whose length is required. The number of revolutions registered by the odometer can be multiplied by the circumference of the wheel to get the distance.

Chaining

Chaining is a term which is used to denote measuring distance either with the help of a chain or a tape and is the most accurate method of making direct measurements.

9.7.2 Chain

The chain is generally composed of 100 or 150 links. The links are formed by pieces of galvanised loops and connected together by means of three oval-shaped rings. The oval-shaped rings afford flexibility to the chain. In good-quality chains, the joints of links are welded so that change in length will be reduced considerably due to stretching. The ends of the chain are provided with brass handles with swivel joints so that the chain can be turned round without twisting. The outside of the handle is the zero point or the end of the chain. The length of a link is the distance between the centres of the two consecutive middle rings. The end links also include the handles. Metallic tags of different patterns called tallies are fixed at specific points of a chain, for quick and easy reading of the distance. For every five metres, there will be a tally. On tallies, the letter M will be engraved so as to distinguish a metric chain from a nonmetric chain. The length of the chain will be available in standard length of 20 or 30 m on the handle for easy identification. The details of a metric chain is shown in Fig. 9.4.

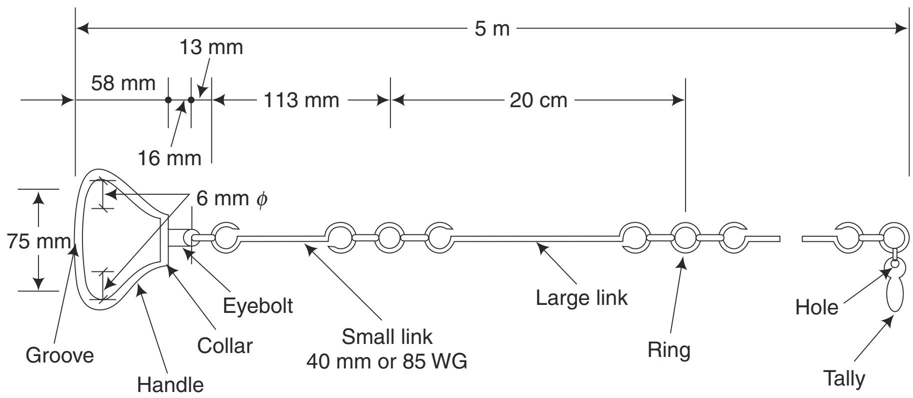


Fig. 9.4 *Details of a metric chain*

9.7.3 Steel Band

A steel band consists of a ribbon of steel with a brass swivel handle at each end. The width of the band is 16 mm and the length may be 20 or 30 m. The graduations in it are marked in two ways:

1. The band is divided by brass studs at every 0.2 m and numbered at every one metre. The first and last links are subdivided into centimetres and millimetres.
2. The graduations are etched as metres, decimetres, centimetres on one side and 0.2 m links on the other side. The band is wound on an open steel cross or in a metal steel case.

Advantages

1. Measurements using steel bands are more accurate than chaining.
2. It is lighter and easier to handle.
3. The length is not altered due to usage as compared to a chain.

Disadvantages

1. It cannot be so easily read.
2. Frequent cleaning is essential to avoid rust formation.
3. It needs proper care while handling as it breaks easily.
4. It cannot be repaired in case it is broken.

9.7.4 Principle of Chain Surveying

The principle of chain surveying is to divide the area into a number of triangles of suitable sides. A network of triangles is preferred here as triangle is the simple plane geometrical figure which can be plotted with the lengths of its sides alone. Chain surveying is the simplest kind of surveying. In this case, there is no need for measuring angles.

9.7.5 Suitability of Chain Surveying

1. It is suitable when the ground is fairly level and open with simple details.
2. When large scale plans are needed, this type is suitable.
3. It is suitable when the area to be surveyed is comparatively small in extent.
4. It is suitable for ordinary works as its length alters due to continued use.
5. Sagging of chain due to its heavy weight reduces the accuracy of measurements.
6. It can be read easily and repaired in the field itself.
7. It is suitable for rough usage.

9.7.6 Unsuitability of Chain Surveying

1. It is unsuitable for large areas crowded with many details.
2. It is unsuitable for wooded areas and undulating areas.

9.7.7 Technical Terms in Chain Surveying

These terms are explained below with reference to Fig. 9.5.

1. Main Survey Station It is the point where two sides of a main triangle meet.

2. Tie Stations These are the stations selected on the main survey lines for running auxiliary lines. These are otherwise called as subsidiary stations.

3. Base Line It is the longest of the main survey lines. This line is the main reference line for fixing the positions of various stations and also to fix the direction of other lines. This should be carefully measured and laid as the accuracy of entire triangulation critically depends on this measurement.

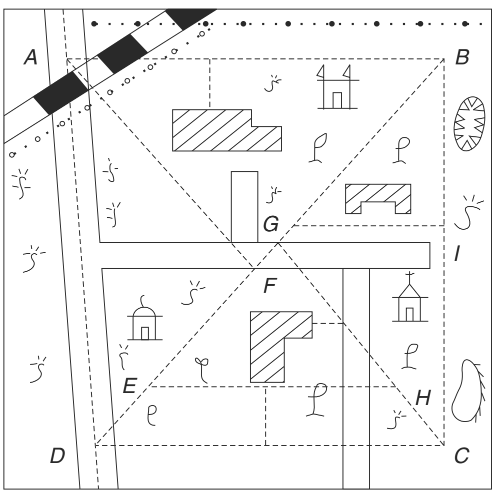


Fig. 9.5 *Layout of a chain survey*

4. Check Line A check line is used in the field in order to check the accuracy of the measurements made.

5. Tie Line The chain line joining the tie stations and subsidiary stations is called so.

6. Offset While survey is carried out, important details such as boundaries, fences, buildings and towers are located with respect to main chain lines by means of lateral measurements. The two types of offsets shown in Fig. 9.6 are the perpendicular offset and the oblique offset.

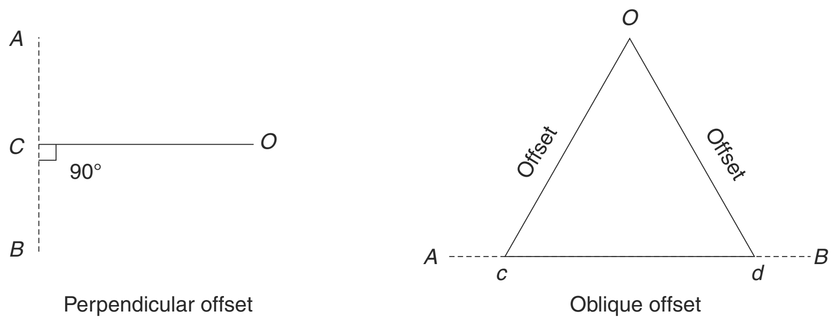


Fig. 9.6 *Offset*

9.7.8 Electronic Methods of Measuring Distance

In the electronic methods, distances are measured with the instruments that rely on propagation, reflection and subsequent reception of either radio or light waves.

Various instruments that are used under electronic methods

(i) Geodimeter

(ii) Tellurometer

(iii) Decca navigator

(iv) Lambda position fixing systems

Geodimeter is based on the propagation of modulated light waves. Other three instruments are based on radio waves for distance measurements. Geodimeter and Tellurometer are chiefly employed for measurement of distance on land. Decca navigator and lambda position of fixing system are used at sea.

9.8 MEASUREMENT OF ANGLES

The instruments commonly used for measurement of angles are the compass and the theodolite. Sometimes, a box sextant is also used.

9.8.1 Method of Measurement of Angles

The horizontal angles may be measured in two ways:

1. Included angles, as indicated in Fig. 9.7(a).

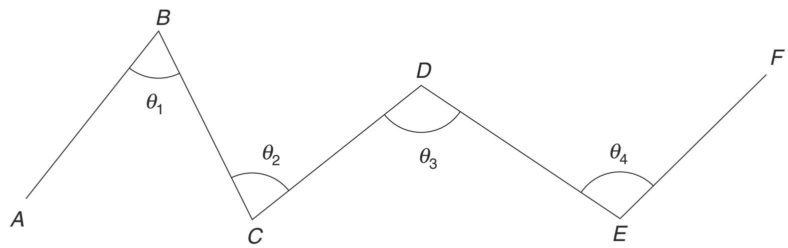


Fig. 9.7 (a) *Included angles*

2. Deflection angles between successive lines, as shown in Fig. 9.7(b).

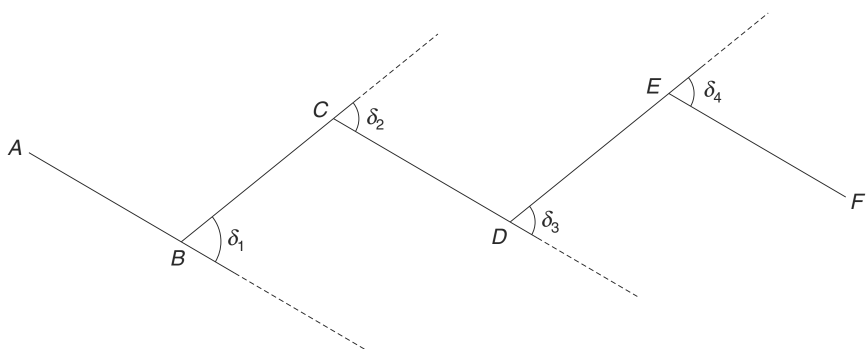


Fig. 9.7 (b) *Deflection angles*

9.8.2 Compass

This instrument essentially consists of a freely suspended magnetic needle on a pivot, which can move over a graduated scale. In addition to the above, it has an object vane and an eye vane which will be useful to get the line of sight. This instrument will be supported by a tripod stand while taking observations.

The two types of compass are the prismatic compass and the surveyor's compass.

1. Prismatic Compass It is the most suitable type of rough surveys where speed is very important rather than accuracy. It is commonly used for the preliminary survey for a road, railway, military purposes, a rough traverse, etc. The result from compass observations may be unrealistic in places where there is more local attraction due to magnetic rock or iron ore deposits. Figure 9.8 shows the different parts of a prismatic compass.

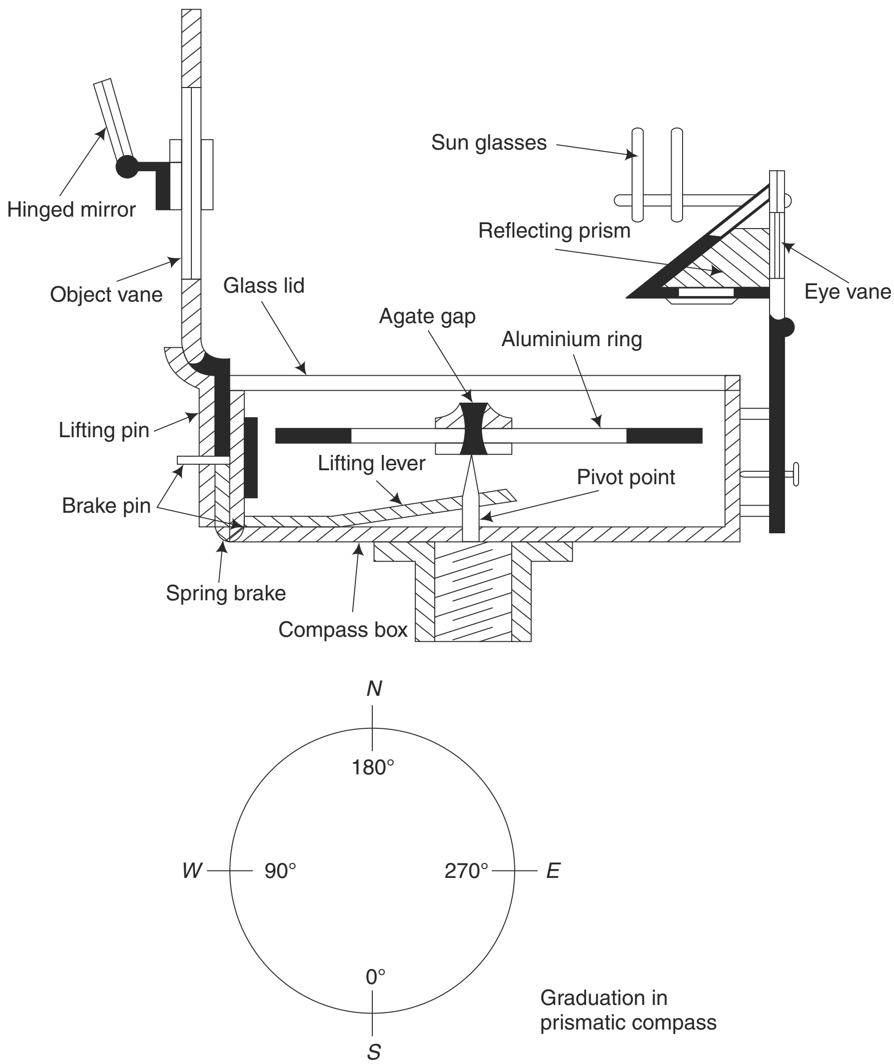


Fig. 9.8 *Prismatic compass*

2. Surveyor's Compass This type is not often used now for land surveying. In general, it is similar to a prismatic compass except that it has another plain sight having a narrow vertical slit in place of the prism as detailed in Fig. 9.9.

9.8.3 Bearing

Bearing is the horizontal angle between the reference meridian and the survey line. It is measured in the clockwise direction. Bearings are classified into different types and each of the type is described in this section.

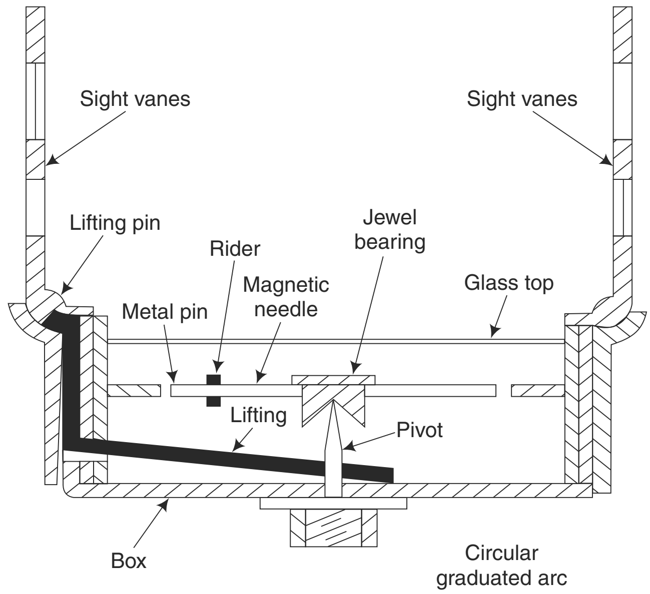


Fig. 9.9 *Surveyor's compass*

1. True Bearing True bearing of a line is the angle which a line makes with the true north or geographical north, measured always in the clockwise direction. The range of measurement is from 0°–360°.

2. Magnetic Bearing It is the angle which a line makes with the magnetic north measured always in the clockwise direction. The measuring range is from 0°–360°.

3. Whole Circle Bearing (WCB) Since the range of 0° to 360° completes a circle, any angle measured in between 0° to 360° directly is called a whole circle bearing. The magnetic and true bearing are just whole circle bearings.

4. Reduced Bearing (RB) This is based on quadrantal system wherein any angle is measured with respect to the north–south line, towards east or west as shown in Fig. 9.10.

5. Fore Bearing (FB) The angle measured from a survey station to the other station, in the direction in which survey is conducted, is called the fore bearing. In Fig. 9.11, the bearing of line *A* to *B* is the fore bearing.

6. Back Bearing (BB) It is the bearing taken from the next station to its preceding station from which the fore bearing was taken. Referring to Fig. 9.11, the bearing taken from station *B* towards station *A* is the back bearing of the line *AB*. In *WCB* system, $BB = FB \pm 180°$ using +ve sign if the *FB* is less than 180° and –ve sign if the *FB* is greater than 180°. In *RB* system, to convert *FB* into *BB* or vice versa, *N* is replaced by *S*, *S* by *N*, *E* by *W* and *W* by *E* without changing the numerical value of its bearing.

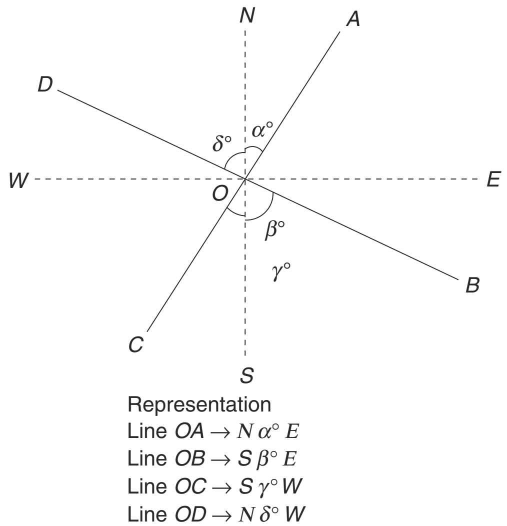


Fig. 9.10 *Reduced bearing (or) quadrantal bearing*

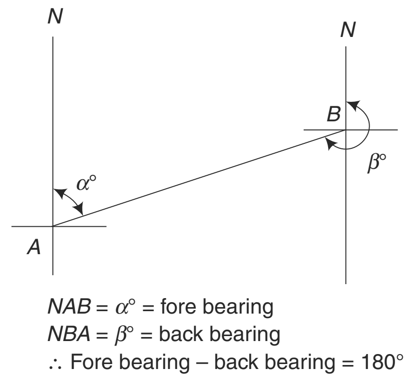


Fig. 9.11 *Fore and back bearing*

Table 9.1 *Comparison between prismatic compass and surveyor's compass*

	Prismatic compass	*Surveyor's compass*
1.	In the prismatic compass, the magnetic needle and the graduated dial are attached together while the prism and the box rotate.	In the surveyor's compass, the magnetic needle remains freely suspended and stationary while the dial is attached to the box.
2.	The graduations are provided in the clockwise direction.	In this case, the graduations are marked from 0° to 90° in all the four quadrants.
3.	Readings are observed by looking through the prism eye-piece from the south end of the compass.	Readings are taken by directly looking on the dial immediately below the north end of the needle.
4.	The zero of the reading is marked on the south end of the instrument.	Here, it is marked on the north and south end.
5.	A mirror is attached to the object vane for sighting objects at higher elevations or depression.	No such mirror is provided in the object vane.
6.	The position of east and west are in their correct positions.	The position of east and west are interchanged.
7.	By using this, one can obtain directly the whole circle bearings.	This is based on quadrantal system having 0° at north and 90° at east and west ends. With this, it is possible to read only the reduced bearings.
8.	The prismatic compass may be held in hand while taking observations.	The surveyor's compass needs a light tripod or a single pointed rod to support it.

Table 9.2 gives the rules to convert WCB to RB and the conversion is illustrated in Fig. 9.12.

Table 9.2 Conversion of WCB to RB

Case	*WCB between*	*Rule for RB*	*Quadrant*
I	0° and 90°	WEB	NE
II	90° and 180°	180° – WCB	SE
III	180° and 270°	WCB – 180°	SW
IV	270° and 360°	360° – WCB	NW

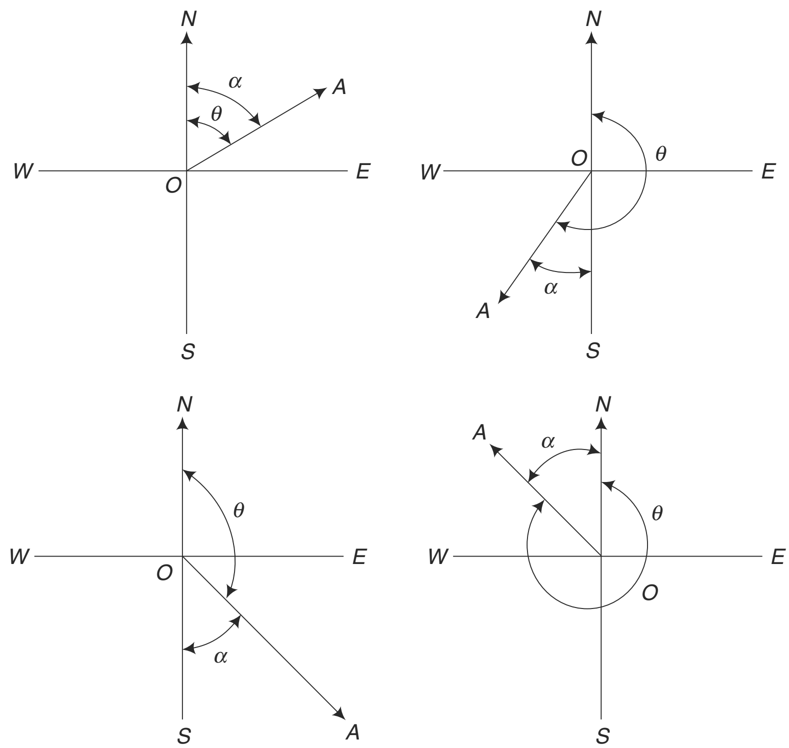


Fig. 9.12 *Conversion of WCB to RB*

When a line lies exactly along North, South, East or West, if

WCB of a line = 0°, then, RB is N

WCB of a line = 90°, then, RB is E 90°

WCB of a line = 180°, then, RB is S

WCB of a line = 270°, then, RB is W 90°

Table 9.3 presents the rules to convert RB to WCB

Table 9.3 Conversion of RB to WCB

Case	*RB Quadrant*	*Rule for WCB*	*WCB between*
I	NE	RB	0° and 90°
II	SE	180° – RB	90° and 180°
III	SW	180° + RB	180° and 270°
IV	NW	360° – RB	270° and 360°

9.8.4 Calculation of Angles from Bearings

Knowing the bearing of two lines, the angle between the two can very easily be calculated with the help of a diagram.

Refer to Fig. 9.13(a), the included angle α between the lines AC and $AB = \theta_2 - \theta_1$ = FB of one line – FB of the other line, both bearings being measured from a common point A. Reference to Fig. 9.13(b), the angle $\alpha = (180° + \theta_1) - \theta_2$ = BB of previous line – FB of next line.

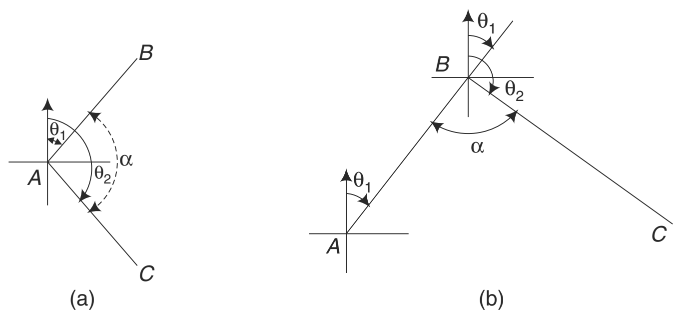


Fig. 9.13

Let us consider the quadrantal bearing, referring to Fig. 9.14(a) in which both the bearings have been measured to the same side of common meridian, the included angle $\alpha = \theta_2 - \theta_1$. In Fig. 9.14(b), both the bearings have been measured to the opposite sides of the common meridian, and included angle $\alpha = \theta_1 + \theta_2$. In Fig. 9.14(c) both the bearings have been measured to the same side of different meridians and the included angle $\alpha = 180° - (\theta_2 + \theta_1)$. In Fig. 9.14(d), both the bearings have been measured to the opposite sides of different meridians, and angle $\alpha = 180° - (\theta_1 - \theta_2)$.

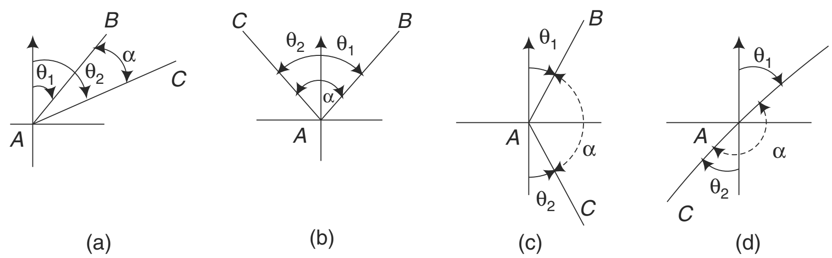


Fig. 9.14

Thus in Fig. 9.14 main advantage of the quadrantal bearings is that they never exceed 90° and the values of their trigonometrical functions can easily be extracted from the ordinary tables. They, however, possess the following disadvantages:

(i) It is necessary to put the appropriate cardinal points without which the bearings will have no significance.

(ii) The alternate clockwise and anticlockwise direction of increase of angle in the different quadrants is sometimes inconvenient and may very easily lead to mistakes being made.

(iii) The noting of the cardinal points may prove to be an extra unnecessary trouble.

The following at the advantages of this system:

(i) It is easy to calculate the included angle between two lines with the help of this system of bearings.

(ii) The convention of reckoning the bearing clockwise from the magnetic north is so simple that it is not necessary to remember whether the bearings are observed with reference to the north meridian or south meridian.

(iii) The plotting of traverse becomes easy because the bearings are to be measured only in the clockwise direction.

(iv) There is no botheration of putting the cardinal points.

The only drawback of this system is that when the bearings are to be used for computation and where the values of the trigonometrical functions are required, they are to be reduced to their equivalent values.

9.8.5 Local Attraction

If external magnetic influences are present in the place of observation using a compass, The needle will be seriously deflected from its normal position. Such disturbance due to the surrounding magnetic field is called local attraction.

The readings observed will be affected due to the presence of magnetic rocks or iron-ore deposits, steel structures, railways, iron lamp posts, electrical steel towers, etc. The actual bearing may be affected if we carelessly keep a bunch of iron keys, knife, iron buttons, steel-framed spectacles, the chain itself, arrows, etc. near the instrument. To detect its presence, one has to find the fore and back bearing of a line and obtain the difference between them. If the difference is not exactly equal to 180° then it indicates the presence of local attraction, provided there are no instrumental and observational errors.

9.8.6 Traversing with Compass and Chain

In compass traversing, the instrument is set at each station successively and the fore and back bearings of each line are noted in the field notebook. The errors in this survey tend to compensate as each bearing is observed independently Distances between the successive stations are measured using the chain. The offset points are located either by chaining or by angular measurements with compass.

9.9 LEVELLING

9.9.1 Definition

It is defined as the art of determining the relative heights of points on the earth's surface. This technique of surveying deals with measurements in vertical planes.

9.9.2 Objectives

Levelling provides an accurate network of heights, covering the entire area of the project. For the execution of many engineering projects levelling becomes very essential. For instance, the construction of railways, highways, canals, dams, water supply, sanitary lines, etc. is done through the determination of elevations of different points along the alignment (alignment involves the fixing of the centre line of railway or highway as the case may be). Greater the accuracy in the observations, the greater will be the saving in expenditure during project execution. A good network of levels provides an excellent idea of the existing terrain for the engineer, who can then plan and design his project keeping in view the economy and safety.

9.9.3 Technical Terms used in Levelling

Level surface The surface which is normal to the direction of gravity at all points is called a level surface. Every point on the level surface will be equidistant from the centre of the earth. For example, the surface of a still lake forms a level surface.

Horizontal plane The plane tangential to the level surface at any point is known as a horizontal plane.

Vertical plane The plane which contains vertical line at a place is called a vertical plane. The vertical line at any point will be perpendicular to the level surface at that point.

Datum surface This is an arbitrary surface with reference to which the heights (elevations) of points are measured and compared.

Reduced level (RL) Reduced level of a point is its height above or below the datum.

Back sight (BS) It is the first staff reading taken after setting up the instrument in any position. This will always be a reading on a point of known height.

Fore sight (FS) This is the last staff reading taken on a point before shifting the instrument. This will always be a point whose height has to be determined.

Intermediate sight (IS) Intermediate sight refers to any staff reading taken on a point of unknown elevation after the back sight and before the foresight. This is necessary if it is needed to take more than two readings from the same position of the instrument.

Change point (CP) A change point indicates the shifting of the instrument. Both the back sight and the foresight are taken on a change point.

Benchmark (BM) A benchmark is a fixed point of reference of known elevation. The reduced level of the benchmark is used to determine the reduced levels of other points.

Benchmarks are classified into the following types:

(a) Great Trigonometrical Survey benchmarks (GTS benchmarks)

(b) Permanent benchmarks

(c) Arbitrary benchmarks

(d) Temporary benchmarks

GTS benchmarks are those established by the Survey of India Department. The notation of a Benchmark is shown in Fig. 9.15. In small levelling works, the reduced level of a well-defined reference point is arbitrarily assumed and is called as an arbitrary benchmark. Temporary benchmarks are the reference points which are established when there is a break in the work.

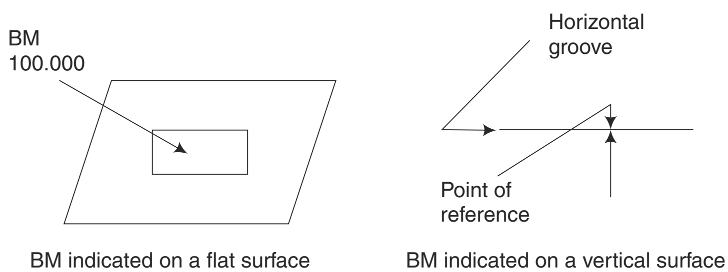


Fig. 9.15 *Notation of benchmark*

9.9.4 Principle of Levelling

Figure 9.16 illustrates the operations of levelling and Fig. 9.17 explains the principle of levelling. The principle of levelling lies in furnishing a horizontal line of sight and finding the vertical distances of the points above or below the line of sight. The line of sight is provided with a level. A graduated levelling staff is used to measure the height of the line of sight.

Let O represent the centre of the earth. A and A' are the points whose difference in elevation is required. C is the position of the instrument (level). The line CO is the direction of plumb line. BB' denotes the line of sight which is perpendicular to CO. AB and $A'B'$ are the readings on a staff vertically held at points A and A' respectively.

$$OA + AB = OA'' + A''A' + A'B'$$

or

$$AB - A'B' - AA' = dh$$

where dh is the difference in elevation between the points A and A'.

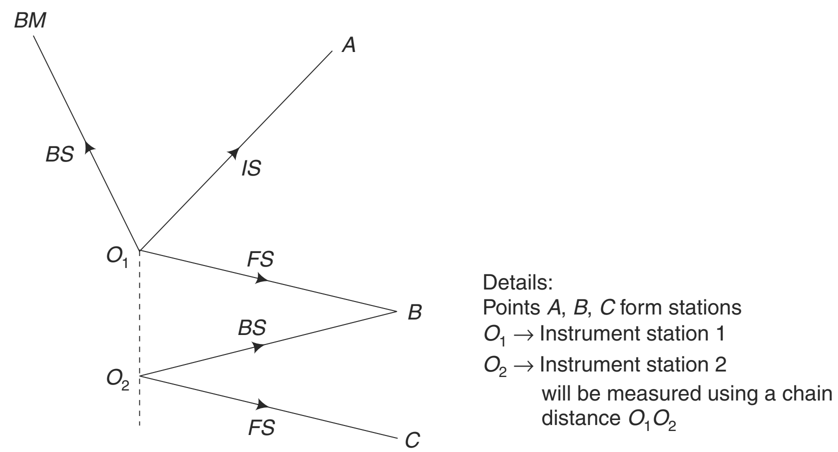


Fig. 9.16 *Explanatory figure of a levelling operation*

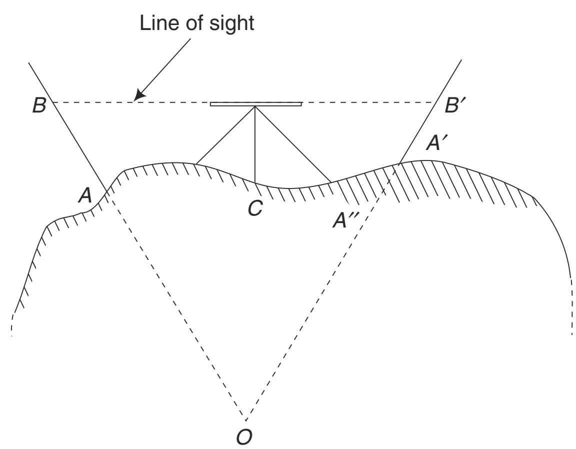


Fig. 9.17 *Principle of levelling*

In order to nullify the effect of curvature of earth's surface, the distances of both the staff positions from the instrument station *C* are kept equal.

9.9.5 Level

The instrument which is used for levelling is known as a level. It essentially consists of the following accessories:

1. A telescope to provide the line of sight.
2. A level tube to make the line of sight horizontal.

3. A levelling head to bring the bubble of the tube level at the centre of its run.
4. The tripod to support the above parts of the level.

In order to take readings of elevations, levelling staffs are used.

9.9.6 Instruments for Levelling

Instruments needed for levelling are the Dumpy levels and the levelling staff.

1. Dumpy Levels Figure 9.18 shows the different parts of a Dumpy level which was designed by Gravatt. This is also called the solid Dumpy level. In this, the telescope is rigidly fixed to the base so that the telescope can neither be rotated about its longitudinal axis nor it can be removed from the supports. This instrument consists of a long bubble tube attached to the fixed telescope. Dumpy literally means short and thick. This is more stable than the other types.

2. Levelling Staff A levelling staff is a straight rectangular wooden rod graduated in metres and smaller divisions. The bottom-most reading is zero and the reading given by the line of sight on the staff is the height of the point on which the staff is held.

The telescopic levelling staff shown in Fig. 9.19 is made of three pieces, the topmost and the central pieces are 1.25 m long, the bottom-most being 1.5 m long. The central and the bottom rods are hollow and the top one is solid. The top staff slides into the central piece telescopically so that the staff is compact when not used. The markings are same as that of the folding staff except the metre numerals are replaced by the alphabet *M* and the graduations marked erect so that when viewed through the telescope, it is inverted.

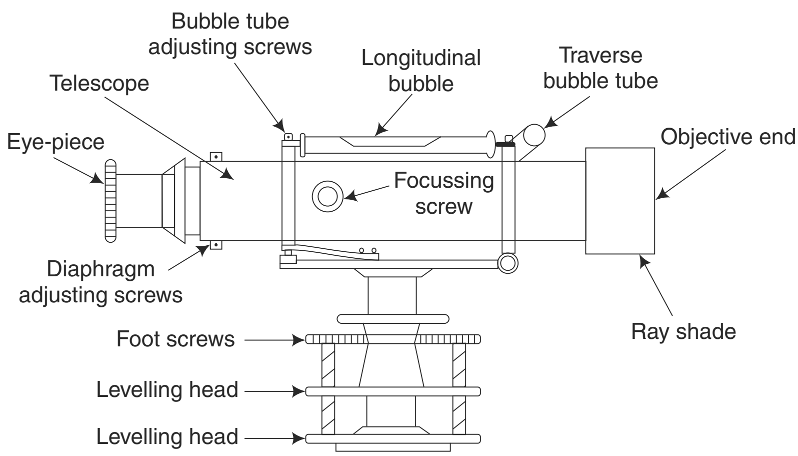


Fig. 9.18 *Dumpy level*

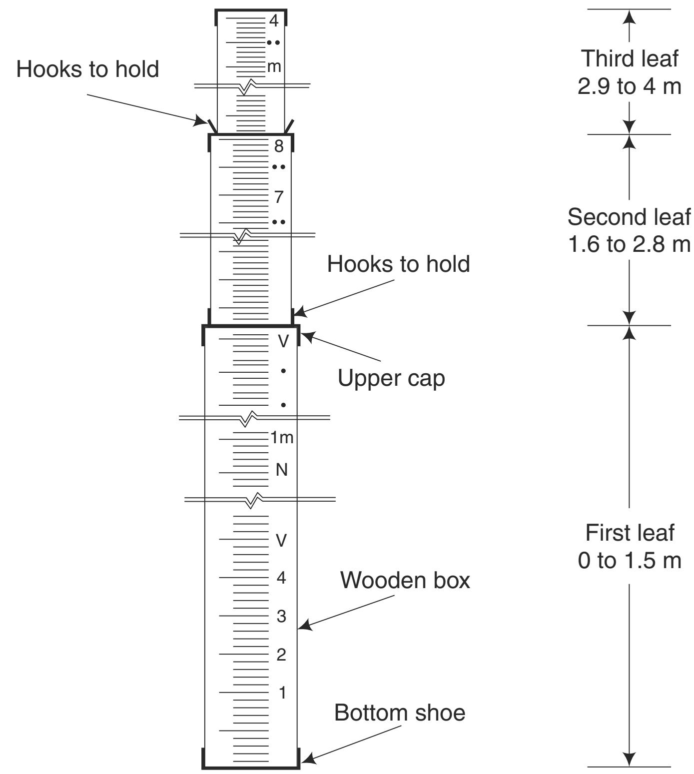


Fig. 9.19 *4 m telescopic levelling staff*

9.9.7 Classification of Levelling

Levelling may be classified as simple levelling and differential levelling.

1. Simple Levelling Figure 9.20 illustrates simple levelling. Simple leveling is the easiest way adopted to find the difference in level between any two points. Let *A* and *B* be the two points and *O* the station point placed approximately midway between *A* and *B*. Station *O* need not lie on the line joining *A* and *B*. The reading of the staff at *A* is first taken. Let this be h_1. Then, the reading of the staff h_2 at *B* is noted after adjusting the bubble to be at the centre. The difference between the two readings, i.e., $h_1 - h_2$ gives the difference in level between *A* and *B*.

If reduced level of *A* is 100, then, RL of *B* can be found as follows:

Height of instrument at $O = 100 + h_1$

RL of $B = 100 + h_1 - h_2$

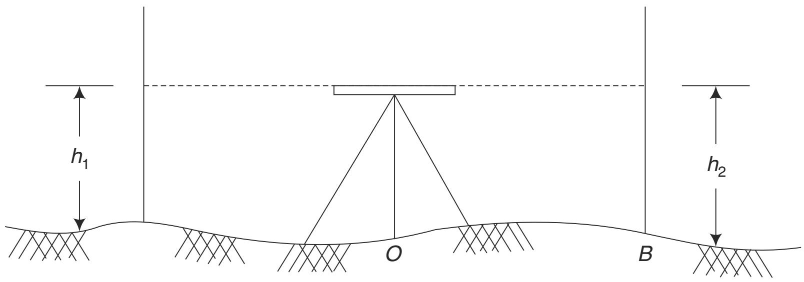


Fig. 9.20 *Simple levelling*

2. Differential Levelling Differential levelling is illustrated in Fig. 9.21. If it is necessary to find the difference in elevation between two points which are too far apart or if there are any obstacles between them or if the difference in elevation is high then differential levelling is adopted. This is a simple levelling adopted in successive stages. Hence, it is also known as compound or continuous levelling.

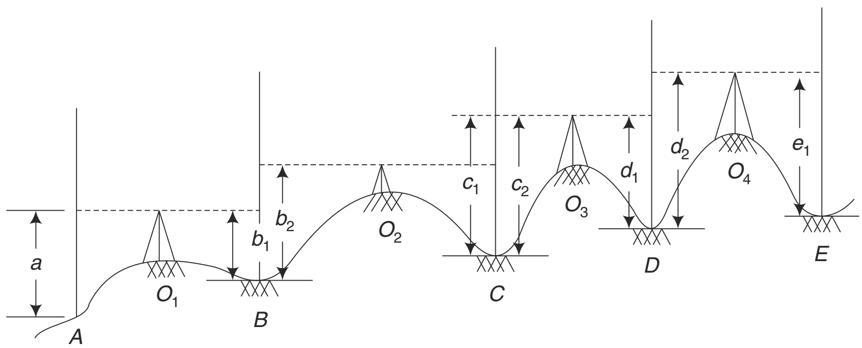


Fig. 9.21 *Differential levelling*

Let *A* and *E* be two points whose difference in elevation is necessary. The staff reading at *A* is noted as *a* from station point O_1. After adjusting the bubble, the staff reading at a firm point *B* is noted from O_1 as b_1. The staff reading *a* is the back sight and *b*, is the foresight. *B* is selected such that AO_I is approximately equal to O_1B. Now, the instrument is shifted to O_2 and the staff reading at *B*, from O_2 is taken and noted as b_2. Another firm point *C* is selected and the procedure is repeated till the point *E* is reached. The difference in level between *A* and *B* is $(a - b_1)$. The difference in level between *B* and *C* is $(b_2 - c_1)$ and so on. The difference in level between *A* and *E* are the algebraic sum of these differences.

9.9.8 Reduction of Levels

There are two methods for calculating the reduced levels of points, the height of collimation or height of instrument method and the rise and fall method. In this section, these methods are discussed.

Table 9.4 Comparison of Height of Collimation Method with the Rise and Fall Method

Height of collimation method	Rise and fall method
1. It is more rapid and saves time and labour.	It is laborious as the staffreading of each station is compared to get a rise or fall.
2. It is adopted for reduction of levels for longitudinal or cross-sectional levelling works.	This is adopted for determining the difference in levels of two points where precision is required.
3. There is no check on the RL of intermediate stations.	There is a complete check on the RLs of intermediate stations.
4. There are only two arithmetic checks, i.e. Σ BS – Σ FS = Last RL – First RL	There are three arithmetic checks, i.e. Σ BS – Σ FS = Last RL – First RL = Σ Rise – Σ Fall
5. Errors in any of the intermediate sights are not noticed.	Errors in the intermediate sights are noticed as these are used for finding out the rises and falls.

1. The Height of Collimation or Height of Instrument Method In this method, the height of instrument (HI) is calculated for each setting by adding the back sight (BS) to the elevation of BM. The reduced level of the first station or of the intermediate station can be obtained by subtracting the foresight at the first station or the intermediate sight at the intermediate station.

For the second setting HI is calculated by adding the back sight taken on the second point to its reduced level. The reduced level of the last point is obtained by subtracting the foresight of the last point from the HI at the last setting. Arithmetic check can be done in the following manner.

$$\Sigma \text{ BS} - \Sigma \text{ FS} = \text{Last RL} - \text{First RL}$$

This method is simple, easy and rapid.

2. Rise and Fall Method In this method, the difference of level between two consecutive points for each setting of the instrument is obtained by comparing their staff readings. A rise is indicated if the back sight reading is greater than the foresight and a fall is shown if it is less than the foresight reading. The rise and fall worked out for all the points give the level difference of each point with respect to the preceding one. If the RL of the back staff point is known, the RL of the following point can be obtained by subtracting its fall from the RL of the preceding point or by adding its rise to the RL of the preceding point. Arithmetic check is done as explained below:

$$\Sigma \text{ BS} - \Sigma \text{ FS} = \Sigma \text{ Rise} - \Sigma \text{ Fall} = \text{Last RL} - \text{First RL}$$

9.10 DETERMINATION OF AREAS

The primary object of land surveying is to determine the area of the tract surveyed. Area is defined as the area of a tract of land as projected upon a horizontal plane and not the actual area of the surface of the land. The units of area in metric system commonly used are square metres or hectares.

9.10.1 Computation of Areas by Direct Field Measurements

The area to be measured may not always be a regular polygon. In this case, the region is divided into a regular polygon and the portion between the irregular boundary and regular polygon. The area can be found by dividing the regular polygon into triangles.

1. By Dividing the Area into Number of Triangles In this method illustrated in Fig. 9.22, the area is divided into a number of triangles and the area of each triangle is calculated by measuring their sides and included angles. Then, the total area of the land will be equal to the sum of areas of individual triangles.

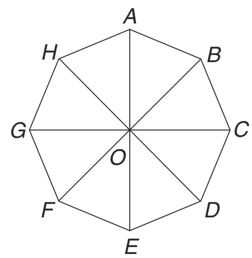


Fig. 9.22

If two sides and one included angle of a triangle is known then area

$$= \frac{1}{2} ab \sin \theta$$

When the lengths of the three sides of a triangle are measured, then,

$$\text{Area} = \sqrt{S(S-a)(S-b)(S-c)}$$

where $S = \frac{1}{2}(a + b + c)$ and a, b, c are sides of the triangle.

2. Areas between the survey lines and boundaries In this method illustrated in Fig. 9.23, a number of offsets are measured from the survey line to the boundary one at regular intervals. Then, the area between survey line and boundary line can be measured by the following rules.

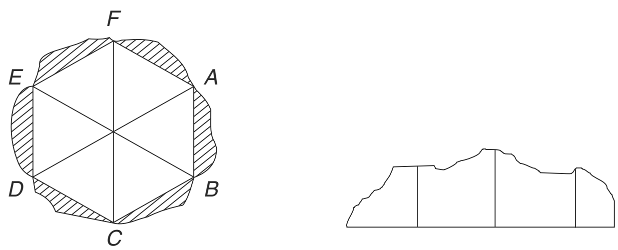


Fig. 9.23

(a) Trapezoidal rule This is based on the assumption that the figures are trapezoids. The base line AB is divided into equal parts. The ordinates are measured and their lengths are scaled off. This procedure is explained in Fig. 9.24.

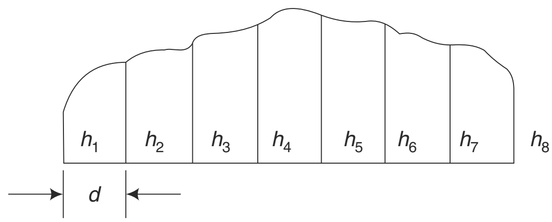


Fig. 9.24

$h_1, h_2, \ldots, h$ – length of ordinates at equal intervals
n – number of divisions
L – length of the base line
d – distance between adjacent ordinates

Note: If h_1 or h_n is equal to zero, that is also included in the formula.

Total area, $A = \frac{d}{2}(h_1 + 2h_2 + 2h_3 + \ldots + 2h_{n-1} + h_n)$

$= \frac{d}{2}$ [first ordinate + 2 (sum of intermediate ordinates) + last ordinate]

(b) Simpson's rule As illustrated in Fig. 9.25, in this rule, the terms and procedures are same as that of the above rule. But total area is given by:

$$A = \frac{d}{3}[h_1 + h_n + 2(h_3 + h_5 + h_7 + \ldots + h_{n-2}) + 4(h_2 + h_4 + \ldots + h_{n-1})]$$

i.e., $A = \frac{d}{3}$ [First ordinate + Last ordinate + 2 (sum of odd ordinates) + 4 (sum of remaining even ordinates)]

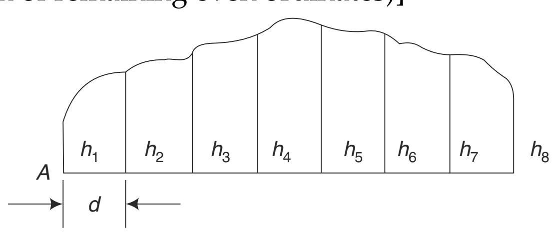


Fig. 9.25

Note:

(i) This rule is applicable only if the number of ordinates is odd. If the number of ordinates is even, the area of the last trapezoid is calculated separately and added to the result.

From Fig. 9.25,

Number of ordinates = 8.

The area for first seven ordinates can be obtained by applying Simpson's rule,

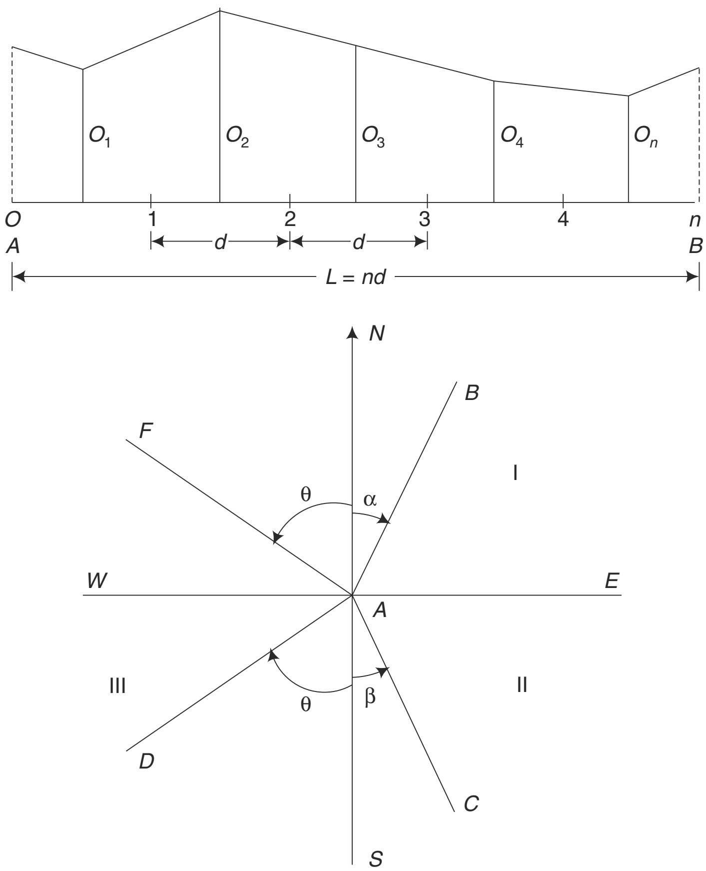


Fig. 9.26

$$A_1 = \frac{d}{3}\,[h_1 + 2(h_3 + h_5) + 4(h_2 + h_4 + h_6) + h_7]$$

$$A_2 = \frac{1}{2}\,(h_7 + h_8) \times d$$

Then, total area $A = A_1 + A_2$.

(ii) If h_1 or h_n is zero that is also included in the rule.

The results obtained using the Simpson's rule are more accurate than those obtained by the Trapezoidal rule.

Comparison between Trapezoidal and Simpson's rule

The results obtained by the use of Simpson's rule are more accurate in all cases. The results obtained by using Simpson's rule are greater or smaller than those obtained by using the trapezoidal rule according as the curve of the boundary is concave of convex towards the base line. In dealing with irregularly shaped figures, the degree of precision of either method can be increased by increasing the number of ordinates.

Mid-ordinate rule

The method is used with the assumption that the boundaries between the extremities of the ordinates (or offsets) are straight line. The base line is divided into a number of divisions and the ordinates are measured at the mid-points of each division, as illustrated in Fig. 9.26.

The average ordinate rule will not give correct results if the range of values of the ordinates is large. The trapezoidal rule and Simpson's rule are the most commonly used rules. Simpson's rule is considered generally more accurate, as the assumption of a curved boundary is more realistic compared to the assumption of a straight-line boundary between ordinates made in the trapezoidal rule. The method of coordinates and the trapezoidal rule give the same results, as both are based on the same assumption. If the boundary is concave towards the survey line, the trapezoidal rule will calculate less area than the Simpson's rule, while if the boundary is convex towards the survey line, Simpson's rule will calculate a lower value.

9.11 CONTOURING

An imaginary line, on the ground, joining the points of equal elevation above the assumed datum is called a contour. Survey work, including office work in the preparation of a contour plan is known as contouring.

The vertical distance between any two consecutive contours is called *contour interval*.

The least horizontal distance between two consecutive contours is called *horizontal equivalent*.

To get a clear concept of contouring, let us consider the case of conducting the survey work on the boundary of still water in a pond. If the level of water surface is 100 m, then the periphery of water represents a contour of 100 m. Now, if the water level is lowered by 5 m, then the new boundary represents a contour of 95 m as shown in Fig. 9.27.

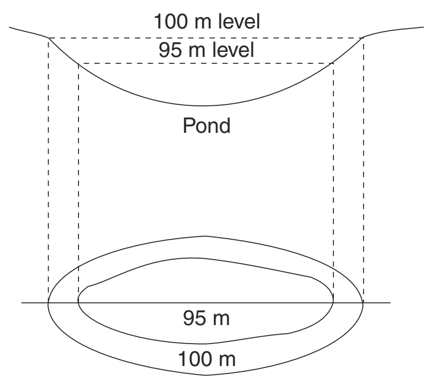


Fig. 9.27 *Contour in still water*

9.11.1 Characteristics of Contours

The characteristics of contour given below are useful in plotting and for interpreting a contour map correctly.

1. Contour which is equally spaced represents a uniform slope whereas one which is closely spaced represents a steep slope.
2. A series of straight, parallel, equally spaced contours represents an inclined plane surface.
3. Contour at any point is perpendicular to the line of the steepest slope at that point.

4. A series of closed contours with higher values on the inside, represents a hill and lower value on the inside indicates a pond or depression without an outlet as shown in Fig. 9.28.

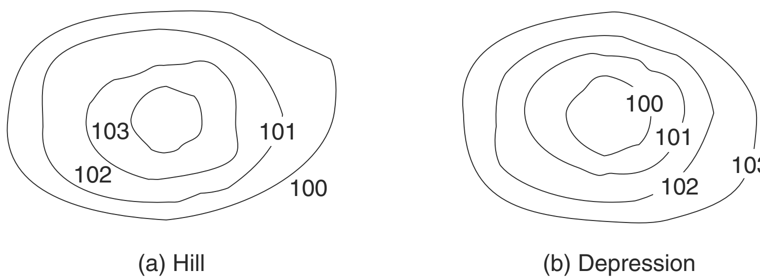


Fig. 9.28 *Contour for a hill and a depression*

5. Contour lines cross a ridge line at right angles, curving round it with the concave side towards higher ground. Whereas for valley line the convex side is towards the higher ground as shown in Fig. 9.29.

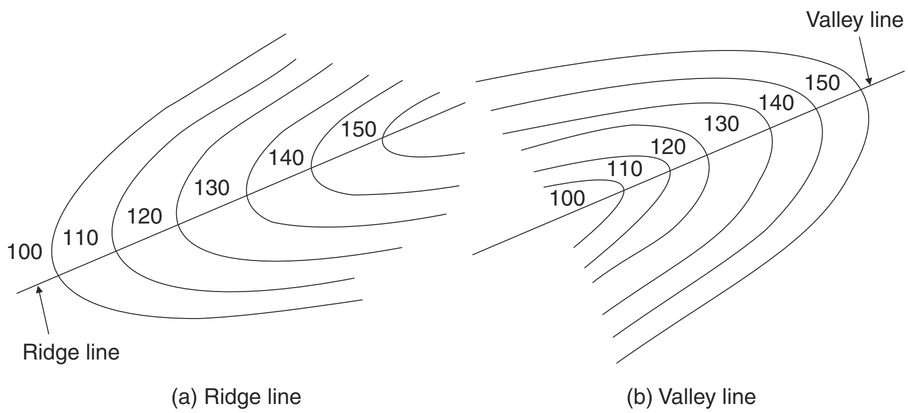


Fig. 9.29 *Contour for ridge and valley*

6. The same contour must appear on both sides of a ridge or a valley.
7. The contour cannot simply end anywhere, it must close on itself, though not necessarily within the limits of the map.
8. Contour lines of different elevations do not unite, except in the case of a vertical cliff as shown in Fig. 9.30.

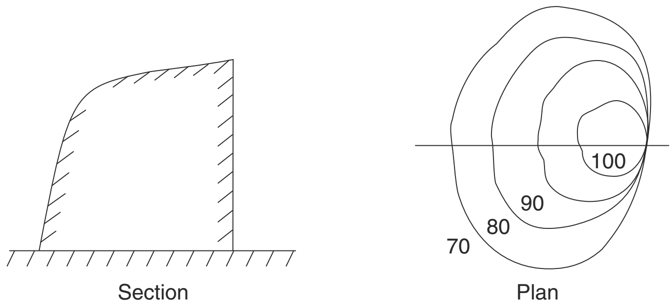


Fig. 9.30 *Contour for a vertical cliff*

9. Contour of different elevations can cross each other only in case of an overhanging cliff as shown in Fig. 9.31.

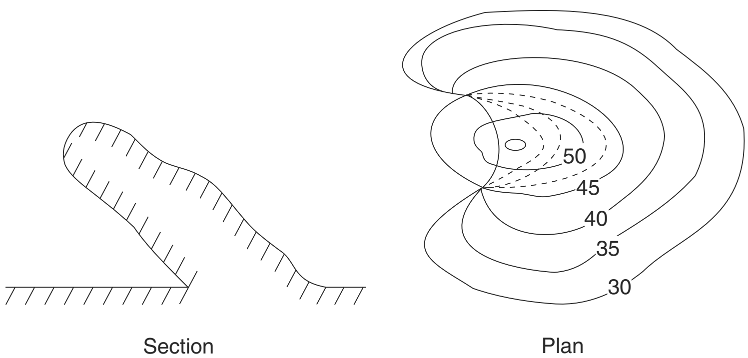


Fig. 9.31 *Contour for an overhanging cliff*

10. Contours do not have sharp turnings.

9.11.2 Uses of Contour Maps

Contour maps are used in many civil engineering works. Some of them are listed below.

1. To study the general topography of the country without doing any survey work.
2. For the site selection of various engineering works such as dams, canals, weirs, roads, railways, etc.
3. The section along any line can be drawn.
4. To determine the quantity of earthwork required for canals, roads, etc.
5. To determine the reservoir capacity.
6. To trace a contour gradient for road, canal and railway alignments.
7. To determine the intervisibility of points.

Illustrative Examples

Example 9.1 Convert the following WCB to RB

1. 20° 30′ 2. 176° 10′ 3. 220° 30′ 4. 295° 40′

Solution Referring to Table 9.2,

1. The given WCB is between 0° and 90°.
   So, WCB = RB 20° 30′ = N 20° 30′E
2. The given WCB is between 90° and 180°.
   So, RB = 180° – WCB
   = 180° – 176° 10′ = S 3° 50′E
3. Here, WCB lies between 180° and 270°.
   So, RB = WCB – 180°
   = 220° 30′ – 180° = S 40° 30′ W
4. WCB lies between 270° and 360°.
   So, RB = 360° – WCB
   = 360° – 295° 40′ = N 64° 20′ W

Example 9.2 The WCB of a line is (i) N 25° 30′ E (ii) S 65° 10′ E (iii) S 32° 30′ W (iv) N 40° 20′ W. What will be the RB in each case?

Solution Referring to Table 9.3,

(i) RB = WCB
N 25° 30′ E = 25° 30′

(ii) WCB = 180° – 65° 10′
= 114°50′

(iii) WCB = 180° + RB
= 180° + 32° 30′ = 212° 30′

(iv) WCB = 360° – RB
= 360° – 40° 20′ = 319° 40′

Example 9.3 The following are the observed fore bearings of the traverse sides: *AB*, 80°30′ *BC*, 150°15′; *CD*, 270°20′ and *DE*, 325° 30′. Find their back bearings.

Solution

BB = FB ± 180°

BB of *AB* = FB ± 180° ± (+ve if FB < 180° and –ve if FB > 180°)
= 80° 30′ + 180° = 260° 30′

BB of the line *BC* = FB + 180°

= 150° 15′ + 180° = 330° 15′

BB of the line *CD* = FB – 180°

= 270° 20′ – 180° = 90° 20′

BB of the line *DE* = FB – 180°

= 325° 30′ – 180° = 145° 30′

Example 9.4 The FB of the lines are as follows:
AB, N 40° 45′ E; *BC*, S 80° 20′ E; *CD*, S 50° 30′ W,′ *DE*, N 70° 15′ W. Find their back bearings.

Solution

BB = FB with opposite letters

BB of *AB* = S 40° 45′ W

BB of *BC* = N 80° 20′ W

BB of *CD* = N 50° 30′ E

BB of *DE* = S 70° 15′ E

Example 9.5 Specimen page of level book with booking of BS, IS, and FS is as follows. Calculate the reduced levels (by height of collimation method).

Solution Refer to the table given below.

1. RL of H.I. at instrument station O_1

   = RL of BM + BS = 100 + 1.350 = 101.350

2. RL of intermediate points

   = RL of H.I. at O_1 – IS or FS

   RL of *B* = 101.350 – 1.150 = 100.200

Inst Station	*Staff Station*	*B.S*	*IS*	*FS*	*H.I.*	*RL*	*Remarks*
O_1	*A*	1.350	–	–	101.350	100.000	BMRL 100.00
	B		1.150			100.200	
	C		1.855			99.495	
	D		0.250			101.100	
O_2	*E*	1.750		1.500	101.600	99.850	C.P1
	F		2.185			99.415	
	G		2.205			99.395	
O_3	H	0.950		1.350	101.200	100.250	C.P2
	I			2.350		98.850	
		ΣBS = 4.050		ΣFS = 5.200			
		ΣBS ~ ΣFS = 1.150		Last RL ~ First RL = 1.150			

RL of C = 101.350 – 1.185 = 99.495

RL of D = 101.350 – 0.250 = 101.100

RL of E = 101.350 – 1.500 = 99.850

3. RL of H.I. at instrument station O_2

   = RL of E + BS = 99.850 + 1.750 = 101.600

4. RL of intermediate points

   = RL of H.I. at O_2 – IS or FS

   = RL of F = 101.600 – 2.185 = 99.415

   = RL of G = 101.600 – 2.205 = 99.395

   = RL of H = 101.600 – 1.350 = 100.250

5. RL of H.I. at instrument station O_3

   = RL of H + BS = 100.250 + 0.950 = 101.200

6. RL of the last point

   = RL of H.I. at O_3 – FS = 101.200 – 2.350 = 98.850

Arithmetical Check

ΣBS ~ ΣFS = Last RL ~ First RL

4.050 ~ 5.200 = 98.850 ~ 100.00

1.150 = 1.150

Example 9.6 The specimen page of level book for BS, IS and FS is as follows: By rise and fall method, calculate the reduced levels.

Solution

Inst Station	*Staff Station*	*BS*	*IS*	*FS*	*Rise*	*Fall*	*RL*	*Remarks*
O_1	*A*	1.250	–	–	–	–	100.000	BMR.L 100.00
	B		1.500			0.250	99.750	
	C		1.850			0.350	99.400	
	D		1.000		0.850		100.250	
O_2	*E*	1.150		2.150		1.150	99.100	C.PI
	F		2.250			1.100	98.000	
	G			0.750	1.500		99.500	Last point
		Σ BS = 2.400		Σ FS = 2.900	Σ Rise = 2.350	Σ Fall = 2.850	Last RL – First RL = 0.500	

Difference of level between consecutive points:

$A - B$ = 1.250 – 1.500 = – 0.250 (Fall)

$B - C$ = 1.500 – 1.850 = – 0.350 (Fall)

$C - D$ = 1.850 – 1.000 = + 0.850 (Rise)

$D - E$ = 1.000 – 2.150 = – 1.150 (Fall)

$E - F$ = 1.150 – 2.250 = – 1.100 (Fall)

$F - C$ = 2.250 – 0.750 = + 1.500 (Rise)

RL of any point = RL of the preceding point ± Difference of level

(Use + sign for rise and – sign for fall)

RL of B = 100.000 – 0.250 = 99.750

RL of C = 99.750 – 0.350 = 99.400

RL of D = 99.400 + 0.850 = 100.250

RL of E = 100.250 – 1.150 = 99.100

RL of F = 99.100 – 1.100 = 98.000

RL of G = 98.000 + 1.500 = 99.500

Arithmetical check

Σ BS ~ Σ FS = Σ Rise ~ Σ Fall = Last RL ~ First RL

2.400 ~ 2.900 = 2.350 ~ 2.850 = 99.50 ~ 100.00

0.500 = 0.500 = 0.500

Example 9.7 The following perpendicular offsets were taken at 10 metre intervals from a survey line to an irregular boundary line: 3.60, 2.80, 4.50, 8.25, 7.85, 6.45, 5.35. Calculate the area enclosed between the survey one and the boundary line by the trapezoidal rule and the Simpson's rule.

Solution In this problem, there are seven ordinates.

By Trapezoidal Rule

$$A = \frac{d}{2}[h_1 + 2(h_2 + h_3 + h_4 + h_5 + h_6) + h_7]$$

$$= \frac{10}{2}[3.60 + 2(2.80 + 4.50 + 8.25 + 7.85 + 6.45) + 5.35]$$

$$= 343.25 \text{ m}^2$$

By Simpson's Rule

$$A = \frac{d}{3}[h_1 + h_7 + 2(h_3 + h_5) + 4(h_2 + h_4, + h_6)]$$

$$= \frac{10}{3}[3.60 + 5.35 + 2(4.50 + 7.85) + 4(2.80 + 8.25 + 6.45)]$$

$$= 345.50 \text{ m}^2$$

Example 9.8 A series of offsets were taken from a chain line to a curved boundary line at an interval of 5 m in the following order: 0, 3.25, 4.10, 6.45, 8.90, 5.75, 8.50, 0. Calculate the area between the chain line and the boundary line.

Solution Number of offsets = 8

$d = 5$ m.

By Trapezoidal Rule

$$A = \frac{d}{2}[h_1 + h_8 + 2(h_2 + h_3 + h_4 + h_5 + h_6 + h_7)]$$

$$= \frac{5}{3}[0 + 0 + 2(3.25 + 4.10 + 6.45 + 8.90 + 5.75 + 8.50)]$$

$$= 184.75 \text{ m}^2$$

By Simpson's Rule

To apply this rule, the number of ordinates should be odd. So, the last offset is ignored to calculate the area. Then, the area between last two offsets is calculated by applying the trapezoidal rule.

$$A = \frac{d}{3}[h_1 + h_7 + 2(h_3 + h_5) + 4(h_2 + h_4, + h_6)] + \frac{6}{2}(h_7 + h_8)$$

$$= \frac{5}{3}[0 + 8.50 + 2(4.10 + 8.90) + 4(3.25 + 6.45 + 5.75)]$$

$$+ \frac{5}{2}(8.50 + 0) = 181.75 \text{ m}^2$$

Short-Answer Questions

1. What are the two basic principles of survey?
2. What is meant by levelling?
3. What are the different types of benchmarks?
4. What are the instruments used for levelling?
5. Name the two methods used for calculating the reduced levels of points.
6. Write the formula for calculating the area by Simpson's rule.
7. What is the length of a link in a metric chain of 30 m length?
8. Write short notes on the types of surveying.
9. Define: (a) Contour (b) Contouring.
10. What is meant by contour interval?
11. What do you understand by horizontal equivalent?
12. Differentiate between contour interval and horizontal equivalent.
13. How will you distinguish between a depression and a hill using a contour map?

Exercises

1. Define surveying. Explain its importance for civil engineers.
2. What are the objectives of plane surveying?
3. Give the classification of surveys.
4. Explain the principles of surveying.
5. What are the advantages and disadvantages of chain surveying?
6. Describe a typical chain with a neat sketch.
7. What are the various instruments used in chain surveying?
8. Explain the principle of chain survey.
9. Which type of area is best suited for chain survey? Give reasons.
10. Define the following:
    (a) Tie stations (b) Base line (c) Check line (d) Offset (e) Traverse
11. Differentiate the following:
    (a) Open traverse and closed traverse
    (b) Perpendicular offset and oblique offset
    (c) Prismatic compass and surveyor's compass
    (d) True bearing and magnetic bearing
    (e) Whole circle bearing and reduced bearing
    (f) Fore bearing and back bearing
12. What is local attraction? How is it detected and removed?
13. What are the advantages and disadvantages of compass surveys?
14. Convert the following WCB to RB
    (a) 66° 30′ (b) 130° 15′ (c) 205° 20′ (d) 265° 10′
    (e) 295° 30′ (f) 320° 15′
15. Convert the following RB to WCB
    (a) N 32° 30′ E (b) S 42° 40′ E (c) S 60° 30′ W (d) N 72° 50′ W
16. Write the back bearings of the following fore bearings:
    (a) 60° 10′ (b) 130° 30′ (c) 200° 15′ C (d) 300° 20′
17. Write the back bearings of the following fore bearings:
    (a) N 75° 30′ E (b) N 60° 30′ W (c) S 40° 45′ W (d) S 55° 20′ W
18. What are the different types of levels used in levelling?
19. Define the following:
    Level surface, horizontal plane, vertical plane, datum surface, reduced level, back sight, fore sight, intermediate sight, change point, bench mark.

20. Explain the principle of levelling.
21. Explain the following with neat sketches:
    (a) Simple levelling (b) Differential levelling
22. The BS reading at *A* is 2.355 m and the fore sight reading at *B* is 1.505 m. Find the level difference between *A* and *B*.
23. Compare the height of collimation method with the rise and fall method.
24. The following consecutive readings were taken with a levelling instrument on a continuously sloping ground. The RL of *A* was 100.000. Find the level difference between *A* and *B* by
    (a) Height of collimation method (b) Rise and Fall method
    Apply usual checks
    0.585, 1.850, 2.550, 3.335, 0.865, 1.750, 2.880, 3.650
25. The following consecutive readings were taken with a dumpy level. 0.860, 1.350, 2.220, 0.780, 1.050, 2.780
    The instrument shifted after the fourth reading. The RL of BM is 500.000 m. Calculate the reduced levels of the stations by the known two methods and apply the arithmetical checks.
26 A series of offsets were taken at 5 m intervals from a chain line to a curved edge.
    1.50. 1.66, 2.25, 2.80, 1.75, 1.95, 0
    Calculate the area between the chain line to a curved edge by the Simpson's rule and the trapezoidal rule.
27. Calculate the area between the chain line and the irregular boundary and the first and last offsets.

Distance (m)	0	3	6	9	12	15
Offset (m)	1.50	3.20	2.75	2.10	1.70	2.20

    Use Simpson's rule.
28. Show with neat sketches the characteristic features of contour lines.
29. Discuss in detail the uses of a contour map.

Chapter 10
ENVIRONMENTAL ENGINEERING

10.1 INTRODUCTION

The term 'sanitary engineering' was originally used to describe the practice of those engineers who designed water and sewerage systems, and other public health protection works. The area of practice then expanded when the society recognised that protection of the air, land and water is necessary for all living things. Thus, in modern times the term environmental engineering has evolved to describe the engineers' increased emphasis on the biological, chemical and physical reactions of the air, land and water environments and improved technology for reuse, recycle and recovery measures. Although the environmental engineering disciplines are reasonably well established, i.e. air, water supply, waste water, storm water, solid waste and hazardous waste, a number of other specialty disciplines also exist. These include noise, radiology, industrial hygiene and oceanography.

Environmental engineering is that branch of engineering concerned with the environment and its proper management. Traditionally, environmental engineers have drawn their basic education and training from civil engineering programmes. Recently, environmental engineers have included course work and training in professional areas including chemical engineering, microbiology, hydrology and chemistry in order to broaden their perspective on potential solutions to environmental problems.

10.2 SOURCES OF WATER

10.2.1 General

- Surface sources of water include rivers, streams, lakes ponds, etc.
- There is large variation in the water yield of such sources, which vary from season to season.
- The development, reliability and quantity of water mainly depend on the following:
  1. The selection of the site for collection works
  2. Preparation and control of the catchment area

3. Type and choice of the reservoir
4. The treatment of the reservoir sites as well as operation of the reservoir
5. The design and maintenance of dams and dikes
6. The design, construction and maintenance of intake and outlet facilities

10.2.2 Drinking Water Supply Systems

Water may be supplied to the consumers by the following two systems:

(i) Continuous systems
(ii) Intermittent systems

(i) Continuous systems

In the continuous systems, water is available to the consumers for all the 24 hours of a day. No doubt, this is the best system since water is available as and when it is needed, but this leads to the waste of useful water. If there are some minor leakages, etc., in the systems, great volume of water is wasted because of long duration of flow. In this system, water is not stagnant in the pipe at any instant, and hence fresh water is always available.

(ii) Intermittent systems

In this system, water is supplied to the consumers only during some fixed hours of the day, say two to four hours in the morning and two to four hours in the evening. This is the most common system adopted in India. This method is adopted when either sufficient pressure is not available or when sufficient quantity of water is not available. Under these conditions, various distribution zones of the city are supplied water by turn. The normal supply timings may be between 6 a.m. to 10 a.m. and 4 p.m. to 8 p.m., though these timings may be changed to suit climatic or seasonal conditions.

10.2.3 Sources of Water

All sources of water can be broadly classified as:

(i) Streams
(ii) Lakes
(iii) Ponds
(iv) Rivers
(v) Reservoirs
(vi) Stored rainwater

These can be further divided as

(i) Springs
(ii) Infiltration galleries
(iii) Porous pipe galleries
(iv) Wells

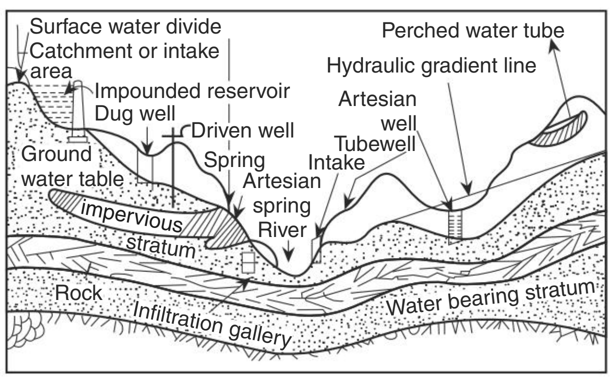


Fig. 10.1 *Sources of Water*

1. Streams

Streams offer a good source of water except for the water of the first run-off. Sometimes the run-off water while flowing over the earth gets mixed with clay, sand and mineral impurities. All the suspected impurities can be restored in settling tanks up to a certain, extent, but the dissolved impurities require special treatments. The steams generally flow in valleys and are the main source of water supply to nearby villages on hill slopes.

2. Lakes

At some places in mountains, natural basins are with impervious beds are formed. Water from springs and streams generally flows towards these basins and 'lakes' are formed. The quantity of water in a lake depends on its basin capacity, catchment area, annual rainfall, porosity of the ground, etc. The quality of water in large lakes is better than that of in small lakes. Lakes situated at high altitudes contain almost pure water which can not be used without any treatment. Lake water is usable for only those towns and cities which are situated near them, such as Nainital.

3. Rivers

Rivers are born in the hills, when the discharge of a large number of springs and streams combine together. In mountains, the quantity of water in rivers remains little, and therefore, at such place these are called youthful rivers. But as the river moves forward, more and more streams combine in it and increase its discharge. Therefore, rivers grow bigger and bigger as they move forward due to increase in their catchment area. River are the only surface sources of water which from which the maximum quantity of water can be easily taken. Therefore, in ancient times, towns and cities usually developed along the banks of rivers. Mostly, all the cities which are situated near rivers discharge their used water, or sewage, in the rivers. Therefore, much care should be taken while drawing water from rivers. River water has the capacity of self-purification, due to which it automatically becomes clean at some distance from the point of disposal of sewage. In summer, the quality of river water is better than that in monsoon, because in the rainy season, the run-off water also carries clay, silt and sand with it which make the water turbid. River-water should always be used after necessary treatment. Some rivers are perennial, and have water throughout the year. Therefore, they do not require any arrangement to store the water. But some rivers dry up wholly or partly in summer, and therefore, they require special arrangement to meet to the water demand during hot weather.

4. Ponds

These are depressions in plains, like those of lakes in mountains, in which water is collected during the rainy season. Sometimes ponds are formed when much excavation is done for house construction in villages, and embankments for road and railways. Generally, the quantity of water is very small and contains large amount of impurities. In villages, the used water mostly flows towards ponds which further contaminate its water. The water of ponds is used for washing clothes, for bathing animals and for drinking. In some underdeveloped villages, people sometimes bathe in the dirty water of ponds. The water of ponds cannot be used for water-supply purposes due to its limited quantity and large amount of impurities.

5. Artificial Reservoirs

Generally, It is found that there is great variation in the quantity of river water during and after the summer season. The discharge in some rivers remains sufficient to fulfill the water demand in the hot weather, but in sonic rivers the flow becomes very small and cannot meet the requirements of this season. In such cases, it becomes essential to store water for the summer season. The water can be stored in the river by constructing a hand, a weir or a dam across the river at such places where minimum area of land is submerged in the water and the reservoir basin can be made cup-shaped in order to have the maximum possible depth of water.

6. Shallow Wells

Construction of shallow wells The shallow wells are constructed in the uppermost layer of the earth's surface. They obtain their water supply from the groundwater table as shown in Fig. 10.2. The diameter of shallow wells varies from 2 to 6 metres. They may be lined or unlined from inside. The lining is also called the *steining* and its thickness varies from 30 cm to 50 cm.

The Fig. 10.2 shows a shallow well with steining. The unlined wells are generally constructed up to a maximum depth of about 7 metres or so. But for greater depths, the soil cannot stand vertically and maximum depth of about 7 metres or so. But for greater depths, the soil cannot stand vertically and hence steining becomes essential for such wells. These wells are also sometimes referred to as *draw wells* or *gravity wells* or *open wells* or *dug wells* or *percolation wells*.

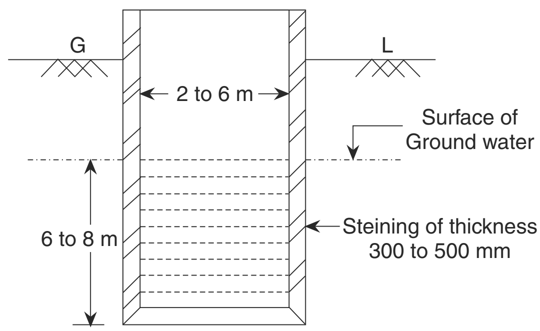


Fig. 10.2 *Shallow Well*

Quantity of water from shallow wells The quantity of water available form shallow wells is generally limited as their source of supply is only the uppermost layer of the earth. Sometimes they even dry up in summer. In order to ensure a steady supply of water from shallow wells, even in dry periods, they are dug up to much below the surface of the groundwater table. The depth below the water table is kept at about 6 to 8 metres so that even if the water table falls, by a few metres, water could still be made available for a longer time. The discharge to shallow wells does not exceed 5 litres per second and hence, they are not suitable for public water-supply schemes.

Quality of shallow well water The quality of water obtained from shallow wells is better than that of river water. But it is not reliable and requires purification. The main source of contamination is the effluent from nearby septic tanks, soak wells, etc. It is therefore desirable to construct shallow wells away from such possible sources of contamination.

It may also be noted that the shallow well water is notoriously liable to intermittent pollution, and hence the samples of water should always be collected after rainfall, when marked deterioration in purity may be revealed.

Use of shallow wells Because of the uncertain supply and poor quality of water, the shallow wells are used as a source of water supply for small villages, undeveloped municipal towns, isolated buildings, camps, etc.

7. Deep Wells

Deep wells obtain their quota of water from an aquifer below an impervious layer as shown in Fig. 10.3. The theory behind the functioning of a deep well is based on the flow of water from the outcrop to the site of the deep well. The *outcrop* is the place where the aquifer is exposed to the atmosphere as shown in the Fig. 10.3 The entry of rainwater takes place at the outcrop, and it reaches the site of the deep well. During its travel, the water gets thoroughly purified; but it dissolves certain salts and may, therefore, become hard. In such cases, some treatment would be necessary to remove the hardness of water.

The depth of a deep well should be decided in such a way that the location of the outcrop is not very near the site of the well. The water of a deep well is contained in the lower embedded aquifers, and hence it is always available at a pressure greater than the atmospheric pressure. The deep wells are, therefore, referred to as *pressure wells*.

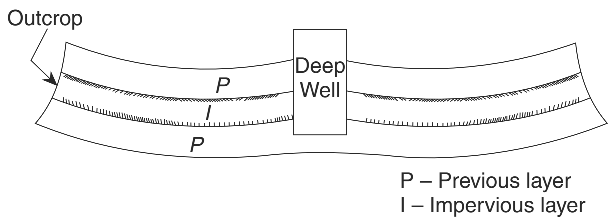


Fig. 10.3 *Deep Well*

10.3 ELEMENTS OF PROTECTED WATER SUPPLY

10.3.1 Objectives of a Water Supply System

1. To supply safe and wholesome water to consumers.
2. To supply water in adequate quantity.
3. To make water easily available to consumers so as to promote hygiene in the society.

10.3.2 Steps Involved in Planning of a Water Supply Scheme

1. Fixing the Design Period Water supply projects are normally designed to meet the requirements over a 30-year period after their completion.

2. Estimating the Amount of Water that is Required This involves determining the number of people who will be served and the per capita water consumption together with an analysis of the factors that may affect the rate of consumption and total consumption.

3. Deciding the Source of Supply By considering the quantity and quality of water available from different sources and their location.

4. Design of the following Elements

(a) Impounding reservoir and intake works
(b) Conveying mains

(c) Treatment plant
(d) Balancing reservoirs
(e) Distribution system

10.3.3 Per Capita Consumption

It is usual to express water consumption in litres per capita per day. If Q is the total quantity of water in litres required by a community per year having P as population, then the per capita consumption in litres per capita per day (lpcd) is given by $Q/(P \times 365)$.

The standard recommended per capita supply for Indian conditions is 135 lpcd.

Estimation of Water Demand

This is required for finding out the total water requirement of a town. Water demand of different heads may be summed up, and the figure may be divided by the population of the concerned area, which will give the equivalent per capita water demand. Thus, both the domestic and non-domestic needs are expressed with relation to population. The following example may be useful for understanding of this statement. The breakup of water consumption rates of a town under heads may be assumed as,

(i) Domestic uses = 100 lpcd
(ii) Institutional/public requirements = 20 lpcd
(iii) Industrial demands = 30 lpcd
(iv) Fire demand = 15 lpcd
(v) Water Uncounted for = 35 lpcd
Total = 200 lpcd

From the above, it can be seen that gross water requirement will be 200 litre per capita per day. If the total population of the town is ascertained, the water demand per day may be assessed.

10.3.4 Consumption for Various Uses

Table 10.1

1.	Domestic	– Around 50 per cent of the total consumption in an average city
2.	Commercial and industrial	– Depends on the number and type of industry
3.	Public use	– About 10 per cent of the total consumption
4.	Loss and waste	– About 15 per cent
5.	Fire demand	– Considered as a function of population

10.3.5 Factors Affecting per Capita Consumption

1. Climate
2. Class of consumers
3. Industries and commerce

4. Quality of water
5. Extent of metering system
6. Pressure in the distribution system
7. System of supply
8. Size of the city

10.3.6 Variations in the Rate of Consumption

In practice it can be seen that the rate of consumption will vary depending upon the season or month, day and hour. These are termed as given below:

1. Seasonal or monthly variation
2. Daily variation
3. Hourly variation

Hourly variation for an average city is plotted in Fig. 10.4

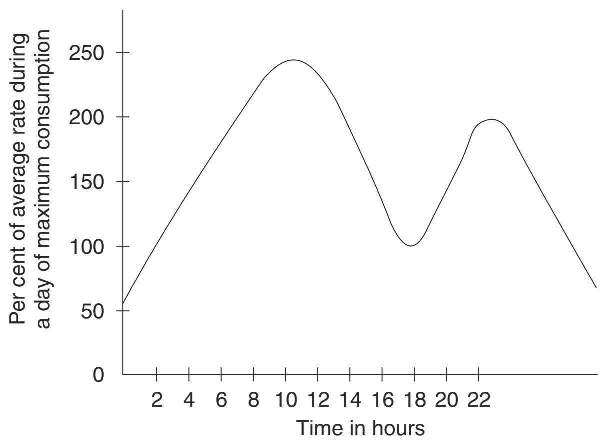


Fig. 10.4 *Hourly variation for an average city*

10.3.7 Infiltration Galleries

These are wells constructed to a horizontal position along the river banks or other seepage areas from where water can be tapped across the line of flow. Infiltration galleries are generally located at 15 m or more from the river bank and are constructed in open cut so as to reach the water bearing stratum. The trench is carried below the minimum level of the water table and a gallery with small numerous openings is constructed. The openings are then back-filled with graded gravel to prevent the entrance of very fine material into the gallery. The infiltration galleries are generally laid with a slope so that the water may be collected first in a suction well and later pumped into the supply systems. Figure 10.5 shows the section of an infiltration gallery.

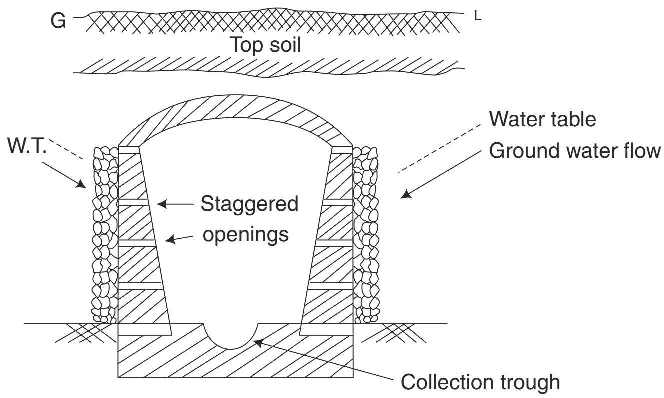


Fig. 10.5 *Infiltration gallery*

10.3.8 Water Treatment

The aim of water treatment is to produce and maintain water that is hygienically safe, aesthetically attractive and palatable in an economic manner.

The method of treatment to be employed depends on the nature of raw water and desired standard of water quality. The unit operations in water treatment are given below:

1. Aeration
2. Coagulation
3. Flocculation
4. Sedimentation
5. Filtration
6. Softening
7. Disinfection
8. De-mineralisation
9. De-fluoridation

The flow chart for giving the necessary treatment for some common types of raw water is given in Fig. 10.6.

Disinfection of Water

When the water comes out of the filters, it is still found to contain some amount of bacteria. Hence the water should be disinfected before supplying to the consumers. Chlorination is the most efficient and simple method to disinfect the water.

Chlorination is the application of small quantities of chlorine or chlorine compounds to water. The dosage of chlorine usually varies from 0.2 ppm to 1 ppm. Chlorine reacts with water to produce hypochlorous acid (HOCL) and hypochloriteion (OCL) which together is known as free available chorine.

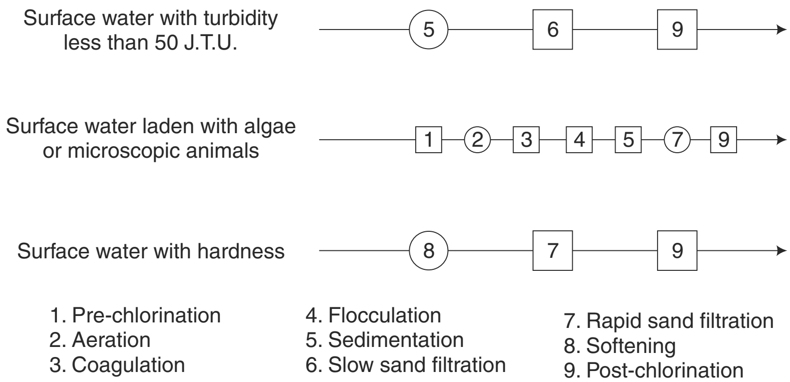


Fig. 10.6 *Flow chart*

$$Cl_2 + H_2O = HCl = HOCl$$
$$HOCl = H + OCl$$

Chlorine partly combines with the cell structure of bacteria and forms toxic poison which destroys the bacteria completely.

The chlorine can be applied in water in the following ways.

(1) As bleaching powder
(2) As chloramines or
(3) As free chlorine gas

Common method of chlorination is in the gaseous state. Chlorine gas is greenish yellow in colour. It is 2.5 times heavier than air and it is added into the water by means of a equipment known as chlorinator.

10.3.9 Methods of Chlorination

1. Plain chlorination If the raw water is sufficiently clear, it is supplied for consumption after giving chlorine treatment only. It is called plain chlorination.

2. Post-chlorination This is the application of chlorine after all treatments of purification of water are completed, and is the standard treatment adopted at all places.

3. Pre-chlorination When chlorine is added to raw water before any treatment, it is known as pre-chlorination. This reduces the bacterial load on the filters.

4. Double chlorination It is addition of chlorine at two points in the treatment process, viz., before and after the treatment.

5. Breakpoint chlorination It is the addition of exact dosage of chlorine so as to oxidise all organic matter, destroy bacteria leaving behind mainly free chlorine.

6. Super-chlorination It is the application of chlorine beyond the stage of breakpoint up to 2 ppm. This is adopted when the water contains a high content of organic impurities. Sometimes it becomes necessary to remove the excess chlorine remaining in the water in this method.

10.3.10 Drinking Water Quality Standards as per BIS

Table 10.2 lists the drinking water quality standards as per BIS.

Table 10.2 Drinking Water Quality Standards as per BIS

S. No.	*Parameters*	*Acceptable*	*Maximum allowable*
1.	Turbidity (JTU)	5	10
2.	TDS (mg/L)	500	2000
3.	pH	6.5–8.5	6.5–8.5
4.	Total hardness as $CaCO_3$ (mg/L)	300	600
5.	Calcium as Ca^{2+} (mg/L)	75	200
6.	Iron as Fe (mg/L)	0.3	1.0
7.	Manganese as Mn (mg/L)	0.1	0.3
8.	Nitrate NO_{3-} (mg/L)	45	100
9.	Chlorides as Cl^- (mg/L)	250	1000
10.	Fluorides as F^- (mg/L)	1.0	1.5
11.	Sulphates (mg/L)	200	400

10.3.11 Distribution Networks

The series of interconnected pipes used to supply water to the consumers is known as distribution network. The following are the major types of distribution networks.

1. Branching system or dead end system or tree system, shown in Fig. 10.7(a)
2. Grid system, presented in Fig. 10.7(b).
3. Ring system, detailed in Fig. 10.7(c).
4. Radial system, shown in Fig. 10.7(d)

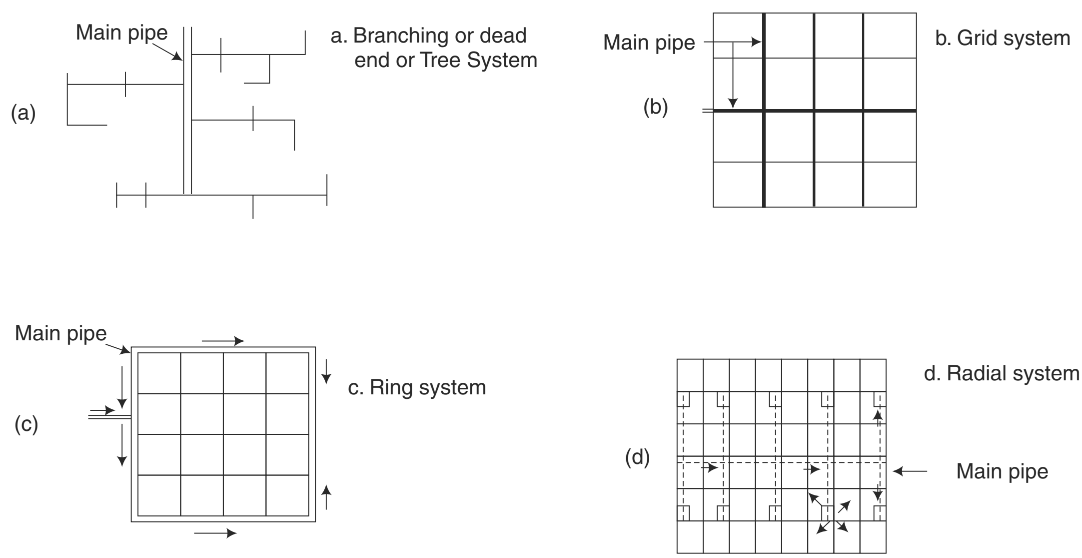


Fig. 10.7 *Distribution networks*

10.4 SEWAGE TREATMENT (SANITARY ENGINEERING)

10.4.1 Treatment Terms

1. Sewage It is the liquid waste from the community. It includes discharge from urinals, industrial waste, storm water and sullage.

2. Domestic Sewage It includes human excreta as well as discharges from kitchens, baths, etc.

3. Industrial Waste It is the waste from manufacturing processes.

4. Refuse In sanitary engineering it is the waste matter which is rejected or left as use. It includes sewage, sullage, storm water, garbage, etc.

5. Sullage It is the liquid discharge from bathrooms, kitchens, washing places, wash-basins, etc. It is merely waste water and does not create odour.

6. Storm water It is the rainwater from roofs, houses, buildings, streets and other town areas.

7. Garbage It is dry refuse and it includes decayed fruits, grass, sewage and vegetables.

8. Sewer The underground conduits or drains through which sewage is conveyed are known as sewers.

9. Sewerage The entire science of collecting and carrying sewage by water carriage system through sewers is known as sewerage.

10. Sewerage system The entire system of conduits and appurtenances involved in sewerage is called sewerage system or sewer system.

10.4.2 Waste Water Flow Rates

Determination of the rates of waste water flows is a fundamental step in the design of waste water collection, treatment and disposal facilities. It can be found that around 80 per cent of the water supply will come back as waste water. Detailed hydrological studies are required for the estimation of storm water. The rate of flow of industrial waste depends on the number and type of industries.

10.4.3 Waste Water Characteristics

An understanding of the nature of waste water is essential in the design and operation of collection, treatment and disposal facilities and in the engineering management of environment quality. The following are the major characteristic parameters.

1. Physical characteristics
   Colour, Odour, Solids, Temperature
2. Chemical constituents
   (a) *Organic*—Carbohydrates, fats, oils, grease, pesticides, proteins, surfactants, etc.
   (b) *Inorganic*—Alkalinity, chlorides, heavy metals, nitrogen, pH, phosphorus, sulphur, toxic compounds, etc.
   (c) *Biological constituents*—Animals, plants, protista, viruses.

10.4.4 Important Contaminants of Concern in Waste Water Treatment

Suspended Solids Suspended solids can lead to the development of sludge deposit and anaerobic condition when untreated waste water is discharged in aquatic environment.

Bio-degradable Organics This consists of proteins, carbohydrates and fats. Biodegradable organics are measured in terms of BOD (Bio-chemical oxygen demand) and COD (chemical oxygen demand). If discharges untreated into the rivers or lakes, their biological stabilisation can lead to depletion of dissolved oxygen and the development of anaerobic conditions.

Pathogens Communicable diseases can be transmitted by the pathogenic organisms in waste water.

Nutrients Both nitrogen and phosphorus along with carbon are essential nutrients for growth. When discharged into rivers, these nutrients can lead into the growth of undesirable aquatic life. When discharged excessive amounts on land they can lead to ground water pollution.

Refractory Organics These organics tend to resist conventional methods of waste water treatment, e.g. Surfactants, Phenols, Pesticides.

Heavy Metals Heavy metals are usually coming from commercial and industrial activities and may have to be removed if the waste water is to be re-used.

Dissolved Inorganic Solids Inorganic constituents such as calcium, sodium and sulphates are added to the original domestic supply as a result of water use and may have to be removed if the waste water be re-used.

10.4.5 Biochemical Oxygen Demand (BOD)

Biochemical oxygen demand of an organic waste is defined as the amount of oxygen required for the complete bio-degradation of the waste under aerobic conditions. BOD determination involves the measurements of the dissolved oxygen used by microorganisms in the biochemical oxidation of the organic matter. Usually this value is determined for the period of five days at a temperature of 20° C. BOD test results are used for the following:

1. to determine the approximate quantity of oxygen required to biologically stabilise the organic matter present.
2. to determine the size of waste treatment facilities.
3. to measure the efficiency of some treatment processes.

10.4.6 Chemical Oxygen Demand (COD)

The COD test is used to measure the content of organic matter of both waste water and natural waters. The oxygen equivalent of organic matter that can be oxidised is measured by using a strong oxidising chemical agent in an acidic media. The COD of the waste is, in general higher than the BOD because more compounds can be chemically oxidised than can be biologically oxidised. COD can be determined in three hours, compared with five days for BOD.

10.4.7 Waste Water Treatment Objectives

Methods of waste water treatments were first developed in response to the concern for public health and adverse conditions caused by the discharge of waste water to the environment. As the cities become large the availability of lands become limited for the disposal of waste water by irrigation. The purpose of treatment is to accelerate the forces of nature under controlled conditions in treatment facilities of comparatively small size. In general, the treatment objectives are:

1. removal of suspended and floatable material
2. treatment of biodegradable organics
3. elimination of pathogenic organisms
4. removal of nitrogen, phosphorus, toxic compounds, refractory organics, heavy metals and dissolved inorganic solids.

10.4.8 Treatment Methods

The following are the list of treatment methods for waste water:

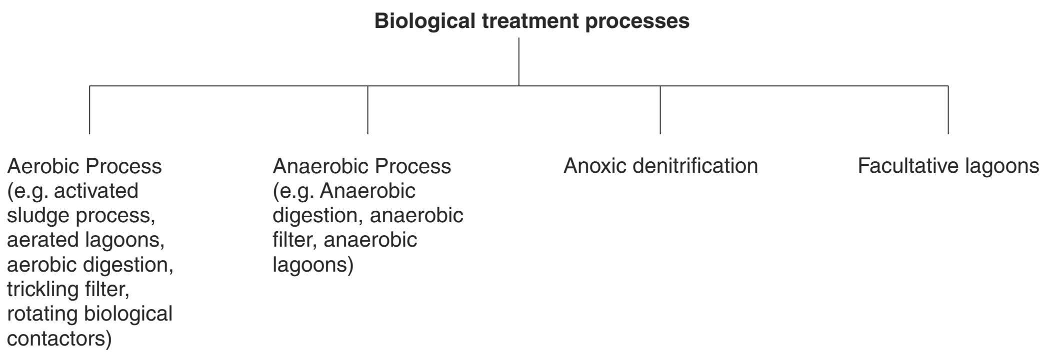
1. Physical Unit Operations Treatment methods in which the application of physical process dominate are known as physical process dominate are known as physical unit operations. For example, screening, mixing, flocculation, sedimentation, floatation and filtration.

2. Chemical Unit Processes Treatment method in which the removal or the conversion of contaminants is brought about by the addition of chemicals or by other chemical reactions are known as chemical unit processes.

For example, precipitation, gas transfer, adsorption and disinfection.

3. Biological Unit Processes Treatment methods in which the removal of contaminants is brought about by biological activity are known as biological unit processes.

The following are the major biological treatment processes:



Sometimes the unit operations and processes are grouped together to provide what is known as primary, secondary and tertiary (advanced) treatment.

1. *Primary Treatment* The term refers to physical unit operations.
2. *Secondary Treatment* This refers to chemical and biological unit processes.
3. *Tertiary Treatment* Tertiary refers to a combination of physical, chemical and biological treatment processes.

10.4.9 Classification of Sewerage Systems

The sewerage system is classified under following heads.

1. Combined system In a combined system, the same sewer is intended to carry the domestic sewage, industrial wastes as well as the surface and the storm water flow.

2. Separate system In a separate system, the domestic sewage and industrial wastes are carried in one set of sewers whereas the storm and surface waters are carried in another set of sewers.

3. Partially combined or partially separated system This is a modification of the separate system in which the separate sewer discharging domestic sewage and industrial waste also contains a portion of the surface water drained from back paved yards and roofs of the houses.

10.4.10 Sewage Disposal

Sewage disposal is carried out by the following two principal methods.

1. Disposal by dilution Disposal by dilution is the process whereby treated sewage or the effluent from treatment plants is discharged into bodies of water or water courses. In some cases when raw sewage is also to be let into the body of water, the ability of the receiving water to carry the pollution load safely without producing conditions of potential nuisance should be taken into consideration. Getting rid of sewage is principally done by its dilution or dispersion into the body of water with large volumes of water contained in it.

2. Disposal by irrigation

(a) Broad irrigation In this process, sewage is made to flow over cultivated lands. A part of the sewage evaporates from this land and the remainder percolates in it, ultimately to escape into surface drainage channels.

(b) Sub surface irrigation Sub surface irrigation is the application of sewage into the land through a system of open jointed pipes or drains. These are laid near the surface of the ground hence enabling sewage to percolate into the surrounding soil.

10.5 SEPTIC TANK

Septic tank is an anaerobic suspended growth biological treatment unit for sewage. Septic tanks are used principally for the treatment of waste from individual residences. In rural areas they are also used for establishments, such as schools and hotels. Although single chambers series are preferable. In a dual chamber septic tank, the first compartment provides for sedimentation, sludge digestion and sludge storage. The second compartment provides additional sedimentation and sludge storage capacity and thus serves to protect against the discharge of sludge and other material that might escape the first chamber. Septic tanks designed for residential use generally have a detention period of 24 hours. For larger installations that serve multiple families or institutions, a shorter detention period may be permissible. In either case it is essential that adequate storage capacity be provided so that the deposited sludge remains in the tank for a sufficient length of time to undergo decomposition before being withdrawn. In general, sludge should be removed every two to three years. Sludge Pumped from the septic tanks is usually discharged to a nearby treatment plant. Effluent from the septic tanks is normally discharged to subsurface by an irrigation system, or dispersion trench system. Figure 10.8 shows the plan and section of a septic tank.

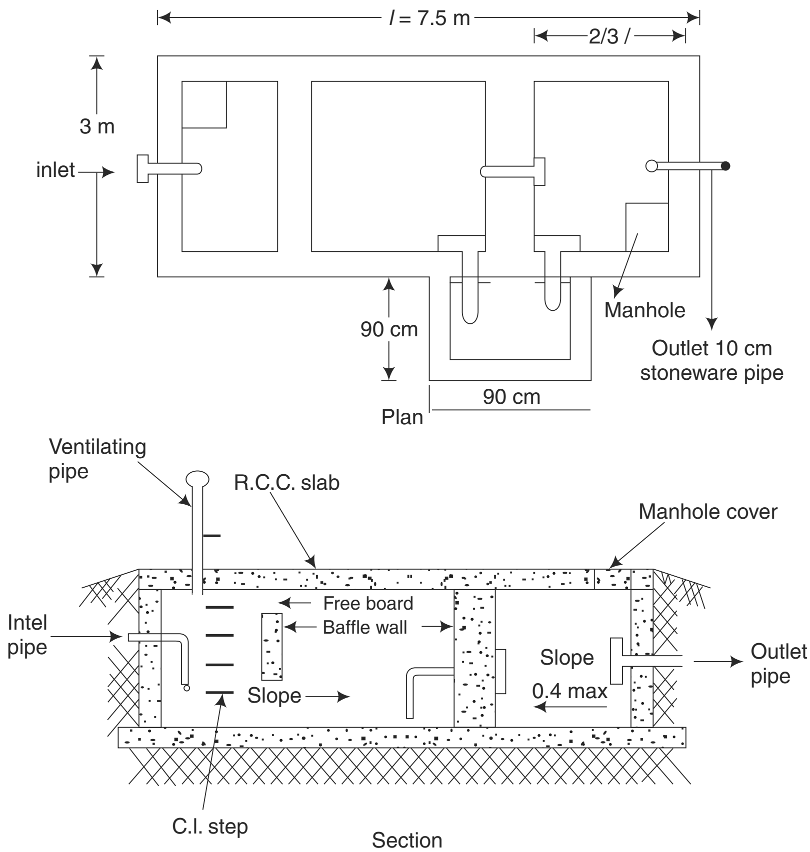


Fig. 10.8 *Septic tank*

10.6 OXIDATION PONDS

Treatment ponds have been used to treat waste water for many years, particularly for small communities. Many terms have been used to describe the different types of systems employed in waste water treatment. For example, in recent years, *oxidation pond* has been widely used as a collective term for all types of ponds. Originally, an oxidation pond was a pond that received partially treated waste water, whereas a pond that received raw waste water was known as a *sewage lagoon*. *Waste stabilisation pond* has been used as an all inclusive term that refers to a pond or a lagoon is used to treat organic waste by biological and physical processes. These processes would commonly be referred to as self-purification if they take place in a stream. To avoid confusion the following classification is made.

1. Aerobic ponds Shallow ponds which are less than 1 m in depth and where dissolved oxygen is maintained throughout the entire depth, mainly by the action of photosynthesis.

2. Anaerobic ponds Deep ponds that receive high organic loadings such that anaerobic conditions prevail throughout the entire pond depth.

3. Facultative ponds Ponds which are 1 to 2.5 m deep, have an anaerobic lower zone, a facultative middle zone and an aerobic upper zone maintained by photosynthesis and surface reaeration.

10.6.1 Aerobic Ponds

An aerobic pond is a shallow pond in which light penetrates to the bottom, thereby maintaining active algal photosynthesis throughout the entire system. During the daylight hours, large amounts of oxygen are supplied by the photosynthesis process. During the hours of darkness, wind mixing of the shallow water mass generally provides a high degree of surface reaeration. Stabilisations of the organic material entering an aerobic pond is accomplished mainly through the action of aerobic bacteria.

10.6.2 Anaerobic Ponds

The magnitude of the organic loading and the availability of dissolved oxygen determine whether the biological activity in a treatment pond will occur under aerobic or anaerobic conditions. A pond may be maintained in an anaerobic condition by applying a BOD_5 load that exceeds oxygen production from photosynthesis. Photosynthesis can be reduced by decreasing the surface area and increasing the depth. Anaerobic ponds become turbid due to the presence of reduced metal sulphides. This restricts light penetration to the extent that alga growth becomes negligible. Anaerobic treatment of complex wastes involves two distinct stages. In the *first* stage (known as acid fermentation), complex organic materials are broken down mainly to short chain acids and alcohols. In the *second* stage (known as methane fermentation), these materials are converted to gases primarily methane and carbon dioxide. the proper design of anaerobic ponds ensures environmental conditions favourable to methane fermentation.

Anaerobic ponds are used primarily as a pretreatment process and are particularly suited for the treatment of high-temperature, high-strength waste water. However, they have been used successfully to treat municipal waste waters as well.

10.6.3 Facultative Ponds

Of the five general classes of lagoons and ponds, facultative ponds are the most common type selected as waste treatment systems for small communities. Facultative ponds are popular for such treatment situations because long retention times facilitate the management of large fluctuations in waste water flow and strength, with no significant effect on effluent quality. Also capital, operating and maintenance costs are less than that of other biological systems that provide equivalent treatment. A generalised diagram of facultative pond reaction is shown in Fig. 10.9.

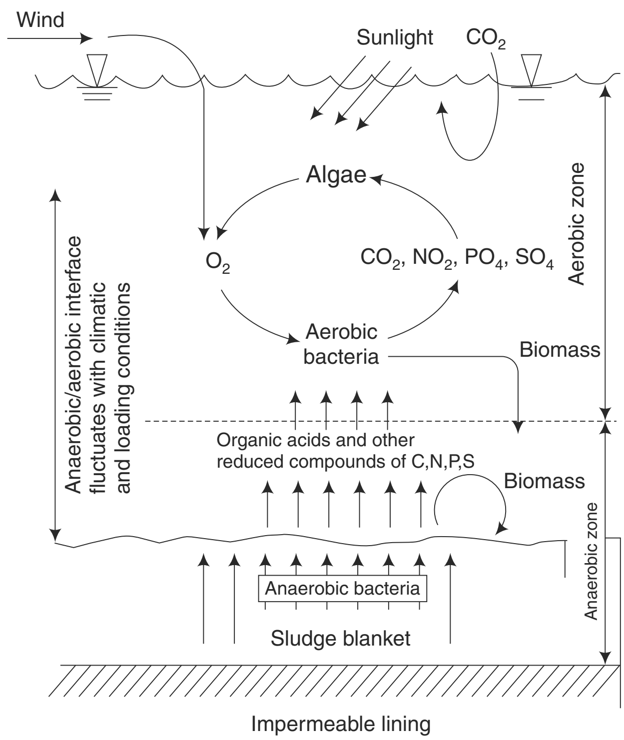


Fig. 10.9 *Generalised diagram of facultative pond reaction*

As raw waste water enters the pond, suspended solids contained in the waste water settle to the pond bottom, where an anaerobic zone develops. Microorganisms occupying this region do not require molecular oxygen as an electron acceptor in energy metabolism, but rather use some other chemical species. Both acid fermentation and methane fermentation occur in the bottom sludge deposits.

The facultative zone exist just above the anaerobic zone. This means that molecular oxygen will not be available in the region at all times. Generally, the zone is aerobic during the daylight hours and anaerobic during the hours of darkness.

Above the facultative zone, there exists an aerobic zone that has molecular oxygen present at all times. The oxygen is supplied from two sources. A limited amount is supplied from diffusion across the pond surface. However, the majority is supplied through the action of algal photosynthesis.

10.7 PLUMBING

10.7.1 Introduction

The installation of pipes, fixtures and other apparatus inside a building for bringing in the water supply and removing liquid and water borne wastes is called plumbing. Good plumbing provides convenience and comfort to the dwellers and ensures protection of health. Plumbing system begins at the point where the water enters the building and ends where the waste water leaves the building.

10.7.2 Objectives of Plumbing

The essential principle of plumbing is to supply water in sufficient quantity at required pressure to a fixture and to drain out used water from the fixture, through a drain pipe to a point outside the building. With the increase in fixtures, the number of supply pipes and take off pipes also increase. Installing them in a proper way without complications such as contamination of water by backflow, leakage of sewer gas into the building, loss of water seal in the traps is the main objective of good plumbing.

10.7.3 Technical Terms

1. Drain Any pipe that carries discharges from sanitary appliances in a drainage system is termed as a drain.

2. Soil Pipe The pipe that carries the discharge of water closets or fixtures having similar functions, with or without the discharges from other fixtures.

3. Vent Pipe The pipe installed for the purpose of ventilation is known as vent pipe. It is provided to facilitate circulation of air within the sanitary pipe work system. Also it protects the trap seals from a partial vacuum caused by air movement, siphonic action and foul gases within the system.

4. Waste Pipe Any pipe that receives the discharge from sanitary fittings such as baths, kitchen, sinks except water closets and carry the same to the drain is called waste pipe.

5. Trap A trap is a depressed or bent sanitary fitting which always retains water to prevent the back passage of foul air without affecting the flow of sewage through. It is technically termed to contain water seal which is measured as the vertical distance between crown and dip of the trap. In practice, depth of water seal varies from 25 mm to 75 mm. Based on their shape and use traps are classified in the following tow ways.

(i) Classification based on shape According to its shape, traps are of the following three types.

(a) P-trap It has the shape of letter P as shown in Fig. 10.10. In this trap the legs are at right angles to each other.

(b) Q-trap It has the shape of letter Q as shown in Fig. 10.11. In this trap the legs meet at an angle other than a right angle.

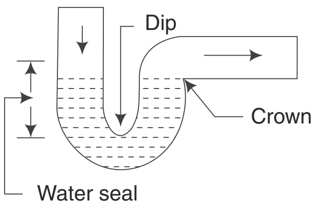


Fig. 10.10 *P-tap*

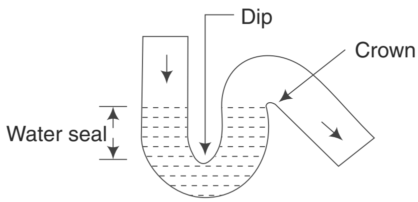


Fig. 10.11 *Q-trap*

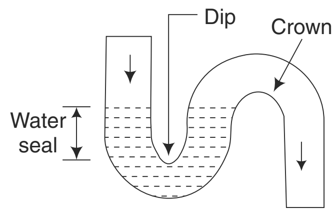


Fig. 10.12 *S-trap*

(c) S-trap It has the shape of letter S as shown in Fig. 10.12. In this trap the legs are parallel to each other.

(ii) Classification based on use According to its use, traps are of the following three types.

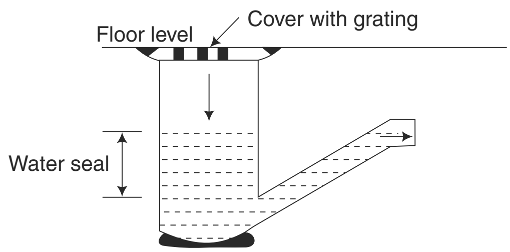


Fig. 10.13 *Floor trap*

(a) Floor trap The floor trap shown in Fig. 10.13 is called Nahni trap. It is made of cast iron and used for admitting waste water from floors of baths kitchens, sinks, etc. into the drains. It is provided with a cast iron grated cover at its top to admit water and to prevent the solid matter entering the drain. This cover can be removed for the cleaning of the trap.

(b) Gully trap Gully trap shown in Fig. 10.14 is housed in a masonry chamber called gully chamber. A water seal of about 60 mm to 70 mm is fixed in a suitable position to collect waste water from the kitchen sink, baths, rain water pipes, etc. The gully trap leads the sewage either to sewer or to inspection chamber or to a manhole. The top of the trap is provided with a cast iron grating to prevent the solid matter entering the drain.

(c) Intercepting trap This trap shown in Fig. 10.15 is used at a place where the house drain joins the main sewer. It has a water seal of about 100 mm depth. The trap is housed in a manhole, which is provided with a removable cover. Figure 10.12 shows the manhole with intercepting sewer trap.

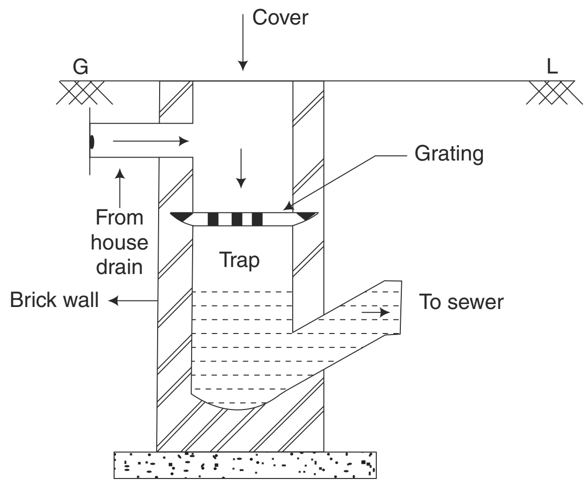


Fig. 10.14 *Gully trap*

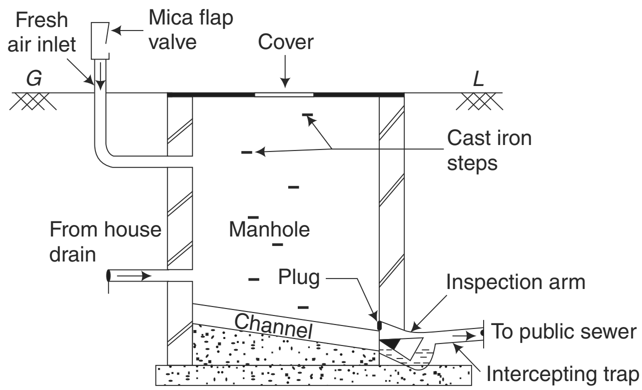


Fig. 10.15 *Intercepting trap*

An intercepting trap is also known as an interceptor or a disconnecting trap. It contains an inspection arm for the purpose of cleaning or inspection and it is fitted with a removable plug. The main idea of providing this trap is to prevent the entry of sewer gases from public sewer line into the house drains.

Essential Qualities of a Trap A trap should possess the following qualities.

1. It must be self-cleaning and watertight.
2. It should be easily fixed with the drain and easy to construct.
3. It must be able to pass used water without allowing sewer air to go in either of its directions.

4. The internal and external surfaces should be free from projections to enable the smooth flow of sewage.
5. It should possess adequate water seal with a minimum of 50 mm.

Anti-Siphonage Pipe A pipe which is installed in the drainage system to preserve the water seal of traps is known as anti-siphonage pipe.

10.7.4 Principles of Domestic Plumbing

The following principles are adopted for the efficient plumbing system in houses.

1. The lavatory blocks should be so located that the length of the drainage line is minimum. In case of multi-storyed building they should be located one above the other. At least one wall of the lavatory block should be an outside wall, to facilitate the fixing of soil and vent pipes.
2. The drainage pipes should be laid by the side of the building rather than below the building.
3. All the drains should be aligned straight between successive inspection chambers. All sharp bends and junctions should be avoided except through chambers.
4. The slope of the drains should be sufficient to develop self-cleansing velocity.
5. The size of pipes should be sufficient, so that flooding of the pipes does not take place while handling the maximum discharge.
6. The drainage system should contain enough number of traps at suitable locations.
7. The house drain should be disconnected to the public sewer by the provision of an intercepting trap. This will avoid the entry of foul gases from entering the house drainage system. It should be seen that the public sewer is deeper than the house drain.
8. Rainwater pipes should drain out rainwater directly into the street gutters from where it is carried to the storm waterdrain.
9. All the connection should be watertight.
10. The entire drainage system should be properly ventilated from the starting point to the final point of disposal. It should permit free circulation of air.
11. All the materials and fitting of the drainage system should be hard, strong and resistant to corrosive action. They should be non-absorbent type.
12. The entire system should be so designed that the possibilities of formation of air locks, siphonage, under deposits, etc., are minimised.

10.7.5 Systems of Plumbing

Following are the four principal systems adopted in plumbing of drainage work in a building.

1. Single stack system
2. One-pipe system

3. Partially ventilated one-pipe system
4. Two-pipe system

1. Single Stack system In this system, a single vertical solid pipe is fixed and all the waste matter from baths, kitchens, water closets, etc. is discharged into it. The pipe, in addition, also acts as a vent pipe. This system is economical, but it is entirely effective in the depth of water seal only. The traps should therefore be filled with water for all the time and the depth of water seal should not be less than 75 mm.

2. One-pipe System In this system, a separate vent pipe is added and hence it is more effective than the single system. The vent pipe provides ventilation to water seals of all traps. Following points should be considered while laying this system of plumbing.

(i) A deep-water seal of 75 mm depth should be provided for all traps.
(ii) All the waste pipes should have airtight joints and they should be directly connected to the common stack.
(iii) The vent pipe should have a minimum diameter of 50 mm.
(iv) The waste pipe should join the stack above the soil branch at each floor.

3. Partially Ventilated One-pipe System It is an intermediate arrangement between the single stack system and one pipe system. Here there is one soil pipe and all the waste matter from water closets, baths, sinks, etc. is discharged in this pipe. In addition, there is a relief vent pipe, which provides ventilation only to the traps of water closets. Following points should be considered while laying this system of plumbing.

(i) A deep-water seal of 75 mm depth should be provided for all traps.
(ii) The fall of waste pipe in the direction of flow should be continuous and gradual. The slope of waste pipe should be between 1 in 12 to 1 in 48.
(iii) The vent pipe should have a minimum diameter of 50 mm.
(iv) The waste pipe should join the stack above the soil branch at each floor.

4. Two-pipe System In this system, two sets of pipes are laid. Soil fixtures such as urinals and water closets are connected to vertical soil pipe. Connections of waste matter from baths, kitchens, etc. are made to another vertical waste pipe. Separate vent pipes are provided for both soil and waste pipes. Hence the number of pipes used increases to four, which will increase the cost. Since the number of pipes on wall face is more, these pipes should be properly maintained to avoid clogging.

10.7.6 Plumbing Fixtures

Plumbing fixtures are the fittings used in the house drainage system for the efficient collection and removal of waste water. Such fittings include the following.

1. Flushing cisterns
2. Sinks
3. Urinals

4. Wash basins
5. Water closets

1. Flushing Cisterns They are used to flush water closets, urinals, etc. and are made of cast iron or porcelain. They are provided at a height of about 2 m and 0.6 m above the ground level for Indian and European water closets respectively. Capacity of standard flushing cisterns varies from 5 to 15 litres.

The flushing cisterns operate on the principle of siphon and they are of the following two types.

(i) Bell type without valve
(ii) Flat bottom type with a valve

(i) Bell type without valve In this type when the chain is pulled down, the bell is lifted and the water enters the outlet pipe. Hence the siphonic action starts and the whole water rushes down into the water closet. The bell type flushing cistern is shown in Fig. 10.16.

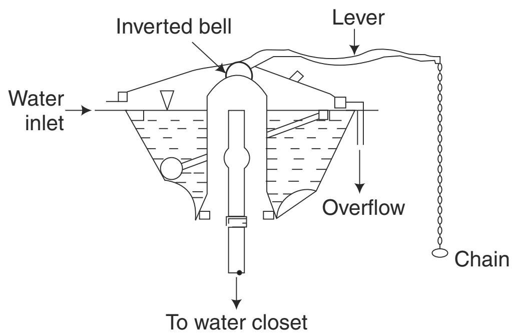


Fig. 10.16 *Bell type*

(ii) Flat bottom type with a valve When the chain is pulled down the disc is lifted which lifts the water in the short limb of the outlet device. The water then enters into the long arm and the siphonic action starts. Capacity of the tank is 12 to 20 litres.

2. Sinks A sink is a rectangular basin used in kitchens for storing used vessels and for washing. It has a flat bottom and all its internal angles are made round for easy cleaning. It has an outlet usually of about 40 mm in diameter. The mouth of the outlet pipe is provided with grating of brass or nickel so that the entry of substances having size greater than the perforations of the grating is prohibited. Sinks can be made of cast-in-situ concrete with suitable finishing surface such as terrazzo, marble, mosaic tiles, etc. The usual dimension of the sink is 600 × 450 × 250 mm.

3. Urinals Urinals are of the following two types.

(i) Bowl type urinals
(ii) Stall type urinals

The stall type is adopted for public buildings and the bowl type is used for private buildings. Figure 10.17 shows the details of a stall urinal with three units. The centre to centre spacing of units is about 600 mm. Contents of urinals are collected and discharged into the soil pipe through floor trap. Urinals are provided with automatic flushing cisterns, which operates at intervals of 10 to 15 minutes. An anti-siphonage pipe is necessary for urinals located on different floors and they are connected to a common soil pipe.

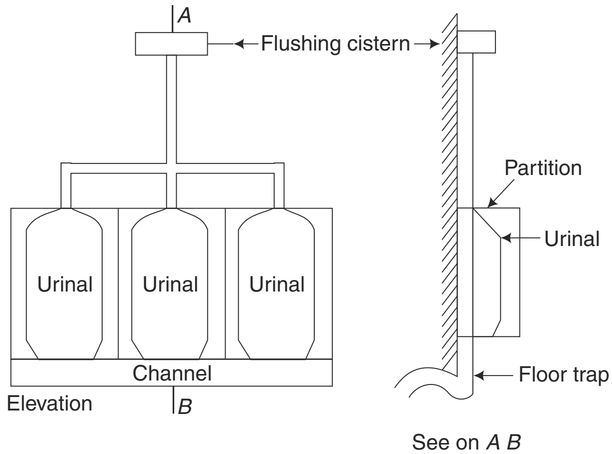


Fig. 10.17 *Urinals*

4. Wash Basin It is similar to a sink and is available in different shapes like rectangular, square, circular or oval. It may directly rest on a wall or may be fixed on a wall with cast iron brackets. The pedestal type of wash basin rests independently on the floor.

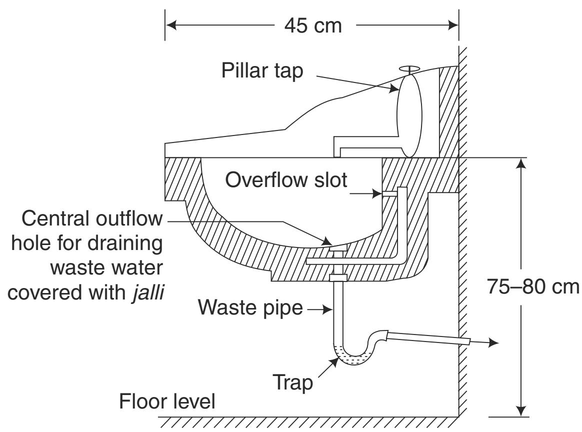


Fig. 10.18 *Section of Wash basin*

The mouth of the outlet pipe is provided with brass or nickel grating. The outlet pipe discharge into waste pipe through a trap. The wash basins are generally made of white glazed earthenware. Figure 10.18 shows the cross section of a typical wash basin.

5. Water Closets The water closet is defined as a sanitary fitting which is designed to receive human excreta directly from the person using it. Types of water closets are as follows:

(i) Indian type water closet The Indian type water closet has a squatting pan with an overall length of 450 mm to 675 mm and a height of 450 mm to 500 mm. The pan is fitted either with a P-trap or S-trap, which is then connected to the soil pipe as shown in Fig. 10.19. It is made of vitreous china or porcelain and the pan and trap are in two different pieces. The trap has an opening for fixing an antisiphonage pipe or a vent pipe. The pan has a flushing rim to spread the flush water. One disadvantage in this type is that the excreta does not fall directly into the trap and hence it is likely to become foul. Thus, it requires plenty of water for flushing.

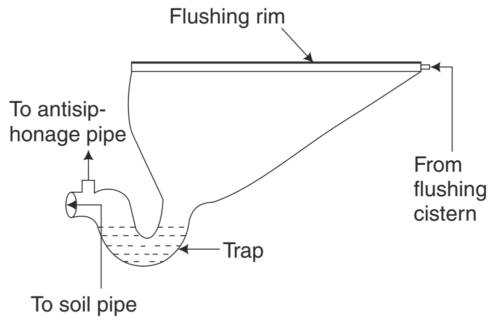


Fig. 10.19 *Indian type water closet*

The following should be considered while fixing the Indian water closet.

(i) The floor slab in the water closet may be suitably depressed than the general floor level to accommodate the water closet.

(ii) The floor should preferably be sloped, so that the waste water is drained into the pan.

(iii) Trap may be provided at a height of 200 mm to 300 mm above the floor level.

(ii) European type water closet This type is also referred as wash-down type of water closet and it is usually made of porcelain. It is provided with a wide flushing rim and a 50 mm trap, which may be either a P-trap or S-trap as desired. This closet is a one piece construction in which the pan and the trap are not separate. It is provided with an inlet

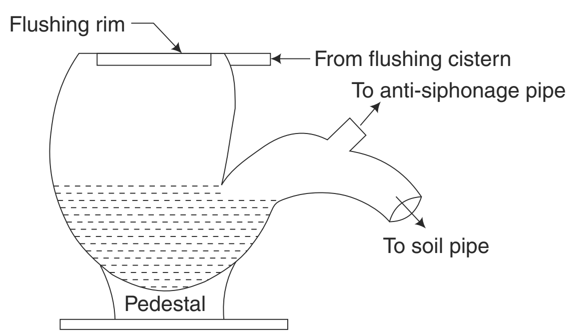


Fig. 10.20 *European type water closet*

or a supply horn for connecting it to the flushing pipe. Excreta falls directly into the trap and with a good flush of water, the pan remains in a clean state. This closet has an overall length of 500 mm to 600 mm and the height varies from 350 mm to 400 mm. A typical European type water closet is shown in Fig. 10.20.

10.7.7 Testing of Sewers and Drains

Each section of sewer line between two consecutive manholes is tested for water tightness before commissioning. Tests made on fixtures should be for similar conditions under which they would be put to use. Following are the tests which are commonly performed to test the house drains.

1. Air test
2. Coloured water test
3. Hydraulic test
4. Smell test
5. Smoke test

1. Air test This test can be applied for underground and vertical pipes. A particular section is selected and plugs are provided at the upper and lower ends. The pipe section is subjected to an air pressure of 100 m of water by means of a hand pump. The allowable pressure drop should not be more than 25 mm of water, if this is not the case, leaky joints can be detected by applying soap solution and observing air bubbles.

2. Coloured Water Test In this test coloured water is allowed to flow from one point to the other point of the drain. Leakage can be detected if the water comes out through the leaky joints and suitable remedies may be adopted to remove it form the joints.

3. Hydraulic Test This is the most common test which is applied for the watertightness of the underground drains. The lower end is provided with a plug and at the upper manhole, water is filled to a height of about 600 mm to 900 mm in case of house drains. Sweated joints are detected and repaired.

4. Smell Test This test is similar to air test but in this case the air is mixed with some smelling gas which can be easily recognised. Such air is allowed to pass through the drain. Escape of air from leaky joints is detected by smell and such joints are then repaired.

5. Smoke Test The test is generally applied for detecting leakage in existing drains. This test is similar to an air test except that smoke is introduced in the drains instead of air.

10.7.8 Maintenance of House Drainage System

For efficient working of the house drainage system it should be properly maintained and cleaned at regular intervals. Following points should carefully be looked at.

1. Entry of undesired elements Users of house drainage system should take extreme precautions to avoid the entry of undesired elements in the system. Such substances include grit, sand, decayed fruits, pieces of cloth, leaves, etc.

2. Flushing It is advisable to flush the house drainage system once or twice in a day in order to maintain it in proper working order.

3. Inspection Various units of house drainage system should be inspected at regular intervals and the obstructions if any should be removed. Damaged pipes should also be replaced.

4. Quality of materials Better quality materials should be used in the house drainage system.

5. Use of disinfectants Disinfectants should be freely used in the lavatory blocks, bathrooms, etc. to maintain good sanitary conditions in the building.

6. Workmanship Laying of drains and fixing of pipes should be carried out by licensed or authorised plumbers only.

10.8 SOLID WASTE MANAGEMENT

10.8.1 Waste Generation

Waste generation encompasses activities in which materials are identified as no longer being of value and are either thrown away or gathered together for disposal. Waste generation is, at present, an activity that is not very controllable. In the future, however more control is likely to be exercised over the generation of wastes. Reduction of waste at source, although not controlled by solid waste managers, is now included in system evaluations as a method of limiting the quantity of waste generated.

10.8.2 Waste Handling, Sorting, Storage, and Processing at the Source

The functional elements in the solid waste management system is waste handling, sorting, storage, and processing at the source. *Waste handling* and *sorting* involves the activities associated with management of wastes until they are placed in storage containers for collection. *Handling* also encompasses the movement of loaded containers to the point of collection. Sorting of waste components is an important step in the handling and storage of solid waste at the source.

On-site storage is of primary importance because of public health concerns and aesthetic consideration. Processing at the source involves activities such as backyard waste composting.

Collection The functional elements of collection include not only the gathering of solid wastes and recyclable materials, but also the transport of these materials, after collection, to the location where the collection vehicle is emptied. This location may be a materials processing facility, a transfer station, or a landfill disposal site.

10.8.3 Sorting, Processing and Transformation of Solid Waste

The sorting, processing and transformation of solid waste materials is the fourth of the functional elements. The recovery of sorted materials, processing of solid waste and transformation of solid waste that occurs primarily in locations away from the source of waste generation are encompassed by this functional element.

Waste processing is undertaken to recover conversion products and energy. The organic fraction of municipal solid waste can be transformed by a variety of biological and thermal processes.

Waste transformation is undertaken to reduce the volume, weight, size or toxicity of waste without resource recovery. Transformation may be done by a variety of mechanical, thermal or chemical techniques.

10.8.4 Transfer and Transport

The functional element of transfer and transport involves two steps:

- the transfer of wastes from the smaller collection vehicle to the larger transport equipment, and
- the subsequent transport of the wastes, usually over long distances, to a processing or disposal site. The transfer usually takes place at transfer station.

10.8.5 Disposal

The final functional element in the solid-waste management system is disposal. Today, the disposal of wastes by land filling or uncontrolled dumping is the ultimate fate of all solid wastes, whether they are residential wastes collected and transport directly to a landfill site, or residual materials from materials recovery facilities. Solid wastes on land or within the earth's mantle create nuisance or hazard to public health or safety, such as breeding of rodents and insects and contamination of ground water.

Currently in India, source separation and collection of dry recyclables is fairly well developed at the household level, commercial centres and institutional areas.

Source separation of bio-wastes, construction and demolition wastes as well as hazardous wastes is rarely done; consequently, most of the waste collected is a mixture of these components. Such mixed waste is rarely suitable for biological processing or thermal processing as it has high content of inert material, of low calorific value.

In some cities, good quality bio-waste is collected from fruit and vegetable markets and subjected to biological processing to produce compost.

Thermal processing of mixed municipal waste has not been successful in India. Biological or mixed municipal waste yields low-quality compost which may have contaminants in excess of permissible limits.

Biological processing becomes viable once construction and demolition wastes and hazardous waste streams are isolated from the bio-waste stream. Thermal processing of waste becomes viable only if sufficient high-calorific-value components are present in the waste.

Waste transformation is usually not a major component in an integrated municipal process prior to land filling.

Effective solid-management systems are needed to ensure better human health and safety. In addition to these prerequisites, an effective system of solid-waste management must be both environmentally and economically sustainable.

- *Environmentally sustainable* It must reduce, as much as possible, the environmental impacts of waste management.
- *Economically sustainable* It must operate at a cost acceptable to the community.

Clearly, it is difficult to minimise the two variables, cost and environmental impact, simultaneously. The waste-management system as far as possible, should be operable within an acceptable level of cost.

An economically and environmentally sustainable solid-waste management system is effective if it follows an integrated approach, i.e., it deals with all types of solid waste materials. An effective waste-management system includes one or more of the following options:

(a) Waste collection and transportation,
(b) Resource recovery through sorting and recycling,
(c) Resource recovery through waste processing,
(d) Waste transformation,
(e) Disposal on land.

Material recycling can occur through sorting of waste into different streams at the source or at a centralized facility.

10.8.6 Sorting at Source

Sorting at source is driven by the existing market for recycling. The desirable home sorting streams are

(a) Dry recyclable materials,
(b) Bio-waste and garden waste
(c) Bulky waste
(d) Hazardous material in household waste
(e) Construction and demolition waste
(f) Commingled MSW

Centralised sorting Centralized sorting is needed wherever recyclable materials are collected in a commingled state. *Hand sorting* from a raised picking belt is extensively adopted in several countries.

Mechanised sorting facilities using magnetic and electric field separation, density separation, pneumatic separation. Size separation and other techniques are used in some developed countries. Such facilities are usually prohibitively expensive in comparison to hand sorting.

In India, centralised sorting is not adopted. However, some intermediate sorting does occur after household wastes reach kerbside collection bins through ragpickers. There is a need to formalise this intermediate sorting system or develop a centralised sorting facility to minimise recyclable materials reaching a waste-processing facility or a landfill.

10.8.7 Sorting Prior to Waste Processing or Landfill

Home sorting and centralized sorting process normally recover most of the recyclable materials for reuse. However, a small fraction of such materials may escape the sorting process.

Wherever manual sorting is adopted, care must be taken to ensure that sorts are protected from all disease pathways and work in hygienic conditions.

Biological or thermal treatment of waste can result in recovery of useful products such as compost or energy.

Biological process Biological treatment involves using microorganisms to decompose the biodegradable components of waste. Two types of process are used, namely,

- *Aerobic process:* Window composting, aerated static pile composting and in-vessel composting; vermin culture, etc.
- *Anaerobic process:* Low-solids anaerobic digestion, high-solids anaerobic digestion and combined process

In the aerobic process, the product is compost. In the anaerobic process, the utilisable product is methane gas. The use of anaerobic treatment has been more limited. In India, aerobic composting plants have been used to process up to 500 tonnes per day of waste.

Thermal process Thermal treatment involves conversion of waste into gaseous, liquid and solid conversion products with concurrent or subsequent release of heat energy. Three types of systems can be adopted, namely:

(a) *Combustion systems* Thermal processing with excess amounts of air
(b) *Pyrolysis systems* Thermal processing in complete absence of oxygen
(c) *Gasification systems* Thermal processing with less amount of air

Combustion system is the most widely adopted thermal treatment process worldwide of MSW though pyrolysis is a widely used industrial process. The pyrolysis of municipal solid waste has not been very successful. However, pyrolysis and gasification can emerge as viable alternatives in the future.

Three types combustion systems have been extensively used for energy recovery in different countries, namely, Mass-fired combustion, systems refuse, and derived fuel.

To be viable for energy recovery through thermal processing, the municipal solid waste must possess a relatively high calorific value. Indian MSW as well as development of combustion system for low-calorific value wastes can result in a reversal of this position in the future.

Other processes New biological and chemical processes which are being developed for resource recovery from MSW are:

(a) Fluidised bed bio-reactors for cellulose production and ethanol production.
(b) Hydrolysis process to recover organic acids.
(c) Chemical process to recover oil, gas and cellulose

The economical viability of these processes is yet to be established.

Solid waste management involves several stages of activities where people's participation is critically required in some and the local body has to do the rest of the work.

Short-Answer Questions

1. What is secondary treatment of sewage?
2. How effluent coming out of septic tank is disposed of?
3. How are sewage systems classified?
4. What is an aerobic pond?
5. What are anaerobic ponds?
6. What are the essential qualities of a trap?
7. What are the various tests commonly performed in house drains?

Exercises

1. What are the domains of activity of environmental engineers?
2. What are the objectives of a water supply system?
3. Outline the steps involved in the planning of a water supply scheme.
4. If the population of a city is 50,000 and the per capita demand of water is 140 lpcd, determine the daily consumption in MLD.
5. What do you understand by the term per capita consumption and what are the factors affecting it?
6. State the various purposes for which provision should be made in the average daily per capita demand of water in a water supply scheme. Give the approximate breakdown of these purposes if the average daily demand is 135 litres.
7. What are the various sources of water used in the water supply schemes? Discuss the merits and demerits from quality and quantity point of view.
8. Write short notes on infiltration gallery and impounding reservoirs.
9. What are the common unit operation adopted in water treatment plants?
10. Draw a flow chart of water treatment plant for river water with a turbidity of 100 JTU.
11. Describe the various layouts of distribution networks in a water supply system.
12. Define sewage, sewer and sewerage.
13. What are the important contaminants of concern in waste water treatment?
14. What are the important physical and chemical characteristics for which the waste water has to be tested?
15. Define BOD and COD and explain its significance in waste water treatment.

16. What are the objectives of waste water treatment?
17. List out the various physical and chemical unit processes adopted in waste water treatment.
18. Classify the biological treatment processes used in waste water treatment and give examples.
19. What do you understand by the following terms in waste water treatment?
    (a) Primary treatment
    (b) Secondary treatment
    (c) Tertiary treatment
20. Draw a neat sketch if a septic tank and explain the processes involved in a typical septic tank.
21. Discuss the drinking water quality standards as per BIS in a tabular form.
22. Write short notes on sewage disposal.
23. Briefly explain the oxidation ponds.
24. Explain the principles of domestic plumbing.
25. Explain the various types of plumbing fixtures with a neat sketch.

Chapter 11
ROADS

11.1 INTRODUCTION

For rapid economic, industrial and cultural growth of any country, a good system of transportation is very essential. Transportation system comprises good network of roads, railways, well-developed waterways and airways. Airways and waterways although help to some extent in transportation within the country, these are the primary modes of transport between countries. Railways, and highways, also to some extent, help in transport between countries, but their main concern is within the country itself. An industrialist has to transport the raw materials and then market his finished products. He can do so efficiently only through a good system of transportation. A farmer can market his products to the nearby market economically only through a good system of roads. As blood transportation through body arteries is essential for the well-being of the human being, a similar good system of transportation has actually become a measure of country's economic and social development.

11.2 ROAD TRANSPORT CHARACTERISTICS

While going to a railway station, harbour or airport for boarding these modes of transports, road is the first mode which leads us to these places. Hence it can be said that out of all the types of transports, road is the nearest to man.

The characteristics of road transport are given as follows:

1. Road can be used by all sorts of vehicles, such as bullock carts, carriages, rickshaws, cycles, scooters, cars, jeeps, buses, trucks and lorries. Roads are equally useful for pedestrians also. Other modes of transport can move only on specific types of paths. Rail wagons, coaches and locomotives can only on the rail track. Ships and boats can move on water and aeroplanes in air.
2. Road can lead to any remote place. If a pucca road is not available, at least kuchha road will exist. Although it may be difficult, one can reach any place through a road system. Railways will lead to railway stations, aeroplanes to airports and ships to harbours, while roads can reach any place.

3. Investment on road transport by government is comparatively small. Road vehicles are cheaper than locomotives, ships and planes. Maintenance of roads is also cheaper than that of rail tracks, docks harbours and airports.
4. There is complete freedom to road users to transfer the vehicles from one lane to another or from one road to another according to the requirements. In other modes of transport this flexibility, particularly in railways, is not present.
5. Local communication among villages, villages and towns is only possible through roads. Other modes of transport cannot go from village to village.
6. Farm products are brought to market only by roads. Similarly remote places can only be reached by roads.
7. Movements on roads are not time bound, as in case of railways and airways.
8. Road transport is the only mode of transport that offers itself for the service of the whole community alike.
9. Possibilities of accidents on roads are more than the other modes of transport. This is because of the flexibility of movements and, secondly, due to mixed traffic conditions on the roads. In case of railways, the possibilities of accidents are very low. In case of air traffic, the possibility of crash always persists.

11.3 BENEFITS OF A GOOD SYSTEM OF ROADS

A good system of roads has the following advantages:

1. Roads are essential for the economic development of a country. For speedy transportation of commodities a good network of roads is essential.
2. Road mileage has nowadays become a symbol of prosperity and advancement of a country.
3. During emergencies such as accidents, the injured person can be rushed immediately to a hospital through a good system of roads. In such cases only a sufferer can understand the value of good system of roads.
4. A good network of roads enables villagers to transport their commodities to the market speedily and easily.
5. A good system of roads helps in the growth of trade and other economic activities all over the country.
6. During floods and droughts, the basic commodities can be efficiently rushed from the other parts of the country through a good system of roads.
7. A good system of roads serves as a feeder line for other modes of transport and thus helps indirectly in their development.
8. For the efficient functioning of the country’s defence force, a good system of roads plays a vital role.
9. For maintaining law and order within the country, a good system of road is an essential feature.

10. An efficient system of roads helps in carrying out exploration works at the remotest places, which are otherwise difficult to reach.
11. Educational and cultural contacts within the people of different communities and different places are better developed. Due to better understanding, the chances of misunderstandings are very much reduced. This aspect has important implication in reducing sectionalism within the country and also outside the country.

11.4 CLASSIFICATION OF ROADS

The roads can be classified in several ways. Various classifications are given as follows:

11.4.1 Classification Based on Materials of Construction

(a) Natural Earth Road This road is the cheapest type of road and is used at places where traffic is rather rare. The pavement structure of this type of road is made totally from the soil available at site. The performance of these roads mainly depends upon the effective maintenance and drainage.

(b) Gravel Road Gravel roads are also considered as unmetalled roads. They are actually intermediate between earthen and metalled roads. The carriage way of these roads is made by compacting a mixture of gravel and earth. The mixture usually consists of 26 per cent, 13 per cent clay and 61 per cent gravel. Gravel roads are considered superior to earth roads. Figures 11.1(a) and 11.1(b) show sections of gravel roads.

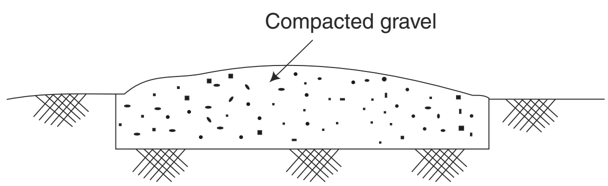


Fig. 11.1(a) *Trench type–Gravel road*

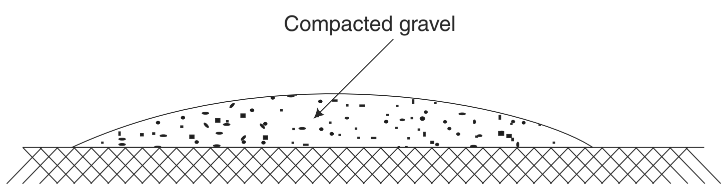


Fig. 11.1(b) *Feather edge type–Gravel road*

(c) Kankar Roads Kankar is nothing but an impure form of limestone. It is a mixture of calcium carbonate and siliceous soils. Hard variety of the kankar may be as strong as stones, but soft variety may be very weak. Roads having pavement layer of kankar are termed as kankar roads. Traffic carrying capacity of this roads is dependent on the type of kankar used in the construction. Approximately, it can carry the same traffic as gravel roads.

(d) Moorum Roads Moorum is obtained due to the disintegration of igneous rocks by weathering agencies. In this road, the surfacing of the traffic way is constructed from moorum. This road is also a low cost type of road and is equivalent to the gravel and kankar road in its performance.

(e) Water Bound Macadam (WBM) Roads Water Bound Macadam road is named after a Scot Engineer John Macadam. Water Bound Macadam (WBM) road is of better quality than the ordinary earth, gravel, Kankar and moorum roads. The term macadam nowadays is referred to the crushed stone which is used in the construction of base course of the road. Crushed stone is also referred by the name of road metal. As the name suggests itself, the WBM roads are such roads in which crushed stone is kept bonded by the action of rolling and voids filled with screening and binding materials with the help of water. WBM base course may be laid on a prepared subgrade, subbase, base or existing pavement as the case may be. Binding action in WBM construction is obtained by using stone dust as filler, in the presence of water.

WBM construction are made in layers, each layer not exceeding compacted thickness of about 10–15 cm. The total thickness of WBM construction may vary from 7.5–30 cm, depending upon the traffic and subgrade requirements. WBM constructions as far as possible should not be put to use as the surfacing layer, because in such conditions it will disintegrate immediately under traffic. Hence to prevent the disintegration of WBM roads they should be covered either by bituminous surfacing or any other suitable surfacing. A section of WBM road is shown in Fig. 11.2(a).

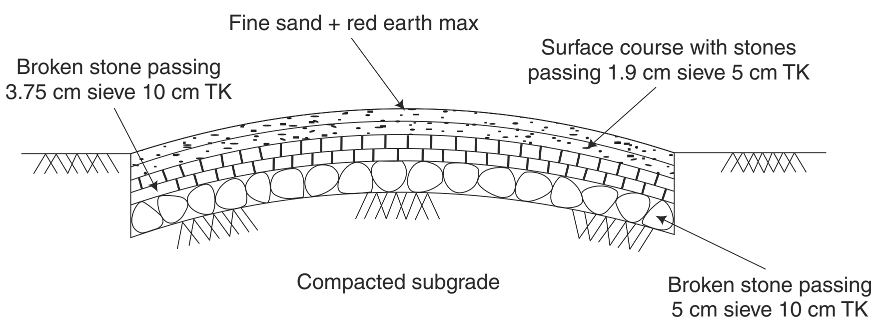


Fig. 11.2(a) *Water bound Macadam road*

(f) Bituminous Roads Roads which have bitumen associated as the binder material are termed as bituminous roads. Since the top of bituminous roads is blackish these are also termed as black top roads. These roads are so popular that most of the roads not only in India, but also in the world are constructed using bitumen one way or the other. These roads are constructed with varying aggregate sizes, composition and with different types of bituminous binders. Hence there are various techniques in their construction.

Bituminous pavements are constructed in thickness varying from the thin layer as in the case of surface dressing to as much as 20–25 cm thickness, depending upon the subgrade and traffic requirements.

When provided on the top of any existing road surface, bitumen pavement increases passenger comfort by eliminating the dust nuisance and it also provides protection to the road strata below it.

(g) Cement Concrete Roads Cement concrete roads are of high standard. These are the costliest of all types of roads. These roads provide an excellent riding surface and pleasing appearance. Cement concrete roads are called rigid pavements because they do not allow any flexibility. These roads although require heavy initial expenditure but because of their long span of life, excellent riding surface and negligible maintenance cost, these prove to be cheaper than bituminous roads. Moreover, engineers have more confidence in cement concrete material and they also like to construct these roads. A section of cement-concrete road is shown in Fig. 11.2(b). The following are some of the advantages and disadvantages of cement concrete roads.

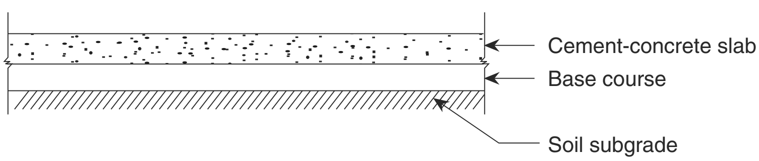


Fig. 11.2(b) *Cement Concrete Road*

11.4.2 Classification According to Location and Function

(a) National Highways National highways are the main highways running through the length and breadth of the country. These highways save to connect national capital with state capitals, major port towns, border areas, pilgrim centres, etc. These constitute the main arteries of transport in the country and are of strategic importance. Roads connecting the neighbouring countries are also called the national highways. National highways should have at least two lane traffic and should have high class surface finishing, together with adequate structural strength.

The actual construction and maintenance works of these highways are done by the state highways department on an agency basis. For this, the state highways are paid 7½ per cent as agency charges. Works relating to planning, survey, investigations, specifications and supervision are done by the state highways departments under the guidance of the roads wing of the Ministry of Shipping and Transport of Government of India. All the national highways are assigned numbers. For example, the highway connecting Varanasi–Madurai–Kanyakumari is called NH 7. A section of a national highway is shown in Fig. 11.4. Some of the important national highways are listed in Table 11.1.

(b) State Highways These are the main roads within the states. These connect important towns and cities of the state. They connect important cities of the state with the national highways and with the highways of neighbouring states. State highways should preferably be two lane wide but if is of one lane only, it must be provided with wide shoulders. It should be structurally sound and possess good surface finishing. These roads form the main arteries of road transportation within the state.

Table 11.1 National Highways

NH Designation No.	*Route*
1	Delhi–Jalandhar–Attari–Pakistan Border
2	Kolkata–Varanasi–Agra–Delhi
3	Agra–Indore–Nasik–Mumbai
4	Chennai–Belgaum–Pune–Thane
5	Jharpokharta–Cuttack–Vishakapatnam–Chennai
6	Kolkata–Nagpur–Akola–Dhule
7	Varanasi–Jabalpur–Madurai–Kanyakumari
8	Mumbai–Ahmedabad–Jaipur–Delhi
9	Vijayawada–Hyderabad–Pune
10	Delhi–Fatehabad–Pakistan Border
45	Chennai–Dindigul
47	Salem–Quilon–Thiruvananthapuram–Kanyakumari
49	Madurai–Rameswaram

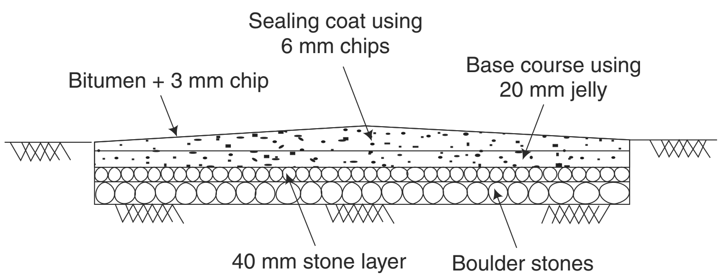


Fig. 11.3 *Cross section of national highway*

(c) District Roads These are the roads which transverse each district. These roads serve area of production and markets and establish connection with national or state highways and railways. These roads should carry the traffic to the interior rural areas. These roads are considered as main branches from National or State highways. District roads are classified into major district roads and other district roads.

(i) Major District Roads These roads connect the area of production and markets with either a state highway, national highway or railway. These roads form the main connections

between the headquarters of the neighbouring districts. These roads should be metalled and at least one lane wide and have a modern type of surface finishing.

(ii) Other District Roads These roads are of somewhat lower specifications than major district and state highways. These roads serve mainly the rural population and establish connections with the major district roads and state highways. These roads should have metalled surface, proper drainage, and should be motorable throughout the year.

(d) Village Roads These roads mainly meant for village use. These connect the villages with each other and also with the nearby towns. These roads can be stabilised earth roads, but if metal surface is provided it can serve more useful purpose. A section of a village road is shown in Fig. 11.5.

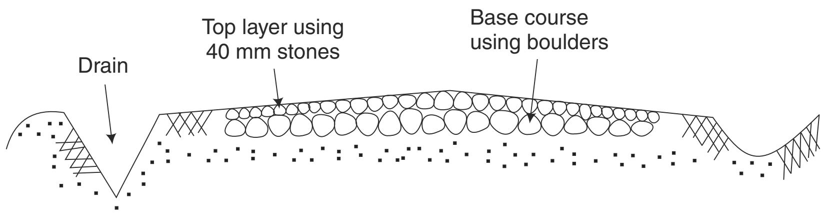


Fig. 11.4 *Cross section of a village road*

11.4.3 Classification According to the Volume of Traffic They Handle

(a) Light Traffic Roads Roads carrying up to 400 vehicles per day is considered as low traffic or light traffic roads.

(b) Medium Traffic Roads Roads handling 400 to 1000 vehicles per day are rated as medium traffic roads.

(c) Heavy Traffic Roads Roads carrying traffic more than 1000 vehicles per day are called heavy traffic roads.

11.4.4 Classification Based on the Width of Road or Number of Lanes

According to the number of lanes, roads are classified into

(a) single-lane road
(b) double-lane road
(c) three-lane road
(d) multi-lane road

11.4.5 Classification Based on Serviceability

Based on serviceability, roads are classified as all weather roads and fair weather roads.

(a) All Weather Roads These roads are negotiable during all weathers, except at major river crossings where interruption to traffic is permissible up to a certain extent.

(b) Fair Weather Roads These roads are negotiable only during fair weather seasons. On these roads, the traffic may be interrupted during monsoon season at causeways where streams may overflow across the road.

11.4.6 Classification Based on the Type of Carriageway or the Pavement

(a) Paved Roads Roads which are provided with a hard pavement course with at least a waterbound macadam base are called paved roads.

(b) Unpaved Roads Roads which area not provided with a hard pavement course are called unpaved roads. For example, earth roads and gravel roads.

11.4.7 Classification According to the Direction of Movement of Traffic

(a) Both Way Roads On such roads same lane is used by the traffic moving in both the directions.

(b) Dual Carriageway Roads In this system separate lanes are provided for the traffic, moving in opposite directions. These lanes are further separated with the help of median strips or grass verges or central reserve spaces.

11.4.8 Classification According to the Area They Traverse

(a) Plain area roads
(b) Hilly roads or ghat roads
(c) Rural roads
(d) Urban roads

11.4.9 Classification According to the Cost of the Roads

(a) Low-cost Roads

(i) Natural soil roads
(ii) Stabilised soil roads
(iii) Gravel roads
(iv) WBM roads

(b) Medium-cost Roads

(i) Bituminous surface treated roads
(ii) Bituminous macadam roads
(iii) Premix bitumen carpet roads
(iv) Cement bound macadam roads

(c) High-cost Roads

(i) Bituminous concrete roads
(ii) Sheet asphalt roads
(iii) Cement concrete roads
(iv) Block pavings or pavements

11.4.10 Classification According to the Rigidity of Roads

(a) Flexible pavements
(b) Rigid pavements

Cement concrete roads are known as rigid pavements whereas all other types of roads are known as flexible pavements.

11.4.11 According to the Type of Traffic They Handle

(a) Footpaths or pedestrian ways
(b) Cycle tracks
(c) Motorways
(d) Expressways

11.5 METHODS OF CONSTRUCTION OF ROADS

There are two methods of constructing a concrete road:

1. Alternate bay method
2. Strip method

11.5.1 Alternate Bay Method

In this method, the whole length of the road is divided into bays. The length of a bay may be 6 m but it can be increased to 9 m. The width is the full width of the road lane. The alternate bay numbers of 1, 3, 5 etc., are first filled in and after the same are completed and cured, the filling in of the remaining alternate bays of 2, 4, 6, etc., is commenced.

It is better to have the transverse joint at 60° to the centre line of the road than at right angles so as to prevent the two wheels of a vehicle to come over the joint at one time, which might sag the slab at the corner and at joints.

11.5.2 Strip Method

In this method, the concreting of a road is done in full width of strip up to the length which could conveniently be finished during the day. The width of a strip should neither be less than 2.5 m not more than 4.5 m. Construction joints are left at the end of the day's work.

This method is useful in constructing narrow roads.

11.5.3 Materials Required for Cement Concrete Works

The main ingredients for constructing cement concrete roads are

1. Cement
2. Sand
3. Water
4. Aggregate

11.5.4 Procedure for Construction of Concrete Roads

The following is the sequence of operations to be adopted for construction a cement concrete road.

1. Preparation of sub-grade
2. Spreading of sub-base
3. Fixing of forms
4. Mixing of cement concrete
5. Placing of cement concrete
6. Finishing of cement concrete surface
7. Providing joints
8. Protecting and curing of concrete

1. Preparation of sub-grade

Subgrade may be defined as the supporting structure on which a pavement and its undercourses rest. It is not filled with the natural soil necessarily but may consist of imported materials from nearby borrow pits. It cuts the original soil below the special courses and is usually designed as subgrade.

The road width is cleared of all shrubs and small bushes removing trees, if any, and disposing off debris as, if they are allowed to remain, they may decay and leave voids that result in settlement. The subgrabe needs to be excavated to the required depth, any weak spots are to filled with lean cement concrete and the excavation bed should be rolled to the required camber. It is essential to see that the subgrade compacted is of uniform strength. The finished subgrade is then checked for its camber by means of a template. The following points should be assured while preparing it: (a) adequate drainage, (b) firmness, and (c) uniformity in grade and cross-section. Say, for example, if the sub-grade consists of springy earth, tile drains should be provided. In case of embankment, the earth should be spread in layers not more than 30 m thick and each layer has to be thoroughly rolled.

Finally, when the subgrade is completed, it should be

(a) of uniform grade,
(b) have uniform cross-section, and
(c) be firm.

The sub-grade should be rolled and reshaped until the specified shape is secured.

2. Spreading of sub-base

Soil conditions sometimes make it necessary to use a sub-base, especially in case of those soils which do not compact readily under the roller or which cannot be effectively drained. These sub-bases are not required in case a concrete road is to be constructed over an old macadam road. In such cases, it is advisable to scarify the entire surface to a depth and spread a layer of sand or other fine material over the bed before concrete is placed. The function of providing a sub-base is two-fold.

1. To distribute the load uniformly over the sub-grade and act as draining agent.
2. To increase the depth of pavement and thus reduce the intensity of pressure on the natural soil.

A satisfactory sub-base may consist of a layer of gravel, broken stones, or any other similar material, of 10 cm to 15 cm thickness, spread over rolled as to remain smooth, firm and uniform.

In every case, a thin cushion of sand is very usefully employed under a concrete pavement to facilitate the sliding of the pavement due to expansion and construction and thus to increase the spacing between construction joints.

3. Placing of forms

Forms are used to prevent cement concrete form spreading out. They may be of metal or wood, though metal forms are preferred in spite of the high initial cost. The wooden forms are usually 6 cm thick and of width equal to the edge thickness of the slab. The forms should be fixed before the subgrade is finished in order to serve as a guide for the finished grading. These forms are secured in place by means of stakes driven to the ground and nailed to the sides so and to prevent them from sagging. These forms should be set true to line and grade and coated with tar or oil on their inside to prevent concrete from sticking when they are removed.

4. Mixing of cement concrete

Cement concrete may be mixed either by hand or by machine. Hand mixing is much more expensive than machine mixing. Also, hand mixing may not give uniform mixture unless great precautions are taken. Uniformity of mixture is important as otherwise cracks will result. Machine mixing may be adopted where the magnitude of work warrants the purchase of such a machine. There is a drum mixture machine in which the materials are put in required proportion, drum which revolves for some time, proper water is added, and the materials laid on the cement concrete platform, from which it is carried away by shovels to the site. It is important to see that each batch is mixed until there are no uncoated particles of sand or coarse aggregate remaining. The amount of water to be added ranges from 23 to 27 litres per 1 bag of cement.

5. Placing of cement concrete

Immediately after the concrete is mixed, it should be deposited on the pavement, without allowing it to set or the materials to separate. Before any concrete is placed over the subgrade, it should be thoroughly sprinkled with water to prevent the sub-rgrade materials from absorbing water from the concrete.

If it is one course concreting, the cement concrete should be deposited in between the forms in such quantity so that when the forms are struck off and the concrete is used up, it should be of the required thickness. The workers who spread concrete should not walk over the concrete as thereby the concrete is pressed down and when the foot is withdrawn, the gap gets filled with mortar only which breaks the uniformity.

When the concrete has been spread to the required depth, it should be struck off with a strike board having slightly more crown than the cross-section of the road, to allow for slight shrinkage during settlement.

In case two-course concreting is required, the second course should be placed before the concrete in the bottom course has set. The bottom course is well compacted before laying the second course.

6. Finishing of cement concrete surface

The surface of cement concrete is to be tempered and given either a rough or a smooth surface. Rough surfaces are usually better on inclines, when it becomes less slippery. A wooden float is any deficiency at any place being made by adding concrete rather than raking mortar into it. Light bridges are provided spanning the width of the road for workmen to use floats.

7. Providing joints

Transverse joints are provided at regular intervals to prevent cracking of concrete with longitudinal joints being provide in case the width of road exceeds 6 m. It is common practice to space the transverse joints from 8 m to 15 m. A 16-mm thick board, shaped to conform to the cross-section, is introduced into the pavement held in place by means of stakes until the concrete is placed against on both sides. The stakes are removed afterwards leaving the board in place. The board is removed later before the concrete is finally set, and the gap is filled with bituminous material or specially prepared bituminous felt boards. A thickness of 6 mm for the joint spaced 9 m apart is satisfactory.

The transverse joints are sometimes skewed at an angle of about 150 degrees to prevent both the wheels of the vehicle striking at one time.

8. Protection and curing of concrete

The strength of concrete depends on the conditions under which it has set. Accelerating the shrinkage of cement concrete rapidly by exposing it to dry air, delays the process of setting and results in cracks. In dry weather, unless the concrete is quickly covered and protected from air, small hairlike cracks result; while in moist air, the concrete may be left uncovered for some time without it developing cracks. Usually, a thoroughly wet canvas is spread over the concrete and it is kept constantly wet. The next day, ponding by building earth ridges is provided or a layer of earth, about 5 cm thick, is spread and kept wet for about two weeks. The road is kept closed to traffic during this period. It is then cleared off earth and opened to traffic.

Advantages

(i) These roads provide excellent smooth surface for driving.

(ii) These roads can deal with very heavy traffic.

(iii) Considering the lifespan, maintenance cost, etc., cement concrete roads prove to be cheaper than bituminous roads.

(iv) Maintenance cost is negligible.

(v) The lifespan of cement concrete roads is very large.
(vi) They provide better visibility.
(vii) Working with cement concrete is much easier and safer than with bitumen materials.
(viii) Cement concrete roads offer comparatively less tractive resistance.
(ix) These perform quite satisfactorily when laid on poor types of sub-grades.

Disadvantages

(i) These involve heavy initial investment.
(ii) A number of joints are to be provided which prove to be weak spots.
(iii) A curing time of 28 days is required after completion before these can be opened to traffic.
(iv) Cement-concrete road surfaces after some time become very smooth and slippery.
(v) They are noisy roads, as bullock carts or steel-tyred vehicles cause a lot of noise while moving on them.

11.6 TRAFFIC SIGNS

A traffic sign is a device mounted on a fixed or portable support whereby a specific message is conveyed by means of words or symbols for the purpose of regulating, warning or guiding traffic. These are usually installed where special regulations apply or unusual conditions or hazards exist.

The traffic signs should be backed by law in order to make them useful and effective. Traffic signs have been divided into three categories according to the Indian Motor Vehicles Act and they are regulatory signs, warning signs and informatory signs.

11.6.1 Mandatory/Regulatory Signs

These signs are used to inform road users about certain laws and regulations to provide safety and free flow to traffic. The violation of these signs is legal offence. The various mandatory signs commonly used are discussed here.

(a) Stop and Give Way Signs

(i) Stop
(ii) Give way

(b) Prohibitory Signs

(i) No entry
(ii) One way
(iii) Vehicles prohibited in both directions
(iv) All motor vehicles prohibited
(v) Truck prohibited

(vi) Bullock cart and hand cart prohibited
(vii) Bullock cart prohibited
(viii) Tonga prohibited
(ix) Hand cart prohibited
(x) Cycle prohibited
(xi) Pedestrian prohibited
(xii) Right/left turn prohibited
(xiii) U-turn prohibited
(xiv) Overtaking prohibited
(xv) Horn prohibited

(c) No Parking and No stopping Signs

(i) No parking
(ii) No stopping/standing

(d) Speed Control and Vehicle Control Signs

(i) Speed limit
(ii) Width limit
(iii) Height limit
(iv) Length limit
(v) Load limit
(vi) Axle load limit

(e) Restriction Ends Signs

(f) Compulsory Direction Control and Other Signs

(i) Compulsory turn left/right
(ii) Compulsory ahead only
(iii) Compulsory turn right/left ahead
(iv) Compulsory ahead or turn right
(v) Compulsory ahead or turn left
(vi) Compulsory keep left
(vii) Compulsory cycle track
(viii) Compulsory sound horn

The size, shape and details of all the traffic signs have been standardised by the I.R.C. A mandatory sign is provided with a red disc 60 cm in diameter and is installed at a height 2.8 m above the

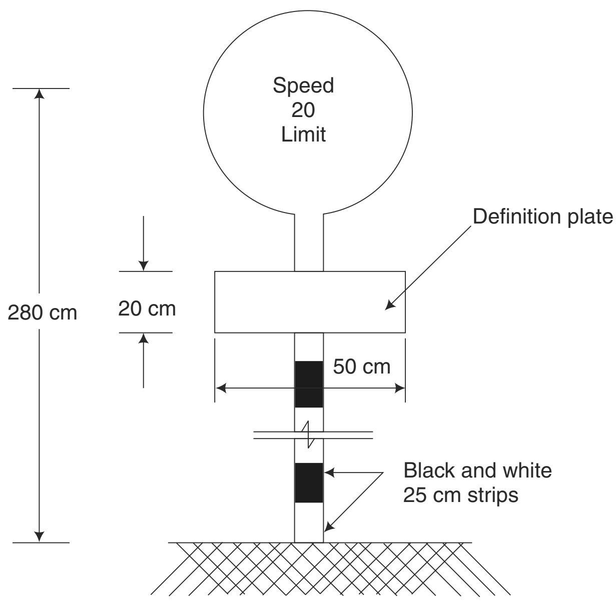


Fig. 11.5 *Regulatory sign*

ground level up to the centre of the plate. It carries a definition plate below the circular disc. The general design of a mandatory sign is shown in Fig. 11.5.

11.6.2 Warning Signs

These are signs used to warn or caution the road users of hazardous conditions either on or adjacent to the road, or to indicate the approach to a place where caution is required. The cautionary sign as standardised by IRC has an equilateral triangle of size 45 cm supported on post at a height of 275 cm above the ground level up to the base of the triangle. A rectangular explanatory device plate of size 45 cm × 45 cm is placed at a distance of 15 cm below the base of the triangle. The general design of the warning sign is shown in Fig. 11.6.

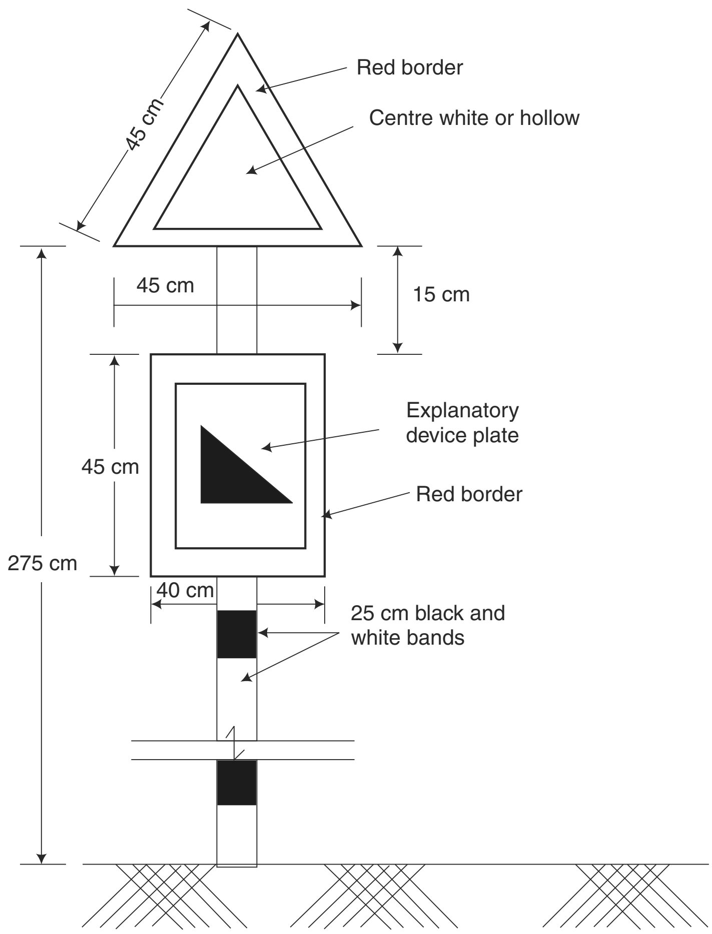


Fig. 11.6 *Warning sign*

The various cautionary signs commonly used are right hand/left hand curve, right/left hairpin bend, right/left reverse curve, steep ascent/descent, narrow bridge, narrow road ahead, road widens ahead, gap in median, slippery road, loose gravel, cycle crossing, pedestrian crossing, school, cattle, men at work, falling rocks, ferry, cross roads, side road, T-intersection, Y-intersection, staggered intersection, major road ahead, round about, dangerous dip, hump or rough road, barrier ahead, unguarded railway crossing and guarded railway crossing.

11.6.3 Informatory Signs

These signs are intended to guide the road user and to give such information as may be of interest during travel. An informatory sign is made of a rectangular board of specific size. The commonly used informatory signs as follows.

(a) Direction and Place Identification Signs

(i) Advance direction
(ii) Destination
(iii) Direction
(iv) Reassurance
(v) Place identification

(b) Facility Information Signs

(i) Public telephone
(ii) Petrol pump
(iii) Hospital
(iv) First aid post
(v) Eating place
(vi) Light refreshment
(vii) Resting place

(c) Other Useful Information Signs

(i) No through road
(ii) No through side road

(d) Parking Signs

(e) Flood Gauge Some of the informatory signs are shown in Fig. 11.7(a) and Fig. 11.7(b). Route marker signs are provided before intersections particularly to indicate National Highway route.

11.6.4 Characteristics of Traffic Signs

The traffic sign should have the following characteristics:

1. The signs should be of larger size on express ways (high speed roads).
2. The spacing between the letters should be large and optically equal.
3. The maximum number of words should be three.
4. The signs to be read in the right must be illuminative or reflective.
5. The size, spacing, shape and colour of traffic signs must be uniform.
6. The signs should be located in accordance with the carriageway requirements.
7. Distraction or advertisement signs and other unnecessary signs should be eliminated wherever possible.

11.6.5 Location of Signs

Mandatory signs, indicting weight limit, total prohibition, direction, no parking, overtaking prohibitions, and use of sound signal prohibition, should be located in the immediate vicinity of the point, where a driver of vehicle is required to observe the mandate or prohibition shown by the sign and if necessary at further points where regulation continues. Similarly cautionary signs showing school and narrow bridge should be put up in their immediate vicinity.

All other signs should be fixed at the following distance in advance of the hazards warned against.

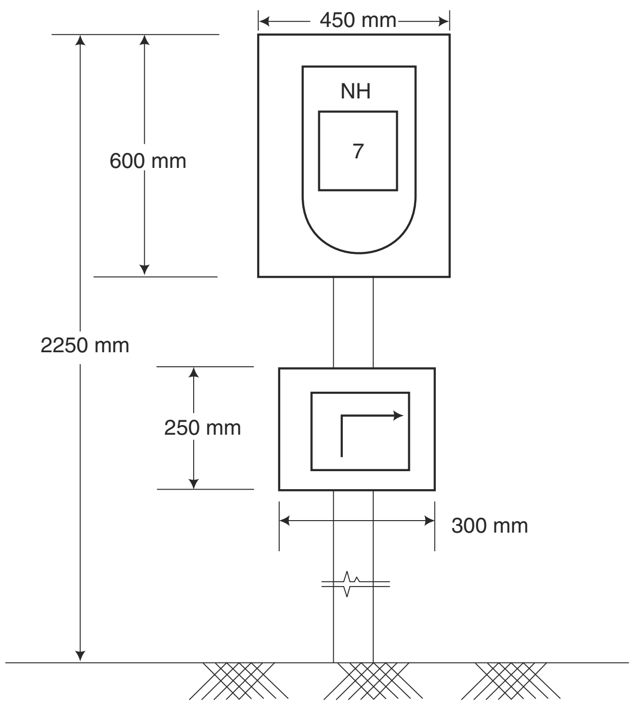


Fig. 11.7(a) *Route marker sign*

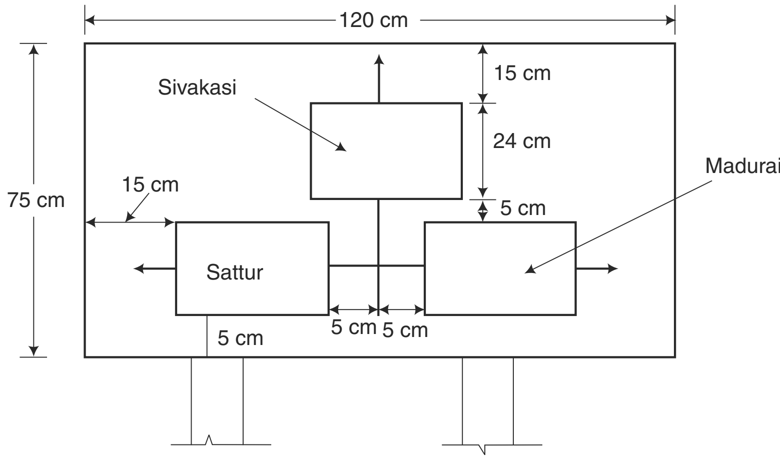


Fig. 11.7(b) *Traffic sign at road junction approach*

1. In Rural Locations

Table 11.2

	In plain and rolling community	*In hilly or mountainous country*
On National and State Highways	120 m	60 m
On major district roads	90 m	50 m
On other district roads	60 m	40 m
On village roads	40 m	30 m

2. In Urban Locations In cities, warning signs usually be placed nearer to the point of hazard than on rural roads.

11.6.6 Colour of Signs

The signs should be painted in colours as per the rules. The reverse side of all sign plates, discs, or triangles should be painted in an unobtrusive grey colour.

The sign post should be painted in 25 cm bands alternately in black and white. The lowest band (next to the ground) should be in black.

11.6.7 Material of Signs

The traffic sign plates, discs, or triangles may be made of stove-enamelled metal plate or other suitable local materials, such as plywood, timber planks with or without metal sheet lining, or reinforced concrete.

The posts for traffic signs may consist of suitable mild steel sections, galvanised iron pipes (5 cm diameter), reinforced concrete (10 cm × 10 cm) or timber scantlings.

If pipes are used these should be anchored to prevent turning.

Short-Answer Questions

1. What is a bituminous road?
2. Classify roads based on materials of construction.
3. How are roads classified based on the width of roads?
4. What are the component parts or water bound macadam road?
5. Distinguish Rigid pavements and Flexible pavements.
6. What are traffic signs?
7. What are the advantages and disadvantages of cement concrete roads over other roads?
8. Write short notes on warning signs with neat sketches.
9. How does a mandatory sign differ from a warning sign?

Exercises

1. What is the importance of roads in the development of a country?
2. Explain the construction of a cement concrete road and bituminous road.
3. What is a water bound macadam road? For which layer can it be adopted?
4. Briefly describe the low-cost roads.
5. How can roads be classified according to their location and function? Explain them.
6. What are the three important traffic signs normally adopted?
7. Explain the general design of a mandatory sign with a neat sketch.
8. What are the requirements of a good traffic signboard?

Chapter 12
RAILWAYS

12.1 INTRODUCTION

Railways form the most important mode of transport in India. Railways have brought about many political, social and economic changes in the life of Indian people. The network of Indian Railways is divided into nine zonal divisions for administrative purpose. These are listed in Table 12.1.

Table 12.1 Zonal Divisions of Indian Railways

S. No.	*Railway zones*	*Head quarters at*
1.	Eastern (E.R.)	Calcutta (Kolkata)
2.	South Eastern (S.E.R.)	Calcutta (Kolkata)
3.	Northern (N.R.)	Delhi
4.	North Eastern (N.E.R.)	Gorakhpur
5.	Southern (S.R.)	Chennai
6.	Central (C.R.)	Mumbai
7.	Western (W.R.)	Mumbai
8.	North East Frontier (N.E.F.R.)	Maligaon (Guwahati)
9.	South Central (S.C.R.)	Secunderabad

12.2 COMPARISON OF RAILWAYS AND ROADWAYS

Table 12.2 Comparison between Railways and Roadways

S. No.	*Item*	*Roadways*	*Railways*
1.	Accidents	More	Few
2.	Cost	High cost	Cheaper
3.	High area	Suitable	Not suitable
4.	Employment	High	Less
5.	Load handling capacities	Limited capacity	Large carrying capacity

6.	Maintenance	Occasional	Regular
7.	Suitability	Suits public needs	Suitable for specific services only
8.	Traction	Nearly six times of railway vehicles on steel rails	Nearly 1/5 to 1/6 resistance of pneumatic types of roadways
9.	Horse power requirement	High	Low
10.	Construction cost	Low	High
11.	Length of Haul	Short distance	Long distance

12.3 ADVANTAGES OF RAILWAYS

Railways have the following advantages over the other modes of transport.

(i) Encourage commercial unity
(ii) Ensure safe and comfort journeys
(iii) Stabilisation of the prices of commodities
(iv) Development of the nation
(v) Helps migration of people on a mass scale
(vi) Mobilising troops during war periods
(vii) Easy access to important places of tourist attractions
(viii) Large-scale movement of commodities

12.4 PERMANENT WAY

The combination of rails, fitted on sleepers and resting on ballast and subgrade is called the railway track or permanent way. Sometimes temporary tracks are also laid for conveyance of earth and materials for construction works. The name permanent way is given to distinguish the final layout from these temporary tracks. The cross-section of a permanent way is shown in Fig. 12.1.

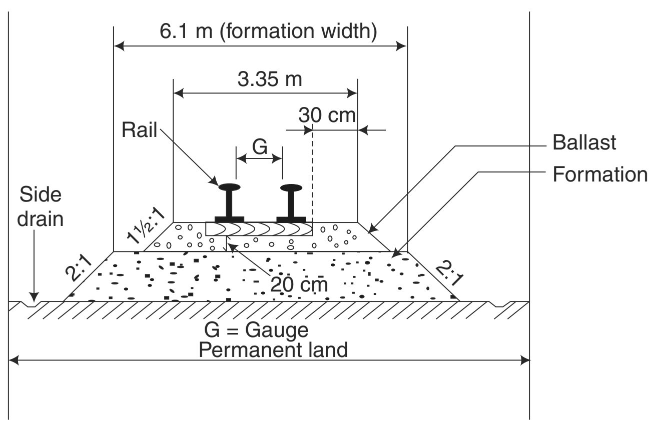


Fig. 12.1 *Typical cross section of a permanent way on embankment*

12.4.1 Requirements of an Ideal Permanent Way

To achieve higher speed and better riding qualities with less maintenance in future, following basic requirements of a permanent way should be taken care of.

1. Gauge should be correct and uniform.
2. The rails should be in proper level.
3. The alignment should be correct, i.e. it should be free from kinks or irregularities.
4. The gradient should be uniform and any change of gradient should be followed by a smooth vertical curve.
5. The track should be resilient, i.e. there must be certain amount of elasticity in the track.
6. The radii and super elevation on curves should be properly designed and maintained.
7. Drainage system should be perfect.
8. Joints, the weakest point in the railway track should be properly designed and maintained.

12.5 COMPONENTS OF A RAILWAY TRACK

12.5.1 Gauge

The gauge of a railway track is defined as the clear distance between inner or running faces of two track rails. Figure 12.2 illustrates a gauge.

The widths of different gauges adopted in our country are given in Table 12.3.

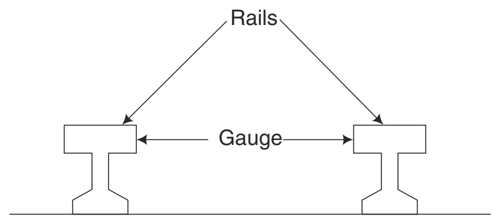


Fig. 12.2 *Gauge*

Table 12.3

S. No.	*Type of gauge*	*Gauge width*
1.	Standard Gauge (B.G.)	1.676 m
2.	Metre Gauge (M.G.)	1.000 m
3.	Narrow Gauge (N.G.)	0.762 m
4.	Feeder Track Gauge or Light Gauge (L.G.)	0.610 m

12.5.2 Rails

The rails on the track can be considered as steel girders carrying axle loads. They are made of high carbon steel to withstand wear and tear.

Functions of rails

(i) Rails provide a hard, smooth and unchanging surface for the passage of heavy moving loads with a minimum friction between the steel rails and steel wheels.

(ii) Rails bear the stresses developed due to heavy vertical loads, lateral and braking forces and thermal stresses.

(iii) Rails transmit the load to sleepers and consequently reduce pressure on ballast and formation.

Types of rail sections

(i) Double headed rails (D.H. rails) [Fig. 12.3 (a)]

(ii) Bull headed rails (B.H. rails) [Fig. 12.3 (b)]

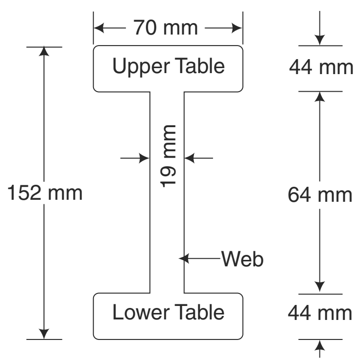


Fig. 12.3 (a) *D.H. rails*

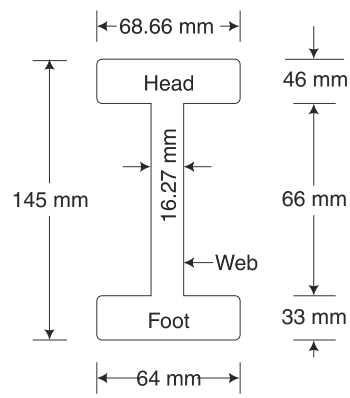


Fig. 12.3 (b) *B.H. rails*

(iii) Flat footed rails (F.F. rails) [Fig. 12.3 (c)]

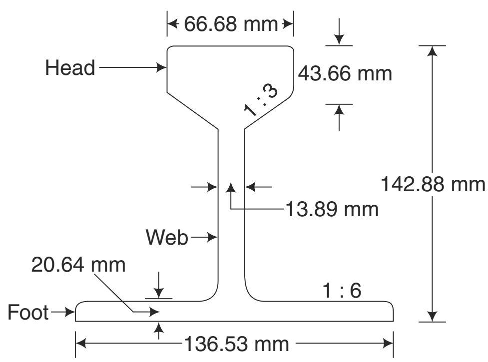


Fig. 12.3 (c) *F.F. rails*

In India, flat footed rails are most commonly used because they have more strength and stiffness, both vertically and laterally than B.H. rails. Fitting of rails with sleepers is simpler and as such they can be easily laid and relaid.

Rail Joints The weakest point of a track is the joint between two rails. An ideal or perfect rail joint is one which provides the same strength and stiffness as the other sections of the track.

12.5.3 Sleepers

Sleepers are laid transverse to the rails. Rails are supported and fixed on them. They are laid to transfer the load from rails to the ballast and subgrade.

Functions

(i) To hold the rails to proper gauge.
(ii) To hold the rails in proper level.
(iii) To interpose an elastic medium in between the ballast and rails.
(iv) To distribute the load from the rails to the ballast underlying.

Classification According to the materials used in their construction sleepers can be classified into following three classes.

(i) Wooden sleepers
(ii) Metal sleepers
  (a) Cast iron sleepers
  (b) Steel sleepers
(iii) Concrete sleepers
  (a) Reinforced cement concrete sleepers
  (b) Prestressed concrete sleepers

Comparison of different types of sleepers is given in Table 12.4.

Table 12.4 Different Types of Sleepers

S. No.	*Point of comparison*	*Wooden sleeper*	*C.I. sleeper*	*Steel sleeper*	*Concrete sleeper*
1.	Life	12 to 15 years for untreated sleepers. 20 years for treated sleepers	35 to 50 years	35 to 50 years	40 to 60 years
2.	Weight per sleeper for B.G.	54.5 kg	113.4 kg	77.57 kg	Depends upon design but heavier than others
3.	Maintenance cost	Higher than other sleepers	Minimum	Moderate	Moderate

Contd...

4.	Overall economy	Cheaper in the initial cost but expensive in long run	Costlier in the initial cost but cheaper in long run	Same as for C.I.	Under trial
5.	Handling	Not liable to break under rough handling	Liable to break under rough handling	Not liable to break	Improved design not liable to break
6.	Rigidity of track	Poor both laterally and longitudinally	Better than timber Sleepers	Better than timber Sleepers	Best because of heavy dead weight
7.	Track fittings	Requires less fittings	Requires more fittings	Requires less fittings	Requires less fittings
8.	Renewal	Easy	Difficult	Difficult	Difficult

Sleeper Density Sleeper density is the number of sleepers per rail length and it is specified as $(n + x)$. The number of sleepers per rails varies in India from $n + 3$ to $n + 6$ for main tracks. Where

n = length of rails in metres.

12.5.4 Track Fittings

Rail fixtures and fastenings are used to keep the rails in a proper position and to set the points and crossings properly. Important rail fittings are as follows.

1. Fish plate
2. Spike
3. Bolt
4. Chairs
5. Blocks
6. Keys
7. Plates

1. Fish Plate Fish plates are used in rail joints to maintain the continuity of the rails and also to provide for any expansion or contraction of the rail caused by temperature variations. They maintain the correct alignment of the line both horizontally and vertically. Section of a fish plate is illustrated in Fig. 12.4.

Requirements of Fish Plates

(i) They must support the underside of the rail and top of the foot.

(ii) They should allow a free movement of rails for expansion and contraction.

(iii) They must be of such a section as to bear the stresses due to lateral and vertical bending moments without getting distorted and must absorb the shock caused by the jumping of the wheel over the expansion gap.

(iv) They should hold the ends of the rail both laterally in line and vertically in level.

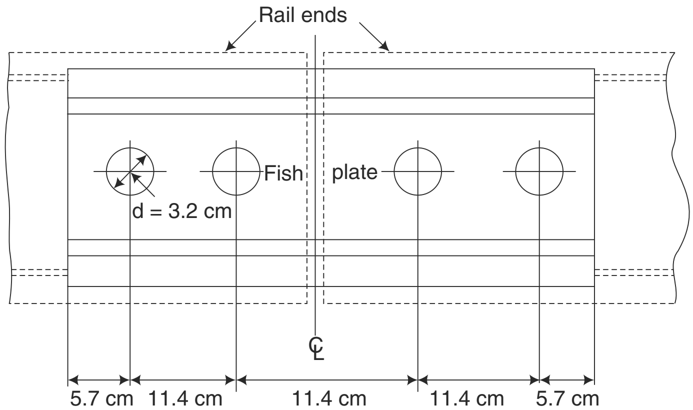


Fig. 12.4 *Section of fish plate*

2. Spikes For holding the rails to the wooden sleepers, spikes of various types are used.

Characteristics of a good spike

(i) A spike should be strong enough to hold the rail in position and it should have enough resistance against movement to retain its original position so that it does not lead to creep under any circumstances.

(ii) The spike should be as deep as possible.

(iii) It should be easy to fix and remove from the sleepers.

(iv) It should properly maintain the gauge.

Various types of spikes are used, the common being dog spikes, screw spikes, round spikes and elastic spikes.

3. Bolts Various types of bolts normally used are dog bolt, fish bolt, rag bolt and fang bolt.

Dog bolt When sleepers rest directly on a girder, they are fastened to the top flange of the girder by bolts called dog bolts.

Fish bolt Such bolts are used to connect fish plates with the rails. At each joint four fish bolts are used.

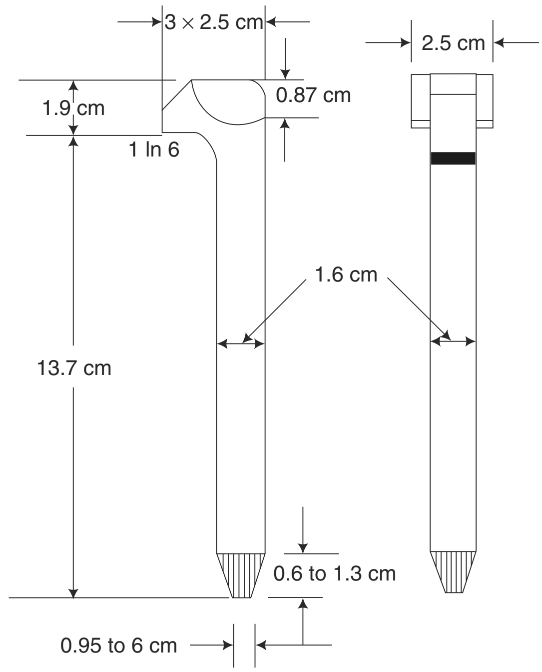


Fig. 12.5 *Dog spike*

Rag bolt These are used to fix longitudinal sleepers of timber or concrete to the walls of ash pits.

Fang bolt These are used for fixing side chairs to sleepers.

4. Chairs In case of double headed and bull headed rails, chairs are required to hold them in position. They help in distributing the load from the rails to the sleepers. This is illustrated in Fig. 12.6.

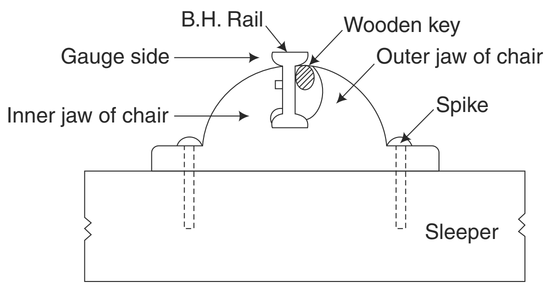


Fig. 12.6 *Chair and key for bull headed rails*

5. Keys Keys are small tapered pieces of timber or steel to fix rails to chairs on metal sleepers.

6. Bearing plates Bearing plates are rectangular plates of M.S. or C.I. and are used below flat rails to distribute the load on a large area of timber sleepers. This arrangement is shown in Fig. 12.7.

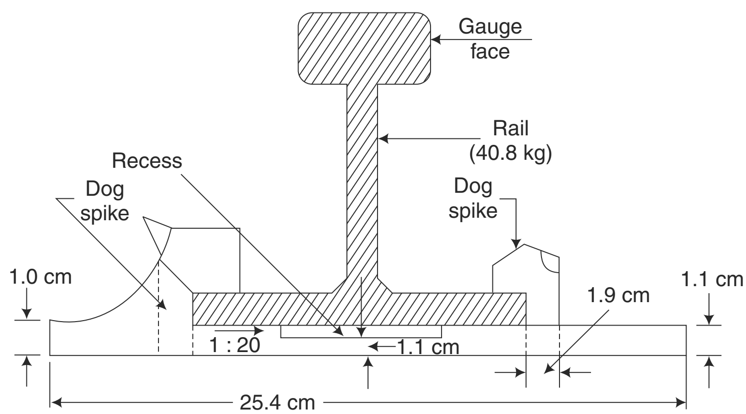


Fig. 12.7 *Bearing plates arrangement*

12.5.5 Ballast

Ballast is the granular material usually comprising broken stone and like blue granite stonearound the sleepers to transmit load from sleepers to formation and at the same time allowing drainage of the track.

It provides a suitable foundation for the sleepers and also holds the sleeper in their correct position by preventing their displacement by lateral or longitudinal thrusts. The lateral stability of a track depends on the ballast.

Size and quantity of ballast The size of stone ballast varies from 19 mm to 51 mm with a reasonable proportion of intermediate sizes (Fig. 12.8).

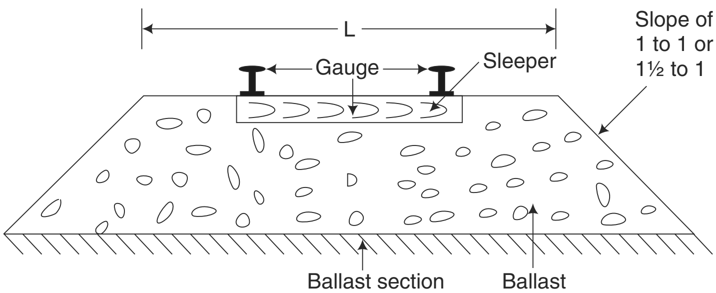


Fig. 12.8 *Size and quantity of ballast*

The depth of the ballast is defined as the distance between the bottom of sleeper and top of subgrade. Details of ballast sections are given in Table 12.5.

Table 12.5 Details of Ballast Sections

S. No.	*Dimension*	*B.G.*	*M.G.*	*N.G.*
1.	Width of ballast (L)	3.35 m	2.25 m	1.83 m
2.	Depth of ballast (D)	20–25 cm	15–20 cm	15 cm
3.	Quantity of stone ballast per metre length	1.036 m^3	0.071 m^3	0.053 m^3

12.5.6 Subgrade and Embankments

Subgrade It is the naturally occurring soil, which is prepared to hold the ballast, sleepers and rails for constructing the railway track. This prepared surface is also called formation. Formation could be in embankments level or cutting, depending upon the ground condition.

Embankment It is a raised bank of earth or other materials constructed above the natural ground. It is constructed when railways have to be carried in low grounds or valleys.

Cutting The raised ground or hill is cut or excavated for constructing the railway line at the required level below ground level.

Formation The prepared surface which is ready to receive ballast is called formation. The stability of the track depends upon the quality of the formation under it.

Functions of the Subgrade of Formation The formation for a track is obtained by either constructing an embankment or cutting. Subgrade material performs the following functions.

(i) It bears the load transmitted to it through the ballast in an uniform manner.
(ii) It prevents the ballast from puncturing into it.
(iii) It drains off the water entering from its top.
(iv) It provides a smooth, regular and graded surface on which the ballast and the track may be safely rested.
(v) It does not change its volume due to variation in moisture, as otherwise it would create stresses on the track material and disrupt the track.

12.6 BASICS OF POINTS AND CROSSINGS

12.6.1 Points

A set of switches consisting of left-hand switch and right-hand switch is known as the points. A switch consists of a tongue rail and a stock rail. The points and crossing is the name given to the arrangement which diverts the train from one track to another, either parallel to or diverging from the first track.

If the train is diverted to the right-hand side as shown in Fig. 12.9, the layout is known as right-hand layout, On the contrary, if the train is diverted to the left-hand side, the layout is known as left-hand turnout.

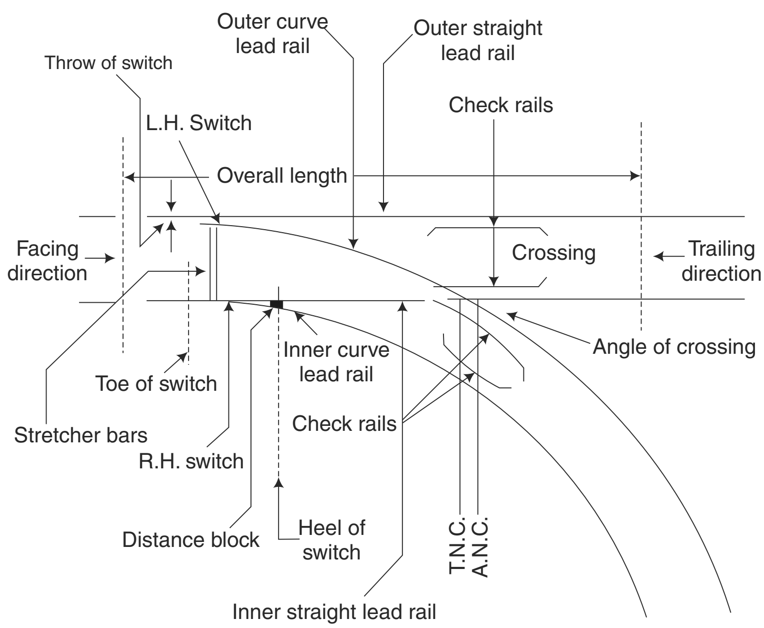


Fig. 12.9 *Right-hand turnout*

Sleepers Laid for Points and Crossings Following are the two methods of laying sleepers below the points and crossings.

1. Through sleepers
2. Interlaced sleepers

1. Through sleepers The through sleepers are laid for points and crossings and are provided in the overall length of points and crossings. It maintains several rails at the same level and it is possible to fix the alignment of the curved track in relation to the straight track as shown in Fig. 12.10.

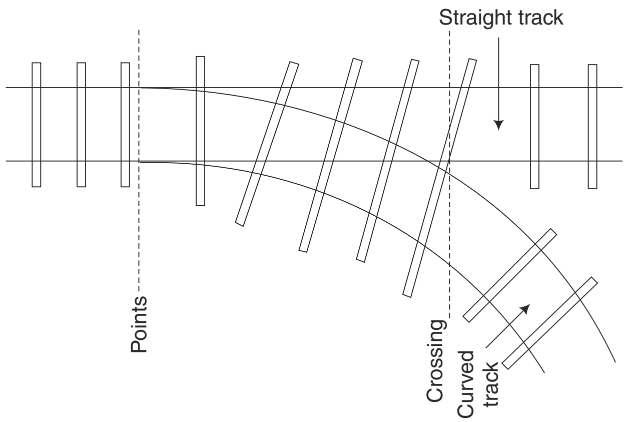


Fig. 12.10 *Through sleepers*

2. Interlaced sleepers Where there is a shortage of long sleepers, the interlacing of sleepers is done between the switches and the crossing as shown in Fig. 12.11.

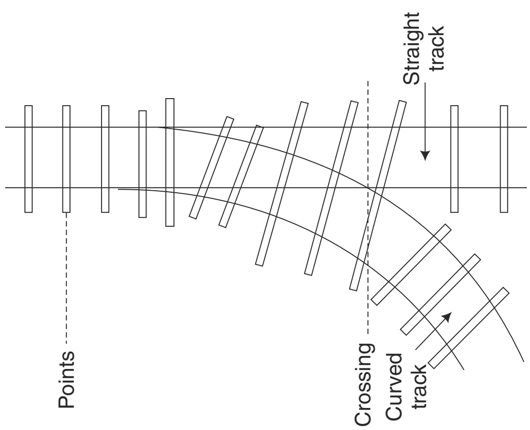


Fig. 12.11 *Interlaced sleepers*

Advantages of interlaced sleepers

(a) Significant amount of super-elevation can be given to the outer curve lead rail.

(b) The curved track can be adjusted to a very smooth curve without depending on the offsets from the straight track.

Disadvantage of interlaced sleepers

(a) The levels of the straight tracks and curved tracks vary.

(b) It is not possible to pack the sleepers satisfactorily.

(c) The deformation of curved track may take place after a number of vehicles have used the turnout.

Generally, the wooden sleepers of larger sections are used for points and crossings. Steel sleepers are rarely used, since they pose corrosion problem due to seasonal variation.

12.6.2 Crossings

It is a device provided at the intersection of two rails so as to permit the vehicles moving along one track to pass across the other track.

The crossings may be built-up, cast at place or a combination of the two. The built-up crossings are very common. But as they are not very rigid, they are not suitable for fast heavy traffic. The cast crossings are very much suitable on fast and heavy traffic lines, even though the initial cost is high. It requires very little maintenance. In the combined type, a cast steel nose is provided to two wing rail pieces.

Types of Crossings Following are the two types of crossings.

1. Ordinary or acute crossing
2. Double or obtuse crossing

1. Ordinary or acute crossing Fig. 12.12 shows a typical ordinary or acute built-up crossing. All the measurements are taken from the theoretical nose of the crossing.

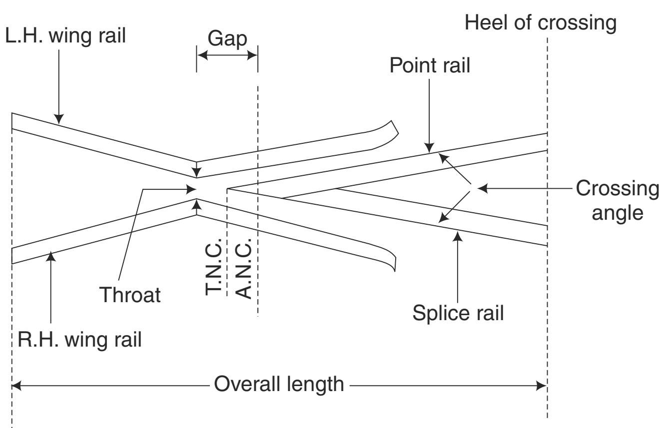


Fig. 12.12 *Ordinary or acute crossing*

2. Double or obtuse crossing A double crossing has two noses and is used in the formation of diamonds. The gauge lines intersect at elbow as shown in Fig. 12.13 and all measurements for locating the crossing are to be taken from the elbow.

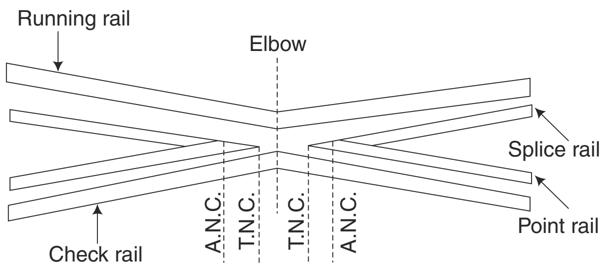


Fig. 12.13 *Double crossing*

The diamond crossings may be situated on straight track or curved track. They may occur between similar tracks or unsimilar tracks. When the angle becomes 90 degree, it is known as the square crossing as shown in Fig. 12.14. But it should be avoided as far as possible because there is rapid wear of the crossings and damage to the rolling stock on account of the heavy impact.

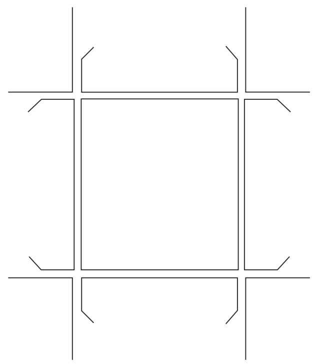


Fig. 12.14 *Square crossing*

When one track crosses another at an angle, as shown in Fig. 12.15, a diamond comprising two acute crossings and two obtuse crossings is formed. For all diamond crossings, the gauge is kept 3 mm tight for the steady running of vehicles on the track. As far as possible, the diamond crossings should be avoided on curves. Otherwise, the speed restriction will have to be imposed on such crossings.

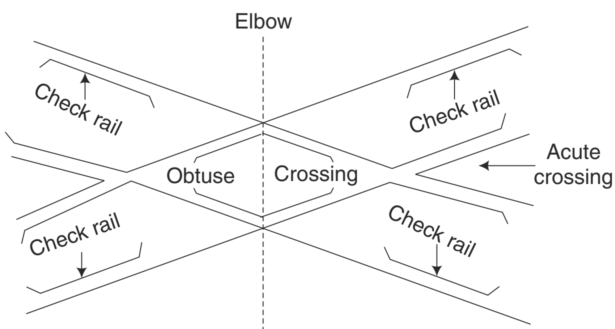


Fig. 12.15 *Diamond Crossing*

Crossing Clearance The distance between the wing rail and crossing rail is known as the crossing clearance. The clearance at the throat is theoretically the same as the crossing clearance. But in actual practice, this is found to be slightly greater as it is not possible to bend the wing rails to a fine point at this spot. The standard minimum clearance are following.

(a) 44 mm to 1435 mm for B.G.

(b) 41 mm to 1067 mm for M.G.

(c) 38 mm to 41 for N.G.

Crossing Number The crossings are designated in terms of the distance required in spreading the point and splice rails by 305 mm. The spread is measured between the gauge faces of the rails and the distance is measured from the theoretical nose of crossing as shown in Fig. 12.16.

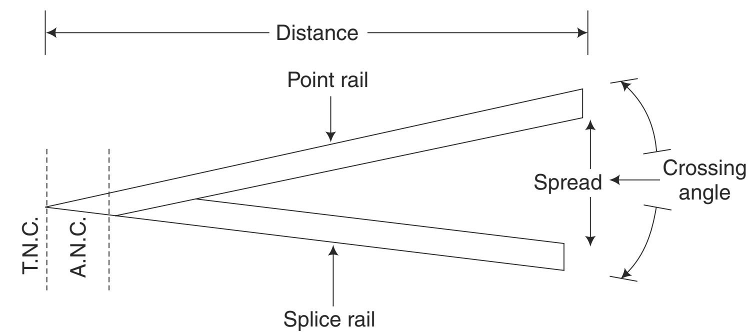


Fig. 12.16 *Crossing number*

Crossing number in Indian Railways are 1 in 8½, 1 in 12, 1 in 16 and 1 in 20. A flatter crossing is a source of danger. As the gap between the throat and nose of crossing increases, there are more chances of the derailment of small wheels.

Crossing Angle The angle which is formed between the gauge faces of V is the crossing angle. In Fig. 12.17, α = angle of crossing and N = crossing number.

Then

$$\tan \alpha = 1/N \quad \text{or} \quad \cot \alpha = N$$

This is the standard method adopted in the Indian Railways.

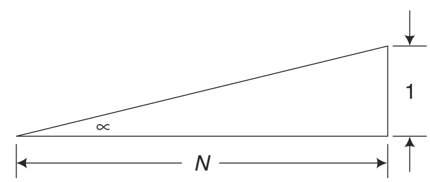


Fig. 12.17 *Crossing angle–right angle method*

Short-Answer Questions

1. Define gauge.
2. What is the gauge width for a metre gauge?
3. What are the different types of rail sections?
4. How are sleepers classified on the basis of materials?
5. What is ballast in permanent way?
6. What are the functions of subgrade?
7. What is embankment and subgrade?
8. What are the various types of crossings?
9. What is a diamond crossing?
10. Define crossing number and crossing angle.

Exercises

1. Compare railway transportation with road transportation and mention the advantages of railway transportation.
2. Sketch a typical permanent way and what are the requirements of an ideal permanent way.
3. What are the functions of rails in a railway track?
4. Compare the various characteristics of different types of sleepers used in Indian Railways.
5. What are the essential requirements of fish plate?
6. Explain the various types of track fittings with a neat sketch.
7. Write short notes on size and quantity of ballast.
8. Draw a neat sketch of right-hand turnout.

Chapter 13
AIRPORTS

13.1 INTRODUCTION

Air transport has grown to be a crucial part of the modern transportation systems in India. The necessity of well-planned airports for efficient air transportation will increase as the community grows and expands both in population and economic activity.

Airport engineering deals with the planning, designing, construction, operation and maintenance of facilities like the landing and take off, loading and unloading, servicing, maintenance and storage of aircrafts. The major phases of airport engineering are planning, designing and construction of airports and operation and maintenance of aircrafts.

13.2 FUNCTIONS OF AIR TRANSPORT

1. It saves travel time tremendously.
2. Long distance travel and reaching inaccessible areas become possible and easy.
3. It facilitates aerial photography.
4. It provides facility for rapid and efficient handling of cargo.
5. It provides uninterrupted service during defence operations.
6. It is highly useful in rescue operations during the natural calamities.
7. It links different cultures, people by linking the countries.
8. It acts as one of the sources of foreign exchange generation.
9. It encourages tourism in a better way.
10. It has provisions for telegraph and telecom services.

13.3 AIRPORTS

An airport is the place which provides facilities for safe landing, take-off movements of aircraft and berthing on loading aprons, It has provisions for hangars, fuel storage and lounges for passengers, cargo handling, etc.

13.4 AIRPORT PLANNING

An airport is a terminal facility for aircrafts. It is also known as an aerodrome. Aerodrome serving international traffic is called an airport. It has customs, health and immigration facilities. It is used for aircraft take off and landing. It also includes facilities for handling passengers, cargo and for servicing aircrafts. The landing area includes primarily the runways and taxiways and the terminal area incorporates all other functions such as the ramp space, loading areas, administrative buildings, and hangars for housing and servicing aircrafts.

It must be integrated with the planning of highway, railway and other existing ground transportation. The necessary data on present and future population growth, business and industrial development and the general control of land use in the proposed airport should be foreseen before planning for an airport. In general, airports are meant for business, industry and agricultural services. Flight training must be well served by highway facilities for handling passengers and cargo.

The development of an airport is a major step for any community. The land requirements may be about 100 to 250 hectares or more depending upon the purposes of the airport, the type of aircrafts and the frequency of flights.

The layout plan prepared must contain all the basic information required for taking up the construction work. The important factors to be considered while planning an airport are the strength and the character of the community to be served, location of existing and proposed civil and military air field, air routes and navigational aids. Community needs, desires and attitudes are also ascertained and considered. Local legislation pertaining to acquisition, expenditure of public funds and zoning is considered before finalising the layout plan.

13.5 SELECTION OF SITE

The foremost consideration in the design of an airport is the selection of a suitable site. It is important that the airport must occupy an easily accessible site located close to the population centre in co-ordination with the other modes of transportation such as highways, railways and waterways. Initial acquisition of land should include sufficient area for future expansion. Dimension and orientation of the land area will depend on the required runway orientation and runway lengths for the largest aircraft and by the direction of the prevailing winds. The approach zones must be free without obstructions for the take off and landing of planes and should not pass directly over residential areas or industries.

Site locations, having a high incidence of low visibility weather are avoided. Flat areas requiring excessive drainage and hilly land requiring a large amount of grading are less desirable than free draining and moderately rolling terrain.

Preliminary subsurface exploration to determine the geological character of each site is necessary to avoid high development and maintenance costs. Aerial photo reconnaissance of possible sites, together with expert photo interpretation, is an important tool utilised in the site selection. Relative cost of providing necessary utility services, such as water supply, sewerage, gas, electricity and communication facilities are also considered. The effect noise over the neighbouring areas is also an important factor which is considered during site selection. In general, the site selected should not have a slope greater than 1.5 per cent, but it should provide easy drainage. An elevated site or a valley site can also be selected but the site selected should be an economical one for provision of drainage structures.

13.6 CLASSIFICATION OF AERODROMES

The aerodromes can be classified in the following heads.

1. International airports
2. General aviation aerodromes
3. Military aerodromes

The design, construction and layout of an international airport should confirm with the standards laid by the International Civil Aviation Organisation (ICAO). This type of an airport should be constructed in accordance with the universal requirements and should cater increasing sizes and number of aircrafts.

The general aviation aerodromes serve on local service routes. They accommodate flights for business and industry. They also facilitate local flying operations such as industrial flying, aerial photography and agricultural flights for crop dusting. These aerodromes mainly support domestic needs and can handle only a limited number of aircrafts per day.

Military aerodromes include all aerodromes used by Navy, Army and Air Force. Sometimes temporary aerodromes are also constructed for this purpose. In many instances, civilian aerodromes have been used by the military and vice versa. Most of the specifications adopted for military aerodromes in all countries are as per the standards of ICAO.

The aerodromes in India have been classified in the following categories.

(i) Central Government aerodromes
(ii) State Government aerodromes
(iii) Privately owned licensed aerodromes
(iv) Defence aerodromes

The ICAO classification for aerodromes is given in Table 13.1 and the runway basic length for different types of airports in given in Table 13.2

Table 13.1 The ICAO Classification for Aerodromes

Code	*Single isolated wheel load (kg)*	*Tyre pressure (kg/cm^2)*
1.	45360	8.40
2.	34020	7.0
3.	27220	7.0
4.	20410	7.0
5.	13610	6.0
6.	3800	4.90
7.	2270	2.90

Table 13.2 Runway basic length for different types of airports

Airport	*Runway basic length (in metres)*
A	>2500
B	2150–2500
C	1800–2150
D	1500–1800
E	1280–1500
F	1080–1280
G	980–1080

13.7 COMPONENTS OF AN AIRCRAFT

The following are the essential components of an aircraft. Figure 13.1 illustrates clearly the arrangement of components in an aircraft.

1. Engine
2. Propeller
3. Fuselage
4. Wings
5. Three controls
6. Flaps
7. Undercarriage

13.8 CHARACTERISTICS OF AN AIRCRAFT

The design of an airport is influenced by the characteristics of aircrafts using the airport, land area available, revenue allotted towards to development and the cost of land acquisition. The following characteristics of aircrafts can influence the design, size and type of airport. Figure 13.2 shows the dimensions of an aircraft.

1. Type of propulsion
2. Size of aircraft which includes wing span, total length and height
3. Wheel base and weight

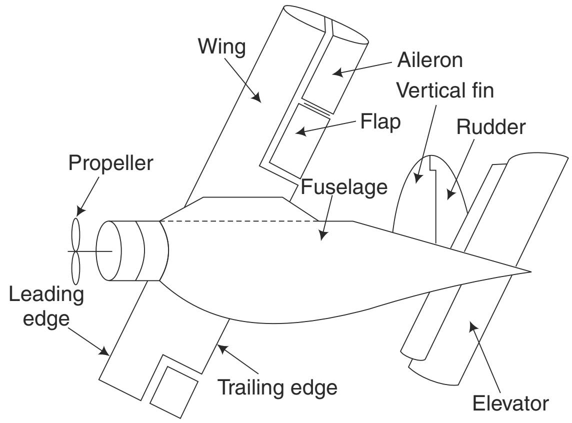


Fig. 13.1 *Components of aircraft*

4. Tail width
5. Speed
6. Capacity

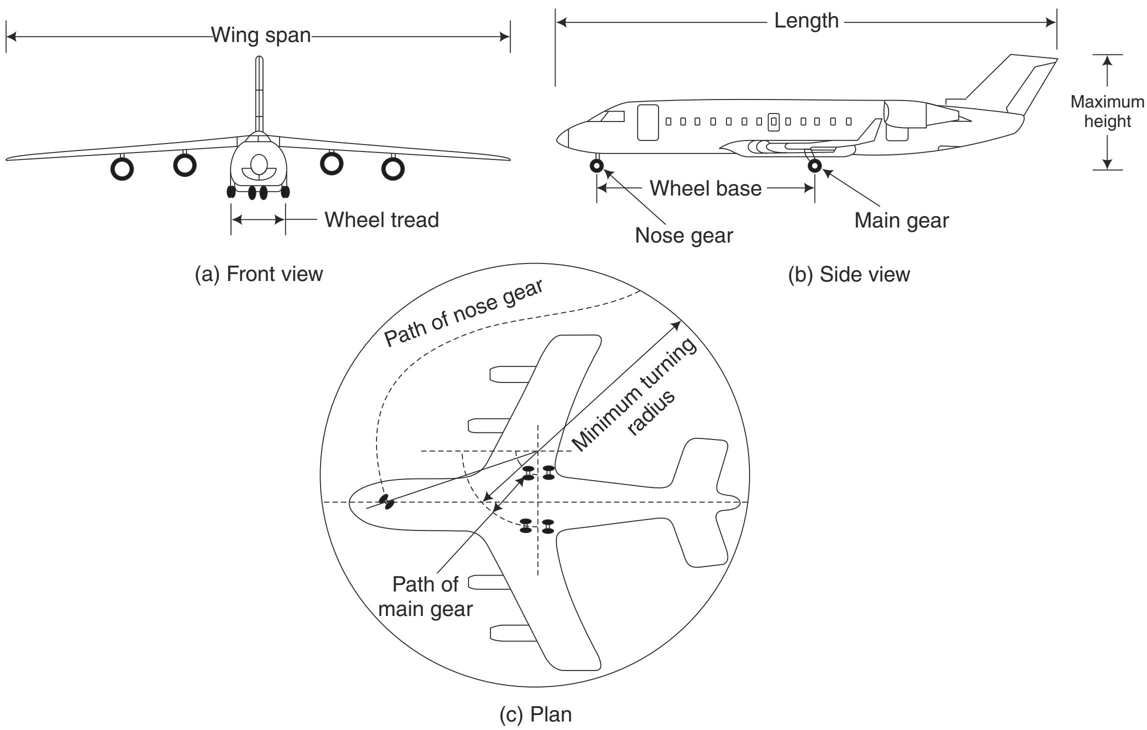


Fig. 13.2 *Aircraft Characteristics*

7. Noise level
8. Minimum turning radius, circling radius
9. Take off and landing distance
10. Tyre pressure and contact area

13.9 COMPONENTS OF AN AIRPORT

An ideal airport essentially consists of runways, taxiways, parking areas and cargo and mail handling building. The final development is often subdivided into suitable stages of construction, such that the completion of each stage provides complete and usable facility, adequate to meet the needs of the area to be served. Figure 13.3 shows a typical layout of an airport.

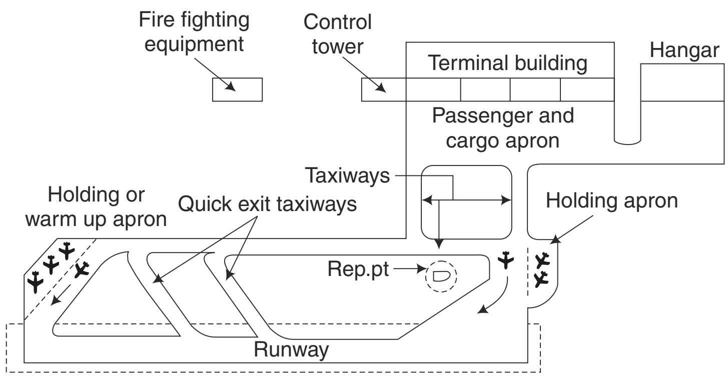


Fig. 13.3 *Layout of an airport*

13.9.1 Runway

A strip of land surfaced for the take off and landing of aircrafts in an airport is called a runway. A runway is a levelled, obstruction free and structurally safe strip. It is necessary to select the type of pavement, location and construction of runways and taxiways which permit maximum use of the landing area. The surface should be durable with minimum maintenance cost. In the design of runways, considerations must be given to the type of lighting which will be used and how it can be installed so as to minimise possible interference with aircraft movements.

The alignment and direction of the proposed runway must be oriented along with the direction of the wind. It is normal to include a second runway at an angle of about 90 degrees to the first one where crosswinds are expected. When traffic is expected to exceed 30 movements at the peak hour, it is desirable to instal more than one runway in a given direction. A satisfactory pavement for a runway is concrete. It gives long life with minimum maintenance cost. The width of runways depends on the maximum size of aircrafts utilising the airports. Runway lengths are based on the category of the airfields and the types of aircrafts anticipated. Runway lengths must be determined by aircraft performance data, airport elevation and temperature, take-off height and runway gradients, if any.

Depending upon the volume of traffic, the wind directions, the shape and size of the surrounding area, one or more runway have to be suitably constructed. Typical basic runway patterns are given below.

1. Single runway
2. Two runway
3. 60 degree runway
4. 45 degree runway
5. 60 degree parallel runway
6. Hexagonal runway

1. Single Runway This is the simplest form of a runway. It is a logical pattern where the winds blow generally from one direction. This type of runway is used when traffic requirements are occasional. Most of the airports in Tamil Nadu have this type of runway.

2. Two Runway The next simple type designed to obtain greater wind coverage consists of two runway, either forming an L, T or X shape depending on the direction of the prevailing winds and the slope of the area as shown in Fig. 13.4.

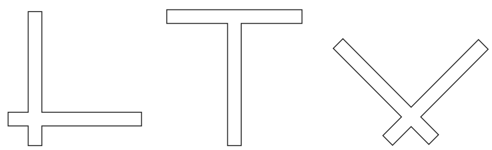


Fig. 13.4 *Two runway configuration*

3. 60 Degree Runway When prevailing winds occur in several directions, it becomes necessary to have a wider wind coverage. This can be obtained by a triangular pattern of 60 degree system. This triangular pattern is sound and if properly arranged, allows enough space for hangars and parking areas. The layout need not be equilateral and the angles can be changed.

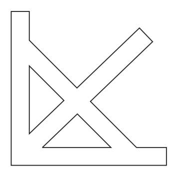


Fig. 13.5 *45 degree runway*

4. 45 Degree Runway When a greater wind coverage is desired for the same airfield capacity, a four way or 45 degree pattern can be adopted as shown in Fig. 13.5.

5. 60 Degree Parallel Runway When the air traffic grows beyond the capacity of the single runway pattern, additional capacity can be obtained by increasing the number of runways, It may be noted that the added runways are larger to accommodate larger aircrafts. There must be perfect traffic control for proper regulation and operation of aircrafts. Figure 13.6 shows this kind of runway.

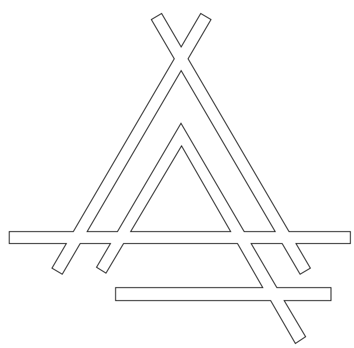


Fig. 13.6 *60 degree runway*

6. Hexagonal Runway System The improved pattern of the parallel type is a hexagonal system. Here, runways can be separated further by arranging them around the terminal. This pattern permits simultaneous take-off and landing movements of aircraft without interference at any time. Figure 13.7 shows a hexagonal runway system.

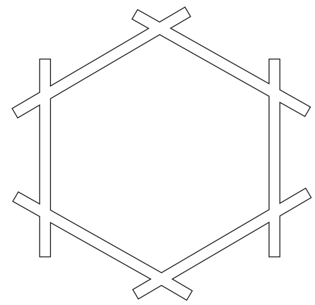


Fig. 13.7 *Hexagonal runway*

13.9.2 Taxiway

The connection between the runway and the terminal building is called a taxiway. It is provided from the terminal area to each end of each runway. At modern airports, it is usual to build some of the taxiways at an angle of about 30 degree to the runway alignment so that the aircrafts can make the transition between runways and taxiways without coming to a stop. The length of a taxiway depends upon the distance of the apron from the entry end or the exit end of the runway. The radius of turning along the centre line from a runway to a taxiway should not be less than 1.5 times the width of the taxiway. At the turning corner fillets are provided at intersection points.

13.9.3 Apron

The portion of airport, which is usually paved, in front of the terminal building or adjacent to hangars, meant for parking, loading and unloading of aircrafts is known as an apron. The size and geometric design of apron depends upon the number and characteristics of the aircrafts expected. The area provided in the case of apron should be large enough to enable an aircraft to bypass another aircraft standing in front by adequate clearances. The slope of the apron must be sufficient for easy drainage.

13.9.4 Terminal Building

Terminal building shown in Fig. 13.8 usually refers to a building mainly used for passengers, airlines and administration facilities. It has a layout which offers the enplaning passengers, a convenient and direct access form the vehicle platform or street side of the building, through the booking and waiting rooms, to the aircraft loading positions on the

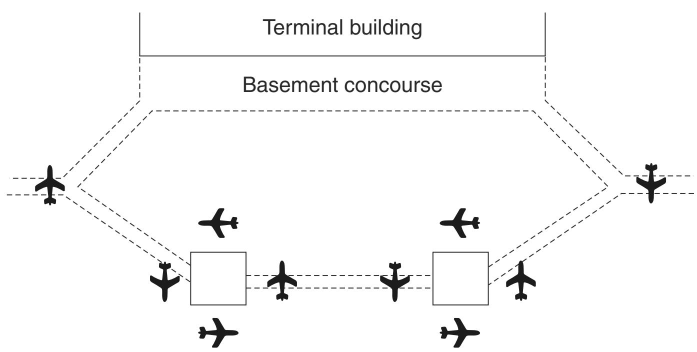


Fig. 13.8 *Terminal building*

apron. Deplaning passengers are also provided with a direct route from the aircraft to the baggage claim counter and then to the vehicle platform.

The operational category includes control tower, weather bureau and other government services related to the aviation. In many cases the terminal building itself fulfils the function of the operational building as well.

13.9.5 Control Tower

The control tower is located in the terminal area. The control tower is nerve centre of an airport. Safety of aircraft operations and the effective capacity of an airport depend upon the skill of the controller operating the system. The controller directs the movement of aircrafts on the ground and in the air within the airport zone. Information is issued to the pilot regarding airport conditions, airway traffic, visibility, speed and direction of ground winds, barometric pressure and other relevant information for safe operations.

The control tower which has approach control facilities, directs the aircrafts to the airports through a number of specific points which are located within a radius of approximately 40 km (25 miles) from the control tower.

13.9.6 Hangar

It is a large shed erected at the airport for the purpose of housing and repairing aircrafts. Hangars are usually constructed by using steel frames and are covered with sheets of galvanised iron. Service hangars are provided with machine shops, stores of spare parts and facilities to carry on the repairs in all types of weather. The number if storage hangars will depend upon the volume of traffic. Erection of a single hangar of huge dimensions is neither economical nor suitable. Figure 13.9 illustrates a hangar.

The components of the airport, such as the terminal building, control tower and service buildings are located in proper relation to the air field and to each

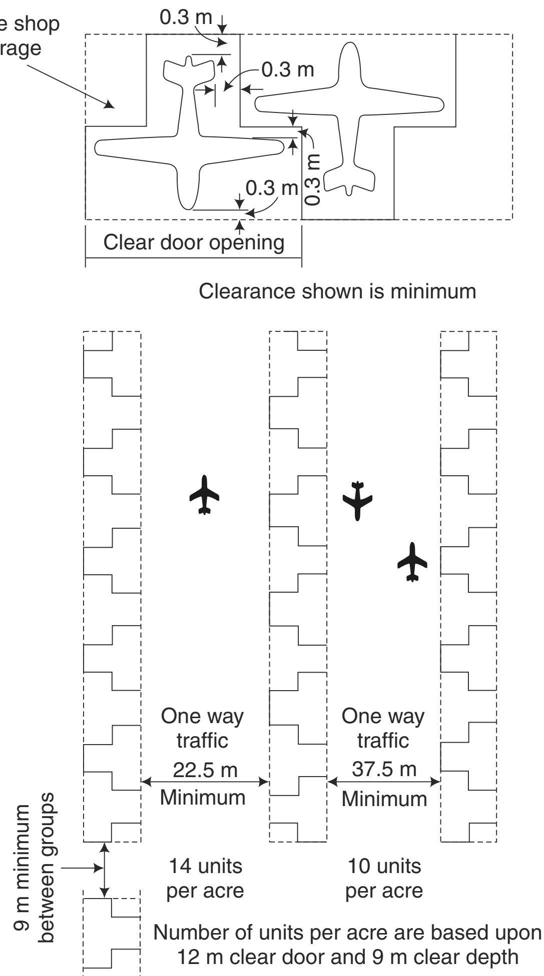


Fig. 13.9 *Hangar*

other. Area allocations for commercial air carriers, general aviation and cargo services are located so as to avoid congestion with each other. The utility services such as water supply connection, sanitary works and electrical power supply are also suitably planned and provided.

13.9.7 Pavement

Airport pavements are designed to support aircraft wheel loads and the intensity of load on the runway surface and to provide an even surface free form loose particles. They should require minimum maintenance and repair. Both rigid and flexible pavements are used.

Rigid pavements are generally composed of rectangular slabs of cement concrete which are interlocked by keys or steel dowels at intervals and supported on a well compacted granular sub-base material.

The flexible type consists of bituminous surface courses on compacted granular base and sub-base layers.

The type selected for a particular site will depend on the availability of materials and equipment cost, existing soil conditions and operational requirements.

13.9.8 Drainage

The design of an airport drainage system is based mainly on the rainfall intensity and frequency and ability of turfed areas to absorb rainfall. The slope of the runway centre line is restricted and transverse slopes of runways and taxiways must be relatively flat. The grades in turfed areas slope away from the paved surface towards drainage structures which carry the water into underground pipes and discharge away from the landing area.

13.9.9 Marking and Lighting

In the interest of safety to air navigation, certain standards have been laid for marking and lighting of airport facilities. The airports should be marked so that pilots can spot it easily. Airport boundary markers should clearly indicate the landing area. Runways and taxiways should be clearly indicated in the landing area. They should also be clearly numbered and centre lines should be marked distinctly.

13.10 LIGHTING ARRANGEMENT AT RUNWAYS, TAXIWAYS AND APRON

Light arrangements for the runways, taxiways and apron are a necessity for night operations. In normal lighting procedure for runways, high intensity lights are used on either side of the runway width and parallel to the centre line of the runway commencing from 60 m from the threshold or the edge of the runway and extending up to the other end of the runway. These lights provided on the runway are white and of flush grid type. Lighting of taxiway is done in the same manner as for a runway. Medium intensity lamps in blue colour are used for this purpose. The main aim of taxiway lighting is to ensure that the pilot does not mistake it for a runway and that he gets adequate guidance up to the apron. Aprons are usually flood lit for the convenience of the service personnel, passengers and pilots. The floodlights are usually mounted on buildings. Figure 13.10 shows the runway lighting arrangements.

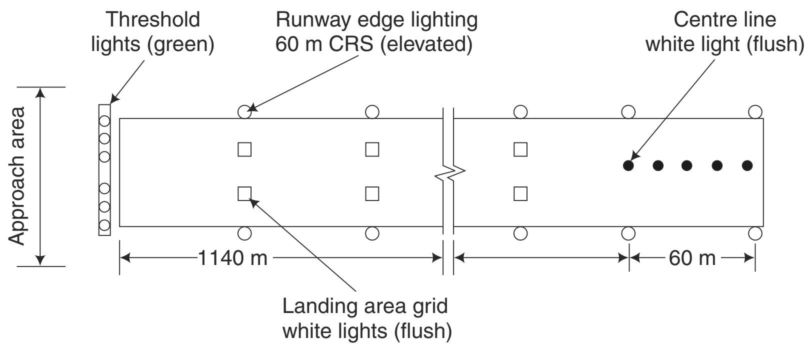


Fig. 13.10 *Runway lighting arrangement*

At night, the following aids are provided in an airport.

1. Airport beacon
2. Approach lighting system
3. Boundary lights
4. Threshold lighting

1. Airport Beacon It is a very strong beam of light sending out white and green flashes. The flashes are visible to the pilot from any direction of approach. The beacon is placed at least 6 m above any building which is nearest to the landing area.

2. Approach Lighting System For an aircraft attempting to land at night, it is difficult for the pilot to locate the alignment of the runway. The lighting within the approach zone, therefore, should be such that the pilot is able to see the lights to bring the aircraft to the correct alignment at a safe distance. Figure 13.10 indicates the layout of approach lights.

3. Boundary Lights In some airports, lights are also arranged to indicate the boundary of landing area of the airport. White lights are spaced at 60 m centre to centre along the landing boundary. This arrangement gives the pilot a definite picture of the landing area during nights.

4. Threshold Lighting One or two rows of lighting, perpendicular to the central line of the runway at both ends, is called threshold lighting. The usual colour of the light use for this is green. These lights guide the pilot to safely touch down at the appropriate location on the runways.

13.11 WINDROSE DIAGRAM

The wind data pertaining to a particular area is presented in the form of a geometrical diagram. It indicates the direction, intensity and duration of wind component. It is correlated with meteorological data to predict the feasibility of construction of the airport components. It gives warning about the bad weather and inform the aircrafts about the feasibility of the check landing or take off. The windrose diagram is shown in Fig. 13.11.

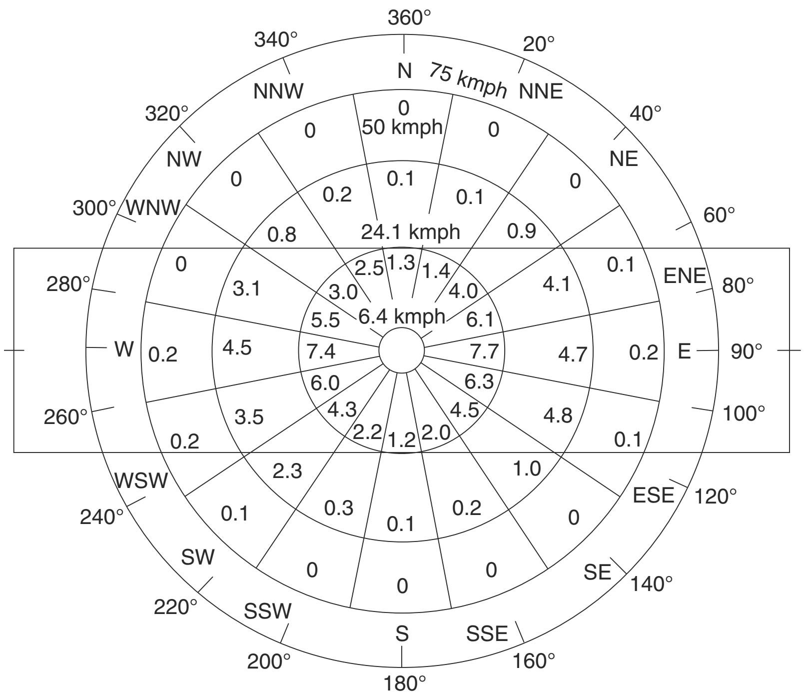


Fig. 13.11 *Windrose diagram*

13.12 AIRPORT ZONING

It is one of the planning by-laws which controls the height of the structures on land, surrounding the airport. Proposals for regulations of the height are based on the proposed land use in the surrounding area, size of the airport and type of the aircrafts. With a view of making the interpretation and application of the zoning ordinance, a zoning map showing property lines, ground contours and permissible structure height contours as related to the approach and turning zones is attached. A zoning ordinance however should not be oppressive, unreasonable, but should promote general welfare of the public, their health, safety and comfort.

13.13 AIRPORT CAPACITY

It is the number of aircraft movements, which an airport can process or handle within a specific period of time (usually one hour). It is influenced by numerous factors like runway pattern, number of runways, connecting taxiways, space kept for loading apron, weather conditions and available navigational aids for landing. It further varies with the type and classifications of airports and frequency of services offered.

13.14 IMAGINARY SURFACES

Several imaginary surfaces are established with reference to the airport and to each runway and on the type of approach planned for that runway. Figure 13.12 shows the

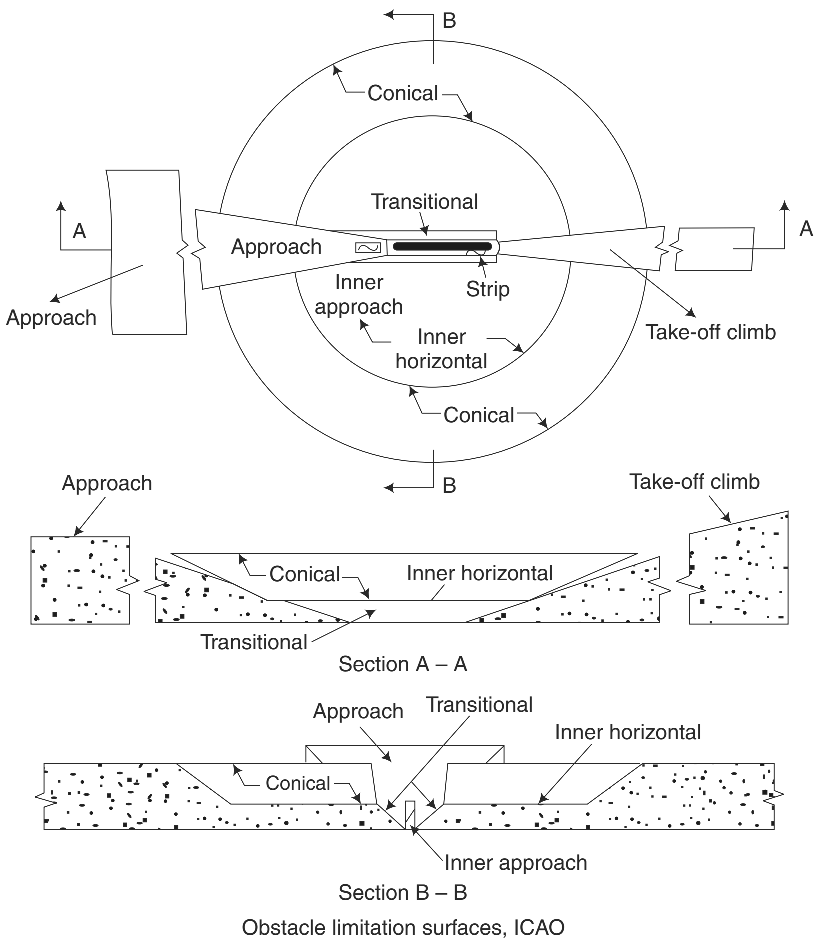


Fig. 13.12 *Imaginary surfaces*

plan and the section of imaginary surfaces. Primary imaginary surfaces can be classified into following five categories.

1. ***Primary Surface*** It is the surface longitudinally centred on a runway, i.e. when the runway is paved, the primary surface extends 200 ft beyond each end of the runway.
2. ***Horizontal Surface*** It is the horizontal plane 150 ft above the established airport elevation. The perimeter of which is made by swinging arc of specified radii from the centre of each end of the primary surface of each runway and connecting the adjacent arcs of lines, tangent to these arcs.
3. ***Conical Surface*** It is the surface extending outward and upward from the periphery of the horizontal surface at a slope of 20 to 1 for a horizontal distance.
4. ***Approach Surface*** It is the surface longitudinally centred on the extended runway centre line.
5. ***Transition Surface*** It is the surface which is extended outward and upward at right angles to the runway centre line and the runway centre line is extended at a slope of seven to one from the side of the primary surfaces.

13.15 FILLETS

These are provided at the joints of intersections of the traffic ways (runway, taxiway, exit taxiway, apron) to change the position of main gears path to go off the pavement onto the shoulder. It helps the aircraft to manuvoe the curves, junctions of runway and taxiway smoothly. If adequate fillets are not provided, one of the main gears of an aircraft, generally the one having large wheel base is likely to go off the pavement on to the shoulder. At all the airports, the fillet radii for exit taxiway, intended primarily to increase the acceptance rate of runway, should be designed according to the exit taxiway design criteria. Figure 13.13 shows the typical runway and taxiway fillets.

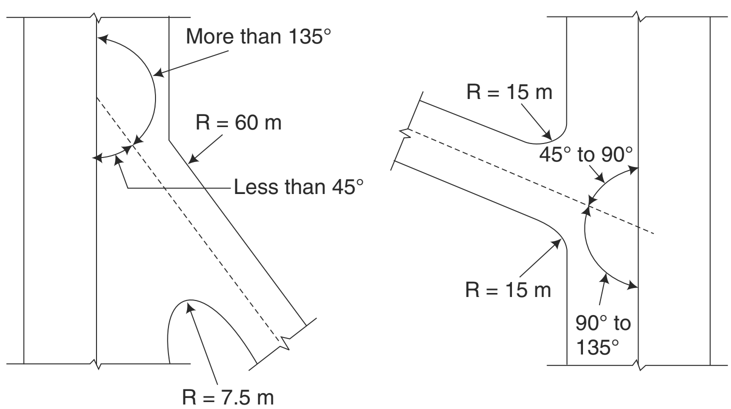


Fig. 13.13 *Typical runway and taxiway fillets*

13.16 BLAST PAD

These are the arrangements used to dissipate or deflect the higher velocity jet exhausts. The suitability of a particular type depends upon the amount of protection desired. US Corps of Engineers have conducted full scale as well as model tests on several types of blast pads. At runway ends and at other places where full thrust is applied, pads of 2.5 m to 3 m heights may be provided.

The location of the pad also has an important bearing on its effectiveness. Generally, if the pad is closer to the source of the blast, the performance is better, provided the extended centre line of the blast falls below the top of the fence. It is advantageous (where it is possible) to place fences so that prevailing winds blow over the fence towards the aircraft. This situation may eliminate the disturbing effects due to the surface winds. Figure 13.14 illustrates a blast pad.

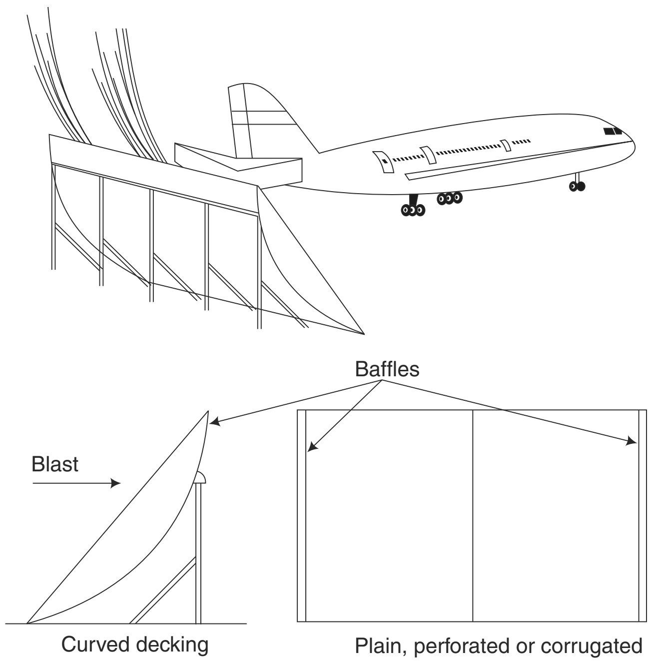


Fig. 13.14 *Blast pad*

13.17 HELIPAD

These are the areas designed to facilitate the take off and landing of helicopters. Helicopter is a rotorcraft. It works mainly on the lift generated by one or more power driven rotors moving about vertical axis to support motion to the machine in air. It works under the principle of VTOL (Vertical Take Off and Landing). It is advantageous in reconnaissance surveys, mercy flights, approaching inaccessible areas and hilly terrains. It is used during bad season (heavy rainfall, snowfall, winters) and when aeroplane operations are risky. Figure 13.15 shows the helipad arrangements.

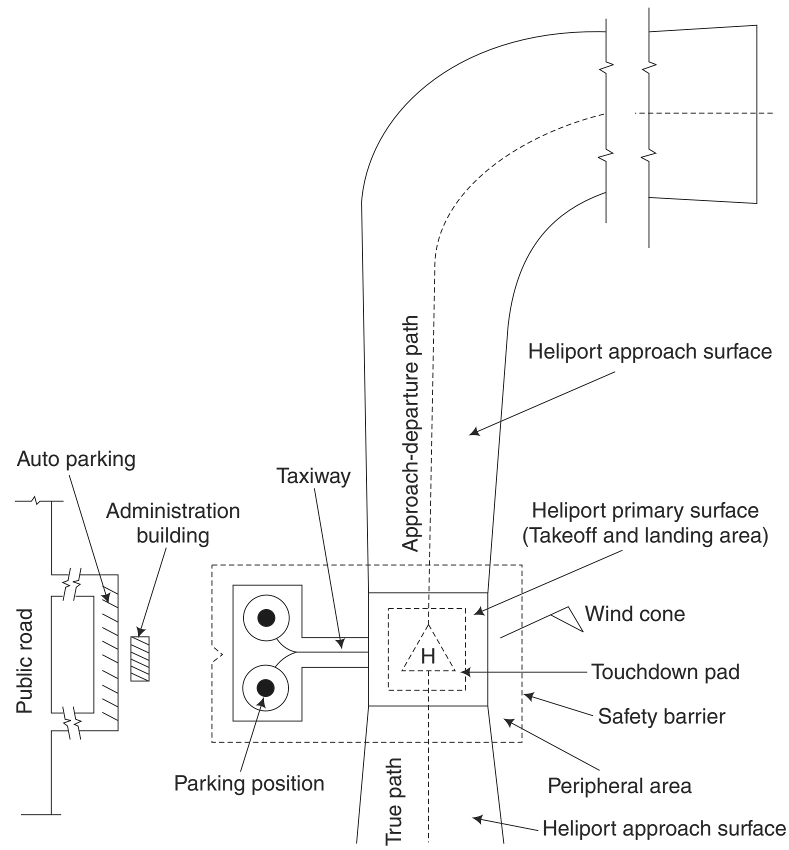


Fig. 13.15 *Helipad*

13.18 LANDING AIDS

Following are the landing aids provided at the airports.

1. ***Wind Direction Indicator*** The direction from which the wind blows is indicated by a wind cone. At least one such cone must be placed in each airport away from the buildings. It is placed within a segmental circle and usually painted in two colours. Usually, the length of the wind cone is 4 m and the maximum diameter is 1 m.
2. ***ILS (Instrumental Landing System)*** By this system, the approaching aircraft is brought to touch down on the runway with the help of radio beam facilities installed in the airport. The pilot operates the controlling instruments as directed by the radio beams. Only by following the instructions of this system, the pilot can

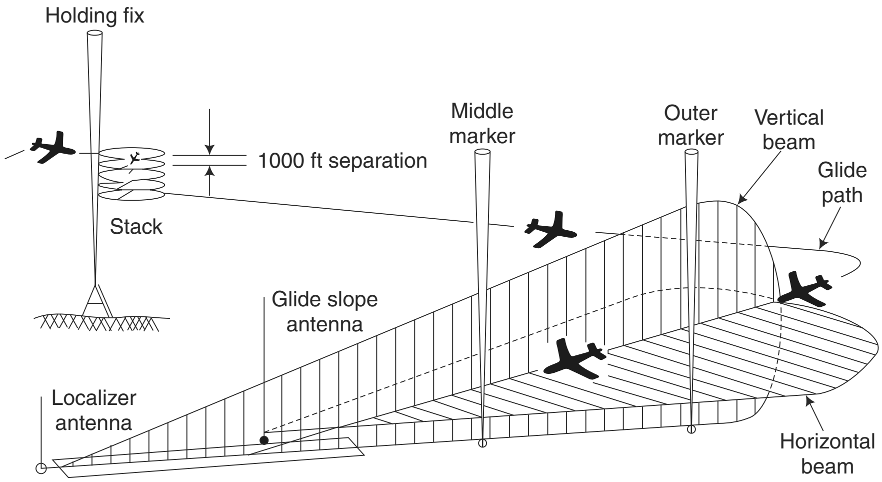


Fig. 13.16 *Instrumental landing system*

make a safe landing even without seeing the runway. Figure 13.16 illustrates an instrumental landing system.

3. ***Radar*** This is an important equipment helpful in air traffic control. Particularly for landing operation of an aircraft and for controlling them during flights. It consists of a radarscope which gives the controller a moving picture of the aircraft approaching the airport, both in plan and elevation. Suitable instructions for safe landing are given to the pilot on seeing the aircraft through the radar scope. Figure 13.17 illustrates a radar.

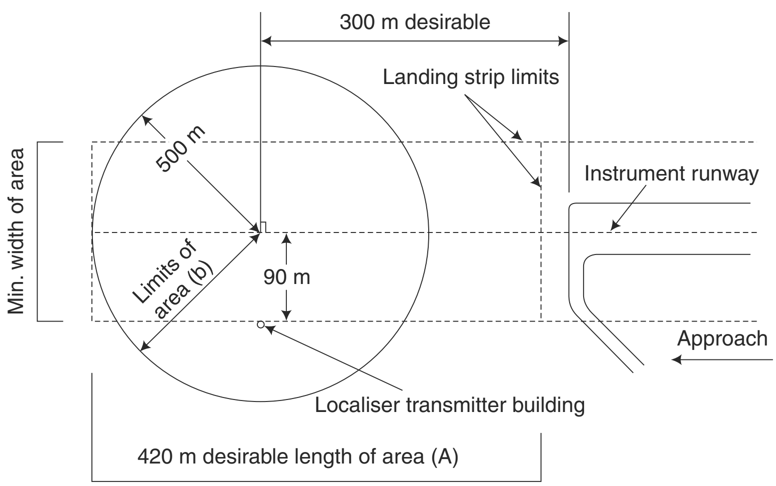


Fig. 13.17 *Radar*

13.19 STANDARDS

The International classification (ICAO) describes various geometric standards of the airport. Table 13.3 lists these standards. The classification has been done by using code letters, viz. A to E, in which A type of airport has the longest runway length and E type has the shortest runway length.

Table 13.3

Airport types	*Basic runway length*				*Runway pavement width*		*Max. longitudinal grade*
	Maximum		*Minimum*				
	m	*ft*	*m*	*ft*	*m*	*ft*	*%*
A			2100	7000	45	150	1.5
B	2099	6999	1500	5000	45	150	1.5
C	1490	4999	900	3000	30	100	1.5
D	899	2999	750	2500	22.5	75	2.0
E	749	2499	600	2000	18	60	2.0

Maximum effective grade

1.0% grade	for A, B, C
2.0% grade	for D, E

Maximum transverse grade

1.5%	for A, B, C
2.0%	for D, E

Rate of change of longitudinal grade

0.1% per 30 m length	for A, B
0.4 % per 30 m length	for C
0.2 % per 30 m length	for D, E

Safety area

Minimum width required for various type of airports are the following.

150 m	for A, B, C
78 m	for D, E

Safety area extends at least 60 m beyond runway end on either side.

13.19.1 Geometric Design Standards

ICAO prescribes several standards for airport geometric design. These standards are adopted in various countries. The following items are to be taken into account during the geometric design of runway.

1. Runway length
2. Runway width

3. Width and Length of safety area
4. Transverse gradient
5. Longitudinal and effective gradient
6. Rate of change of longitudinal gradient
7. Sight distance

13.19.2 Design Standards of Taxiway

The speed of a plane is much lower on a taxiway than on a runway during the landing or take off. Hence the standards for the geometric design differs with runway. The following elements are to be taken into consideration while designing a taxiway.

(i) Length of taxiway
(ii) Width of taxiway
(iii) Width of safety area
(iv) Longitudinal gradient
(v) Transverse gradient
(vi) Rate of change of longitudinal gradient
(vii) Sight distance
(viii) Turning radius

13.19.3 Geometric Standards for Taxiway (ICAO)

Table 13.4 lists the geometric standards for taxiway as per ICAO.

Table 13.4

ICAO Classification	*Taxiway width*		*Max. longitudinal gradient*	*Min. transverse gradient*	*Max. rate of change of longitudinal gradient per 30 m*	*Safety area width*
	m	*ft*	%	%		
A	22.5	1.5	1.5	1.5	1.0	Paved
B	22.5	1.5	1.5	1.5	1.0	shoulders are
C	15.0	3.0	3.0	1.5	1.0	not mandatory
D	9.9	3.0	3.0	2.0	1.2	but are suggested
E	7.5	3.0	3.0	2.0	1.2	if needed

Length of Taxiway It should be as short as possible to save the fuel consumption. No specification limiting the length of taxiway is recommended by any organisation.

Width of Safety Area It includes pavements of taxiway with its shoulders on either side. This may extend to point where, it meets a parallel runway, taxiway or an apron.

Short-Answer Questions

1. Define Airport.
2. Enumerate the components of an airport.
3. Enumerate the classifications of an airport as per ICAO.
4. What is meant by imaginary surfaces?
5. What is a fillet? Where is it used?

Exercises

1. Write briefly about airport zoning and airport capacity.
2. Explain briefly a runway and taxiway.
3. Write a brief note on landing aids.
4. Explain with neat sketches the principle of ILS.
5. Write a short note on windrose diagram.

Chapter 14
DOCKS AND HARBOURS

14.1 WATERWAYS

In all types of the surface transport systems, water transport is almost as old as human habitation on this globe. Man initially exploited the resources use in water transport as means of travel from place of place. This resulted in the discoveries of new continents and new resources and a need for large, better designed and equipped sea going vessels was felt.

The technology of boats and boat building did not change rapidly until the nineteenth century. River boats and canal barges were extensively used in inland waterways such as navigable rivers and major lakes. Ocean going ships used sails for travel. Early ships were built with wood. It had a safety factor, i.e. the ship's hull floated even after the ship had been wrecked.

In the case of bulk carrier and tankers, the sizes are increasing. In water transport the capacity of vessels has increased rapidly in a short period and has reached a high value compared to any other mode of transport. Consequently, the other transport modes, terminal facilities and handling equipment have undergone a transformation to meet the challenge posed by the ocean going vessels. Containerisation cargo is one such young area of coordination, for operation of different transport modes.

14.2 FUNCTIONS OF WATER TRANSPORT

1. It is the easiest and cheapest mode for long distance travel.
2. It provides efficient and speedy bulk cargo handling.
3. It provides just in time assistance during war period to safeguard nation's interest.
4. It promotes development of industries like scrap work, ship building, loading and packaging.
5. It connects different countries of varied cultures and languages hence promoting harmony.

6. It is best suited for movement of huge and heavy machinery.
7. It provides higher safety level than airways since even after wrecking the passenger can be rescued.
8. It is one of the oldest mode which uses the channels, canals, river (inland waterways) effectively.

14.3 COASTAL STRUCTURES

These are structures designed to cater to the needs of water transport to facilitate safe and better movement of passengers and bulk cargo from one place to another place. The coastal structures are highly advantageous as they protect the vessels during stormy periods. The quays, wharves and jetties cater to the inland transportation.

14.4 CLASSIFICATION OF SHIPS

The transport ships are broadly classified as passenger cargo, bulk carrier, tanker and container ships. In addition, there are tugs and ferry vessels. According to the type of propulsion, they are classified as steam, motor, turbo-electric, diesel-electric, gas turbine, gas turbo electric and nuclear powered ships.

Its length and maximum width, known as a beam and draft, in addition to its capacity, measures the characteristics of a ship. The draft is the depth of submersion when loaded to capacity. The capacity is expressed in terms of displacement which is the weight of water displaced by the floating ship. Thus, the displacement is the weight of the ship plus its contents. For tankers and bulk carriers, the weight of the cargo alone is measured as the dead weight tonnage. A measure of cubic capacity is used for mixed cargo and passenger vessels.

14.5 SEAPORTS

A seaport is one which provides sheltered berthing for ships and has facilities for embarking and disembarking of passengers, loading and unloading of varied cargo, storing and sorting of various consignments and servicing of ships. A harbour is the main component of a seaport which is a partially enclosed water area where the ships can find refuge from storms and waves. Here, there are facilities for refuelling, repairs and cargo handling in addition to other services. There are two classes of harbours, namely, natural harbours and artificial harbours. Chennai and Tuticorin harbours are artificial harbours where a portion of sea is enclosed by the construction of suitable breakwaters. Mumbai and Cochin have natural harbours where the ships get protection by existing islands, bays and mountains around the water spread. The wave action is minimised in these enclosed areas. Harbours are further classified as military, commercial, fishing and refuge harbours.

To fulfill its function, a harbour must satisfy the following three requirements.

1. The harbour should have sufficient depth of channel for the draft of vessels using it.

2. Sufficient protection for ships should be provided against destructive wave action.
3. The bottom of the harbour area should provide sufficient anchorage for ships against high winds.

River ports serve for landing of freight from river boats and barges in up country locations. Some river ports are developed at a river mouth for serving ocean traffic. Kolkata (Calcutta) harbour is an example. Layout of an harbour is shown in Fig. 14.1.

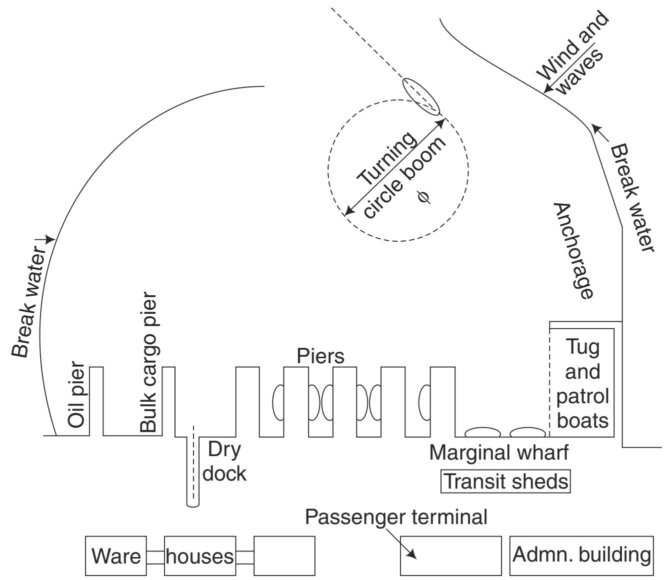


Fig. 14.1 *Layout of a harbour*

A harbour requires extensive area for its operation. The extent of area depends on the sizes, number and types of ships which it attracts. Considerable space is required for a ship at anchor in a harbour basin. So the harbour basin has to be planned for receiving the ships, anchoring them, mooring them to wharves for loading and unloading operations and for guiding the ships out of the basin after loading operations. The basin is to be planned taking future traffic requirement in terms of changes in size, weight and draft of ships. In addition, sufficient land area should be provided for corresponding increase in shore operations.

A marine terminal is that part of a port or harbour which provides docking for ships, cargo handling and storage area. The wharf area exclusively used for passenger embarkation and disembarkation and light cargo transshipment is called a passenger terminal. When cargo traffic is the main function, the terminal is referred to as a freight or cargo terminal. When ores, petroleum products, cement and grains are stored and handled, it is known as a bulk cargo terminal.

14.5.1 Port Planning and Location

The factors contributing to the decision to locate a port are its need, economic justification, prospective tonnage of goods to be handled, adequate inland water and land communication. After taking a decision for planning a port, technical studies of the harbour are made. Several locations need to be studied for finding the most protected location. The site investigation will usually include the following surveys.

(i) Hydrographic survey
(ii) Topographic survey
(iii) Soil investigation
(iv) Tide and current observation
(v) Data collection on the wind, waves and earthquakes, if it is an area of seismic disturbance
(vi) Information on the availability and cost of construction materials and labour
(vii) Collection of details regarding local ordinances, building codes and housing facilities.

After planning and designing of harbour, it is a sound engineering technique to conduct the testing of hydraulic models of the harbour layout.

14.5.2 Breakwaters

A breakwater is a structural in the sea to provide an enclosed water basin for safe berthing of ships. The breakwater has an opening known as the harbour entrance with enough channel depth for navigation. The purpose of a breakwater is to break the force of the sea waves.

There are different types of breakwaters. Natural rock, concrete or a combination of both are extensively used in the construction of breakwaters. Steel and timber are also used in the construction. Sometimes, the breakwater is so designed and constructed to serve the dual purpose of giving protection and becoming a part of a pier or a supporting roadway. In the former case, it is termed as a breakwater pier or quay and in the later, a mole.

There are two main type of breakwaters, the mound type and the wall type. The materials commonly used for mound type of breakwater are natural rock, concrete block or a combination or rock and concrete block and concrete. For wall type breakwater, concrete block, gravity walls, concrete caissons, rock-filled sheet-pile cells, rock-filled timber cribs and concrete or steel-pile walls are used. Figure 14.2 shows the cross section of a vertical type of breakwater.

The type of breakwater selected for any harbour is based on the availability of construction materials, condition of sea bottom, functions in the harbour, the depth of water in the basin, the manpower, period and equipment available for construction. Vertical type of breakwater are limited to a depth of 20 m or less, below water level due to practical considerations.

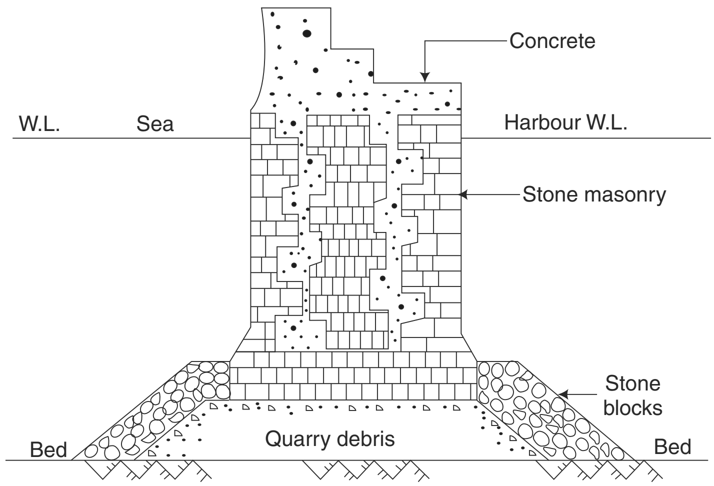
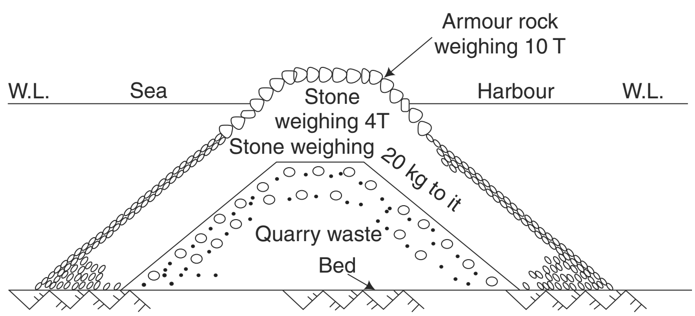
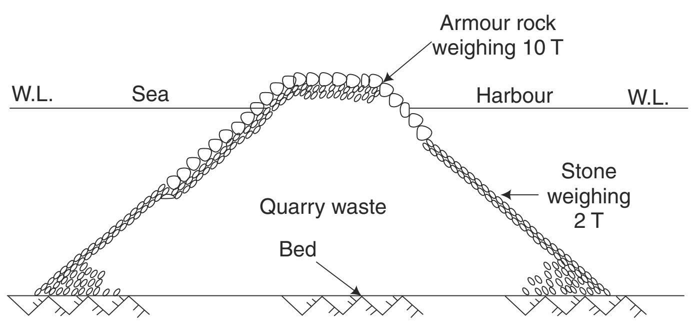


Fig. 14.2 *Vertical type breakwater*

There are two distinct types of mound breakwater. In the first type, the core material extends as a mound above water level and is covered by armour rock layer. In the second



Type with shortened core



Type with extended core

Fig. 14.3 *Mound type breakwater*

type, the core fill is stopped at a considerable depth below water level and is then filled and covered with medium weight rock. This is topped by a heavy armour capping. Figure 14.3 shows the two types of mound breakwater.

14.5.3 Wharves, Piers and Bulkheads

A dock is a general term used for a marine structure for mooring or tying of ships. More specifically, a dock is referred to as a pier, wharf or a bulkhead in American practice. In European terminology, they are referred to as jetty, quay and quay wall. A wharf or a quay is a dock for ships which is parallel to the shore. A bulkhead or quay is similar to a wharf but is away from the shore line and is packed up by ground. A pier or a jetty is a dock which is projecting into the water. The pier may be perpendicular or inclined to the shore line. Compared to a wharf, a pier may be used for docking on both sides. A pier is also referred to as a mole and is termed as a breakwater pier in combination with a breakwater.

14.6 PORT STRUCTURES

A modern port may require the following buildings, passenger terminal, transit sheds, warehouses, silos, storage tanks, cold storage, administrative and customs offices, repair shops, garages, fire-house and powerhouse.

The passenger terminal and customs are located in one building. Transit sheds are to be located very close to the wharf area. They provide temporary storage for incoming goods arriving by land meant for export. Transit sheds should not be used as warehouse. The transit sheds need more aisle space for quick handling of goods by mobile equipment. There should be enough door openings and circulatory space around transit sheds for operations. The warehouses are similar to transit sheds except that they have wider column spaces, heavier floor design and larger floor areas. Some of them are provided with gantries for operating overhead cranes. Special purpose warehouses are planned for specialised cargo items. There should be cold storage facilities for perishable items.

Sufficient buildings are required for various shipping companies, importers, repair shops, police station, fire and ambulance stations and miscellaneous requirements. The planning of a port administrative building depends considerably upon the system of administration, the geographical location of the port and its size. There is no universal standard procedure for operation of a port. It is generally recognised that a centralised administrative agency with broad powers is essential for the efficient and economical operation of a port. The port may be administered by the national government, the municipality or a port authority. The seaport at Chennai is administered by a special body called the Chennai Port Trust headed by a Chairman and a council of members.

14.7 BERTHING STRUCTURE

It is a facility where the vessel may be safely moored. The berthing arrangements can be classified as along side type, open dolphin type or ferry type.

The berthing structure can be also classified as vertical face type or open type structure. In vertical face structures, sheet pile wall, block wall, caissons are used. Further, they are classified on the basis of the type of cargo handled. The Chennai port outer harbour basin has oil berth and container berth where oil, ore and containers are handled respectively. The berthing structures can also be classified as follows.

14.7.1 Gravity Structures

The onshore structures are classified into gravity and berthing structures. The gravity structures can be broadly classified into the following.

(i) Masonry wall
(ii) Concrete block walls
(iii) Concrete caissons
(iv) Flexible structures
(v) Steel sheet piles
(vi) Diaphragm walls
(vii) Jetties

14.7.2 Loading on Berthing Structures

The berthing structures are to be designed for

1. Berthing force
2. Mooring force
3. Dead load
4. Live load
5. Active earth pressure
6. Environmental factors
7. Seismic force
8. Secondary stresses due to shrinkage, creep temperatures

Live Loads Surcharge due to stored and stacked material such as general cargo, bulk cargo, containers and loads form vehicular traffic of all kinds including trucks, trailers cranes, container handling equipment and plant constitute live vertical loads.

Truck Loading and Uniform Loading The berths is generally designed for the truck loading and uniform loading by IS: 4651 (Part III) 1974 (Table 14.1).

Table 14.1

Function of berth	*Truck loading (IRC class)*	*Uniform vertical live load T/sq.m.*
Passenger berth	B	1.0
Bulk unloading and loading berth	A	1 to 1.5
Container berth	A or AA or 70R	3 to 5
Cargo berth	A or AA or 70R	2.5 to 3.5

Heavy cargo berth	A or AA or 70R	5 or more
Small boat berth	B	0.5
Fishing berth	B	1.0

14.8 DOCKS

It is an essential component of the harbour and ports. It is necessary to build the ships, repair and renovate the ships. In every harbour some sort of repair facilities for ships are desirable. In terminal ports these facilities are essential. The old practice for harbours with some tidal range was to push up the vessel at high tide and leave it there beached, when the tide recedes. For this, an easy gradient of the ground and hard bottom to take the weight of the ship, are necessary. The practice is quite satisfactory for sailing crafts and even now, in some ports, where a huge number of sailing crafts take shelter during monsoon and need annual inspection, this is perhaps a very cheap method.

14.8.1 Dock Dimensions

Each dry dock is characterised by physical dimensions which define the size of the ship that can be built or repaired in it.

(a) Length The effective length should be 3–4 m greater than the total length of the ship using the dock.

(b) Width The effective width can be taken as the distance between the fenders is calculated by taking the greatest width of the ship plus an allowance on each side ranging from 3–6 m. Usually, the ratio of effective length and effective width is between 5–7 m.

(c) Depth The effective depth is the depth of sill at the design water level. For design purposes, the depth corresponding to the average level of low water should be taken. In cases when waiting of a ship cannot be allowed, the depth of entrance is determined with respect to absolute lowest sea level. In tidal harbours, the largest ships are usually docked during high tide. Because of the regularity of tides, the waiting period for the correct water level is relatively short.

14.8.2 Classification of Docks

In general, docks are classified into several categories, viz.

1. Dry dock (Graving dock)
2. Lift dock
3. Floating dock
4. Spillway and marine railway

Figure 14.4 shows the plan and elevation of dry dock.

1. Dry Dock The arrangement in a dry dock is to take in a vessel, close the gate and pump out the water. Sometimes, it is possible to take advantage of tidal variation so as to obviate or reduce the need of pumping.

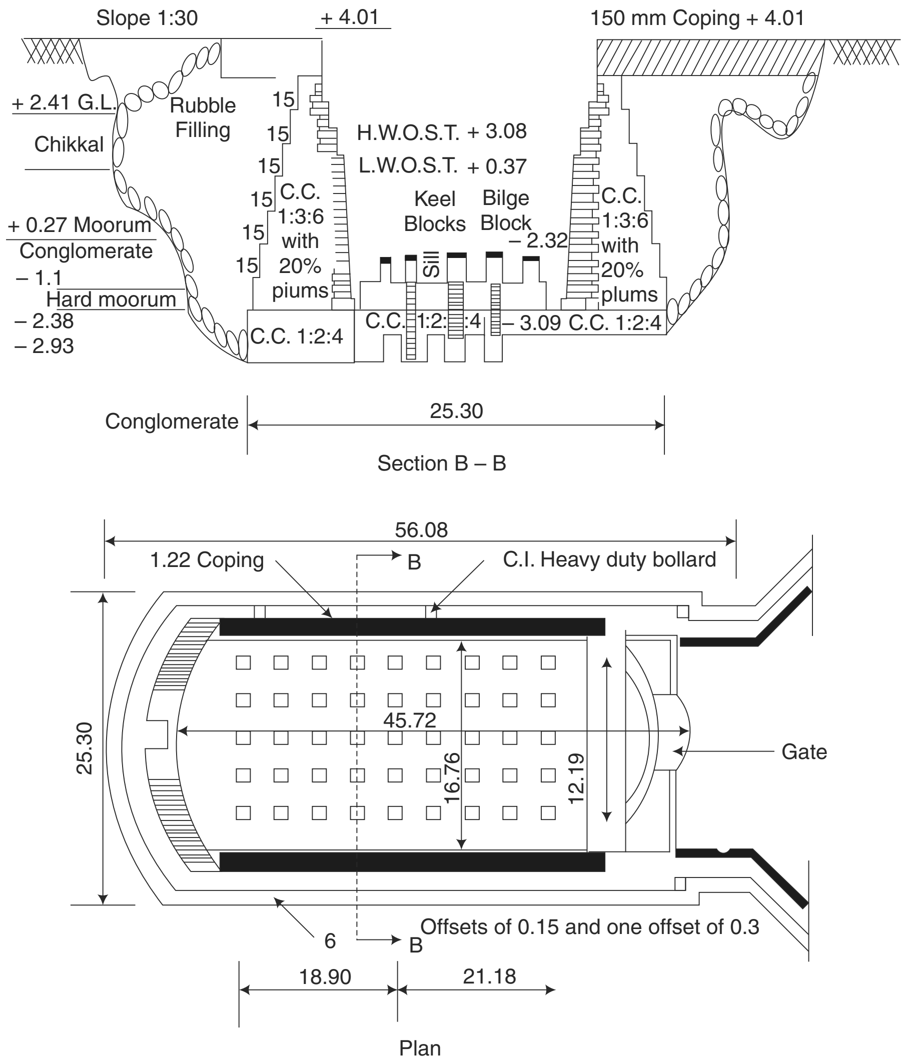


Fig. 14.4 *Dry dock*

2. Lift Dock This is a small dock intended to dock crafts like tugs, dredgers and barges. The arrangement of parabolic arch type gate is simple and comparatively light and cheap. The parabolic arch has the advantage of uniform distribution of stress. The crane employed for lifting the gate is also available for working in the dry dock to lift heavy steel pieces or machinery.

3. Floating Dock Floating dry dock is a hollow structure, made of steel or of reinforced cement concrete. To receive a vessel for repairs, the floating dock is sunk to the required depth by allowing buoyancy chambers to be filled with water. When the vessel is berthed, the water is pumped out of buoyancy chambers, thus causing the dock to rise bodily and hence lifting the vessel above the water line.

A floating dry dock is required to be moored in deep and calm waters. Cost of repairs to ships also increases, as men and materials have to be moved from shore to the floating dry dock.

4. Slipway and Marine Railway In a slipway, rails laid on a firm ground at a uniform slope, from some distance under water to a point at which the longest vessel to be accommodated is completely cut off the range of the tide. The slope of a slipway may range between 1 in 12 to 1 in 25 depending on the local circumstances. Easier the slope, the longer is the slipway, with a possibility of it being a hindrance to navigation. The slipway extends into water to some length. It is also sufficiently above high water to accommodate the full length of the biggest vessel likely to be slipped.

14.9 TRANSIT SHEDS

A transit shed as shown in Fig. 14.5 is a necessary facility attached to a berth. A port, therefore, does not, charge any rental for its use. But, as it is a facility only for goods in transit, a certain period, usually 3 to 5 days, is prescribed for its free use. Beyond this period demurrage is charged. The idea of demurrage is to discourage the use of a transit shed beyond the free period allowed. In doing so the space can be used for other cargo could be handled at the berth. Demurrage charges are usually at increasing rates as the period of occupancy increases.

The factors to be considered while designing the transit shed are the following.

1. Nature of cargo, height of its stacking and allowance for movement and other non-storage areas.

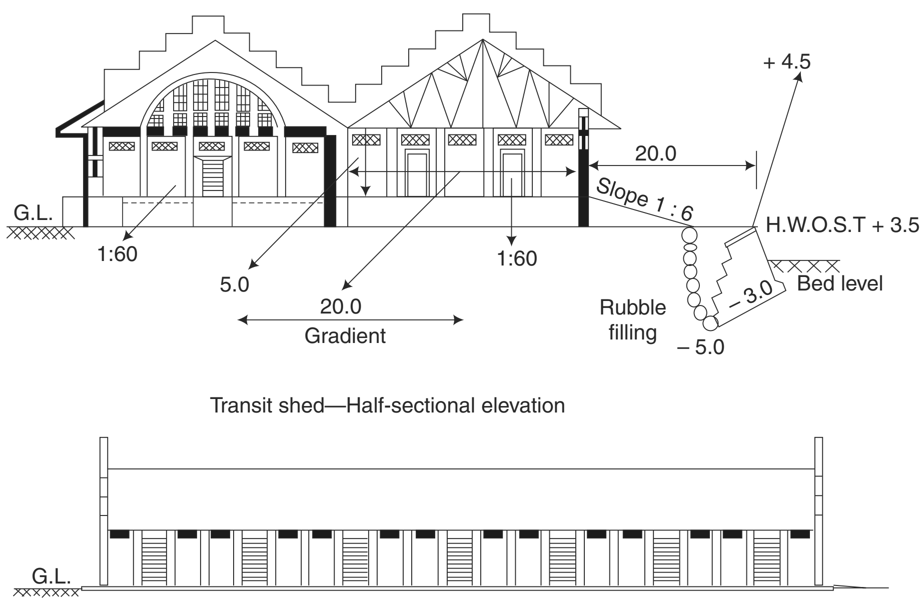


Fig. 14.5 *Transit shed*

2. Size of the vessels and frequency of calling.
3. Amount of goods to be exported per day.
4. Seasonal variations prevailing in that area.
5. Extent of land available for development.

14.10 WAREHOUSES

The users of a port, sometimes, need storage facilities for periods much longer than what the transit sheds will permit. For this, the port sometimes constructs or permits others to construct storage facilities which are known as storage godowns or warehouses. Unlike transit sheds, these warehouses are away from the berths. They should not be closer to an operating berth than the length of the berth. They are provided with railway sidings and roads.

The capacity of a shed or a warehouse is determined by the load of goods it can accommodate. This, in turn, will depend upon the nature of goods. As for example, cotton bales, cement bags, groundnut bags and deoiled cakes require different areas for the same load. A warehouse is shown in Fig. 14.6.

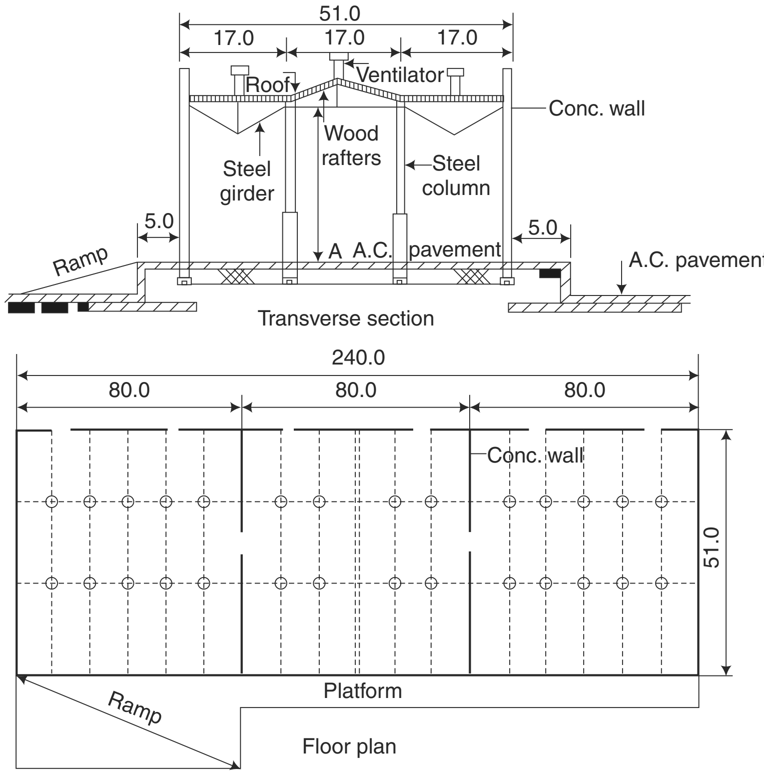


Fig. 14.6 *Warehouses*

14.11 DOLPHINS

Dolphin is a structure located at the entrance of a locked basin or alongside a wharf of pier, to absorb the impact force of the vessel or to provide mooring facility. Breasting dolphins are designed to take the impact of the ship when docking and are equipped with fenders. They also usually have bollards or mooring posts. Breasting dolphins are in front of the sea-face of the berth.

Mooring dolphins are located behind the seaward face of the berth and hence are not hit by the ship. Mooring lines, provided by breasting dolphins, are not sufficient to hold the vessel against currents away from berth. And for this, mooring dolphins are provided to which mooring lines from the ships are taken. The mooring dolphins are usually smaller than the breasting dolphins. Figure 14.7 depicts the breasting dolphin.

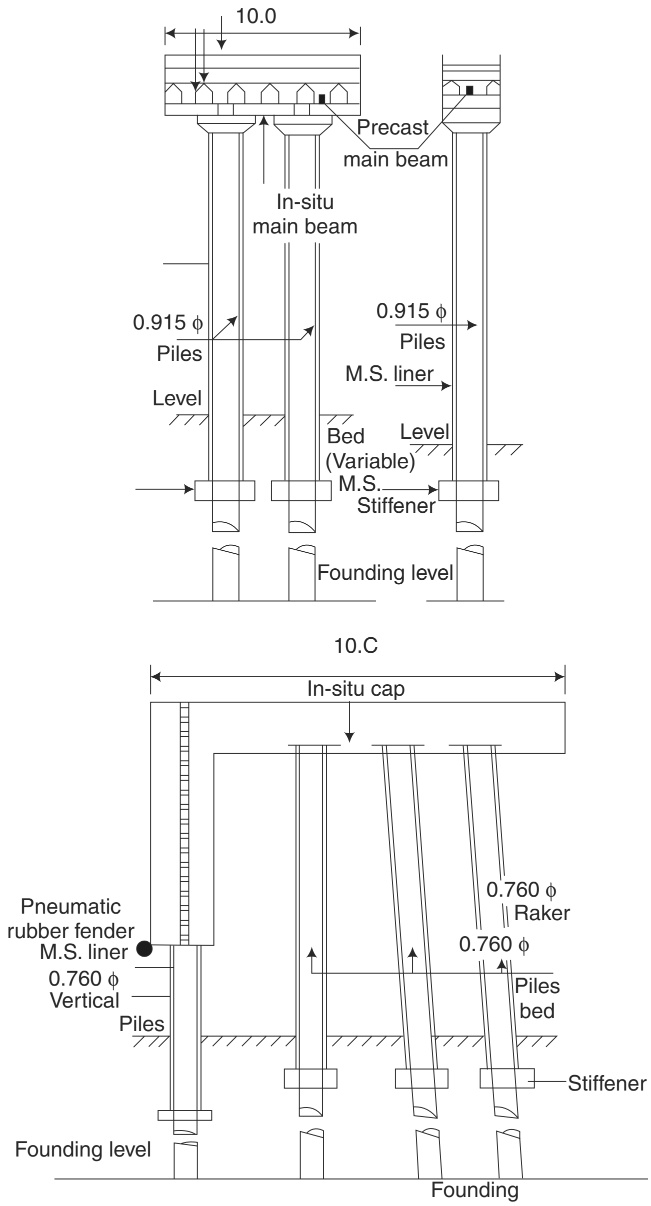


Fig. 14.7 *Breasting dolphin*

14.12 FENDERS

A jetty face is provided with a cushion for ships to come in contact with. This cushion is known as fender. It is provided in various forms and is made of different materials. Considerable ingenuity is, sometimes, displayed in devising and providing these fenders. In sheltered places, for gravity wharves, ordinary rubbing strips of rubber, timber or merely woven coir padding is sufficient. These extend from wharf coping to the low tide level, attached to the wharf face, at the intervals of 3 to 4 m. Where only very small crafts, such as barges and launches are to come alongside, old car or truck tyres are also used. The idea is to absorb hull.

When a ship is brought alongside a berth (Fig. 14.8) it first strikes the fenders. The contact is generally near the quarter point, that is near one-fourth the length of the ship. The fender is pressed and simultaneously the ship swings towards the berth and also somewhat move forward, absorbing the energy of impact. If the berth is a non-grid structure, such as a piled quay or much more a dolphin, it deflects and absorbs some energy of impact. Figure 14.8 depicts the typical rubber fenders.

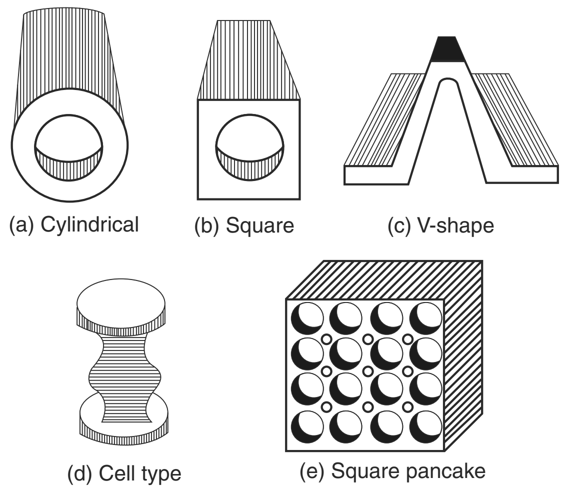


Fig. 14.8 *Rubber fenders*

14.12.1 Fender System

The fender system is used to prevent damage to both the vessel and berth, during the berthing process and while the vessel is moored. As the vessel approaches a berth, it possesses kinetic energy by virtue of its displacement and motion. As the vessel contacts the berth and is brought to stop, this kinetic energy must be dissipated. Fender systems are provided to absorb or dissipate the kinetic energy of the berthing ship.

14.12.2 Types of Fender Systems

The different types of fenders systems are as listed below.

1. Standard pile fenders
2. Rubber fenders
3. Pneumatic fenders
4. Gravity type fenders

14.12.3 Fenders Systems Selection Criteria

The selection of an optimum fender for a given service depends on the following factors.

1. Type, kind, size, draft and allowable hull pressure of a vessel
2. Berthing velocity and angle
3. Distance between the berthing point and the vessels gravity centre measure along the face of the pier
4. Water level, tidal range, wind velocity, direction of wind
5. Structure and strength of berthing facilities
6. Velocity of currents
7. Behaviour of dock fenders

14.13 MOORING ACCESSORIES

Mooring is referred to the parking of ships or vessels in harbour. In a sheltered harbour, natural or artificial, but there should be a water area where ships can wait. This area, which will have sufficiently deep water and will be out of the path of harbour channel, is called the anchorage or anchorage area. Normally, ports provide wharves and jetties for

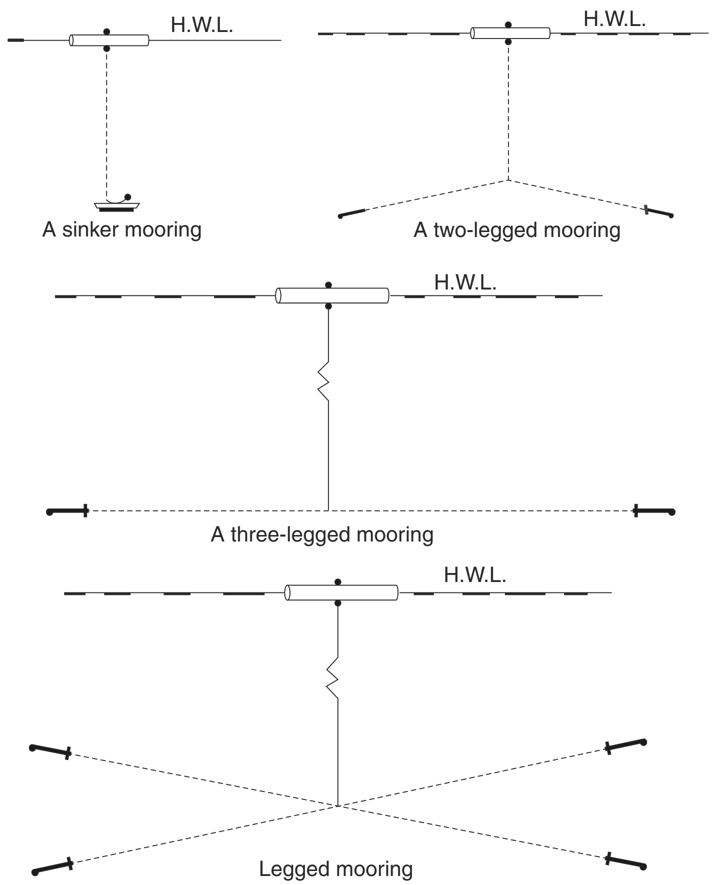


Fig. 14.9 *Typical Mooring System*

berthing of vessels so that cargo and passengers can be moved conveniently. The mooring accessories include mooring buoy, anchor, PLEM, mooring chain, floating hose, mooring pendent, floating buoy, etc. Figure 14.9 shows a typical mooring system.

14.14 BUOY

Buoys are diverse designs. The important types are cylindrical, drum, pear-shaped and spherical. These are shown in Fig. 14.10. Cylindrical buoys, as they can readily heel over, are convenient for small crafts. Drum buoys are more suited than cylindrical buoys, for less sheltered positions, as they have a small surface to present to waves. Pear-shaped is very widely used as it has substantial carrying capacity with stability and it possesses considerable rigidity. Spherical buoy is technically rigid and convenient to ride the waves, but it is expensive to construct and has very little room to accommodate men to make fast the vessel.

Buoys intended for moorings or other purposes may be of any shape or colour, according to the discretion or the authority within jurisdiction they are laid. But they are not such so as to be confuse with other buoys. Buoys fitted with sound signal devices have, if practicable, the characteristics appropriate to their position in accordance with the foregoing rules.

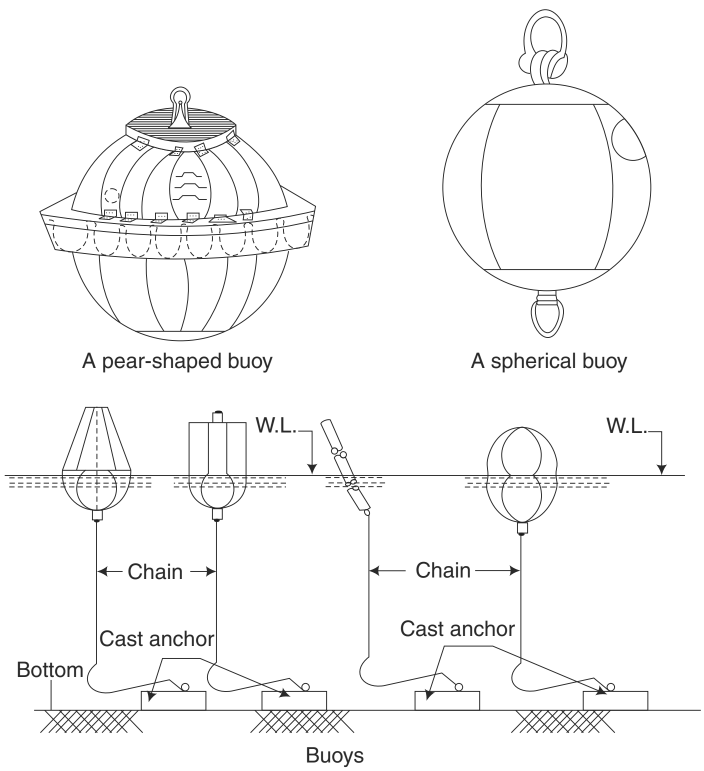


Fig. 14.10 *Buoys*

14.15 NAVIGATIONAL AIDS

These are the accessories used to guide the ships in their routes and to warn them of hit and danger. They give information about the hidden dangers. There are several accessories and aids available to help the ships to avoid such dangers. The navigation lights commonly adopted are lights along the coast, light ships, lighthouse, fixed lights (on piers, wharves and dolphins) and beacon light.

14.15.1 Lighthouse

These structures are made of concrete, brick and or stone masonry to withstand heavy weather along the coast and to guide the ships during days and nights. The structures are illuminated by beacon light lantern on the top. The light may be white or coloured flashing lights powered by share electric current batteries. The flashing of lights is done by revolving the entire lens by electric motor. The height of lighthouse varies with locations, the height should be such that the light beam should be visible to the vessels in the horizon. The larger lighthouses are equipped with fox signals produced by various types of sounding devices. The lighthouse may be attended or unattended depending upon its size and location. Figure 14.11 shows a typical lighthouse.

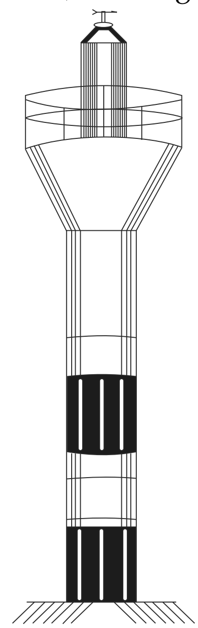


Fig. 14.11 *Lighthouse*

14.15.2 Light Ships

In locations where lighthouse is not available light ships are used to serve the same purpose. They vary in size and form full manned ships. They are equipped with automatic lights, fog lights, etc. They are usually held in position by a single anchor. Lighted buoys have central framed or tower structures mounted on a broad metal base to provide adequate buoyancy and stability in strong weather. Bases are required to contain required acetylene gas in steel tanks. Storage batteries are also used. They are operated by atmospheric light and automatically extinguish the lights at dawn and relight them at twilight. Figure 14.12 depicts a typical light ship.

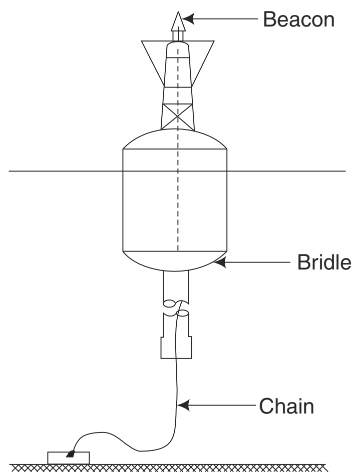


Fig. 14.12 *Light ships*

14.15.3 Fixed Lights

These are all fixed on piers, wharves and mooring dolphins. They are placed at each end, to outline their limits and are powered by shore electric current. Besides the lights on piers, wharves and mooring dolphins, beacon-light lanterns are sometimes placed at each end in order to show their limits. At the ends of breakwaters, at harbour entrances, and on points of special danger to shipping, beacon lights on fixed structures are placed. These lights are powered by shore electric power supply, storage batteries, or acetylene gas. Fixed-structure channel markers are lighted. They are fixed into the channel bottom, supported on pipes or piles and beacon lanterns are mounted on top.

Short-Answer Questions

1. Write short notes on waterways.
2. What are the functions of water transport?
3. What are coastal structures and why are they called so?
4. Enumerate the classification of ships.
5. Define seaports.
6. What are the surveys to be conducted while planning a port?
7. Write notes on dock dimension.
8. Write notes on uniform loading.
9. Write notes on tender system.
10. What is meant by fixed lights?

Exercises

1. Briefly explain what are breakwaters.
2. Explain briefly wharves, Jetty and warehouses.
3. Distinguish between dock and harbour.
4. Briefly explain the mooring accessories.
5. Explain what is a lighthouse with a neat sketch.

Chapter 15
INTERIOR DESIGN

PART A — INTERIOR DESIGN

15.1 INTERIOR DESIGN

'Interior design is a multi-faceted profession in which creative and technical solutions are applied within a structure to achieve a built interior environment. These solutions are functional, enhance the quality of life and culture of the occupants, and are aesthetically attractive.*

Designs are created in response to and coordinated with the building shell, and acknowledge the physical location and social context of the project. Designs must adhere to code and regulatory requirements, and encourage the principles of environmental sustainability.*

The interior-design process follows a systematic and coordinated methodology, including research, analysis and integration of knowledge into the creative process, whereby the needs and resources of the client are satisfied to produce an interior space that fulfills the project goals'*

15.2 FUNCTIONAL REQUIREMENT OF AN INTERIOR DESIGNER

A professional interior designer is a person qualified by education, experience and examination who

- analyses the client's needs, goals and safety requirements
- integrates findings with knowledge of interior design
- formulates preliminary design concepts that are appropriate, functional and aesthetic
- develops and presents final design recommendations through appropriate presentation media

*Note: Definition of Interior Design as per 'National Council for Interior Design Qualification'.

- prepares working drawings and specifications for non-load bearing interior construction, materials, finishes, space planning, furnishing, fixtures and equipment
- collaborates with licensed practitioners who offer professional services in the technical areas of mechanical, electrical and load-bearing design as required for regulatory approval
- prepares and administers bids and contract documents as the client's agent
- reviews and evaluates design solutions during implementation and upon completion

15.3 BASIC ELEMENTS OF INTERIOR DESIGN

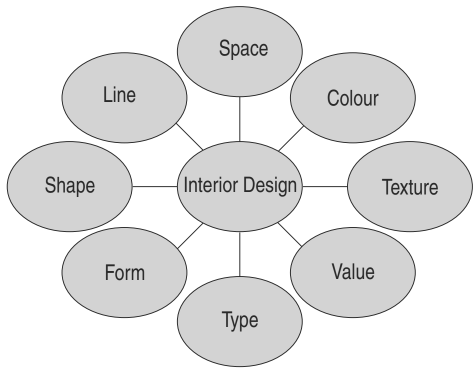


Fig. 15.1 *Elements of interior design*

15.3.1 Shape or Form

Shape is the primary means by which we distinguish one form from another. Appealing interiors can be designed using appropriate shapes. The following are some categories of shapes:

Natural shapes represent the images and forms of the natural world. These shapes may be abstracted.

Non-objective shapes make no obvious reference to a specific object or to a particular matter. Some non-objective shapes may result from a process such as calligraphy and carry meaning as symbols.

Geometric shapes are of two types—rectilinear and curvilinear. Curvilinear shapes are circular while rectilinear shapes include a series of polygons, which can be inscribed within a circle. Extended into the third dimension, these primary shapes generate the sphere, cylinder, cone, pyramid and cube.

15.3.2 Colour

Colour plays an important role in interior design. Specific colours can be used to enhance the characteristics of a space based on its specific function.

Choosing Colours for Different Places

(a) Comfort Colours The comfort colour palette is a good choice for kitchens and family rooms since they wrap the room in warmth and comfort. The most common comfort colours include biscuit and wheat neutrals; cocoa browns, pumpkin oranges; and cinnamon apple-pie shades.

(b) Natural Colours Natural colours can be used as a delicate accessory or a bold accent. They are great for bedrooms and bathrooms since they remind a sense of the outdoors. Natural shades such as yellows, blues, greens, and organic browns are often used in combination with rich metallic or rust and copper accents.

(c) Contrast Colours Stark contrast colours such as deep reds, plums, and brisk blacks and whites, all add an elegant touch of sophistication to a room. Contrast colours can be used as an accent, or an elegant backdrop. They are mostly used in formal dining rooms, living areas or powder rooms with polished brass and metallic decorations as complimentary accessories.

15.3.3 Texture

Texture is the visual or physical feel of the fabrics, colours, and other elements. There are two types of texture—visual texture and texture which you can sense with your five senses.

15.3.4 Light

The first function of lighting design is to illuminate the form and space of an interior environment and allow users to undertake activities and perform tasks with appropriate speed, accuracy, and comfort. There are three methods for illuminating a space:

- Ambient or general lighting
- Task or local lighting
- Accent lighting

Ambient or General Lighting General or, ambient, lighting illuminates a room in a fairly uniform, general diffuse manner. General lighting can also be used to soften shadows, smooth out and expand the corners of a room and provide a comfortable level of illumination for safe movement and general maintenance.

Task Lighting Local or task lighting illuminates specific areas of a space for the performance of visual tasks or activities. The light sources are usually placed close to either above or beside the task surface.

Accent Lighting Accent lighting is a form of local lighting, which creates focal points or rhythmic patterns of light and dark within a space. Accent lighting is used to emphasise a room's feature or highlight art objects or prized possessions.

Natural Light The building should be constructed in such a way that the daylight can be utilised to a maximum for routine activities inside the building. The number and size of openings such as windows, ventilators, doors, etc., in the building should be designed in such a way so as to get more natural light. Natural light should not create any shade or glare.

Daylight Factor The ratio of illumination at the working place inside a room to the total light available outside is called daylight factor.

Recommended daylight factor

Living room	0.625%
Study room	1.9%
Bedroom	0.313%
Kitchen	2.5%

15.3.5 Space

Space is the area provided for a particular purpose. It may be two-dimensional (length and width), such as a floor, or it may be three-dimensional (length, width, and height), such as a room. Space includes the background, foreground and middle ground.

15.3.6 Type

Type is the use of letter form to convey a message which would be difficult to convey using other elements.

15.3.7 Line

Line is the mark made by a moving point, such as a pencil or brush. The edges of shapes and forms also create lines. Lines and curves are the basic building blocks of two-dimensional shapes like a building's plan.

15.3.8 Value

It gives objects depth and perception. Value is also referred to as tone.

15.4 DESIGN PRINCIPLES

15.4.1 Proportion

Proportion refers to the relationship of one part to another or to the whole or between one object and another. This relationship may be one of magnitude, quantity or degree.

15.4.2 Scale

Proportion pertains to the relationships between the parts of a composition, while scale refers specifically to the size of something, relative to some known standard or recognised constant.

15.4.3 Balance

Symmetrical Balance Symmetrical balance results from the arrangement of identical elements, corresponding in shape, size and relative position, about a common line or axis. It is also known as axial or bilateral symmetry.

Radial Balance Radial balance results from the arrangement of elements about a centre point. The elements can focus inward toward the centre, face outward from the centre, or simply be placed about a central element.

Asymmetrical Balance Asymmetry is recognised as the lack of correspondence in size, shape, colour or relative position among the element of a composition. Elements that are visually forceful and attract our attention such as unusual shapes, bright colours, dark values and variegated textures must be counterbalanced by less forceful elements which are larger or placed farther away from the centre of the composition.

15.4.4 Harmony

Harmony can be defined as consonance or the pleasing agreement of parts or combination of parts in a composition. While balance achieves unity through the careful arrangement of both similar and dissimilar elements, the principle of harmony involves the careful selection of elements that share a common trait or characteristic, such as shape, colour, texture or material.

15.4.5 Unity and Variety

To get variety and interest, include dissimilar elements and characteristics. For example, asymmetrical balance produces equilibrium among elements that differ in size, shape, colour or texture. Another method for organising a number of dissimilar elements is simply to arrange them in close proximity to one another.

15.4.6 Rhythm

The design principle of rhythm is based on the repetition of elements in space and time. This repetition not only creates visual unity but also induces a rhythmic continuity of movement.

The spacing of the recurring elements, and thus the pace of the visual rhythm, can be varied to create sets and subsets and to emphasise certain points in the pattern. The resulting rhythm may be graceful and flowing or crisp and sharp.

15.4.7 Emphasis

The principle of emphasis assumes the coexistence of dominant and subordinate elements in the composition of an interior setting. Point of emphasis can be created by a perceptible contrast in size, shape, colour or value. An element or feature can also be visually emphasised by its strategic position and orientation in a space.

15.5 INTERIOR DESIGN FOR SPACIOUS ROOMS

The factors to achieve spacious rooms are the following:

1. **Lighting the Room** Eliminate the shadows that tend to slice the room into smaller spaces to create a feeling of largeness in the room. Even lighting and soft lighting will have an effect on space. Ceiling lights should be avoided as they tend to make the ceiling appear a little lower. Diffused and ambient lighting will tend to enlarge the room.
2. **Surface** Smoother surfaces tend to reflect more light and make the room appear larger. Surfaces should be kept free of heavy textures.
3. **Flooring** Heavy textural flooring should be avoided. Tiles over patterned or textured carpeting can be chosen. Reflective and shiny surfaces such as mirrors and chrome can be used effectively.
4. **Colour of Walls, Floor and Ceiling** Soft colours and monochromatic colour schemes should be adopted. Colours like cream, beige, gray or cool pastels on walls and floors can be used to make them recede. Use lightest colours for ceilings.
5. **Furniture** Keep the largest pieces of furniture against the walls to create feeling of more space. Furniture colours similar to wall and floors should be chosen.

15.6 INTERIOR DESIGN FOR COMFORTABLE ROOMS

The factors for design of comfortable rooms are the following:

1. **Colours** Strong colours for walls and floors should be adopted to bring them in closer towards one another.
2. **Flooring** A dark floor with walls of brown or deep red, blue or green will create a feeling of a smaller and comfortable space (cozier space).
3. **Lighting** Spaces can be created through directed light. Lighting from the ceiling will seem to lower it. A reading lamp or down-shaded lamp will cast light only in its vicinity.

   Incandescent, rather than halogen or fluorescent, lamps can be used for a warmer glow.
4. **Texture** Heavy, soft textures add warmth to a space. Rougher texture for the hard elements in a room—iron instead of chrome and brick instead of glazed tiles can be used.

5. **Furniture** Dark finished fabrics can be chosen to create a sense of the piece being larger than it actually is. Heavy textured fabrics and large patterns gives a cozy feeling to a sofa or chair. Tall pieces can be chosen to divide and define smaller spaces within a room for greater intimacy.

15.7 INTERIOR DESIGN FOR THEME ROOMS

In order to give the room personality, choose from the following basic elements and modify them to suit the needs and taste and implement them in such a way which is just right as required.

1. ***A Theme*** A themed rooms says something about the person who lives in it, who has decorated it, his family or the place where he lives. A theme will also provide a place to showcase collections, prized possessions, and arts and crafts.
2. ***Artifacts*** A piece of artistic value will give the room that special touch that is always wanted. It can add texture and depth to the room.
3. ***Collections*** It is the most effective way to display the collections in a special arrangement. The shells, dolls or trinkets collected should be arranged tastefully instead of lining things up in a row. If small objects are arranged in a line it will still give a worse effect. Instead, they can be grouped to project variety within the collections.
4. ***Colour*** Use colours in walls, carpets, fabrics, linen, pillows, shelves, curtains, etc., that make people feel good. The colours should be blended to suit the taste.
5. ***Fabrics*** The fabrics with prints that contain the colour of the upholstery can be added to maintain harmony in colours and the same accent can be used thrice around the same room.

15.8 INTERIOR DESIGN OF CORNERS IN BUILDINGS

1. Natural or artificial trees can be placed in the corners to fill up the void.
2. Pedestals of different sizes add beauty to the corners.
3. An up-light will add beauty to a corner.
4. A table top covered with good choice of fabric with a lamp and favourite pictures placed on the top will give a beautiful look to the corner. A couple of chairs on each side of the table with the same fabric on the seats will enhance beauty.
5. A corner cabinet or hanging cupboard is another solution so that the storage as well as display area can be increased.
6. Bonsai pieces can increase the ambience in a room. Photographs and sculptures are retrogressive.
7. Placing rocks and pebbles near the base of the Bonsai trunk will increase its visual effect.

15.9 INTERIOR DESIGN OF LIVING AREAS

1. Multifunctional furniture is the best choice if space is limited. Sofa cum bed, stacking chairs nesting table and portable pieces are good selections for small space.
2. Modular furniture with perfect modules in vertical and horizontal dimensions can be a good choice.
3. Mechanisms and fittings that transform single items into multifunctional pieces of furniture can be chosen.
4. Every corner space should be used for storage potential and narrow gaps can be fitted with small shelves for CDS or to store sports equipment.
5. Book shelves can be moved to provide an instant screen.
6. Natural or artificial trees can be placed at corners to add beauty.
7. Decorative display cabins with attached TV cabins add beauty.

15.10 INTERIOR DESIGN OF COOKING AREAS

1. Realistic arrangement of cooking requirements should be made and accordingly, interior should be planned.
2. The fridge or freezer should be chosen to suit the occupants' lifestyle and cooking habits.
3. A combination oven which provides the speed and compact design of a microwave oven with the advantage of a convection oven and grill can be selected.
4. Storage shelves should be provided under the table top to store kitchen instruments.
5. An exhaust fan is a must for comfortable cooking.
6. A washing sink should be placed at the appropriate place to get water connections and to avoid water spill-over.

15.11 INTERIOR DESIGN OF DINING AREAS

1. A block of colourful stacking chairs with a matching table will form an attractive dining room.
2. Extra folding chairs matching with the regular dining chairs can be propped against the wall liberating floor space.
3. With the correct choice of furniture fittings for this area, the difficulties of eating can be resolved so that dirty dishes are quickly cleared from view.
4. Extra tables and chairs can be folded away or stacked in a corner when not in use.
5. Proper flower arrangements with natural or artificial flowers on the table will add beauty to the existing dining environment.
6. Storage cabins to house the dining plates and cups and saucers can be placed near the dining table and fitted against the wall.

15.12 INTERIOR DESIGN FOR HOME OFFICES

1. A home office can be built from a combination of fixed and mobile units or a hinged, fold-away desk. A simple workshop on trestles can also be chosen.
2. A workstation which can be easily moved out of sight or folded away when not in use makes an ideal home office when the space is restricted.
3. A design that will provide ample storage space for all work-related equipment, files and accessories as well as features such as pull-out sections and adjustable shelving for maximum flexibility will be ideal.
4. Wall-hung, stacking and mobile storage units can also be utilised for a restricted office space in a home.
5. Vertically arranged designs offer maximum storage capacity while occupying the least floor space. Multifunctional mobile units are also useful.

15.13 INTERIOR DESIGN FOR SLEEPING AREAS

1. The bed is the most important and largest item in any sleeping space. Hence, comfort and space are important parameters for design. If the space is limited, a bed that doubles as seating or storage or both during the day as well as provides a comfortable place to sleep at night will be of good choice.
2. A bed that folds up into the wall during the day will provide a lot of free space.
3. A bed that is concealed behind a vertical surface can be used for decorative purposes.
4. Curtains for windows can be selected matching the colour of the walls.
5. Mirror arrangements at appropriate places will enhance the ambience.

15.14 INTERIOR DESIGN FOR BATHROOMS

1. The best selection should be made for closet, preferably of western type to meet the requirements of elderly people and to maintain hygienic conditions.
2. The most convenient type of hot-and-cold water system should be selected to suit the space.
3. The position of the showers, bath tubs and basins should be designed in such a way as to give space for washing area, if a separate washing area is not provided.
4. Exhaust fans may be provided to add comfort.

15.15 INTERIOR DESIGN FOR PUBLIC/PRIVATE BUILDINGS

Public buildings include banks, schools, hotels, corporate offices, hospitals, shopping malls, restaurants, theatres, and IT parks, etc.

1. Each building has its own special character. Depending upon the function of the building, different units have to be planned. All these units are to be combined together to form the entire building.

2. Common blocks required for the public buildings are

(a) Reception	(b) Office of the head
(c) Other office rooms	(d) Conference/meeting hall
(e) Sanitary or toilet blocks	(f) Parking area
(g) Security cabin, and	(h) Garden.

(a) Reception Those who enter the building should have their attention drawn directly to the reception desk. The reception must then be placed so that it is the first thing seen as the person enters. Reception counters can be designed to suit the cost of public buildings with all central information corrections to them. A variety of sofa arrangements should be placed based on the need in the reception area.

(b) Office of the Head It should have easy access from the reception area along with total privacy. False ceiling or wallpapers and colour scheme on the walls should be chosen in such a way that this area provides a good ambience for discussion. Self-adjusting chairs and tables with side cabins may be selected to give comfortable seating.

A small dining/discussion table can be arranged in addition to a comfortable sofa set for the visitors. Attached bathrooms with good comfort arrangements for personal requirements can be designed. Small green trees at the corners will add beauty.

(c) Office Rooms System furniture which provides flexibility to suit the need can be adopted. System furniture in modules that can be assembled in different configurations can be designed. The modules may have full or partial height panels, or divider units with filing cabinets, bookshelves, storage bins, computer stations, etc. Green trees in small sizes can be placed at appropriate places to enhance the ambience.

(d) Conference/Meeting Hall Conference tables of 'U' shape of length and size based on the requirement may be provided. Self-adjusting chairs to accommodate the body and to support the human form and lumbar area may be chosen. These chairs can absorb the shock of sitting down and support the body for a long time. They reduce physical strain and muscle fatigue in the lower back.

Suitable greenery can be placed at corners to improve the ambience of the hall.

Attached bathrooms and side rooms for serving dishes will add comfort.

(e) Sanitary and Toilet Blocks Toilets for visitors nearer to the reception and at the corners for the office staff with separate provision for ladies and disabled can be provided. Toilet size and numbers can be designed based on the needs.

(f) Security Cabin A separate security cabin with intercom and cover for rain and sun at the entry and exit gates may be provided. Required furniture should be provided to the guard, taking into account the comfort aspects.

(g) Parking Area Parking area, either at the basement or nearer the security area in open space, with area based on the need can be designed.

(h) Garden Landscaping with plants and lawns at suitable places outside the office adopting water-conservation policy may be provided to enhance the ambience.

(i) Furniture Special types of furniture for different buildings to meet the requirement of different procedures and purposes adopting latest technology and developments can be provided. For example, different types of furniture for hospitals or restaurants or banks can be thought of. Colours of furniture can be chosen matching that of curtains and carpets.

15.16 STORAGES

Multiple-purpose accessories and furniture that do double or triple duty for storage will be ideal for small spaces.

(1) A sofa-cum-bed for the living room will serve the main purpose of the owners.
(2) Hanging wardrobes with an ingenuous range of storage containers can be wisely adopted for a small space living.
(3) Fabric wall pockets and hanging shelves are useful for storing small items in an organised way.
(4) Tables containing shelves are useful for furniture storage.
(5) Bookshelves will be appropriate for entertainment centres, home offices, kitchen storage or bedroom storage.
(6) Bathroom storage units are useful for under-sink storages and increase the storage space.

PART B — LANDSCAPING

15.17 LANDSCAPING

Landscaping is the activity of modifying the various visible features of an area of land to give a pleasant appearance.

(a) It includes gardening to create a beautiful environment and systematic arrangement of plants to enhance the beauty of the place.
(b) It includes beautification of land forms such as lily pond, fountain, trees, lawns, etc.
(c) It covers weather and lighting arrangements, colouring, etc.

A landscape expert has to understand the elements of nature and required constructions and blend them according to the need.

15.18 ELEMENTS OF LANDSCAPE ARCHITECTURE

Colour is used to convey emotion and influences the mood and character of the overall landscape design or parts of the design.

Lines create order by directing eye movement or flows. Lines in a landscape design give the eye directions about where to look.

Form defines the shape and structure of an object in landscape design.

Texture is the surface quality of an object. Texture is how something feels when it is touched or looks like it would feel if touched.

Scale refers to the size of an object in relation to its surroundings. Scale in landscape design is inferred by the size relationship between adjacent objects.

15.19 SPECIALIZATION IN LANDSCAPE

1. Landscape engineers and designers like garden planners and executives design all varieties of green spaces and plantation. They work both with the government and private architects.
2. Landscape scientists have skills in hydrology, soil sciences and botany and they deal with practical solutions of landscape work.
3. Landscape managers have knowledge of plants and natural environment and give advice on long-term development of landscape. They work in estate management, floristry, conservation of nature and agriculture and horticulture.
4. Landscape planners do the planning for location, recreational aspects of all types of land use.
5. Garden designers deal with design of gardens in outdoor spaces and interiors.
6. Green roof designers design roof gardens, storm-water management aesthetics and creation of habitat.

15.20 LANDSCAPE PRODUCTS

It includes walls, fences, gardening tools, lighting, water features, foundations, garden furniture, garden ornaments, pond liners, garden building, fountains, etc.

The skills of combining all these products to develop plans are known as landscape design and detailing.

15.21 LANDSCAPE MATERIALS

(a) Hard Landscape Materials This term is used to describe the construction materials which are used to improve a landscape by design. A wide range of hard landscape materials are brick, gravel, stone, concrete, timber, bitumen, glass, metals and outdoor furniture, etc.

The designer should choose hard landscape materials which go together with the interior design and architecture.

(b) Soft Landscape Materials It is used to describe the plant and vegetative materials which can be used to improve landscape by design. The range of soft landscape materials include aquatic plants, semi-aquatic materials, field layer plants, shrubs and trees.

15.22 WATER-EFFICIENT LANDSCAPING

Landscaping normally means growing large grass with few plants to fulfil aesthetic requirements. It means that the front portion of the office or industry or residence should have lawn arrangements with grass and plants. A lot of water is poured to keep the grass green. During summer, the water requirement increases drastically. Choosing the right plants, especially those of native species, results in more water-efficient landscaping. The use of sprinklers, micro sprinklers, drip irrigation system leads to water conservation and efficiency.

Xeriscaping is another method where plants like xerophytes are used in dry climatic conditions and it requires low amount of water.

Edible landscaping is another method of landscaping which can be adopted during scarcity of water, fertilisers and food conditions. A landscape with Bermuda or Mexican Grass in an acre is an example. If this has to be converted into a *ragi* field then the same area can yield 8000 to 10000 kg of *ragi* or millet every year.

An edible landscape also yields fresh food, vegetables and grains with the same water requirement as for a normal landscape or sometimes even less. Non-functional water-guzzling landscapes can be transformed into functional beautiful ones by edible landscaping.

15.23 DESIGN GUIDELINES FOR INTERIOR LANDSCAPING

The aesthetic design considerations involve choosing the proper variety of plant textures, heights and spacing to give the desired effect. The growing considerations involve the proper matching of light intensity, soil and water, as well as proper container size, to the plant environment requirements.

1. Plant Texture The term is used to describe the general structure, shape and appearance of the plant, regardless of height. It includes the size, shape, edging and thickness of the plant leaves as well as overall shape, arrangement and number of leaves on the plant.

2. Plant Height Plant height not only determines the scale of the design but adds variety to the plant groupings. There are six general rules regarding plant-height selection to keep in mind:

- In the plant grouping, build-up with the low plants in front. If the grouping can be seen from all sides, the grouping must be well balanced throughout and built up to the centre height.
- If a plant has cones with no lower foliage, try to place the lower plants in front to conceal the absence of foliage of the taller plant in the rear.

- Uneven sizes throughout a grouping add more interest than consistent level of foliage.
- If a single plant is desired to hide a column or some other object then be sure that the plant height including its container is above three-fourths the height of the object to be concealed.
- Keep the scale of the surroundings in mind when choosing a plant height. A 3-ft plant is fine next to a desk, but a plant of at least 6 ft should be selected if it is to be viewed when entering a room.

3. Plant Spacing Under certain conditions, the plants of an interior landscaping design will grow. Therefore, any possible change in the plant size must be considered by the designer. If the lighting intensity is at or below the recommended level, there will be little or no plant growth and the plant size and relationships will change little over time. If the lighting intensity is well above the required level, there will be plant growth with different plant species growing at different rates.

If a full plant design is desired, the required number of plants should be placed close together at the time of installation since future growth will seldom fill in the bare slots. Space should be designed in such a way that the plant will get required light and grow.

4. Light Intensity Of all the growing conditions, the most important is light intensity. The plant needing the lowest light requires 50 to 75 foot-candles to remain healthy. Even if the light intensity is below 100 foot-candles, these low-light plants need to be slowly acclimatised prior to installation.

5. Soil Separator If the plants are removed from their growing cans and replanted in growing soil, it is usually best to use a soil separator between the drainage layer and the planting soil. The separator is a semi-porous sheet, often composed of fibreglass wool, which serves to keep the soil from falling into the drainage material. If the separator is not used, soil will clog the drainage material. Fibreglass wool of building-material grade should not be used, as it contains chemicals that will damage the plant.

6. Planting Medium Because the root systems of tropical plants are much finer than those of outdoor plants, pure topsoil is too heavy and too easily compacted to be used as a planting medium; it will construct the plant roots and will retain too much water.

7. Plant Containers A plant container should be more decorative. Its proper selection is the first element of proper maintenance, since the container must provide the plant roots with sufficient growing room and with adequate drainage.

The decorative container should be chosen so that it's inside dimensions are large enough that the plant-growing container can be dropped directly into it.

8. Feeding A liquid fertiliser should be applied every 4 to 6 weeks and every two months in the winter seasons.

Plants require nitrogen, phosphorus and potassium; and commercial plant foods give the ratio of these constituents in the same order. A 15:30:15 ratio indicates 15 parts of nitrogen, 30 parts of phosphorus and 15 parts of potassium. The other common feeds give a ratio of 13:36:14.

9. Pest Control Inspect all plants every few days or at the time of watering. Inspect all newly potted plants. Inspect plants moved indoors from the outdoors. Before buying plants, rinse all pots and plants with a sprinkling can or hose. All pests and caterpillars can be picked off by hand or with a pointed tool. Fungi and other growth should be washed or brushed off.

Here, we give a brief description of some common pests and how to get rid of them. This will help a lot in your day-to-day care of plants. *Mealy bug* is the common insect which can be controlled by dipping cotton swabs in methylated spirit and then swabbing down the plant. *Red spiders* and *aphids* can be eradicated with good dousing of any general-purpose insecticide. *White flies* can be got rid off by spraying malathion. *Ants* can be removed using ant powders.