Unit -1

Traditional and organic Building Materials:

- In construction, traditional materials are those which have been used to construct shelters and buildings for a long time in a locality, region or nation.
- However, a traditional material in one locality, flint in Kent for example, may not be deemed to be traditional in Yorkshire due to the lack of flint for building in that county.
- In addition, some building materials used for thousands of years may be deemed traditional in one area but may not even exist or be regarded as building materials in another area.
- As an example, blocks of ice have been used for millennia to build igloos in the Arctic, however, ice is not used – or regarded – as a building material at all in more temperate zones.

Despite regional variations, traditional materials often continue to be used up to the present day whether for functional, planning or aesthetic reasons, often in conjunction with more modern materials. However, some building types are usually seen as being visually incompatible with traditional materials: for example, a thatched roof on a modern office building.

Traditional building materials

Mud:

- As far back as 7000 BC, mud was hand-moulded to form bricks which were later left to dry in the sun.

Timber:

- Timber is one of the earliest materials used to build shelters.
- Initially, this would have started with tree branches used to form frameworks that would be covered with leaves or skins and smaller branches.
- This progressed to the creation of cruck-framed houses which led to the creation of timber-framed construction with wattle and daub or brick infill panels.
- Timber is still used in a wide range of traditional and modern constructions.

Straw:

- Straw could be used to make thatch, one of the earliest roof coverings. Today, it is used mostly to re-roof country farmhouses and cottages built before the 20th century, but also as an insulation material in walls.

Stone:

- Stone has been a valued building material since it was used for domestic huts in areas where it was plentiful and timber scarce.
- Traditionally used mostly as a load bearing material, today stone is more used as a facing for building facades, paving and high-status interiors.

Clay (bricks):

- Bricks are distinguished from mud bricks by being fired rather than simply left to dry in the sun.
- Fired bricks were produced in the Near East as far back as 3000 BC but it was the Romans who introduced the technique into the UK in the first century AD.
- Brick was later to flourish in the Middle Ages for use in houses and churches, and its use extended through Georgian and Victorian periods.
- It is still widely used in the UK, both for traditional and modern buildings. Quarry tiles (fired brick) are also regarded as traditional and still used, mostly for kitchen floors and worktops.

Slate:

- Due to the way it is cleaved, slate has been used for centuries for roofing, paving and to form the wearing surface on steps and stairs.
- It is still highly valued as a roof covering but also as a cladding for contemporary steel and concrete buildings.
- In recent years, natural slate has faced competition (particularly in terms of price) from man-made slates.

Lead:

- Mined by the Romans 2,000 years ago, lead has been in continuous use in the UK right up to the present day, used mainly in sheet form as a roof covering, but also for gutters and downpipes, and for the cames in stained-glass windows.

Copper:

- For centuries copper has been used in Holland, Germany, Scandinavia and eastern Europe, mostly for roofing.

Iron:

- Historically, iron has played a part in most British buildings whether as cramps, nails, cornices, finials and pinnacles, the tops of spires and chimney stacks, for door straps, and for decorative applications.

Materials used for centuries but not regarded as traditional:

Cement: Since its use by the Romans, cement as a constituent in concrete has only really seen significant use since the end of the 19th century. However, even given this more than century-old heritage, it is not usually regarded as 'traditional'.

Glass: Wealthy Romans in England had glass in their windows but its use developed substantially in 12th century France. Despite this long history, glass is sometimes not regarded as a traditional material although some types, such as stained glass, are.

Plaster: Introduced into England around the middle of the 13th century, plaster has been in widespread use ever since, but is not always considered traditional.

Steel: Early forms of steel have existed since around 1800 BC, and it has subsequently be used through history by the Greeks, Romans, Indians and Chinese, however it is generally not considered traditional.

Stone:
Stone found in nature, have to be quarried from their thick beds. After quarrying large pieces of rocks, it is essential to break them into smaller sizes so that they can be used in buildings.

The stone dressing is a process of surfacing and shaping of rocks available naturally. The place where the rocks are abundantly available is called as a quarry. The process of taking stones from the natural bed is known as 'Quarrying'.

The operation of stone dressing is generally carried out at the site of quarry so as to reduce the transportation cost.

The dressing of stone is generally done using hand tools like Chisel, Pickaxe etc using heavy machines or blasting using explosives. Once quarried, the stones are cut into the suitable size and surface finishes. This process is termed as dressing of stones. The effective dressing of stones would help in making your structure attractive and economical.

Different Stages Involved in Stone Dressing:
Sizing: The irregular quarried rock is cut into desired dimensions by removing extra portions. It is generally done using hammers and chisels or cutting machines.
Shaping: Once cut to desired dimensions extra projections are removed to shape the stone.
Plaining: It is the process of removing irregularities from the stone surface.
Finishing: It is done by rubbing the stone surface with an abrasive material like silicon carbide.
Polishing: In this stage the stone is polished by hand or machine to make it more attractive. It is generally done in stone like lime stones, marbles and granite. The effective dressing of stones would help in making your structure attractive and economical.

Different Types of Stone Dressing:
The types of dressing of stone may vary from place to place. Now a day's mechanical tools are used for dressing of stones as more time is saved. Most common type of stone dressing used in the construction field are as followed:

1. Hammer Dressing:
- Hammer dressed stones do not contain any sharp and irregular corners these stones suit well for masonry construction.
- These are most adopted type of dressing of stones.

2. Chisel Drafting:
- In this method the stone is made of drafts or groups with the help of chisels at different stages of dressing of stones.
- In this type of dressing excessive stones at the centre are also removed.
- These stones are used commonly in plinths and corner of the building.

3. Fine Tooling:

- In this type of dressing most of the projections of the stones are removed and a fairly smooth surface is gained.
- Due to this the appearance of the stone improves.

4. Rough Tooling:

- In this type of dressing a rough tooled surface that has a series of bends are made of the stone.
- The bends are more or less parallel to tool marks make all over the surface.

5. Punched Dressing:

- This type of dressing is an extension of rough tool dressing.
- In this type of dressing a rough tooled surface is further dressed with the series of parallel ridges.
- The chisel marks are visible on the face.

6. Closed Picked Dressing:

- In this type for dressing of a stone a punched stone is further dressed to obtain a finer surface.

Modern Building Materials:

The modern methods of construction primarily involve the manufacture of components in factories, with potential benefits such as **faster construction, fewer housing defects, and reductions in energy use and waste**, all of which offer significant potential to minimize construction waste.

1. Concrete:

- The material that's the backbone of modern architecture, concrete is composed of cement, fine and coarse aggregates bonded together in a fixed ratio.
- The compound can be easily molded into the desired form using the appropriate scaffolding, forming a column, beam, slab, foundation etc.
- The brutal material inspired one of the greatest architects Le Corbusier. Further research about concrete has led to the development of more materials like durable concrete, high-performance concrete, self-healing concrete, translucent concrete and bendable concrete.

2. Brick :

- The brick blocks are like the Lego blocks which can be combined together to form creative masterpieces through innovative thinking and skilled craftsmanship.
- Despite the rigid form of a brick block, they have shown a wide variety and resulted in the formation of beautiful specimens over a course of time.
- The researchers these days are working towards transforming the small building material into a sustainable unit of building construction.

3. Steel:

- Steel is the material that can be used as a structural material as well as a visible material.

- Its property of withstanding tensile forces makes it an effective structural material, as an R.C.C. reinforcement as well as structural materials such as space frames, I-section beams, trusses etc.
- Additionally, it is used as window and door frames, handrails, balustrades, door handles, etc. Steel as a building material possesses the qualities like durability, strength, lightweight, can be recycled, can withstand the variance in climatic conditions.

4. Glass :

- The modernistic material used to achieve transparency and light, the glass, is the most common façade element which offers both visibility as well as protection from the changing climate.
- The architecture specimens, the Farnsworth House by Mies van der Rohe and the Glasshouse by Phillip Johnson justify the extent of the application of glass as a building material.
- The researchers have been able to develop the glass with a lower U-value, high thermal insulation property, which suits the environment and helps in decreasing the energy requirement of a building.

5. Aluminium:

- Aluminum is a non-ferrous metal abundantly available. It is not readily available and is to be extracted from the bauxite ore.
- Possession of qualities like high strength to weight ratio, airtightness, ease in fabrication and assembling, low handling and transportation cost, high reflectivity, corrosion resistance and its behavior at extreme temperature, makes it an appropriate construction material.
- Usually, the glass façade of modern buildings is supported by a sturdy and lightweight aluminum frame. The building industry has developed a new material called the 'transparent aluminum' which offers excellent transparency as well as **form in architecture**. Transbay Transit Centre, San Francisco has updated its façade from glass to transparent aluminum.

6. Natural Stone :

Stone being used since the time of evolution of mankind is still a trendy building material. Despite its heaviness and bulkiness, it is appreciated in the building industry because of its large variety of textures, colors, and sizes. The material is durable and naturally available.

7. Wood

The only renewable building material whose addition in the building gives not just the warm feeling but an emotion of joy and comfort share in designing when compared with aesthetics and functionality. These specific materials can transform any space. Its high tensile strength, sound absorption and other features like heat resistance and electrical resistance make it an exceptional material to be used in modern architecture.

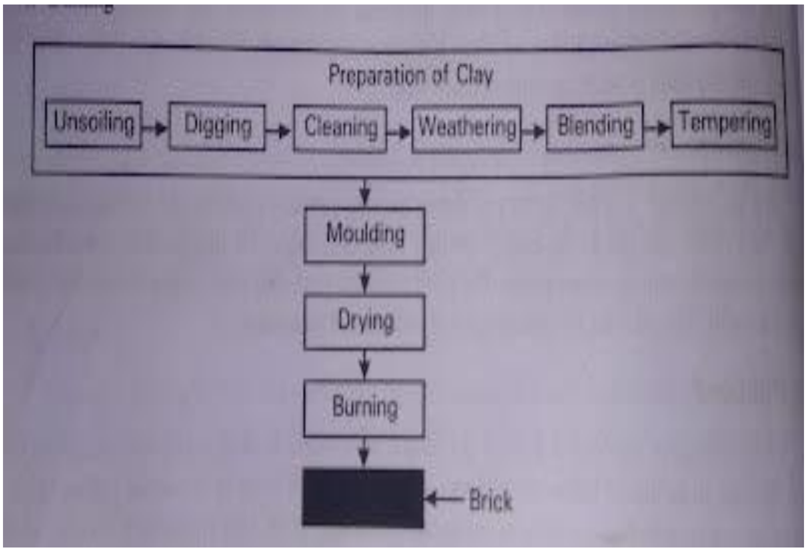
8. Tiles :

A modular unit, made up of hard materials such as ceramic, stone or even glass, applied as a covering material over floors, walls, tabletops etc. is an efficient finishing material commonly used in modern buildings. Easy transportation, easy repair, and availability of comfortable sizes and a variety of colors and textures make it a popular choice among designers. The tile industry these days is working towards the concept of recycling in order to attain sustainability goals.

Bricks:

- These are obtained by moulding clay in rectangular blocks of uniform size and the drying and burning these blocks.
- A bricks are of uniform size, they can be properly arranged and further, as they are light in weight, no lifting appliance is required for them.
- If bricks are large, it is difficult to burn them properly and they become too heavy to be placed with a single hand.
- On the other hand, if bricks are small, more quantity of mortar is required. Hence BIS has recommended the bricks of uniform size.
- Such bricks are known as the modular bricks and the actual size of a modular brick is 190mm*90mm*90mm.
- With mortar thickness, size of such a brick becomes 200mm*100mm*100mm and it is known as the nominal size of the modular brick.

The manufacturing process of bricks are as follows:



1)Preparation of clay

2)Moulding

3)Drying

4)Burning

1)Preparation of clay

- Un soiling
- Digging
- Cleaning
- Weathering
- Blending
- Tempering

i. **Un soiling:**
- The surface of the site selected for obtaining brick earth (clay) is cleared by removing the top layer of soil containing vegetable matter, about 200mm in depth.
- The clay in topsoil is full of impurities and hence it is to be rejected.

ii. **Digging:**
- The digging of the earth is generally carried out by manual labour, but for large work, excavators may also be used. The excavated earth is spread on the levelled.

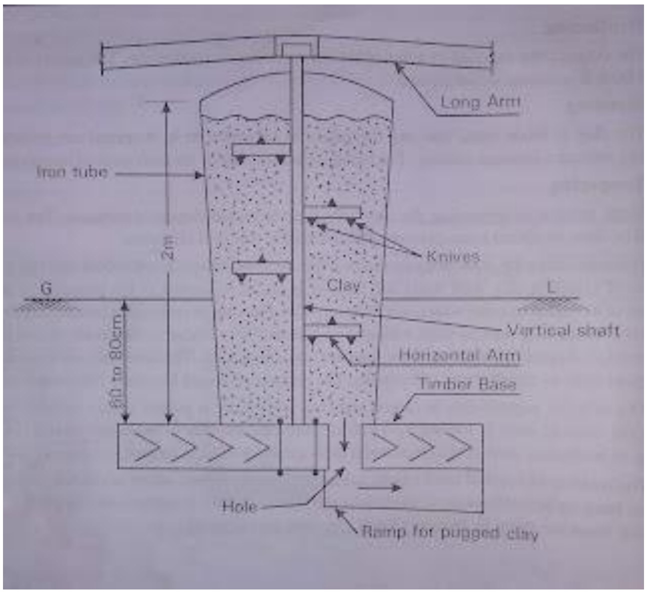
iii. **Cleaning:**
- All stone pebbles, gravel, kankar and roots of grass or plants, etc., are completely removed.

iv. **Weathering:**
- The clay is then exposed to the atmosphere for softening or mellowing. The period of exposure varies from a few weeks to full season.

v. **Blending:**
- The clay is made loose and any ingredient to be added to it, is spread out at its top. The blending indicates intimate mixing. The blending makes clay fit for the next stage of tempering.

vi. **Tempering:**
- In the process of tempering, the clay is brought to a proper degree of hardness. The Tempering should be done to obtain a homogeneous mass of clay of uniform character.

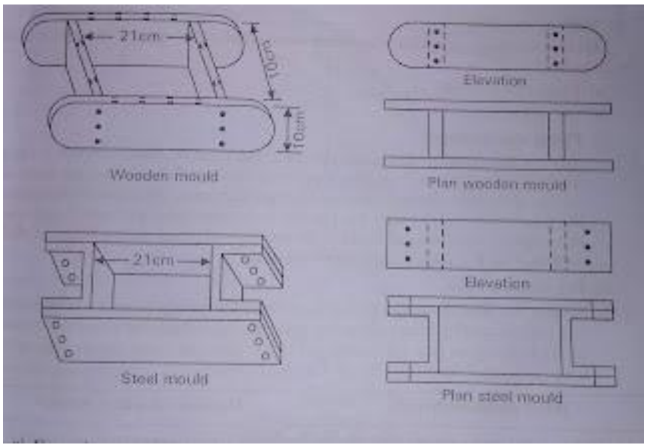
For manufacturing good bricks on large scale, the tempering is usually done in a pug mill.



2)Moulding:

Moulding may be carried out either by hand or with the help of a machine.
Following are the two types of moulding:

i) Hand moulding
ii) ii) Machine moulding



i) Hand moulding
Bricks are moulded manually. It is cheap and hand moulding is suitable for small scale brick production. The mould is rectangular boxes that are open at the top and bottom. They may be of wood or steel.

The bricks are prepared by hand moulding are of two types:

a) Ground-moulded bricks
b) Table-Moulded bricks

a) Ground – moulded bricks

In this process, the bricks are moulded by keeping the mould directly on the ground. Following operations involved in ground moulding:

1. The ground is first made level.
2. Fine sand sprinkled over it.
3. The mould is dipped in water and placed over the ground.
4. The lump of tempered clay is taken and it is dashed in the mould.
5. The clay is pressed in the mould.
6. The extra clay is removed by metal or wooden strike.
7. The mould is then lifted up and raw brick is left on the ground.
8. The process is repeated until the ground is covered with raw bricks.

b) Table-Moulded bricks:

The process of moulding the bricks is the same as ground moulding but in this case, the moulder stands near a table of size about 2m x 1m. The cost of a brick is more compare to ground moulded bricks as the number of bricks produced per day is less. Approximately 1000 bricks per day can be moulded by the team of a moulder and his assistant by this method.

ii) Machine moulding:

Machine moulding is adopted for large scale manufacturing. The types of machines used for moulding are:

a) Plastic clay machines
b) Dry clay machines

a) Plastic clay machines:

Such machines contain a rectangular opening of size equal to the length and width of a brick. The pugged clay is forced through a rectangular opening of size equal to the length and the breadth of the brick. The clay comes out through the opening in the form of a continuous bar, it is cut into strips by wires fixed in frames. therefore are also known as the wire cut bricks.

b) Dry clay machines:

In these machines, the strong clay is first converted into powder form. A small quantity of water is then added to form a stiff plastic paste. Such paste is placed in a mould by machine to form hard and well-shaped bricks.

3)Drying:

After the bricks are moulded, they are dried. If bricks are not properly dried before they are burnt, they may get cracked and distorted during the burning process.

Following are the objects of drying the bricks:

a) To remove as much moisture from the bricks as possible, so as to save time and fuel during the burning.

b) To avoid the chances of cracking and distortion of bricks during the burning.
c) To increase the mechanical strength of the bricks without any damage to the bricks.

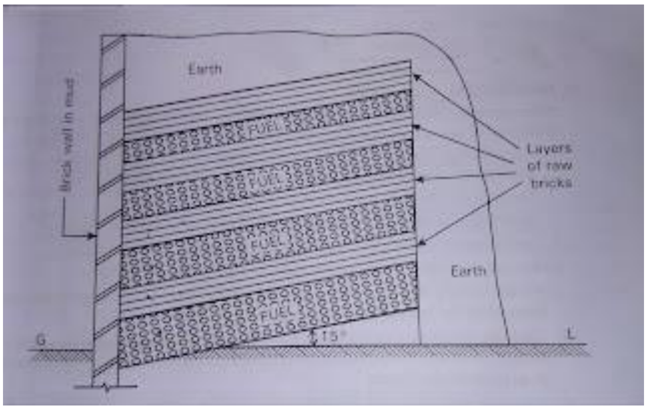
Following two methods of drying bricks:

- Natural drying
- Artificial drying.

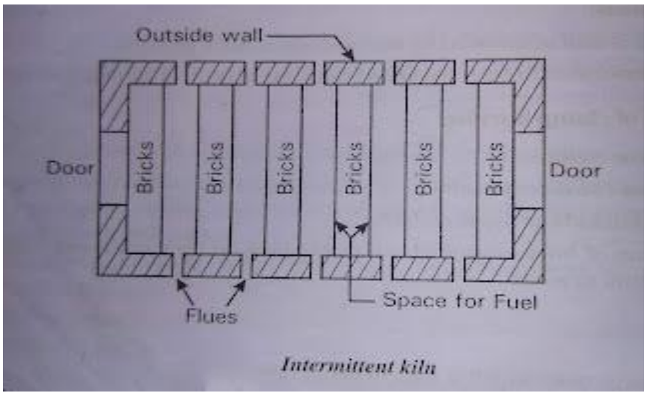
4)Burning:

This is a very important operation in the manufacture of bricks. It imparts hardness and strength to the bricks and makes them dense and durable. Bricks are heated up to 700 to 1000° C.
At this temperature **alumina and silica** in the clay **fuse** together resulting in a compound that is strong and stable.

The purpose of burning is:
1. To impart hardness and strength to the bricks.
2. To increase the density of the bricks so that they will absorb less quantity of water.
The bricks may be burnt in any one of the following:
a) clamps



b) Intermittent kilns:



Intermittent kiln

c) Continuous kilns

Clamps are temporary structures, and they are used to burn bricks on small scale, but kilns are permanent structures and are used to manufacture bricks on a large scale basis.

Low cost Building Materials:

Low-cost building materials not just increment access to perpetual housing for individuals from low and middle class people also in addition contributes towards sustainability, especially when locally accessible structure material is utilized.

The materials generally used for modern low-cost construction are hollow concrete blocks, bamboo, extruded clay bricks, compressed earth bricks, concrete panels, along with non-conventional materials like polymers and recycled composite blocks, as they can decrease constn time significantly. We'll take a look on types of building materials reasonable for low-cost housing in India.

1. **Bamboo:**

- One of the oldest building materials used by man along with stone and wood, bamboo is utilized even today in rural regions.
- It is a green structure material, which is extremely famous in India because of its low cost, low weight and strength yet ought to be treated with proper chemicals concoctions to make it termite proof.
- As India produces almost 50% of the world's bamboo, houses in seismic zones of the nation are made with bamboo.
- The material has preferred rigidity over steel and is also fire proof.
- Recently, corrugated sheets of bamboo have been created, and these are utilized for roofing as specialists believe it to be a perfect substitute for asbestos and galvanized sheets.

2. **Concrete Blocks:**

- Concrete blocks are manufactured at factories as per necessities of house developers.
- Made by blending Portland cement, water, stone or quartz, these blocks can either be strong or hollow and are commonly lightweight, sturdy and fire proof.
- These are utilized for the foundation, basement walls and partition walls as their centers can be loaded up with steel rods for improving strength.
- As they are made of cement, they are termite safe, soundproof and give natural protection against heat and cold.

3. **Prefabricated houses:**

- These are progressively being utilized for meeting necessities of perpetual housing as the expense of normal brick and mortar houses keeps on rising exponentially.
- These houses are made of parts that are factory fabricated and afterward collected at the house site.
- The parts incorporate steel outlines, wooden boards, concrete and gypsum for floors alongside factory fabricated doors, windows, ceilings and walls.
- Contingent upon the necessities, components like wall and ceiling panels, as well as structural steel frames, can be specially designed and afterward amassed.
- Despite the fact that these materials are about 15% more costly than normally used materials, their significant level of productivity and low work costs cut down the general development costs.

- They evacuate the requirement for helper exercises like wiring, plumbing and plastering, which are done at the casting stage.

4. **Compressed Earth Bricks:**

- These blocks are created out of soil and r/fed with a blend of lime and cement.
- Otherwise called adobe bricks, they are lightweight, harmless and fire proof.
- Compacted earth bricks are thick and for the most part utilized for outside plaster work and are viewed as one of the least expensive among low-cost building materials.

5. **Interlocking bricks:**

- These bricks are structured with a projection on one side and a downturn on the other so they line up with blocks of a comparable sort, similar to a jigsaw puzzle, to make walls.
- Interlocking bricks are made out of laterite stone powder, cement and rock.
- They are viewed as green structure materials when contrasted with heated bricks as they dry naturally and are similarly as solid.

6. **Mud bricks reinforced by natural fibres from straw and coconut:**

- This feasible structure material is normally utilized in rural regions to built weatherproof houses as they give both strength and durability.
- Naturally available fibres like coconut and straw increment the strength and sturdiness of unadulterated soil while a covering of sulphur makes walls waterproof.
- Different sorts of fiber bricks are made with oat straw, bagasse, corn straw and rice husk, which are mixed with cement to make them corrosion resistant and solid.

7. **Magnesium oxide cement:**

- Also known as ‘eco cement’, this material is made out of a few waste materials however has high sturdiness and requires just 20-40% of the vitality required for the creation of Portland concrete.
- It doesn’t make any damage to people of houses where it is applied as a maintainable structure material.

8. **Fly ash Hollow bricks:**

- These bricks are utilized for developing load-bearing walls of low ascent structures and made of fly ash, stone powder or sand, slag and cement or gypsum for holding.
- A few classifications of fly ash bricks are additionally made out of mineral buildup, glass, water, and fly ash and are vitality proficient, water-safe and give natural thermal protection to a low-cost house.

9. **Shipping container houses:**

- Houses made of steel containers are quick getting popularly known among individuals investigating recyclable structure materials.
- While the littlest one can make a 100 sq ft house, one shall require around 8-9 large containers to set up a 1500 sq ft home with two stories.
- It’s a cost-effective as a pre-assembled house as the container just should be organized on a ready foundation.

10. **Autoclaved aerated Concrete or AAC:**

- Made out of gypsum, lime, quartz sand, water and aluminum powder, these blocks are built under heat and pressure inside an autoclave as indicated by explicit necessities.
- The blocks can be utilized for both outside and inside walls and are known to be heat safe and lightweight.
- The material decreases vitality costs as it is permeable and non-toxic. It is environment safe too as it creates 30% less solid waste in contrast with normally used concrete.

Utilisation of Wastes for alternative Building Materials:

In the last decades, due to the modern lifestyle, the progresses in industry and technology had led to an important increase in the amount and type of wastes. The problem of waste accumulation every year is all over the world. These industrial and agricultural wastes are by-products, slag, rice husk ash,fly ash, cement dust, brick dust, sludge, glass, tires, etc. The wastes represent a major problem for the environment because the air pollution (the dust and very fine particles which spread in the atmosphere) and leaching toxic chemicals (arsenic, beryllium, boron, cadmium, cobalt, lead, manganese, mercury, molybdenum, selenium, strontium, thallium, hydrocarbon compounds, etc.) when are dumped in landfills, quarries, rivers or oceans. The capitalization of waste is difficult because of their variety, as well as their unknown properties over time.

Waste classification

For many years a lot of wastes have been accumulated in the entire world and they influenced the environment and people life. The necessity of eliminating or at least, reduction of huge quantities of wastes is a priority of researches. Their use in the building material and construction industry is a one of the possibilities which can help to keep the environment clean.

In the building material industry there are used a lot of types of wastes, which can be classified as follows:

- **By-product waste** is the waste produced by industry which includes any material that is rendered useless during a manufacturing process from plants, mills and mines. Usually they are storaged in landfills, which are placed on agricultural fields or around big cities. Some examples of industrial waste are silica fume, slag, sludge, fly ash, sand paper, metals, glass, etc. [1].

The by-products which are used in construction are:

- **Silica fume** is resulted from the processes of obtaining ferrosilicon industry, as a very fine powder which is recuperated by filters from furnaces. The quantity of dust involved by burnt gases from the furnace represents about 35% from the quantity of the end product. Silica fume generally contains more than 85% SiO_2, and also other components in smaller quantities, such as: Fe_2O_3 (1.3 - 4%), Al_2O_3 (0.85 - 2.5%), CaO (0.4 - 0.8%), Mg (0.6 - 1.5%), C (1.1 - 2.5%). Silica fume has the shape of particles spherical and the specific surface is between 13000 and 23000 m^2/kg. Its spreading in the atmosphere has as effect the environment pollution.

- **Slag** is a co-product of the iron and steel production. Slag is usually a mixture of metal oxides and silicon dioxide. However, slags can contain metal sulfides and elemental metals. Slag is a valuable waste which can be used in agriculture, environment processes and construction industry. In agricultural domain the slag is used for treatments for soil improvement. Other properties such as porosity, water holding capacity, bulk density make the slag suitable for using as adsorbent.
- **Sludge** refers to the residual material left from industrial wastewater or sewage treatment processes. It can also refer to the settled suspension obtained from conventional drinking water treatment and numerous other industrial processes. This waste can be contaminated with toxic organic and inorganic compounds.

Another source of sludge and slag is from steel industry and they are generated as waste material or byproduct. They contain considerable quantities of valuable metals and materials. Different technologies are used for recovering the metallic parts, such as: classification, magnetic separation, leaching, roasting, etc. The wastes are then transformed in different sorts of waste, such as powder, conglomerate, etc. function the necessity of applied technology for a better use of natural resources and environment protection.

The paper industry that uses recycled paper as raw materials has as by-product paper sludge, which has a high content of calcium carbonate, organic materials and other minerals. Because its pozzolanic activity, the paper sludge can be used as cementitious materials in building industry.

- **Fly ash** is a residue from power plants or from different processes of incineration of solid materials. The fly ash is disposal on the landfill.
- Toxic substances in the waste - including arsenic, mercury, chromium, and cadmium - can contaminate drinking water supplies and damage vital human organs and the nervous system. Ecosystems are also been damaged by the disposal of coal plant waste.

Fly ash produces environmental damage by causing air and water pollution on a large scale while the cost of storage of this waste is very high. The most serious problem is the hazard to atmosphere and underground water quality which would be a potential risk to the health and property of citizens and cause a huge stress to the economic and environmental system.

- **Organic wastes** are generally biodegradable materials which are accumulated rapidly and for their storage it must design and realize great disposal landfills.
- Biodegradable waste can be decomposed in a short period of time, under the natural conditions into the basic compounds, usually micro-organisms, bacteria, etc. This type of waste is found in municipal solid waste and is resulting from food, paper, biodegradable materials, etc. The wastes which are decomposed in the absence of oxygen are also considered as biodegradable waste and here are included wastes from manure, sewage, animal fat, palm fruit bunch, sugar bagasse, banana leaves, etc.

- **Mineral wastes** are resulted from the industry processes where the natural resources are transformed in products. In construction industry a lot of natural raw materials are used in natural state. Mining, from the exploration to the closing stage, has a severe impact on the environment. Environmental impact can be direct through the activities:

prospecting; exploration; site improvement; extraction; mineral preparations; mineral storage and preparation for delivery; transportation to beneficiary.

- All technical stages in the minerals exploitation have an important impact on the environment and community life; the dust waste is very aggressive in the atmosphere, in water and soil because of the fine particle and toxic elements. The huge noise from technological processes is also an inconvenient for the community.

- **Inert waste** is waste which is neither chemically or biologically reactive and will not decompose in time. Examples of inert wastes are sand, drywall, and concrete. The inert waste typically requires lower disposal fees than biodegradable waste or hazardous waste.

In the industry of building materials the raw materials are used in natural state and as processed materials (case in which they are transformed in other materials (lime, cement, plaster, additives, etc). Among the raw materials there are: clay, calcareous, gypsum, dolomite, marble, mica, granite, etc. Natural aggregates are obtained from gravel from river or from quarry. Because the aggregates are used in different sorts as sizes, the natural aggregates are usually crushed for obtaining an imposed granulometry. A lot of powder waste remains after aggregate selection and their disposal affect the vegetation of the environment.

- **Agricultural wastes** are resulted from agricultural domain. They are biodegradable in time, but during the degradation process they must be storage in special places. For eliminating the wastes usually these wastes are burned, the powder resulted can be used as fine part in construction.
- **Construction demolition wastes** are resulted from new construction, rehabilitation or the demolition. As waste materials from construction can be: wood, drywall, masonry, metal, concrete, plastic, glass, cardboard. The construction waste quantities are bigger in metropolitan areas, where there are more buildings. Usually the construction waste is storage in landfills.

Construction wastes are obtained during the building process or after demolition. Different types of materials such as bricks, concrete, mortar, wood, steel rebar, insulation material, electrical wiring, plastic materials, glass, iron plate, tile, sanitary pieces, etc. which can be unused or damaged. According to specialty literature about 10% to 15% of materials are lost from the total building material, quantity which varies from site to site [4]. The uncontrolled disposal of this waste is very dangerous for the environment because building materials can contain toxic substances such as lead, asbestos, aluminum, etc.

The recycling demolished waste as aggregate in ordinary concrete offers a solution to the preservation of natural resources and the disposal of construction residues.

- **Transportation industry wastes** are represented by used tires, asphalt and concrete aggregate. Huge quantities of tires were used in artificial reefs, break waters, dock bumpers, soil erosion control mats, etc.

Wastes from industry used in building materials

The concrete became a more interesting building material because it has improved its properties and also it is suitable for combining with different types of wastes. The presence of additions and/or fibers is also important because it can improve the performances of concrete or they allow the use of smaller quantities of cement.

The use of different waste in the concrete mix or for obtaining new types of concretes had as result the development of a new type of construction materials: green materials. In this category is included inorganic polymer concrete which is obtained predominantly from industrial waste materials. Concrete of any type had been used as it is or in combination with other materials, the most known being the steel with which had resulted reinforced concrete and prestressed concrete, that are still today very common and useful in construction industry. Polymer concrete is a new type of concrete in which the cement is replaced by a polymer. A high variety of waste are used for obtaining concretes of different requirements related to strength, to chemical resistance, with high durability, rapid hardening, etc.

An important way to use the wastes is to introduce them as a powder or filler in the composition of construction materials (cement, concrete, asphalt, etc.) or to use as aggregates (concrete or bricks from demolition can be used as an aggregate, steel slag can be transformed into aggregates, etc.). Concrete is one type of building material that can incorporate many types of waste such as silica fume, fly ash, cinder, husk, tires, glass, etc. Concrete is used for obtaining structural elements and constructions of any type.

3.1. By-product wastes

- **Silica fume** is specially used as mineral admixture in concrete because of the fineness of the particles which can fill better the spaces between the components of concrete mix. The new types of concretes (the high strength and high performance concrete, ultra-high performance concrete, with compressive strengths going to 150-180 MPa), high strength polymer concrete, etc. that are used in the new modern structures are obtained by adding in the mix silica fume in dosages between 8-12% [3]. Experimental studies shown that the compressive strength of concrete can increase with about 20% in the case of a dosage of 10% silica fume [10]. The behavior of different types of elements realized with high strength concrete under loading is improved, their resistant capacity is higher and the sizes of structural elements are reduced in comparison with structures realized of ordinary concrete.

In the ordinary cement concrete or polymer concrete, silica fume is added in different percentages, as replacement or not of cement, for improving the properties, in particular the compressive strength, durability characteristics, bond strength [10, 11]. These good effects of silica fume on the concrete are resulting from the fact that the particles of silica fume are very small and also from the pozzolana reaction of silica fume with cement paste components. In the behavior of structural elements it was observed according to experimental studies, that the failure of beams was improved, the concrete with silica fume had a better behavior to shear force, the number of cracks in tension zone at failure was reduced, which indicate that elements are less destroyed at failure.

In the hydraulic constructions, concrete with silica fume responds better to requirements of hydraulic construction because this concrete has a better behavior to frost-thaw cycles, to abrasion, cavitation, is resistant to chemical attack and it is less permeable, facts which result in a smaller dosage of cement.

Silica fume is also used for obtaining other types of concrete, such as self-compacting concrete, fiber reinforced concrete, polymer concrete. In the case of polymer concrete from experimental studies it was concluded that the increase in compressive strength is not too much as in the case of tensile strength.

Also the addition of silica fume decreased the content of polymer, which is an expensive material. The good behavior of concretes with silica fume can be used for realizing hybrid elements for constructions such as beam or columns, to which the tension zone is realized of polymer concrete, that has a better behavior in tension, and the compression zone of high strength concrete, having in view the better behavior of concrete in compression [11].

Slag can be used in preparing composite cements or as aggregates in preparing concrete.

Slag cements are used in concrete structures because it gives some advantages, such as: less carbon dioxide emission, during the production, lower hydration heat during hardening, low permeability and good resistance to sulphate attack.

Ground granulated Blast Furnace Slag (GGBFS) improves the flexural strength and compressive strength of concrete and asphalt mixes, which recommend its use in roads, highways, pavements, hydraulic constructions, etc. Ground granulated slag is used in producing cement concrete as mix compound of the concrete or as component of cement. The use of ground granulated slag as component of concrete has the advantage of using it in different dosages, which is important in obtaining desired properties. Ground granulated slag can be used in obtaining Portland blastfurnace cement, which contains up to 5% until 95% of filler. Also, this type of waste can be used in preparing concrete as cementitious material due to its hydraulic property. In this case the fineness of ground granulated slag must appropriate to that of cement or even greater. The use of ground granulated slag used in obtaining concrete is benefic for the environment, but also it improves some properties of concrete such as: fresh concrete has a better workability, structure of hardened concrete is more compact, that resulting in increasing the long term strengths and durability. The content of ground granulated slag in the mix and its fineness depend on the purpose for which it is used in obtaining specific properties of concrete. Research studies reported a replacement of cement with dosages between 10 and 80% from the cement mass. The smaller quantities of waste are for increasing mechanical properties and high dosages are for improvement the resistance to chemical attack.

The ground granulated blast furnace slag is also used in asphalt concrete for roads, highways, pavements, etc. An important utilization in the last time is to obtain high performance concretes, with improved durability, which is required in bridges, marine constructions, hydraulic dams, etc.

Another possibility of consuming ground granulated slag waste is to manufacture fibers which can be used in production of insulation material as slag wool.

Experimental studies on concrete with aggregates obtained of steel slag had shown that this type of waste can be used in road construction or in infrastructure works because the presence of steel increased the density of hardened concrete. Good mechanical properties were obtained in the case of cement concrete and polymer concrete with slag aggregates and addition of silica fume.

Sludge

It is used in the production of concrete as filling material because its benefits such as improving the compressive strength, freeze-thaw resistance and waterproofness. Also it can be used as replacement of fine aggregates in asphalt paving .

The paper sludge is used for obtaining blended cements which contain 90% Portland cement and 10% waste. Also, the paper making waste can be processed to obtain a composition of cellulose fibers and clay which is suitable to use as insulating material or as filler in building materials.

The utilization of paper waste sludge obtained from a paper industry, as a replacement to the mineral filler in various concrete mixes was experimentally analyzed [18]. Concrete mixes containing various contents of the waste (3, 5, 8 and 10%) were studied and the results shown a recommended replacement of sand of about 5% for obtaining concrete for masonry construction.

Fly ash

The fly ash utilization is diversified in time and referring to construction industry this waste is used in: cement and concrete manufacturing, production of bricks, tiles and pavements, lightweight aggregates, etc. The new researches used fly ash in obtaining eco-concrete, which eliminated from the mix the cement, the geopolymer obtained being a material more friendlily with the environment. Although a large proportion of global FA is used by the building industry, there is a still proportion which is disposed of in ponds or landfills [4].

In the cement production the fly ash is used in the composition, in different quantities and the cement obtained are named composite cements [6].

In the cement-concrete production, a part of cement is replaced with different dosages of fly ash, normal dosages being between 10-40% and up to 75%. The advantages of using fly ash in concrete are given by the reduction of cement dosage, and also by the beneficial effects which improve concrete properties (mechanical strength and durability resistance), reduce bleeding, reduce cracking, decrease the heat during hardening of concrete [4, 19]. Experimental studies on cement concrete with fly ash shown that the addition of fiber, near fly ash is beneficial in improving the properties. Statistical optimization of mechanical properties for a concrete with 10% replacement of cement recommended for example for glass fiber type, a percentage of 1% from the concrete mass and a length of fiber of 35 mm in the case of compressive strength and higher percentages and smaller length, in the case of tensile strengths.

In obtaining the inorganic polymer concrete, which is a “green” material, fly ash that is considered alkali activated cement, replaces totally the cement from the mix. In fly ash-based geopolymer binder, fly ash reacts with an alkaline solution and the geopolymer paste acts as only binder for aggregates. The basic ingredients of fly ash-based geopolymer concrete are fly ash, sodium hydroxide, sodium silicate, fine aggregates and coarse aggregates [20].

The formulation of high-performance materials that are stronger and more durable than conventional cement-based materials has emerged as an issue of considerable importance in the construction industry. It is possible to utilize fly ash to produce a high-performance material at a potentially lower cost and without compromising its structural integrity. The high-performance polymer concrete made with fly-ash fillers presents the compressive strength, flexural strength, creep deformation and bond strength with values bigger than that of Portland cement concrete. Even in the case of fly ash the polymer dosage can be higher than in the case of other additions, the mechanical properties are increased in comparison with polymer concrete without addition. The use of fly ash as an aggregate in polymer concrete is very promising because it could be used as an overlay in pavement, bridges, and runways or in precast applications such as utility, transportation, and hydraulic components [21].

Industrial fly ash is also used for the production of low-strength material, also known as 'flowable fill'. It is used as a replacement of compacted soil in cases where the application of the latter is difficult or impossible. Also other wastes such as the cement kiln dust, asphalt dust, coal fly ash, coal bottom ash and quarry waste are used for preparing low-strength building materials. The content of these wastes in the mix is between 25-50%.

3.2. Organic wastes

One of the methods of consuming sewage waste was the obtaining of methanol gas or caloric fuel which is used for generation electrical powder. Another use is to transform it in powder and to use as fine addition in building materials.

The use of sewage sludge as an organic fertilizer has become of particular interest in the light of the EU Directive concerning the use of sewage sludge, which creates the need for cleaner production technology.

Sewage sludge can be an alternative for the protection of ecosystems. Firstly, sludge-borne organic matter is a crucial factor in improving aggregate stability and water holding capacity of soils, so that the risk of erosion may be reduced. Secondly, sludge-borne nutrients can make sewage sludge an excellent and cheap organic fertilizer for the crops [22]. However, the presence of inorganic and organic contaminants can hider such use of sewage sludge [23]. Moreover, it is well known that the application of organic materials to soil can sequester C, and thus contributes to the improvement of reduction of CO_2 in the atmosphere.

The sludge or the ashes obtained by burning the sludge can be used for obtaining ceramic products such as tile, brick block, pavement, etc. Several works have been carried out in this field [24]. The results from these works concluded that the use of treatment plant sludge as an additional component in a construction material, Portland cement concrete, is possible. The characteristics of sludge were evaluated. Also, it was necessary to analyze other properties such as the origin of the sludge, the components used, and the compatibility of the sludge within the cement matrix and the production of samples. Studies were conducted on the effect of sewage sludge ash on the workability of cement mortars.

A nonlinear reduction of workability in mortars containing sewage ash was observed. In their researches Monzo et. al. [24] reported the influence of sewage sludge ash (SSA) on the properties of cement mortar: a reduction of workability when a part of cement is replaced by sludge ash because it's higher water absorbtion characteristic. Studies on pozzolanic activity of SSA have shown that it contributed to the improved of compressed strength, but its effect is influenced by the sulfur content. The high sulfur content of sewage waste seems to have little influence on compressive strength of mortars containing sewage ash.

Moreover, Casanova et al. [25] observed that cement degradation processes had been observed when gypsum contaminated aggregates or sulfide-bearing aggregates are used in concrete mix.

The sludge or the ashes obtained by burning the sludge can be used for obtaining ceramic products such as tile, brick block, pavement, etc.

The sewage sludge ash can also is used as replacement of sand addition to brick clays which presented a high resistance to fire than normal brick clays.

Sewage sludge can be converted into slag, and as glass materials it is used to produce crystallized glass for ceramics technology.

From the environment point of view, the researchers Cenni at al. [26] studied the possibility of using fly ash resulted from co-firing of coal and sewage slag as additive in bilding materials, because the European standards forbid their use. Their studies shown that the ash from co-firing contained components such as unburned carbon, alkali, magnesium oxide, etc. with a reduced concentration as standard requirements. The authors required modifications in European standards for limiting elements that can be unfavorable by using them in building materials. Fytily and Zabaniotou [27] re-analyzed in a review article the use of sewage sludge in construction industry. Other use, such as incineration of sewage sludge is another way for consuming this waste, but it needs a rigorous control of gas compounds which depends on the technology that is used.

3.3. Mineral waste

The inert mineral waste resulted from quarries, from industrial processes can be used as aggregate or fine part in obtaining building materials and construction products. In any type of concrete these waste can replace different sorts of aggregates, contributing to preservation of natural resources.

The research studies in this domain shown that in building material industry a lot of inert waste can be used, such as granite, marble, limestone in the production of different materials: concrete, bricks, prefabricated elements, etc. The use of marble and granite waste in concrete preparing has shown that they improved the mechanical properties, workability and chemical resistance of concrete [28]. The polymer concrete with marble waste is of great interest because the marble addition or the marble used as aggregates improve the properties of concrete and contribute to a reduction of polymer content. The marble waste can also be used in the production of other building materials, such as ceramic products, where can be used as mix component, or in asphalt production as aggregate sort.

3.4. Construction demolition waste

The construction sector produces high quantities of wastes, over80% being solid waste which is dumped. Some of these wastes may have particular health, safety and environmental concern, such as, asbestos materials with lead-based paint coating and lighting waste. These materials are not included in the present review.

Until now, the construction practice was thought unsustainable because, not only it is consuming enormous quantities of stone, sand and drinking water, but also huge quantities of cement [4]. Modern reinforced concrete structures begin to deteriorate in 10 to 20 years. So, an important problem of concrete structures is that of increasing their durability. New types of concretes obtained by using Portland cement replacement materials and recycling the concrete removed from structures will contribute to the sustainability of building material industry [29]. Also, it must realize that the resources for construction industry are limited and the new technologies of obtaining building material must be based on the existing wastes.

The construction wastes are easier for recycling because they were parts of constructed buildings and as raw materials they were analyzed as raw materials. The concrete from demolition can be used as aggregate. Recycled-aggregate concrete is prepared by completely substituting of natural aggregates [30]. In many cases in the concrete mix there are also used superplasticizers and supplementary cementing materials (for example fly ash). Also, in the recycled-aggregate concrete mix, the cement can be replaces by fly ash or other by-product.

The other materials resulted from constructions such as wood, masonry, metal, plastic, fiber glass, polystyrene granules, etc. can be used in building industry. In the category of “green concrete” which means a concrete with waste, they are introduce in the mix different additions, some as filler. Cement concrete with wood waste is a concrete of low strength, and with characteristics of a lightweight concrete. In the case of cement concrete with polystyrene granules, experimental studies shown that the mechanical characteristics can be comparable with that of an ordinary concrete, even the density indicates a lightweight concrete [3]. A specific property of cement concrete with polystyrene is that of elastic behavior of material under loads, in the case of high dosages of polystyrene.

The concrete with polystyrene spheres was studied from a long time, and near the fact that it is a lightweight concrete other advantages recommend its use in construction. Concrete with polystyrene can be prepared in site or to obtain prefabricated units in factories. The properties of concrete with polystyrene are influenced by polystyrene dosage and by the size of granule. It has been shown that these properties can be significantly improved by adding steel fibers or additions (silica fume, fly ash, etc.) in the concrete matrix or by decreasing expanded polystyrene sphere size.

The polystyrene waste can be also used in manufacturing lightweight concrete blocks or surface units, with improved thermal insulating properties, by introducing the polystyrene sphere as lightweight aggregate in the concrete mix [33].

3.5. Transportation industry waste

The used tires are occupying a large landfill space and generate important problems to the society: one is that of hazard fire which is almost impossible to extinguish and the other is related to the people health. The European Association of Tyres and Rubber producers had estimated in 2009 that a quantity of 3.2 millions of tons of used tyres, from which 96% were re-used: 18% were retreated, 38% were recycled and 40% were used for burning in production of energy [32]. In Romania the recovery ratio is under 10%, in this context capitalization is a challenge for researchers.

The wastes of tyres are used in different purposes: for fixing and sealing soils in agricultural domain, in hydraulic domain (retaining walls, breakwaters), etc. [32].

The tyre waste can be used in natural form, cut in aggregates or in powder. Rubber aggregate is often used in construction works for obtaining light concrete or for road pavements. The experimental studies showed a percentage of around 25% from the mass for obtaining properties comparable with that of ordinary concrete. Higher quantities of tire waste result in decrease of mechanical properties [34]. The rubber increases the capacity to absorb energy from impacts, thus reducing the damage from collisions and increases the deformability and ductility of concrete. Rubber granulate is used for kindergarten play areas.

Once asphalt-rubber mixtures started to be regulated in the 1990s their use in pavements for roads and highways increased significantly [4]. The main advantages of pavements containing tires are their greater resistance to temperature variations and frost-thaw cycles, reduced noise, lower maintenance costs, a better drainage and an increase service life.

In different types of concrete the tire waste is used in various ways. In the concrete mix, the aggregates can be replaced by rubber particles in dosages between 0 - 45 % by volume. As indicated in the literature the concrete with used tire presented an decrease in mechanical characteristics, the use domain of materials obtained with this type of waste presents some advantages which derive from good damping properties, good thermal and acoustic performances [17].

In this direction, obtaining tough materials can be realized by introducing rubber particles in any mix. Concrete of any type is a brittle material. Small quantities of rubber in combination with other additions, can contribute to a better behavior of concrete, without affecting its mechanical properties.

Waste tire can be used as powder in obtaining cement concrete, polymer concrete, concrete with fibers, etc. Tire powder can be introduced in the mix as filler or to replace a part of fine aggregates. In the case of epoxy polymer concrete with powder of tire waste the experimental tests shown that the concrete is lightweight concrete with low mechanical properties, that recommend this concrete for pavement, prefabricated elements for sound protection, thermal insulation, etc [34]. Also this type of concrete showed a very good behavior to attack of chemical agents, abrasion resistance, so its use as floor in chemical industry or as pavements can be a possibility.

Waste tire can be used also in combination with other materials, such as glass fiber reinforced composite, in this case the tire waste being used as replacement of sand and for a better protection against pollution caused by noise. This composite can be used as façade panels for the cover of different buildings.

Rubber tires can be used in embakement as a lightweight filling material for soil reinforcement.

3.6. Other types of wastes used in building materials

- **The plastic materials** represent today an important category of waste. Most of them are re-used in different domains. Polypropylene, polyethylene, polyvinyl alcohol, polyvinyl chloride, nylon, aramid, polyesters are used as short plastic fibers in concrete elements. In the concrete production these fibers are currently used for obtaining high strength concretes, shotcrete, self-compacting concrete, etc [35]. Polyethylene terephthalate (PET) is one of the most used plastic in the entire world, especially for obtaining beverage containers, which are generally thrown away after single usage and their disposal creates serious problems to the environment. Some PET wastes are recycled for obtaining new products, other wastes are used as short fiber reinforcement in structural concrete, also as synthetic coarse aggregates for lightweight concrete, or as resin for polymer concrete [35].

- **The inorganic solid waste** can also be vitrified in solid-like glass materials that are used to manufacture aggregates for the construction industry for obtaining tile and bricks. No ashes are produced because at more than 5,000ºC, all the molecules are disintegrated.
- **Wastes of fiber** of different types (glass, polypropylene fiber, carbon, polyester, textile, etc.) and length are used din obtaining concrete with disperse reinforcement. The properties of fiber reinforced concrete depend on the fiber type, the geometry, the percentage of fiber, orientation and distribution of fiber, mixing and compaction of concrete.

The various applications of fiber reinforced concrete such as shotcrete in underground works, precast products, architectural panels, hydraulic constructions, etc. had contributed to the rapid development of this new building material.

3.7. Agricultural waste used in building material

Wastes from agricultural activities are in very high quantities, especially in some places of the world and they are another source of environment pollution and social problems because their accumulation in landfills and uncontrolled burning.

- **Rice husk** is generated by the rice milling process, from which 78% of weight is rice, broken rice and bran and the rest of 22% is husk. Some quantities of rice husk is burnt, which is polluting the environment. In the composition of rice husk there is nearly 20% silica, which after thermal treatment converts to a crystalline form that is with high reactivity, ultrafine size and large surface area. Because it's high pozzolanic activity the rice husk silica is used in obtaining high strength concrete instead silica fume. The cementing properties of rice husk offer the possibility of its use in ordinary concrete as cementitious material, for replacing cement or in production of supplementary cementing material [31]. Other uses are referred to its use as filler in polymer concrete, green concrete or in production of green building materials.
- **Banana leaves ashes** had been studied because it's pozzolanic activity which arises from the content of amorphous silica. The banana leaf ash is obtained by burning at a controlled temperature. The use as addition in mortar and concrete for civil structures had some advantages such as a reduction of costs of building materials and the consumption of huge quantities of banana produced every year [36].
- **Bamboo leaf** waste was experimentally analyzed because it's pozzolanic property which can be used for introducing this waste in cement composition. The test results shown that in composition of bamboo leaf waste the SiO_2 are 78.7%., being a very reactive pozzolan, comparable to silica fume. The blended cements obtained with bamboo leaf waste in a percentage of 10 and 20% showed the same compressive strength as the witness cement [37, 38].
- **Bagasse ash** is a waste sugar factory and it is used in obtaining blended Portland cements [39] or as replacement of cement in concrete in dosages of 10 to 30% of binder.

Natural cellulosic fibers can be used in the design and manufacturing of composite materials. The natural cellulosic fibers are bagasse from sugar cane, banana trunk from the banana plant and coconut coir from the coconut husk. The banana fiber exhibited the highest ash, carbon and cellulose content, hardness and tensile strength, while coconut the highest lignin content [40]. In combination with other additions, the concrete prepared with natural fibers exhibits good mechanical properties.

SUSTAINABLILITY:

It is Defined as meeting the needs of present generations without compromising the ability of future generations to meet their needs. Sustainable building or green building refers to the structure which are both environmentally responsible & resource efficient throughout a building life cycle. Sustainable building design involves balance between home building & suatainable environment.

OBJECTIVES:

- Low impact on natural environment.
- Energy efficient.
- Minimizing usage of water.
- Protecting occupant's health & increasing productivity.
- Minimizing waste.

GOALS:

- Environmental, economic & social benefits.
- Taking advantage of renewable resources.
- Sunlight as solar energy.
- Reduction of rainwater as run off.
- Using plants & trees or roof gardens.

SUSTAINABLE MATERIAL:

- Any material that can be put to effective use in the present without compromising its availability for use by latter generations.
- Mainly renewable materials or materials which can be recycle & reused.

SOURCES RENEWABLE REUSE FROM WASTE:

RENEWABLE MATERIALS	REUSE FROM WASTE MATERIALS
➢ MATERIALS SIGNIFICANTLY OF PLANT ORIGIN	➢ PRODUCTS OF RECYCLED MATTER
➢ SOLAR ENERGY, WIND ENERGY, BIO-GAS.	➢ DISMANTLED & REUSED AGAIN.
➢ WOOD, NATURAL FIBERS, POLYMERS ETC.,	➢ OLD PLUMBINGS, DOORS, CRUSHED GLASS, WOOD CHIPS ETC.,

,

Wool brick:

- Obtained by adding wool and a natural polymer found in seaweed to the clay ofthe brick, 37% More strength than burnt bricks
- Resistant for cold and wet climate
- They are dry hard & don’t need to be fired like other bricks.

Sustainable Concrete:

- Crushedglass ,Wood chips or slag- a byproduct of steel manufacturing.
- Reduces the emission of CO2

Solar Tiles:

- Exist to simplyprotect abuilding ¬
- Theyspend alarge portion of the day absorbing energy from the sun.
- Fully integrated into the building. ¬Protects from weather.

Paper Insulation:

- Made from recycled newspapers and cardboard
- Then filled with chemical foam
- Insect resistant &fire retardant

Triple-Glazed Windows:

- Super-efficient windows
- Stops heat to enter the building & from direct sunlight
- Low emissivity coatings to glass prevent heat from escaping.

Merits

- Efficient Technologies
- Easier Maintenance

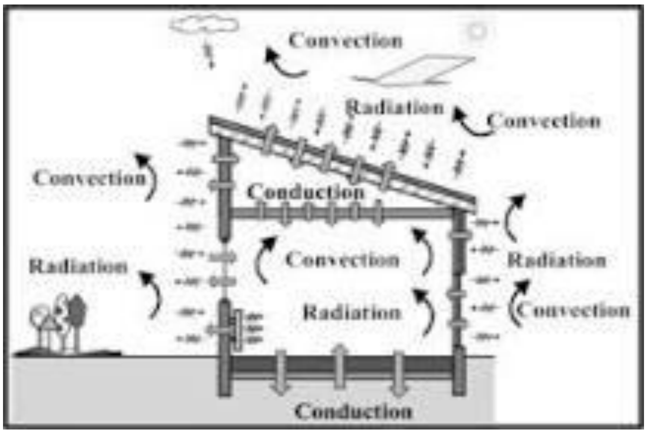
- Return On Investment
- Improved Indoor Air Quality
- Energy Efficiency
- Water Efficiency
- Waste Reduction
- Temperature Moderation
- Water Conservation
- Economical Construction For Poor
- Healthier Lifestyles and Recreation
- Improved Health.

DEMERITS:

- Initial Cost Is High
- Availability Of Materials
- Need More Time To Construct
- Need Skiled Worker

Energy Conservation Building Code (ECBC):

Building envelopes of energy-efficient buildings are not simply barriers between interior and exterior; they are building systems that create comfortable spaces by actively responding to the building's external environment, and substantially reduce the buildings' energy consumption



- The Energy Conservation Building Code (ECBC) was developed by the Govt. of India for new commercial buildings on 27th May 2007.
- The purpose of Energy Conservation Building Code (ECBC) is to provide minimum requirements for energy-efficient design and construction of buildings and their systems.
- The building sector represents about 33% of electricity consumption in India, with commercial sector and residential sector accounting for 8%and 25% respectively.
- Estimates based on computer simulation models indicate that ECBC-compliant buildings can use 40 to 60% less energy than conventional buildings.
- It is estimated that the nationwide mandatory enforcement of the ECBC will yield annual savings of approximately 1.7 billion kWh.
- The ECBC is expected to overcome market barriers, which otherwise result in under-investment in building energy efficiency.

- The ECBC was developed as a first step towards promoting energy efficiency in the building sector.
- The ECBC is the result of extensive work by the Bureau of Energy Efficiency (BEE) and its Committee of Experts.

The ECBC provides design norms for:

- Building envelope, including thermal performance requirements for walls, roofs, and windows;
- Lighting system, including day lighting, lamps and luminaries' performance requirements;
- HVAC system, including energy performance of air distribution systems;
- Electrical system; and
- Water heating and pumping systems, including requirements for solar hot-water systems.
- Energy Conservation Building Code (ECBC)

Unit-2

Fenesration:

The arrangement of all the cutouts in the building which are a natural source of air, light and ventilation are known as fenestrations.

- The building elements which are a part of the fenestration designs are doors, windows, louvers, curtain wall glazing, vents, skylights, storefront glass, etc.
- Daylighting is introduced into the building through the fenestrations so as to complement or replace the artificial electrical lighting.
- A well-automated control system can modulate the amount of daylight that can be admitted and cut the electrical lighting thus reducing electricity costs.

A good fenestration design has the following benefits-

- Improves the comfort level of the occupants by providing good air, light, and ventilation.
- Increases the amount of daylight but does not allow heat absorption into the building through efficient glazing systems.
- Good fenestrations can result in energy savings by reducing the air conditioning and heating costs.
- A good louver design can let natural diffused light into the building but reduce the glare and direct sunlight.
- Good shading devices like chhajjas, jaalis, and pergolas can be aesthetically designed such that they allow diffused light into the interiors and reduce solar gain and glare.
-

GLASS

Glass may be defined as a hard, brittle and transparent or translucent material. Technically glass is any substance or combination of substances that has solidified from the liquid state without crystallisation.

<u>Constituents of Glass</u>

The main constituents of glass are silica, sodium or potassium carbonate, lime, manganese dioxide, cullet and colouring materials.

1. Silica

Silica is the principal constituent of glass. Silica alone when fused at a very high temperature would give a good glass on cooling. However, it is essential to add some quantity of alkaline materials along with lime to make the molten silica glass sufficiently viscous so as to get good workability and resistance against weathering agencies.

2. Sodium or Potassium Carbonate

It is an alkaline material that is also an essential component of glass. This is being added in a certain proportion so as to reduce the melting point of silica and to impart viscosity to the molten glass.

3. Lime

This is added in the form of chalk so as to impart durability to glass. In order to make the glass bright and shining, lead oxide is added in place of lime.

4. Manganese Oxide

This is added in a certain proportion so as to correct the colour of the glass due to the presence of iron in raw materials of glass.

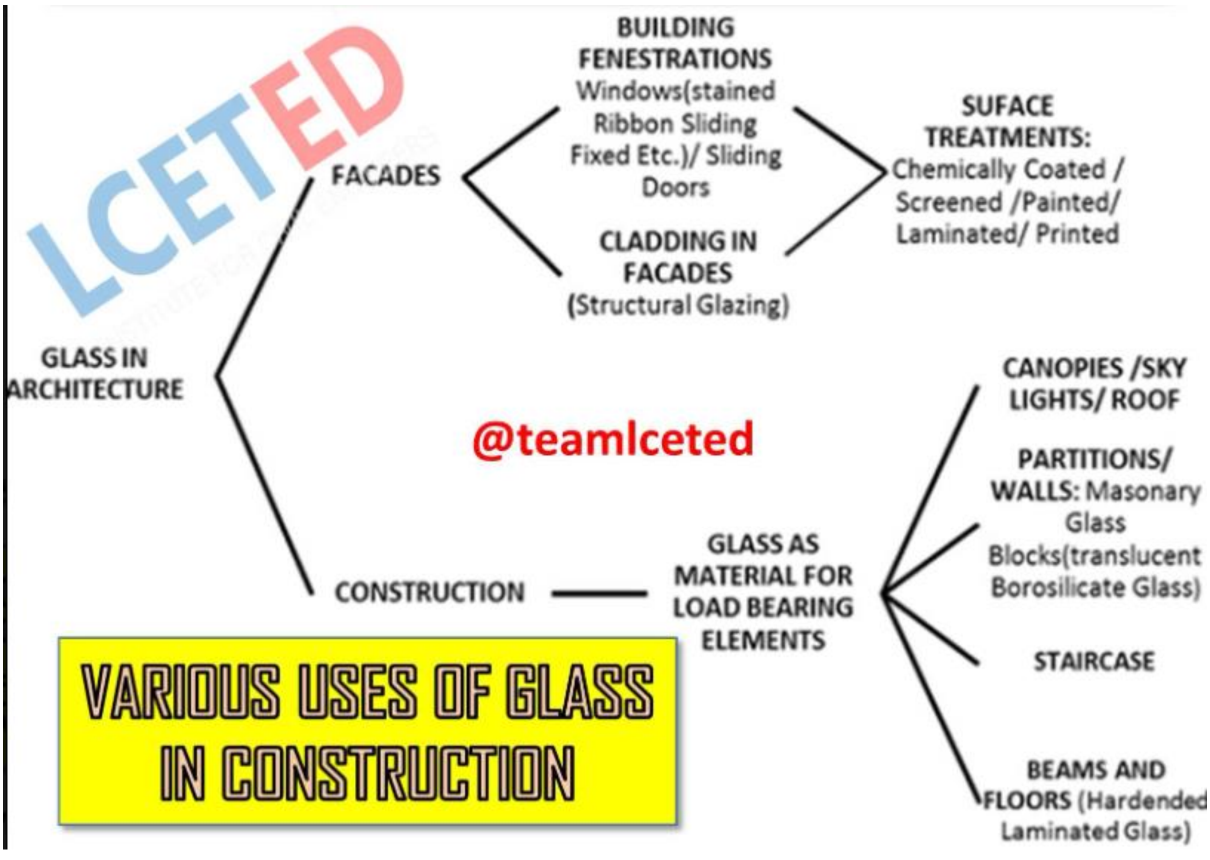
5. Cullet

Cullet is the old broken glass of the same type as that is intended to be manufactured.

6. Colouring Substances

At the time of manufacturing a coloured glass, a suitable colouring substance is added at the fusion stage to provide the desired colour to the glass.

Various Uses Of Glass In Construction



Properties of Glass

Properties of glass are mainly governed by the factors such as the composition of constituents, state of the surface, thermal treatment, dimensions of the object, etc. Glass has been popular and useful due to the following properties:

Transparency:

- This property allows visual connection with the outside world. Its transparency can be permanently altered by adding admixtures to the initial batch mix. By the advent of technology clear glass panels used in buildings can be made opaque. (Electro chromatic glazing)

U value:

- The U-value is the measure of how much heat is transferred through the window. The lower the U-value the better the insulation properties of the glass– the better it is at keeping the heat or cold out.

Strength:

- Glass is a brittle material but with the advent of science and technology, certain laminates and admixtures can increase its modulus of rupture(ability to resist deformation under load).

Greenhouse effect:

- The greenhouse effect refers to circumstances where the short wavelengths of visible light from the sun pass through glass and are absorbed, but the longer infrared re-radiation from the heated objects are unable to pass through the glass. This trapping leads to more heating and a higher resultant temperature.

Workability:

- It is capable of being worked in many ways. It can be blown, drawn or pressed. It is possible to obtain glass with diversified properties- clear, colorless, diffused and stained. Glass can also bewelded by fusion.

Recyclable:

- Glass is 100% recyclable, cullets (Scraps of broken or waste glass gathered for re-melting) are used as raw materials in glass manufacture, as aggregates in concrete construction etc.

Solar heat gain coefficient:

- It is the fraction of incident solar radiation that actually enters a building through the entire window assembly as heat gain.

Visible transmittance:

- Visible transmittance is the fraction of visible light that comes through the glass.

Energy efficiency and acoustic control:

- Energy-efficient glazing is the term used to describe the double glazing or triple glazing use in modern windows in homes. Unlike the original single glazing or old double glazing, energy-efficient glazing incorporates coated (low-emissivity) glass to prevent heat escaping through the windows. The air barrier also enhances acoustic control.

Other properties of Glass:

- It has no sharp melting point and no definite crystalline structure.
- It is capable to absorb, refract or transmit light.
- At elevated temperatures acts as an excellent electrical insulator.
- It can take up the high polish and can be used as a substitute for any costly gem.
- It is not affected by air or water.
- It can not be attacked by ordinary chemical agents.
- It can be altered to meet certain requirements by changing fusibility, hardness, refractive power, etc.
- It is transparent and translucent.
- It is possible to weld pieces of glass by fusion.
- It is affected by alkalis.
- Based on advanced technology, it is possible to make glass lighter than cork or softer than cotton.
- The only drawback is that it is brittle.

Glass Manufacturing

General:

- Commercially produced glass can be classified as soda-lime, lead, fused silica, borosilicate, or 96 percent silica.
- Soda-lime glass, since it constitutes 77 percent of total glass production, is discussed here.
- Soda-lime glass consists of sand, limestone, soda ash, and cullet (broken glass).
- The manufacture of such glass is in four phases:
  (1) Preparation of raw material,
  (2) Melting in a furnace,
  (3) Forming and
  (4) Finishing. Figure is a diagram for typical glass manufacturing.

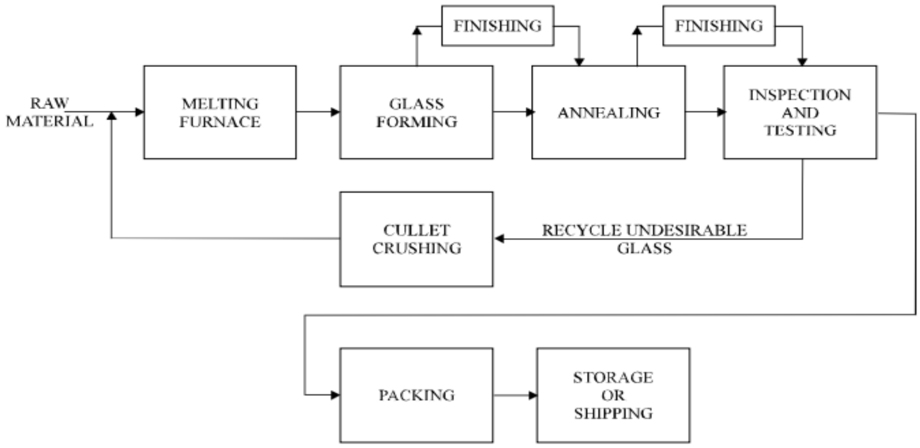


Figure 11.15-1. Typical glass manufacturing process.

- The products of this industry are flat glass, container glass, and pressed and blown glass.
- The procedures for manufacturing glass are the same for all products except forming and finishing.
- Container glass and pressed and blown glass, 51 and 25 percent respectively of total soda-lime glass production, use pressing, blowing or pressing and blowing to form the desired product.
- Flat glass, which is the remainder, is formed by float, drawing, or rolling processes.

Preparation of raw material:

- As the sand, limestone, and soda ash raw materials are received, they are crushed and stored in separate elevated bins.
- These materials are then transferred through a gravity feed system to a weigher and mixer, where the material is mixed with cullet to ensure homogeneous melting.
- The mixture is conveyed to a batch storage bin where it is held until dropped into the feeder to the melting furnace.
- All equipment used in handling and preparing the raw material is housed separately from the furnace and is usually referred to as the batch plant. Figure 11.15-2 is a flow diagram of a typical batch plant.
- The furnace most commonly used is a continuous regenerative furnace capable of producing between 45 and 272 megagrams (Mg) (50 and 300 tons) of glass per day.

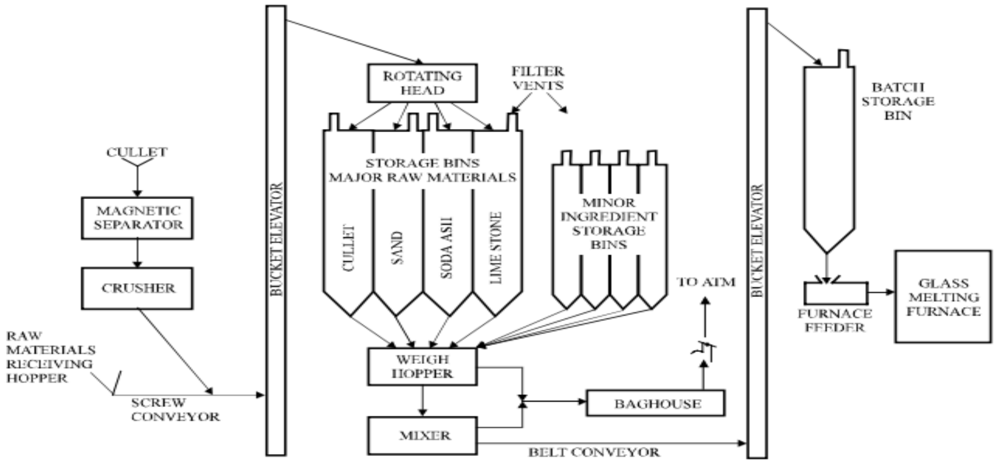


Figure 11.15-2. General diagram of a batch plant.

Melting in a Furnance:

- A furnace may have either side or end ports that connect brick checkers to the inside of the melter.
- The purpose of brick checkers (Figure 11.15-3 and Figure 11.15-4) is to conserve fuel by collecting furnace exhaust gas heat that, when the air flow is reversed, is used to preheat the furnace combustion air.
- As material enters the melting furnace through the feeder, it floats on the top of the molten glass already in the furnace.
- As it melts, it passes to the front of the melter and eventually flows through a throat leading to the refiner.

Forming:

- In the refiner, the molten glass is heat conditioned for delivery to the forming process. Figures 11.15-3 and 11.15-4 show side port and end port regenerative furnaces.

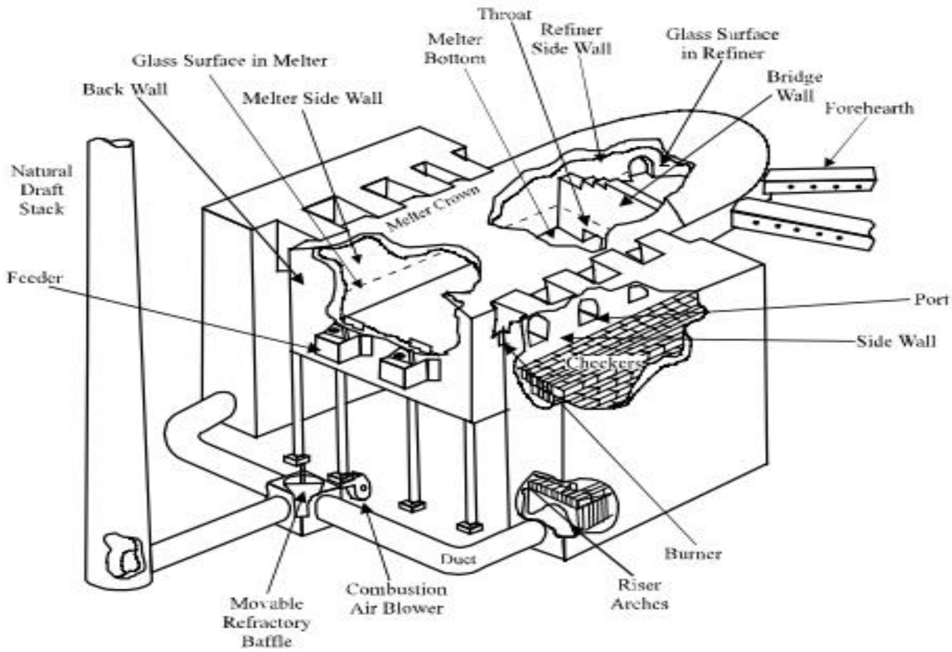


Figure 11.15-3. Side port continuous regenerative furnace.

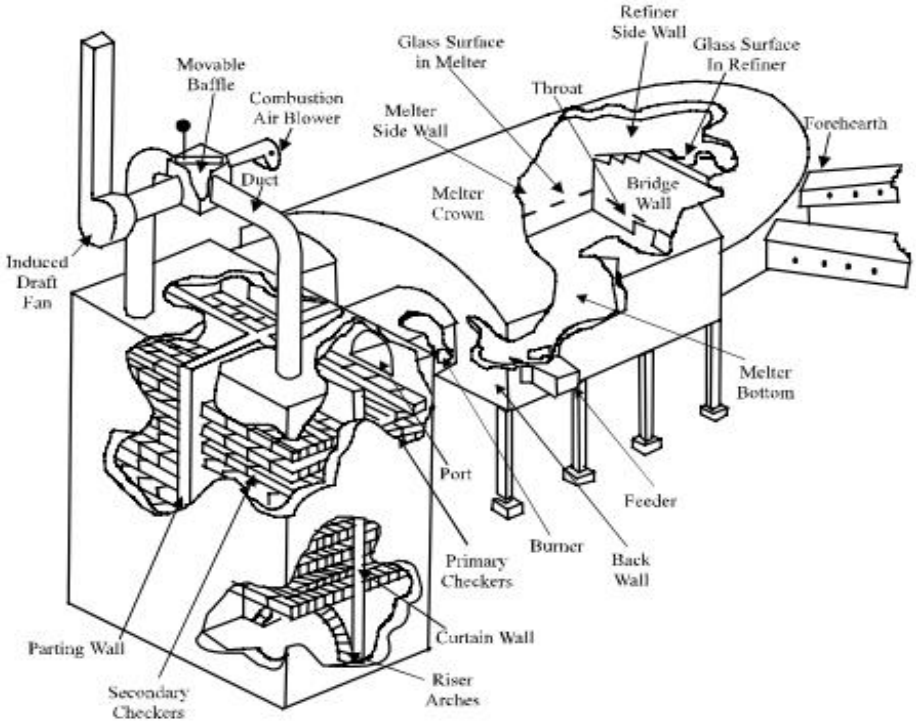


Figure 11.15-4. End port continuous regenerative furnace.

After refining, the molten glass leaves the furnace through forehearths (except in the float process, with molten glass moving directly to the tin bath) and goes to be shaped by pressing, blowing, pressing and blowing, drawing, rolling, or floating to produce the desired product.

Pressing and blowing are performed mechanically, using blank molds and glass cut into sections (gobs) by a set of shears.

In the drawing process, molten glass is drawn upward in a sheet through rollers, with thickness of the sheet determined by the speed of the draw and the configuration of the draw bar.

The rolling process is similar to the drawing process except that the glass is drawn horizontally on plain or patterned rollers and, for plate glass, requires grinding and polishing.

The float process is different, having a molten tin bath over which the glass is drawn and formed into a finely finished surface requiring no grinding or polishing.

Finishing:

- The end product undergoes finishing (decorating or coating) and annealing (removing unwanted stress areas in the glass) as required, and is then inspected and prepared for shipment to market.
- Any damaged or undesirable glass is transferred back to the batch plant to be used as cullet.

Types and Uses of Glass:

1. Conventional Types

Based on composition and properties, the conventional glass may be classified as soda-lime or crown glass, flint glass, and Pyrex or heat-resistant glass.

Soda Lime or Crown Glass:

The composition by weight, in general, is sand 75 parts, lime 12.5 parts, soda 12.5 parts, alumina 1 part and waste glass 50 parts. It can be easily fused at comparatively low temperatures. It is quite cheap and available in clean and clear state.

It is principally used for window glass, plate glass and container glass (such as bottles, tumblers, etc.).

Flint Glass:

The composition of flint glass is sand 100 parts, lead 70 parts, potash 32 parts and waste glass 10 parts. It liquefies at a lower temperature compared to soda-lime glass and has better lustre. As the lead compounds are reduced easily, the glass must be melted in an oxidising atmosphere, etc.

It is used for tableware and for optical works. It has also a wide range of use as electric lamps, thermometers, electron tubes, laboratory apparatuses, containers for foods, etc.

Pyrex or Heat-resistant Glass:

Both the above two glasses when subjected to sudden temperatures are not able to sustain because of large coefficients of thermal expansion. Only the basic oxides make them susceptible to chemical attack by water and acids. Elimination of the basic oxides and inclusion of boron oxide produce a glass that is very resistant to thermal shock and to attack by water and acids. The composition of material for such a glass by weight are silica 80 parts, boron oxide 14 parts, sodium oxide 4 parts, alumina 2 parts, with traces of potassium oxide, calcium oxide and magnesium oxide. In order to melt such as mixture, a very high temperature is required.

These glasses are called borosilicate glasses which are extensively used for cooking utensils and laboratory wares.

2. Special Types of Glasses

Special types of glasses are sheet glass, plate glass, float glass, wired glass, translucent glass, glass blocks, safety glass, bullet-proof glass, tinted glass, structural glass, etc.

Sheet Glass:

This is mainly used for small panels of doors and windows. These glasses are to be free from blisters, scratches, waves, bubbles, etc. It is manufactured in thickness varying from 1.5–5 mm and sizes up to 1.5 m × 1 m.

Plate Glass:

It is available in thickness varying from 3–32 mm. This type of glass is stronger and more transparent with very little waviness. It is generally used for large-sized panels such as waiting halls, shopping complexes, etc. There are three varieties of this type of glass, namely roughcast, rolled (or patterned) and polished glass. Generally, the polished variety is denoted as plate glass.

Flutted Glass:

These are the glasses that have corrugations on one side of the plate glass. The other side is wavy but smooth. In this type, the light is admitted without the glare of the sun. It is used in situations where privacy without the obstruction of light is needed. Ribs may be in the horizontal or vertical directions. Horizontal ribs give more light in the middle and less at the sides. The upright ribs give more light at the sides and less in the middle. It is thus more ideal to use for skylight roofs and

Float Glass:

This type of glass is prepared by passing the molten glass through a molten tin bath (float bath). Because the free-standing surface of the tin bath is very smooth, the float glass is of uniform thickness. It possesses excellent optical clarity and aesthetic appearance. Finally, it is annealed to relieve all the stress. This is mainly used for large-sized shop windows and facades of tall buildings.

Wired Glass:

In this type of glass, wire-netting material is embedded during the time of manufacture. It has high resisting power compared to ordinary plate glass. Because of wire-netting, it does not fall into pieces when broken. It is used for fire-resisting doors and windows and for skylights and roofs.

Translucent Glass:

This glass is also called obscured glass or frosted glass. In such glasses, a pattern or texture is imprinted on one or both faces. This prevents the image from being seen through. The textured side should face the inside of a place (to be made obscure) and the plane glass side should face the other side. This type of glasses is used for doors and windows of the bedroom, bathroom, lavatories, etc.

Bullet-proof Glass:

This type of glass is prepared by following special techniques. Here, the glass is made of several layers of plate glass with alternate layers of vinyl resin plastics. Further, the inner layers are thicker than the outer layers. At the time of manufacturing, special care is taken for heating and cooling of layers. The thickness of this type of glasses varies from 15–75 mm. The special quality of the glass is that it will not allow bullets to pierce through it. It is used in a special type of car, bank counters, jewellery stores, etc.

Glass Blocks:

These are glass units that consist of two halves fused together so as to form a hollow inside. These blocks provide insulators against heat, cold and noise. These blocks are used for constructing wall panels.

The Advantages of using glass as a building material

Easily moulded:

- Glass is basically a translucent material, created by the application of heat to sand. It can easily be moulded into any shape which makes it one of the most versatile materials to be used in the construction of buildings and also, one of the most frequent ones.

Visible transmittance:

- Using glass in architecture not only allows you to get visually connected to the outer world, but it also allows natural light to flow in even if the house is closed.

Weather and rust resistance:

- Unlike any other material, glass can withstand the effects of water, wind, sun and other environmental effects, without losing an inch of its appearance and integrity.

Excellent insulator against electricity:

- Glass is considered to be an excellent insulator. In the absence of free electrons, it ensures that you are safe from any possible electric hazards.

Recyclable:

- A glass is 100 percent recyclable i.e. it does not degrade during the recycling process and can even be used as a raw material in the construction industry.

Adds to the beauty of the structure:

- Using glass as a building material accentuates the beauty and elegance of the building. It has a smooth and a glossy surface, which makes it an ideal material for showrooms and showcases.

The Disadvantages of using glass as a building material

Easily breakable:

- Glass, when subjected to the slightest of stress, breaks without strain. Further, the broken edges of glass are sharp enough to cause injury.

Unsafe for earthquake proven areas:

- Buildings in the earthquake proven areas need to be specially designed in order to take the additional stress. However, glass, being brittle in nature, tends to collapse easily.

Heat absorbent:

- Glass generates a high level of solar radiation and traps heat which eventually warms up the interiors. Therefore, it might not be suitable for the construction of buildings, typically existent in the hot regions.

Increase in the cost of security:

- Using glass in a building enhances the cost of security because of the transparency that it offers.

Increase in the overall cost of the building:

- Glass, being an expensive material as compared to the other materials used in the construction industry, eventually augments the total cost of the building.
- Glass is one such material that is colossally being used in modern architecture nowadays. The versatility of the material has increased by leaps and bounds, and it is now being used as an insulation material, structural component, external glazing material, and cladding material etc. in the construction of buildings, worldwide. Despite being on the costlier side in comparison to the other building materials, the intensifying popularity of glass in building construction cannot be denied.

Polymerisation:

Introduction:

Throughout the 1990s, polymer based building materials, especially plastics, have been used widely in construction industry. Superior strength in weight performance, corrosion resistance, environmental stability, insulation properties, lower cost are the main properties of polymer based building materials. Although, polymer based building materials have some important superior properties compared to traditional materials, they have some disadvantages, like their flammability and smoke toxity.

However employing additives or combining with other materials, helps plastics gaining superior properties. Quality level of polymer based building materials can be evaluated through the new results. Durability of the material will be affected also by the quality level of the material

Polymer Based Building Materials:

- Polymers are organic compounds which are the main substance of plastic.
- Monomers are the 'building blocks', polymer is the completed plastic and the reaction is called polymerization.
- During production processes, as well as oil-based chemicals, chlorine, hydrochloric acid, fluorine, nitrogen, oxygen and sulphur are the other substances used. Nearly all plastics include additives like plasticizers, pigments, stabilizers against solar radiation, preservatives and perfumes.
- Plastic is a substance that contains natural or synthetic high molecular organic material which can be liquefied and thereby cast in specific moulds
- Plastics were first used as ornament, superficial finish, or as secondary parts for enclousure systems, in building and construction.
- Although, plastics are in construction industry as a wider scope of uses such as interior finishes, glazing, plumbing fixtures and even structural components today, only recently they began to gain respect and appreciation as a viable primary material.
- Having a lower fire-rating and limited usage in applications of requiring fire resistance are the weakness of plastics compared to other construction materials.
- However, there are some advantages plastics can offer like they are lightweight, lower in cost, resistant to corrosion and moisture, can be relatively strong and are readily shaped.
- One of the other disadvanges of plastics was their being short-lived fad that is brittle and prone to discolor, but has recently been revised due to enormous advances in the plastics industry, which has manufactured unprecendented variety of new products with improved physical properties. Since the material is intrinsically man-made, there is no limit for the charasteristics and expanding will continue.

Properties of Polymers:

- Mechanical and chemical properties of polymer materials are crucial for designers and engineers since these characteristics demonstrate whether these materials are suitable to be used in construction or not.

- High strength or modulus to weight ratios, toughness, resilience, resistance to corrosion, lack of conductivity (heat and electrical), color, transparency are properties which are present in most of polymer materials. It is possible to modify the properties of polymer materials by either adding stabilizer or plasticizers.

- Engineers are chiefly concerned with mechanical properties and with the physicochemical which determine durability. The mechanical response of Polymer materials may change appreciably over quite a small temperature range.

Properties of Polymer Materials

1. Density

- The density of polymer materials is low because it mainly composed of light elements. The density of Poly Methyl Pentane is 830 kg per cubic meter, Polypropylene (PP) is 905 kg per cubic meter, and Polytetrafluoroethylene (PTFE) is 2150 kg per cubic meter. These densities are considerably low compared with that of steel which is 7850 kg per cubic meter.

2. Thermal expansion

- Thermal expansion of polymers is relatively large. This must be considered in the design and use of polymer components, particularly when used in conjunction with other engineering materials.

- Polymers can expand by differing amounts in different directions due to its composition. It contains strong covalent bonds along the polymer chain and much weaker dispersive forces between the polymer chains.

3. Thermal Conductivity

- The thermal conductivity (K factor) of polymers is very low. This make it as suitable insulator materials. Polymers also have outstanding electrical insulation properties.

- At ambient temperature unfilled polymers have conductivities in the range of 0.15-0.13 W/m°C, about 240 W/m°C and that of copper is about 385 W/m°C W/m°C.

- Solid polymers have thermal conductivities in the range of 0.16 to 0.45 W/m/K. In foamed polymers, thermal conductivity is as low as 0.024 W/m/K (watt per metre per degree Kelvin).

4. Permeability

- Generally, solid polymers do not contain interconnected pores and may generally be regarded as practically impermeable. That is why Polymers are frequently used as protective coatings, vapor barriers, sealants, caulking compounds and proof against gases and vapors.

5. Chemicals Resistant

- Polymer can withstand chemicals which makes it a suitable construction material in various circumstances.

6. Strength

- There are several types of the strength such as tensile, compression, flexural, torsional, and impact strength. The impact strength is strongly influenced by change in temperature, impact strength generally falling as the temperature falls.

- The strength of polymer material is based on molecular weight, cross-linking, and crystallinity. The tensile strength of the polymer rises with increase in molecular weight. Similarly, large molecular weight provides high strength.

- Moreover, cross-linking decrease motions of chains and increases the strength of the polymer. The crystallinity of the polymer increases strength, because in the crystalline phase, the intermolecular bonding is more significant.

7. Durability

- The durability is based on the type of polymer, its composition and structure, and on the synergistic effect of the conditions of exposure. The durability of a polymer determines whether it is suitable for external construction applications

- The changes which bring about environmental degradation in polymers and ultimately determine durability are complex and varied. The complexity arises from the conjoint action of a number of agents of degradation, notably ultraviolet radiation (from sunlight), heat, oxygen, ozone and water.

- The list of main agents and modes of degradation in polymer materials is given in table.

Table 1: Main agents and modes of degradation in polymer

Main agents	**Mode of degradation**
Oxygen at moderate temperature	Thermal oxidation
Oxygen at higher temperature	Combustion
Oxygen + ultraviolet radiation	Photo-oxidation

Water	Hydrolysis
Heat alone	Pyrolysis
Ionizing radiation	Radiolysis
Micro-organisms	Biological attack
Atmosphere oxygen + water + solar radiation	Weathering atmospheric degradation

8. Toxicity

- Some of the organic monomers from which polymers are synthesized are recognized as toxic and severe controls are placed on the handling of these substances. Residual free monomer levels in thermoplastics are extremely low and these materials are not normally considered hazardous.

- However, if exposed to high temperature, partial pyrolytic decomposition may occur, releasing monomer or other volatile and toxic substances. Unpolymerized substances should be handled with strict attention.

- Furthermore, toxicity problems arise with certain polymer additives and additives permitted in formulations for contact with potable water should be subject to tight control.

Examples of polymer materials in construction applications:

Epoxy resins

- Solid resin and Terrazzo flooring
- Anchor fixings
- Adhesives

EpoxEthyl vinyl acetate (EVA)y resins

- Solar panel encapsulants

Expanded polystyrene (EPS)

- Concrete moulds
- Insulation
- Packaging

Polycarbonate

- Lighting housings
- Fittings in hot water systems
- Glazing

Polyester (thermosetting)

- FRP Bridge sections
- Cladding Panels
- Sinks
- Surfaces
- Coatings
-

Polyethylene

- Foam underlay
- Damp-proof membranes
- Coatings
-

Polyisobutylene (PIB)

- Glazing sealants
- Waterproof membranes

Polymethylmethacrylate / Acrylic (PMMA)

- Surfaces
- Sinks

Polypropylene (PP)

- Sound insulation
- Water pipes
- Waste pipes

Polyurethane (PU)

- Sealants
- Concrete jointing

Polyvinylchloride (PVC)

- Sealants
- Concrete jointing

Rubber

- Bridge bearings
- Flooring

Plastic:

a synthetic material made from a wide range of organic polymers such as polyethylene, PVC, nylon, etc., that can be moulded into shape while soft, and then set into a rigid or slightly elastic form.

Classification of Plastic:

Plastics can be divided into two basic categories:

Thermoplastics

Thermoplastics are plastics that do not undergo a chemical change in their composition when heated, and hence, they can mould several times. Examples are polypropylene (PP), polyethylene (PE), polyvinyl chloride (PVC) and polystyrene (PS).

Thermosets

- Thermosets polymers are plastics that can melt and mould into any shape only once. They'll undergo an irreversible chemical reaction when heated, hence, if heated again they decompose instead of melting.

Conductive Polymers

- Intrinsically Conducting Polymers (ICP) are electrically conductive organic polymers. Example: Polyacetylene.

Biodegradable Plastics

- Biodegradable plastics are plastics that degrade or break down when exposed to sunlight or ultraviolet radiation, bacteria, certain enzymes, dampness or water, or wind abrasion. In certain circumstances, rodents, pests or insect attacks can also act ad biodegradation modes or environmental degradation. Example: Starch-based plastics, Cellulose-based plastics, Soy-based plastics.

Bioplastics

- While most plastics are products of petrochemicals, bioplastics are plastics produced substantially from renewable plant materials such as cellulose and starch. Due to the finite limits of petrochemical resources and the risk of global warming, bioplastics is still a growing field.

Recycling of Plastic

- The recycling process of plastic is an essential procedure. If not recycled at the correct time, the plastic mix with other chemicals or materials, making it tougher to recycle and become a source of pollution.

- They are non-biodegradable and so, do not decompose by microbial activity. It is essential to use biopolymers or biodegradable polymers to prevent this.

When it comes to construction, plastics have been extensively used by various construction companies. The components such as hinges, screws, and bigger construction parts are made from plastic and are used in wall covering, electric wiring, waterproofing, flooring, and decoration.

FRP comes in various types and forms. For instance, many different fiber reinforcements are made of carbon, aramid, basalt, and glass. These fibers can be easily woven, braided and stitched to ensure better tensile capacity and stiffness. Various additives and fillers are blended with FRP's to improve mechanical properties and reduce shrinkage.

The reason why plastic is widely preferred by construction professionals is because of the following criteria:

Durability:

- When compared with their metal counterparts, plastic materials are way stronger and durable.
- Plastic hardware is also resistant to harsh weather and corrosion, thereby, increasing its longevity and enhancing its usability.

Cost-Effectiveness:

- Regardless of the type of industry, cost-effectiveness is a vital factor, and the construction industry is no different.
- Plastic materials are extremely economical compared to metal, wood, and other counterparts, making them a preferred choice by builders and construction professionals.

Recycling:

- Unlike metals, plastics can be used and even recycled over and over again without losing their chemical properties.

Energy Saving:

- Compared to metals, plastics consume less heat.
- The insulating properties of plastics can also reduce sound pollution levels.

Safety:

- The lightness of plastic materials makes it comfortable and easy to carry/lift to different places.
- Metals on the other hand are much heavier and can cause injuries if not handled properly.

Easy to Install:

- Since plastic materials are lightweight, they can be easily installed.

Uses of Plastics in Various Aspects of Construction:

Flooring:

Plastic materials like polyethylene and PVC are widely used to manufacture following that is less prone to wear and tear. Moreover, it also decreases the level of sound pollution and can be easily cleaned.

Roofing:

Two layers of plastic materials are used to ensure that there is no damage to the roof. One layer of plastic, which is the upper part, is made of thermoplastic olefin or vinyl, whereas the lower part is made of polyurethane foam. These plastic materials consume less heat and ensure that the interior of the house is kept cooler.

Insulation:

Polyurethane spray is frequently used for insulation when constructing green or low-energy buildings. Rigid polyurethane foam is known for its high thermal resistance which promotes temperature consistency. Polyurethane foam is also popular because it is lightweight, chemical resistant, and flame retardant. Due to its closed-cell nature, polyurethane insulation performs as an air barrier, resulting in significant energy savings.

Pipes:

Pipes that are used in construction are commonly made from polyethylene, PVC, acrylonitrile butadiene styrene (ABS), and CPVC. They are known for being extremely lightweight and flexible, making them easy to install. They are also water and chemical resistant, making them ideal for harsh environments.

Windows:

Compared to regular glass windows, polycarbonate is known for being more burglar-proof. Plastic materials like fiberglass and vinyl are also used to manufacture window frames. Vinyl is extremely inexpensive and strong, whereas vinyl is known for its impact resistance.

Doors:

Many construction projects use polyurethane foam with a fiber-reinforced plastic (FRP) coating for manufacturing doors. This structure makes them incredibly strong.

Uses of Plastic

- Plastics are highly durable, lightweight and, most significantly, can be moulded into any form or shape. These properties are a few reasons for the use of plastics. Plastics are extremely versatile materials that can be useful for a wide range of applications. Below given are some applications;

- The potential to be moulded makes plastic ideal packaging material. Plastics in packaging help keep food healthy and fresh.

- As durable and lightweight, plastics have helped in the field of electronics. From computers and cell phones to TV and refrigerator, nearly all of the appliances around us use plastic.

- Plastics help in making safety gears such as helmets, goggles, etc.

- Plastics are also useful in the construction sector because of their low maintenance and high durability.

- Because of plastic's strength and it's lightweight properties, it is useful in making toys, electrical switches and other household goods.

- As it is non-reactive to air and water, they help store water in plastic bottles and chemicals in chemical laboratories.

- Plastic is a weak conductor of electricity and heat, so its insulation properties help in the coating of electrical wire and various household products like utensils handles, etc.

Advantages:

- Plastics are highly flexible and cheaper in comparison to metals.

- The manufacturing process of plastic parts is budget-friendly.

- Plastics are highly durable and can last for a longer time.

- The specific gravity of plastic is much lower, which makes it a lightweight material.

- The manufacturing process of plastic is a lot faster than metals.

Disadvantages:

- The natural decomposition of plastics will last from 400 to 1000 years and, few types of plastics are non-degradable.

- Plastic materials affect water bodies like oceans, seas, lakes etc., killing marine animals.

- Many animals are consuming plastic products and dying on a daily basis. About 90% of all seabirds have plastic in their stomachs.

- Plastic is widely popular in food packaging, but research studies show that eating food out of plastic containers may cause cancer.

- Both the production and recycling of plastics produce harmful gases and residues that pollute the air, water and soil.

Fabrication of Plastics

BY COMPRESSION,INJECTION,BLOWN FILM & EXTRUSION MOULDING

What is Fabrication?

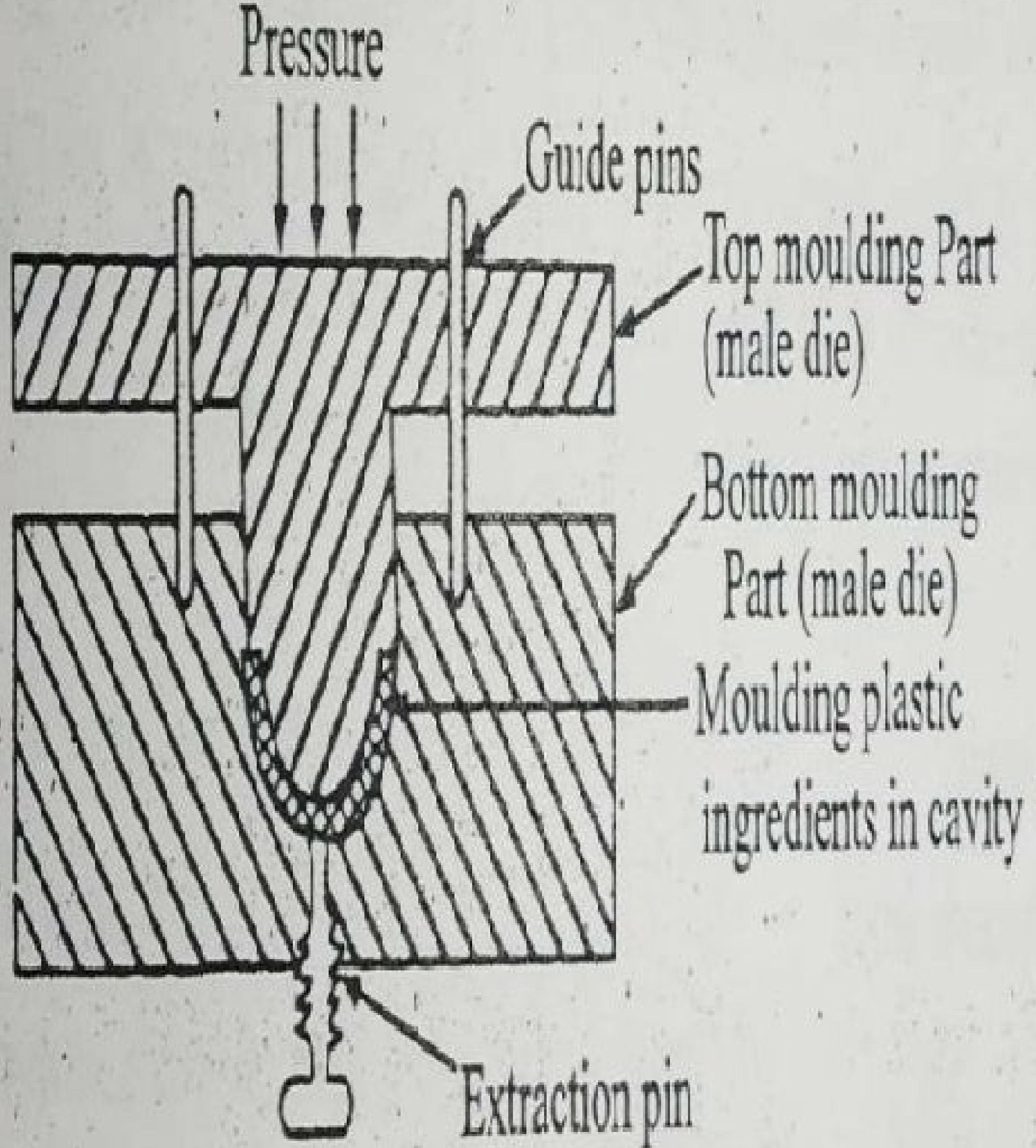
- Giving desired Shape to Plastics is called Fabrication of plastics.

Methods used for Fabrication

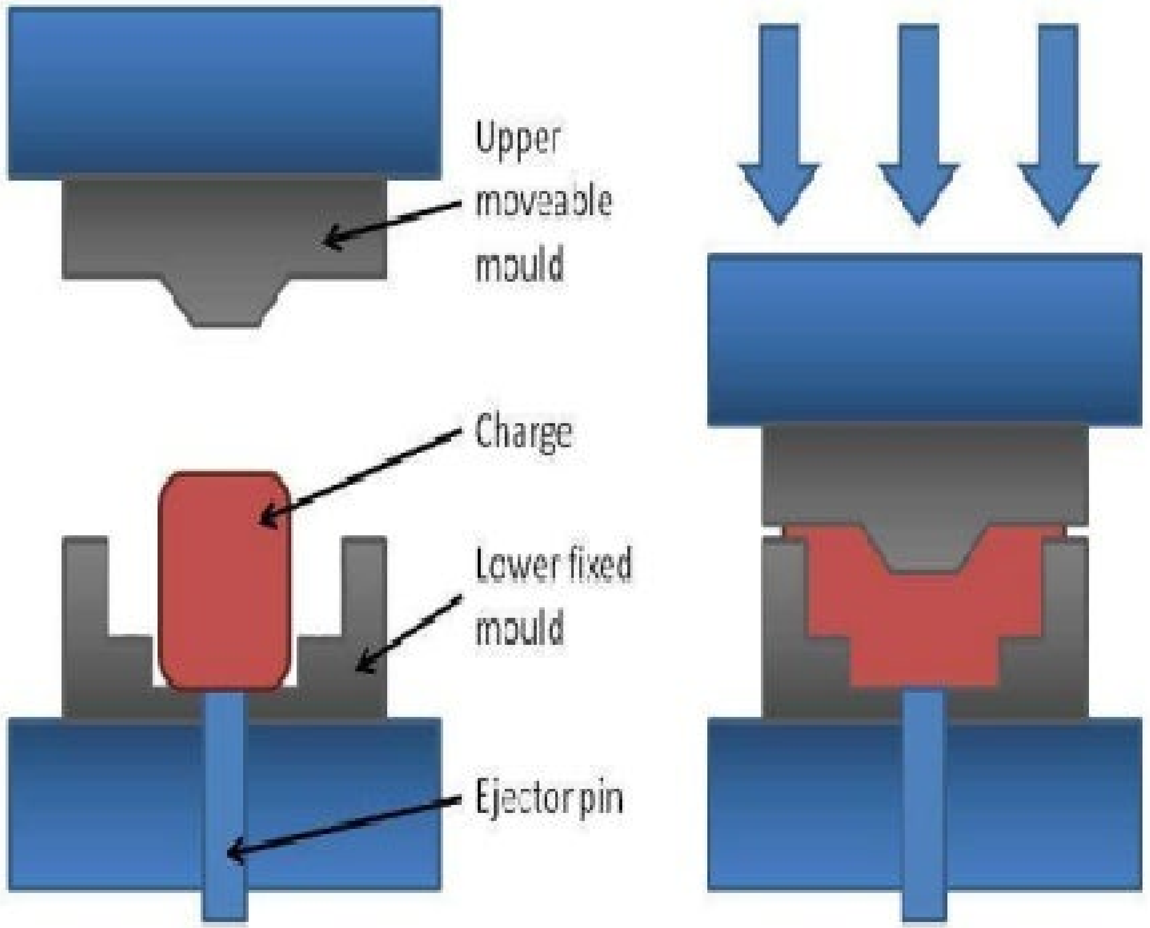
- Fabrication is depends upon types of plastics or Resin used.
- i.e Whether thermosetting or thermo plastics.
- **Methods of Fabrication:**
- 1.Compression Moulding
- 2.Injection Moulding
- 3. Blown Film
- 4. Extrusion Moulding
- 5.Transfer Moulding
- 6.Co Extrusion

1.Compression Moulding

- Compression moulding method is used in fabrication of both thermo plastics and thermosetting resins.
- In this process, initially, a synthetic plastic material with added fillers and ingredients is placed between the mould and heated(130-180°C) under pressure(100-500Kg/cm^2.
- The plastic material is converted in to fluidized plastic in the mould and gets moulded in to the required shape after curing.
- Curing is done by cooling in thermoplastics where as heating in thermosetting plastics.
- Hence the required moulded article is taken from the opening of the moulded parts.



Compression Moulding



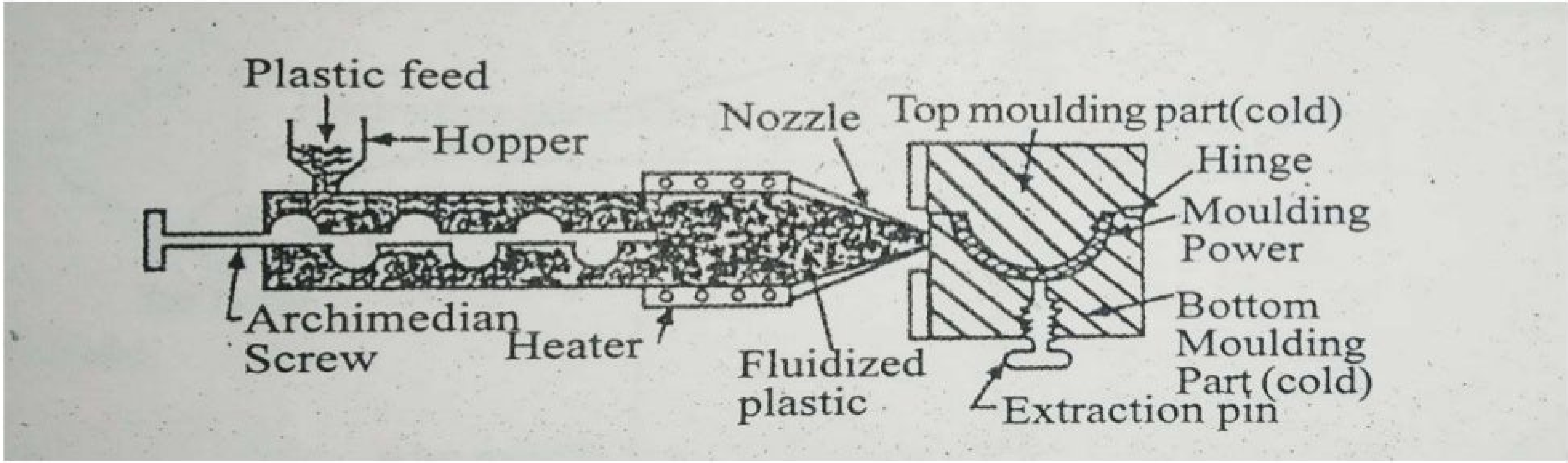
Compression moulding can be used to shape polymer matrix composites. The charge is placed between two steel platens and is heated and cured under pressure. This technique produces components with a high quality surface finish and also has a short cycle time, making it ideal for processes where a high throughput is required. For lower volume production, high machine costs may make this process prohibitively expensive.

Compression Moulding

- **Advantages:**
- The initial Setup cost is low
- It gives good surface finish
- The material loss is less
- Low mould maintenance
- Product has low residual stress.
- **Applications:**
- It is used in fabrication of electrical parts like switches, switch boards etc.
- It is used in fabrication of buttons, gram phone records, cooker handles etc.
- Rubber products like springs, anti vibration mounting pads.

Injection Moulding

- Injection moulding is used in the manufacture of thermoplastics. The setup for injection moulding of plastics is



Injection Moulding

Working of Injection Moulding:

- In this process, the powdered plastic **is heated under 90-260°** temperature in the presence of oil or electricity.
- The **hot 🔥 softened plastic** from hot cylinder is then **injected** in to a tightly locked **mould** at a controlled rate with the **help of Screw** arrangement or a piston plunger.
- Screw is turned by gear driven by an electric motor.
- The **Mould** is Kept **Cool** in order to allow the hot plastic to be **cured** and become **rigid**.
- The Sufficiently **cured moulded material** collected from **extraction pins** without any deformation by **opening upper part of the mould.**

Injection Moulding

- **Advantages:**
- 1. The speed of production is high.
- 2.The cost of moulding and finishing is less.
- 3 The wastage or loss of material 1s very less.
- 4.Making complex shapes in single operation.
- **Limitations:**
- Since, a large number of cavities cannot be filled simultaneously, the design of the articles to be moulded get affected.
- High Capital cost of injection moulding machine.
- **Applications**
- 1.It is used in fabrication of mugs, bottle caps etc.
- 2.It is also used in chairs, buckets, dust bins etc.
- 3.Safety Helmets, Ice block trays, mobile phone cases, computer parts, TV Cabinets.

Q15. Write down the differences between compression and injection moulding techniques.

Answer :

Differences between compression moulding and injection moulding are,

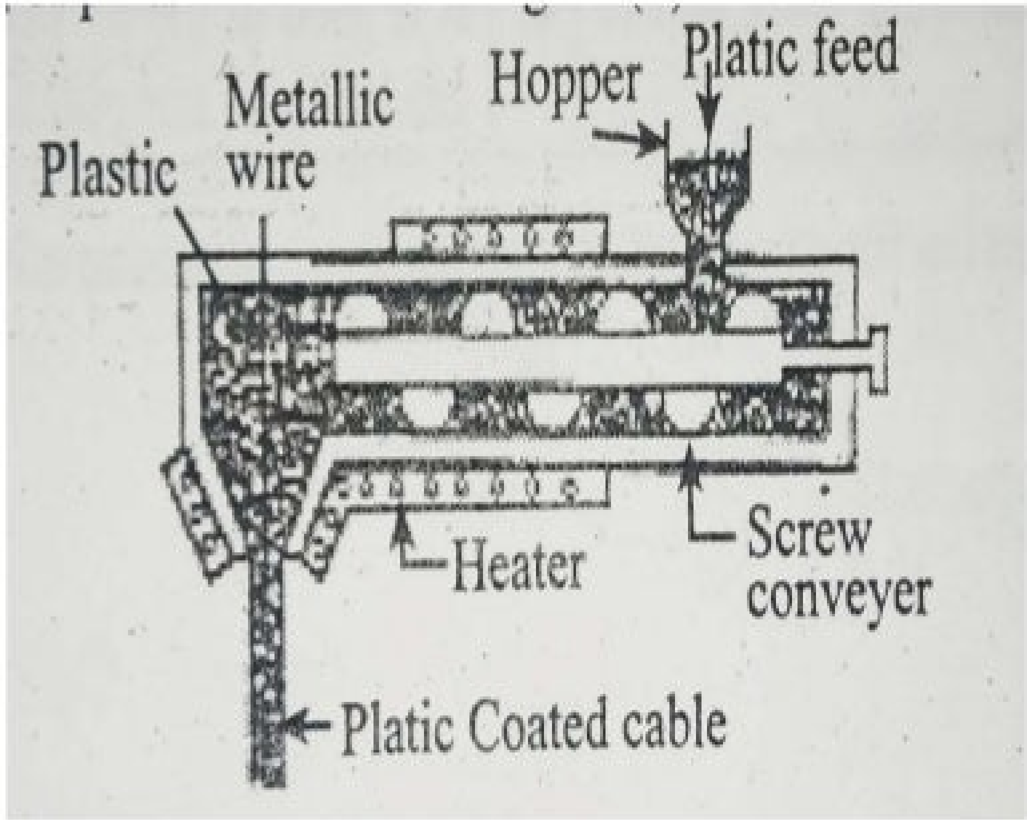
	Compression Moulding		Injection Moulding
1.	Compression moulding is a fabrication technique which is used to mould thermoplastic and thermo-setting materials.	1.	Injection moulding is a fabrication technique which is used to mould only thermoplastic resins.
2.	A proper proportion of plastic is filled in between the two half portions that move relative to each other. On applying sufficient heat and pressure, the required part is obtained.	2.	A plastic material which is heated is injected into a mould cavity. The mould cools the hot plastic to obtain a required part.
3.	The process of moulding is simple.	3.	The process of moulding is complex.
4.	The operation time of the process is high.	4.	The operation time of the process is less.
5.	The rate of production is less.	5.	The rate of production is high.
6.	The cost of moulding is high.	6.	The cost of moulding is less.
7.	The design of the articles that are to be moulded have no limits.	7.	The design of the articles that are to be moulded have limit.
8.	It is economical.	8.	It is expensive.

Extrusion Moulding

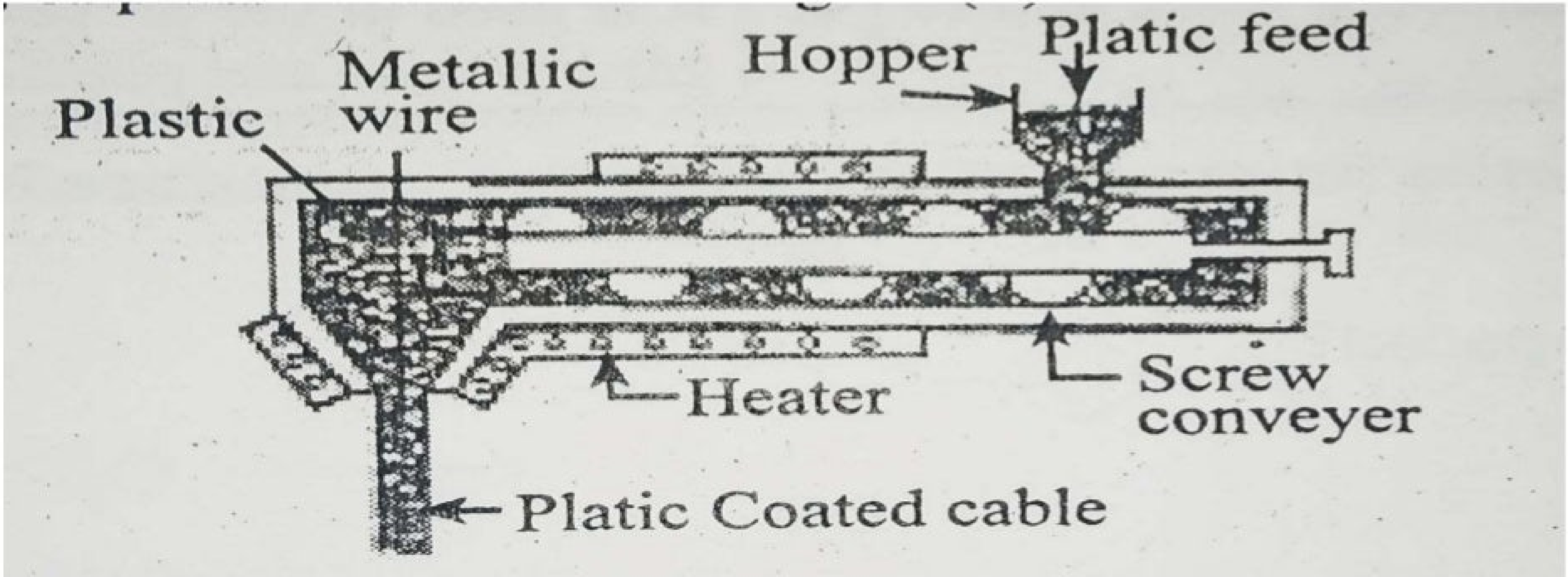
- Extrusion moulding is used to mould thermo plastic materials continuously in order to make articles of uniform cross section.
- In this process, the powdered plastic is passed through a heated chamber to produce hot softened plastic.
- This softened plastic forced into a die by screw conveyor.
- The finished product from the die is cooled by spraying water or exposing to air.

Applications:

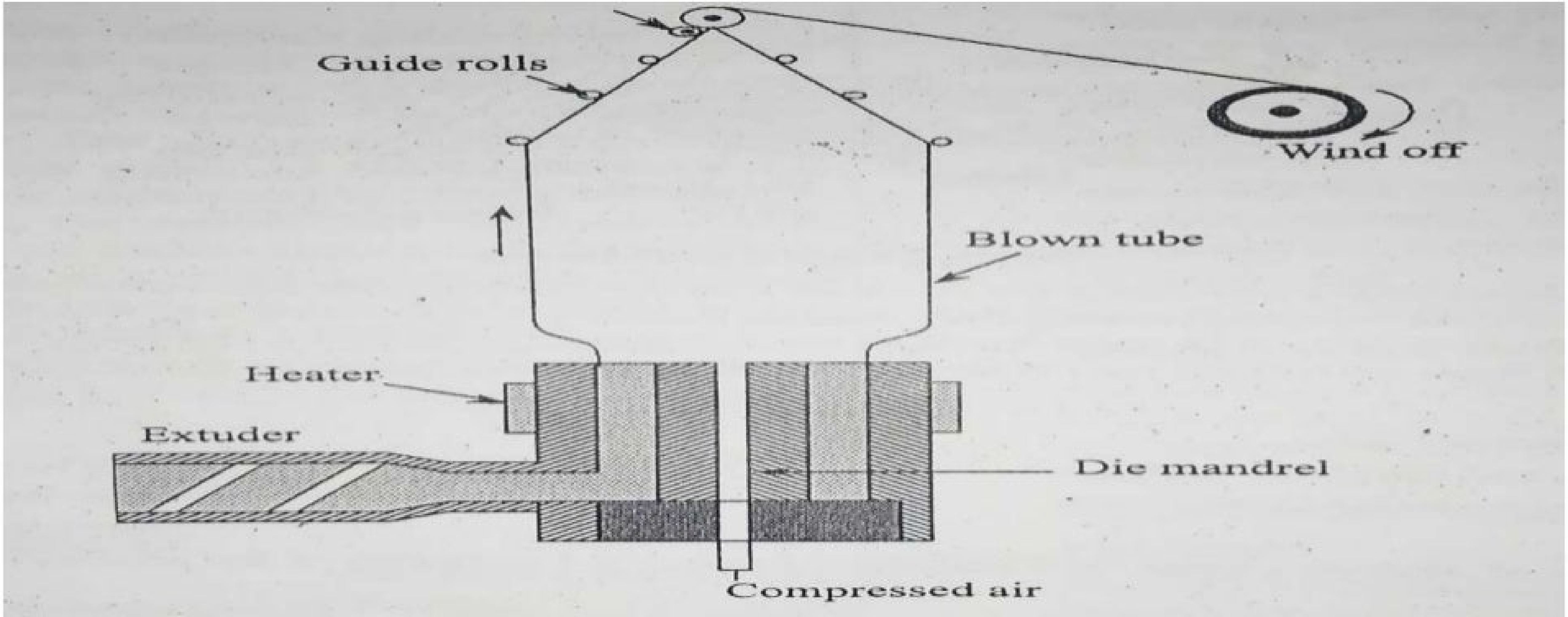
- This method is used in manufacturing of tubes, electric cables, optical fibres, pipes etc.



Extrusion Moulding



Blown Film Moulding



Blown Film Moulding

- This method is used in the design of hollow shaped plastic items.
- In this process, the liquid state plastic is injected into blown film machine and then air is blown through it.
- As a result , vertical shaped bubble will be formed and gets solidified by cooling and then it is guided and flattened by the guide and pinched rollers respectively.
- The resulted flattened balloon is called as lay-flat tube
- **Applications:**
- This method is used in manufacture of plastic bags or plastic sheets etc.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UNIT-3

The laws of heat transfer established that when a temperature difference between the internal and external or different parts of the building exists, this resulting in transfer of heat from the hotter to colder zones and this is referred as to thermal insulation.

This transfer of heat can take place by any of the three methods.

- Conduction.
- Convection.
- Radiation.

The rate of heat flow from one part to the other depends on the capacity of the building material or building unit such as wall, floor, roof, doors, windows etc. to transmit the same.

This property is measured by thermal transmittance denoted by ‘U’. The main objective of ***‘Thermal Insulation’*** is to observe a constant heat or temperature inside building, irrespective of temperature changes outside.

Advantages of Thermal Insulation:

Advantages of thermal insulation are as follows:

- Thermal insulation keeps the room cool in summer and hot in winter.
- Due to thermal insulation the demand of heating in winter and refrigeration in summer, is considerably reduced. This results in lot of fuel saving and maintenance cost.
- Use of thermal insulating material inside a room results in prevention of condensation on interior walls and ceiling etc.
- The use of thermal insulating materials further reduces the risk of water freezing in case of pipes and heat loss in case of hot water systems.
- Thermal insulation is the reduction of heat transfer (i.e., the transfer of thermal energy between objects of differing temperature) between objects in thermal contact or in range of radiative influence.
- Thermal insulation can be achieved with specially engineered methods or processes, as well as with suitable object shapes and materials.
- Heat flow is an inevitable consequence of contact between objects of different temperature.
- Thermal insulation provides a region of insulation in which thermal conduction is reduced; creating a thermal break or thermal barrier, or thermal radiation is reflected rather than absorbed by the lower-temperature body.
- The insulating capability of a material is measured as the inverse of thermal conductivity (k).
- Low thermal conductivity is equivalent to high insulating capability (resistance value).

- In thermal engineering, other important properties of insulating materials are product density (ρ) and specific heat capacity (c).

Thermal Insulation Materials:

List of Thermal Insulation Materials

The various types of thermal insulation materials and some of the most important and useful are described below:

1. Slab or Block Insulation
2. Blanket Insulation
3. Loose Fill Insulation
4. Batt Insulating Materials
5. Insulating Boards
6. Reflective sheet Materials
7. Light weight Materials

Slab or Block Thermal Insulation Material :

They are known as blocks or boards, 2.5 cm thick and 60 cm x 120 cm in area. These may be made of cork board, mineral wool, verimiculite, cellular glass, cellular rubber, saw dust, asbestos cement etc. There are fixed to walls or roofs.

Blanket Insulation :

They are made up of flexible fibrous material and are available in rolls. These fibrous materials are made from mineral wool, wood fibre, cotton, animal hair etc. The blanket insulations are prepared in thicknesses of 1 to 8 cm in rolls and are directly spread an the surface of walls and ceilings.

Loose Fill Insulation :

These may consist of fibrous materials like rock wool, slag wool, cellulose or timber fibre wool etc. filled loosely in the studding space.

Batt Insulation Materials :

They are soft materials similar to blanket insulations but are smaller in size and greater in thickness usually 5 to 9 cm. They are also spread on the surface of walls and ceilings.

Insulating Boards :

These are used for interior lining of walls, and also for partition walls. Structural insulating boards is manufactured by first making a pulp of wood, cane or other materials and then pressing them in form of boards by adding suitable adhesives. They are available in different sizes and thickness.

Reflecting Sheet Materials :

Reflecting sheet materials have high reflectivity and low emission rate, thus offering high heat resistance. Solar energy striking reflective surfaces get reflected and amount of heat which may get transmitted is greatly reduced. Reflective insulations may consist of gypsum boards, steel sheet reflective materials, aluminium foils, sheet aluminium reflective material etc.

Light Weight Materials :

The cement and concrete products have lower insulation value. But with the use of light weight materials such as blast furnace slag, burnt clay aggregate, porous aggregates etc or concrete, its resistance against heat can be improved.

Selection Criteria for Insulation materials:
In any construction project, whether ecological or standard, insulation plays a key role in ensuring optimal comfort for occupants and saving energy. To make the right choice from the long list of insulators available on the market, discover our criteria.
In passive house construction, excellent insulation of the external building envelope is one of the 5 pillars of this building concept. Poor insulation can lead to high heat loss, discomfort in the house, and even signs of unhealthiness, such as mould. It is therefore necessary to pay particular attention to the choice of insulation material, based on 8 criteria:

Embodied energy:

In a green building project, it is important to consider the embodied energy of a material, i.e. the energy required to extract, manufacture and transport the material. Bio-sourced insulation materials are largely known for its low embodied energy.
Low embodied energy insulation: linen fibre, hemp fibre

Thermal performance level:

To identify the thermal performance of an insulation, two main indicators should be taken into account:

- Thermal conductivity (lambda – λ): The ability of the material to transmit heat by conduction. This determines the insulating capacity of a material: the lower the lambda coefficient, the more insulating the material.
- Thermal resistance (R): The ability of the material to resist to cold and heat. The R-value depends on the thickness of the material and the thermal conductivity.

Insulation with low lambda coefficients: hemp fibre, cork fibre

Humidity control:

The humidity control of an insulation material is its ability to absorb and release humidity efficiently without deteriorating. Insulation with good humidity control ensures dry and healthy indoor air for the occupants.
Insulation with good humidity control: wood fibre, cellulose wadding

Non-flammable or fire-protected:

Some insulation materials are considered non-flammable and can even protect against fire by slowing the spread of flames. This is the case for some mineral insulation materials (made from sand, recycled glass, clay, etc.).
Non-flammable insulation: foam glass, rock wool

Resistance to rodents:

Rodents can cause serious damage to a building’s insulation by burrowing into it, which will significantly alter the insulating properties of the material. If possible, make sure you choose an insulation that will also be resistant to insects.
Rodent-resistant insulation: expanded cork, hemp

Health risks:

Some insulation materials can cause respiratory problems (e.g. rock wool) or emit toxic substances in case of fire (e.g. polyurethane). Insulation has a role to play in maintaining healthy air in the home.
Non-harmful insulation: wood fibre, hemp

Durability:

For insulation to last, it must be resistant to external aggression (rodents, insects or humidity) but also not settle over time (which is the case with cotton wool or linen, for example).
Insulation with good durability: wood fibre, straw

Acoustic performance:

Although we tend to focus on thermal performance, some insulating materials also have excellent acoustic performance, to minimise noise pollution at home.
Acoustic insulation: cork, coconut fibre
Before choosing an insulation material, think about the installation! Depending on the location of the insulation, certain forms are to be preferred (bulk, panel, roll, etc.), and may influence the choice of material. Finally, be careful when installing the insulation: if it is badly installation, all the properties of the material will be altered.

Insulation – Basic Facts:

Insulation represents a material which is designed to reduce the transfer of heat and sound, therefore there are two basic types of insulation: thermal and sound insulation. Thermal insulation reduces heat transfer leading to a more stable house temperature, which again leads to a reduced heating and cooling bills. Sound insulation makes your house more pleasant to live in, by protecting you from the outside noise. In order to decide which insulation product is best for you I decided to make this **insulation materials classification**. Also, always check the R-value of the material, since that is the measurement of the heat transfer resistance, so the higher the R-value, the better.

Classification of Insulation Materials

Glass wool

It is made of recycled glass and sand, soda ash and limestone. The glass is then spun into millions of fine fibres, then by applying the resin, the fibres are connected together. It can be produced in rolls and slabs.

Rock wool

It is made of molten rock in a furnace through which a steam is blown at around 1600 °C. They can be pressed into rolls and sheets and because of that, this type of insulation acts as a good thermal and sound insulator.

Rigid insulation boards

These are divided into: PUR, PIR and Polystyrene boards. Polyurethane (PUR) boards are filled with non CFC gas, but in order to prevent the escaping of the gas, they are faced with aluminium foil. Polyisocyanurate (PIR) boards are similar to PUR boards, but these boards also involve long strand glass fibres in their structure. Polystyrene boards are very good insulators against extreme temperatures and noise.

Reflective foil insulation

It represents a very clean and very effective product which is often used in the building industry. Insulation foil reduces the heat transfer by up to 97%. Reflective foil works as a great vapour barrier and reduces the moisture condensation which can be a problem for some fibreglass insulation materials.

Eco products

It include environmental friendly types of insulation. Those products are: thermal and acoustic slabs and rolls, sheep's wool insulation, hemp insulation and recycled polyester insulation.

Dry lining

It is the type of construction method which involves plasterboard panels, and it is used as a replacement for wet plaster.

Breather membranes, damp proofing materials, renders, adhesives and insulation accessories are also available at **Insulation Shop**.

Reflective Insulation System:

- The radiant heat is invisible and has no temperature, just energy.
- When this energy strikes another surface, it is absorbed and increases the temperature of that surface.
- In summer, radiation from the Sun strikes the outer surfaces of walls and ceilings and is absorbed causing the surface to heat up.
- This heat flows from the outer wall to the inner wall through conduction which is then radiated again, through the air spaces in the building, to other surfaces within the building.
- Radiation between surfaces is through invisible, infra-red heat rays.
- Different types of insulation products reduce the heat transferred by conduction, convection and radiation to varying degrees.
- As a result, each provides different thermal performance and corresponding "R" values.
- The primary function of reflective insulation is to reduce radiant heat transfer across open spaces, which is a significant contributor to heat gain in summer and heat loss in winter.
- There are many types of materials that reduce heat gain and heat loss.
- Some materials provide greater resistance than others, depending on the mode of heat transfer: convection, conduction or radiation.

- Most insulation materials work on the principle of trapped air gas being a good insulator.
- Mass insulation like, 'INSUshield'- closed cell, FR crosslinked polyethylene foam- use cellular walls of plastics.
- Fibre glass wool uses glass fibers to reduce convection thereby decreasing the transfer of heat.
- These materials also reduce heat transfer by conduction due to the presence of trapped air. However, these products, like most building materials, have very high radiant transfer rates.
- Most building materials, including fiberglass, foam and cellulose have "E" values in excess of 0.70.
- Reflective insulation typically has "E" values of 0.03 (again, the lower the better). Therefore, reflective insulation is superior to other types of insulating materials in reducing heat flow by radiation.
- When reflective insulation is installed in building cavities, it traps air (like other insulation materials) and therefore reduces heat flow by convection thus addressing all three modes of heat transfer.
- In all cases, the reflective material must be adjacent to an air space.
- Aluminum, when sandwiched between two pieces of plywood or between two concrete layers for example, will conduct heat at a high rate.
- The conductive insulation material should always be in contact with the substrate for better insulation.
-

Understanding a Reflective Insulation System (RIS)

- A reflective insulation system is typically formed by layers of aluminum or a low emittance material and enclosed air spaces which in turn provide highly reflective or low emittance cavities (Air bubble film) adjacent to a heated region.
- The performance of the system is determined by the emittance of the material(s), the lower the better, and the size of the enclosed air spaces.
- The smaller the air space, the less heat will transfer by convection. Therefore, to lessen heat flow by convection, a reflective insulation, with its multiple layers of aluminum and enclosed air space(INSUreflector), is positioned in a building cavity (stud wall, furred-out masonry wall, floor joist, ceiling joist, etc.) to divide the larger cavity (3/4" furring, 2" x 4", 2" x 6", etc.) into smaller air spaces.
- These smaller trapped air spaces reduce convective heat flow.
-

Reflective insulation differs from conventional mass insulation in the following:

1. Reflective insulation has very low emittance values "E-values" (typically 0.03 compared to 0.90 for most insulation) thus it significantly reduces heat transfer by radiation
2. A reflective insulation does not have significant mass to absorb and retain heat
3. Reflective insulation has lower moisture transfer and absorption rates, in most cases
4. Reflective insulation traps air with layers of aluminum & Air bubble film plastic as opposed to mass insulation which uses fibers of glass, particles of foam, or ground up paper

5. Reflective insulation does not irritate the skin, eyes, or throat and contain no substances which will out-gas
6. The change in thermal performance due to compaction or moisture absorption, a common concern with mass insulation, is not an issue with reflective insulation.

Commonly used Insulation Materials:

Insulation materials come from different sources like minerals, vegetable fibers, animal products, and synthetic compounds. Like in many engineering decisions, each material has advantages and disadvantages that must be considered when selecting insulation for buildings.
This article provides an overview of the main options in the market, and how they perform in actual projects. There are insulation materials that are no longer used, but may be found in older constructions - one example is insulation with an asbestos content, which has been outlawed.

Fiberglass

Fiberglass is one of the most popular insulation materials, made by weaving fine strands of glass. It is manufactured mostly from recycled glass.

Characteristics:

-Minimizes heat transfer
-Non-flammable
-R-values range from R-2.9 to R-3.8 per inch
-Low cost
-Environmentally friendly
-Does not absorb water
-Can be dangerous for installers, requiring special protection equipment.The small particles of glass can damage the eyes, lungs and skin.
-Loose-fill insulation is applied using an insulation-blowing machine

Available in:

-Blankets (batts and rolls): fiberglass batt can be found as medium or high-density, with higher R-values than standard batts
-Loose-fill and blown-in
-Blow-in Blanket System (BIBS): a variation of loose-fill insulation that is blown dry, and tests have proven a higher insulation level than other types of fiberglass
-Rigid boards
-Duct insulation
-Rigid fibrous insulation

Mineral Wool

Mineral wool refers to two types of insulation material:

- Rock wool, made from basalt or diabase
- Slag wool, made from blast furnace slag from steel mills

Characteristics:

-Contains an average of 75% post-industrial recycled content
-Does not need additives to make it fire resistant
-Not recommended in extreme heat environments
-Non flammable
-R-value ranging from R-2.8 to R-3.5
-Environmentally friendly
-Does not melt and is not combustible

-Moderate cost

Available in:

-Blanket (batts and rolls)
-Loose-fill and blown-in
-Rigid fibrous or fiber insulation

Cellulose

Cellulose is made from recycled paper products, mainly newspapers. During the manufacturing process, paper is first broken down into smaller pieces and then fiberized. Cellulose is one of the most eco-friendly forms of insulation, and is available in loose-fill and blown-in versions.

Characteristics:

-Environmentally friendly
-Most of its content is recycled (82-85%)
-Inhibits airflow
-Mineral borate is added to ensure fire and insect resistance
-Requires no moisture barrier
-R-values range from R-3.1 to R-3.7
-Excellent product for minimizing fire damage
-Due to its compactness, it contains almos not oxygen within
-Can generate allergies
-Requires skilled workers for installation
-Moderate cost

Polystyrene

Polystyrene is a colorless and transparent thermoplastic. Polystyrene insulation is available in many versions:

- **Molded expanded polystyrene (MEPS),** commonly used in foam boards and as small foam beads.
- **Expanded polystyrene (EPS),** made of small plastic beads fused together
- **Extruded polystyrene (XPS),** is a molten material that is pressed into sheets, also known as styrofoam

Characteristics:

-Low cost, but not environmentally friendly
-Flammable, needs to be coated with a fireproof chemical
-Lightweight
-Tends to accumulate static electricity
-Can be difficult to control
-Thermal drift or ageing occurs over time-R-value depends on density: expensive XEP has an R-value of R-5.5, while EPS offers R-4
-Waterproof
-Excellent sound and temperature insulation
-Smooth surface

Available in:

-Loose fill (small beads)
-Concrete block insulation and insulating concrete blocks
-Insulating concrete forms (ICF)
-Structural insulating panels (SIP)
-Foam board or rigid foam

Polyurethane

Polyurethane is available in closed-cell foam and open-cell foam. Closed-cell foams possess high-density cells filled with a gas (non-HCFC), which allows the foam to expand. Open-cell foams are not as dense and are filled with air, producing a spongy texture when applied. However, some low-density varieties use carbon dioxide as the foaming agent.

Characteristics:

-High cost
-Not environmentally friendly
-Fire resistant
-Great sound insulator
-New foams use non-CFCs gas as a blowing agent
-Lightweight
-R-value of R-6.3 per inch
-Contains low-conductivity gas in its cells
-Thermal drift or ageing occurs only in closed-cell foams in the first two years after application. To slow down thermal drift, a layer of foil and plastic facings can be applied facing the open aire space creating a radiant barrier.
-Sprayed foam is cheaper than foam boards and performs better.
-Sprayed foams can expand rapidly or slowly depending on the user demands
-Resistant to water vapor diffusion

Available in:

-Foam board or rigid foam
-Sprayed foam and foamed-in-place
-Structural insulated panels (SIP)

Natural Fibers

Many natural fibers have applications in building insulation. Some examples are cotton, sheep's wool, straw and hemp.

Cotton

It is available in batts and rolls, and it offers the following features:

- Consists of 85% recycled cotton and 15% plastic fibers
- Treated with borate (flame retardant and insect repellent)
- Minimum energy requirements for manufacturing

Sheep wool

It is also available and batts and rolls, and it has the following characteristics:

- Treated with borate to resist pest, fire and mold.
- Holds water, but repeated wetting and drying reduces borate effect

Straw has been used as insulation since the 1930s. It is available as boards or structural insulated panels (SIP), which are sound-absorbing and with typical width of 2" to 4".

Hemp is not a common insulation material in the US, although it has R-values comparable to those of other fibrous insulation types.

Polyisocyanurate

Polyisocyanurate or polyiso is a closed cell thermoset plastic similar to polyurethane. It contains a low-conductivity HCF-free gas and can be foamed in place, which is cheaper and more efficient than using foam boards.

Polyiso experiences thermal drift or ageing in the first 2 years after manufacturing, but foil and plastic facings can be applied facing the open air space. This works as a radiant barrier, stabilizing the R-value

Polyiso is available in the following forms:

- Foam board or rigid foam
- Sprayed foam and foamed-in-place

- Laminated insulation panels
- Structural insulated panels (SIPs)

Cementitious Foam

As implied by its name, this insulation material is cement-based. It is nontoxic and nonflammable, and made from minerals extracted from seawater. Cementitious foam is similar to polyurethane foam, and can be sprayed and foamed-in-place.

Phenolic Foam

Phenolic foam is another type of insulation that is sprayed and foamed-in-place. It uses air as a foaming agent, and can shrink up to 2% after curing.

Insulation Materials That Are No Longer Used

Some insulation materials that were used in the past are now outlawed, unavailable or not used due to health issues. Some examples are vermiculite, perlite and urea-formaldehyde.

Vermiculite and perlite were used to insulate attics before the 1950, but are not used anymore because they contain asbestos. These insulation materials were mostly available as loose-fill or pellets.

- Certified contractors in handling asbestos are required for removal from existing buildings
- Were applied by heating rock pellets until they popped
- Allowed mixing with cement

Urea-formaldehyde:

It is a sprayed foam that was commonly used in the 1970s and 1980s. However, due to improper installations, many health-related court cases took place. As a result, urea-formaldehyde was prohibited in residential buildings, but is still used for masonry walls in commercial and industrial buildings.

- Uses compressed air as the foaming agent
- Does not expand as it cures
- Nitrogen- based UF takes longer to cure
- Water vapor can pass through
- Does not contain a fire retardant

Foundation:

Foundation is the lowest part of the building or the civil structure that is in direct contact with the soil which transfers loads from the structure to the soil safely. Generally, the foundation can be classified into two, namely **shallow foundation** and **deep foundation.**

A shallow foundation transfers the load to a stratum present in a shallow depth. The deep foundation transfers the load to a deeper depth below the ground surface. A tall building like a skyscraper or a building constructed on very weak soil requires deep foundation. If the constructed building has the plan to extend vertically in future, then a deep foundation must be suggested.

To construct a foundation, trenches are dig deeper into the soil till a hard stratum is reached. To get stronger base foundation concrete is poured into this trench. These trenches are incorporated with reinforcement cage to increase the strength of the foundation. The projected steel rods that are projected outwards act as the bones and must be connected with the substructure above. Once the foundation has been packed correctly the construction of the building can be started.

The construction of the foundation can be done with concrete, steel, stones, bricks etc. The material and the type of foundation selected for the desired structure depends on the design loads and the type of underlying soil. The design of the foundation must incorporate different effects of construction on the environment. For example, the digging and piling works done for deep foundation may result in adverse disturbance to the nearby soil and structural foundation.

These can sometimes cause the settlement issues of the nearby structure. Such effects have to be studied and taken care before undergoing such operations. Disposal of the waste material from the operations must be disposed properly. The construction of foundation has to be done to resist the external attack of harmful substances.

The foundation for each structure is designed such that:

- The underlying soil below the foundation structure does not undergo shear failure
- The settlement caused during the first service load or have to be within the limit
- Allowable bearing pressure can be defined as the pressure the soil can withstand without failure.

Purpose of Foundation:

Foundations are provided for all load carrying structure for following purposes:

- Foundation are the main reason behind the stability of any structure. The stronger is the foundation, more stable is the structure.
- The proper design and construction of foundations provide a proper surface for the development of the substructure in a proper level and over a firm bed.
- Specially designed foundation helps in avoiding the lateral movements of the supporting material.

- A proper foundation distributes load on to the surface of the bed uniformly. This uniform transfer helps in avoiding unequal settlement of the building. Differential settlement is an undesirable building effect.
- The foundation serves the purpose of completely distributing the load from the structure over a large base area and then to the soil underneath. This load transferred to the soil should be within the allowable bearing capacity of the soil.

Functions of Foundation in Construction:

Based on the purposes of foundation in construction, the main functions of the foundation can be enlisted as below:

1. Provide overall lateral stability for the structure
2. Foundation serve the function of providing a level surface for the construction of substructure
3. Load Distribution is carried out evenly
4. The load intensity is reduced to be within the safe bearing capacity of the soil
5. The soil movement effect is resisted and prevented
6. Scouring and the undermining issues are solved by the construction of foundation

Requirements of a Good Foundation

The design and the construction of a well-performing foundation must possess some basic requirements that must not be ignored. They are:

1. The design and the construction of the foundation is done such that it can sustain as well as transmit the dead and the imposed loads to the soil. This transfer has to be carried out without resulting in any form of settlement that can result in any form of stability issues for the structure.
2. Differential settlements can be avoided by having a rigid base for the foundation. These issues are more pronounced in areas where the superimposed loads are not uniform in nature.
3. Based on the soil and area it is recommended to have a deeper foundation so that it can guard any form of damage or distress. These are mainly caused due to the problem of shrinkage and swelling because of temperature changes.
4. The location of the foundation chosen must be an area that is not affected or influenced by future works or factors.

Different Types of Footing:

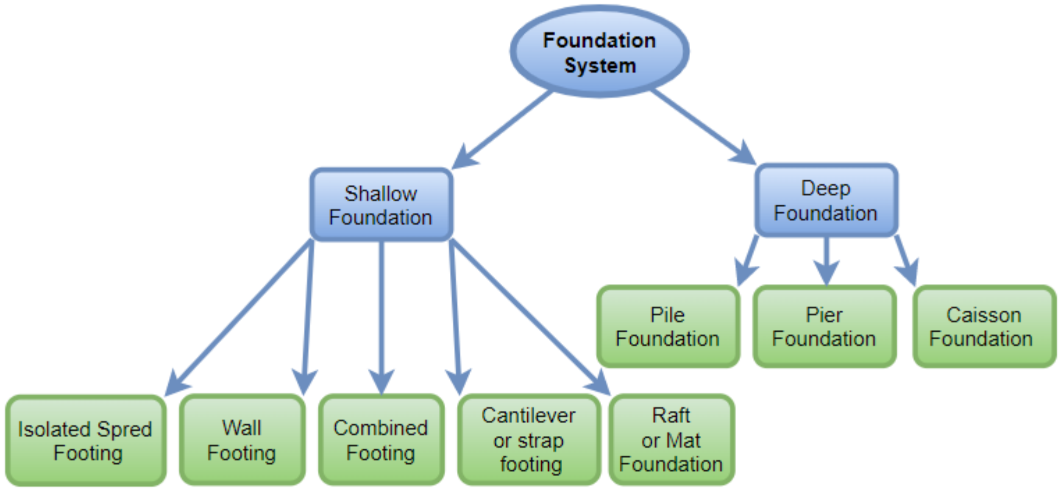
As we know that there are different types of soil, and the bearing capacity of the soil is different for each type of soil. Depending on the soil profile, size, and load of the structure, engineers chose different kinds of foundations.

Types of Foundation:

In general, all foundations are divided into two categories, - shallow and deep foundations. The terms Shallow and Deep Foundation refer to the depth of the soil at which it is placed.

Generally, if the width of the foundation is greater than the depth, it is labeled as the “Shallow Foundation”. If the width is smaller than the depth of the foundation it is called a

"Deep Foundation." However, deep foundation and shallow foundation can be classified as shown in the following chart.



Shallow Foundations

As the shallow foundation depth is low and it is economical, it is the most popular type of foundation for lightweight structures. Several types of shallow foundations are discussed below.

Types of Shallow Foundation

The followings are the types of shallow foundations.

1. Isolated Spread Footing

This is the most widely recognized and most straightforward shallow foundation type, as this is the most economical type. They are typically utilized for shallow establishments to convey and spread concentrated burdens caused, for instance, by pillars or columns. They are generally used for ordinary buildings (Typically up to five stories).

Figure: Isolated shallow foundation image

Isolated footing comprises a foundation directly at the base of the segment. Generally, every section has its footing. They straightforwardly transfer the loads from the column to the soil. It might be rectangular, square, or roundabout. It can comprise both reinforced and non-reinforced material. For the non-reinforced footing, however, the stature of the footing has to be more prominent to give the vital spreading of the load. They should possibly be utilized when it is sure beyond a shadow of a doubt that no differing settlements will happen under the whole structure. Spread footings are inadmissible for the orientation of large loads. It is given to lessen the twisting minutes and shearing powers in their primary areas.

The size of the footing can be roughly calculated by dividing the total load at the column base by the allowable bearing capacity of the soil.

The followings are the types of spread footing.

i. Single pad footing.
ii. Stepped footing for a column.
iii. Sloped footing for a column.
iv. Wall footing without step.
v. Stepped footing for walls.
vi. Grillage foundation.

To decide when to use shallow foundations, it is necessary to know when it is economical. It is economical when:

- The load of the structure is relatively low.
- Columns are not closely placed.
- The bearing capacity of the soil is high at a shallow depth.

2. Wall Footing or Strip footing

Wall footing is also known as continuous footing. This type is used to distribute loads of structural or non-structural load-bearing walls to the ground in such a way that the load-bearing limit of the soil isn't outperformed. It runs along the direction of the wall. The width of the wall foundation is usually 2-3 times the width of the wall.

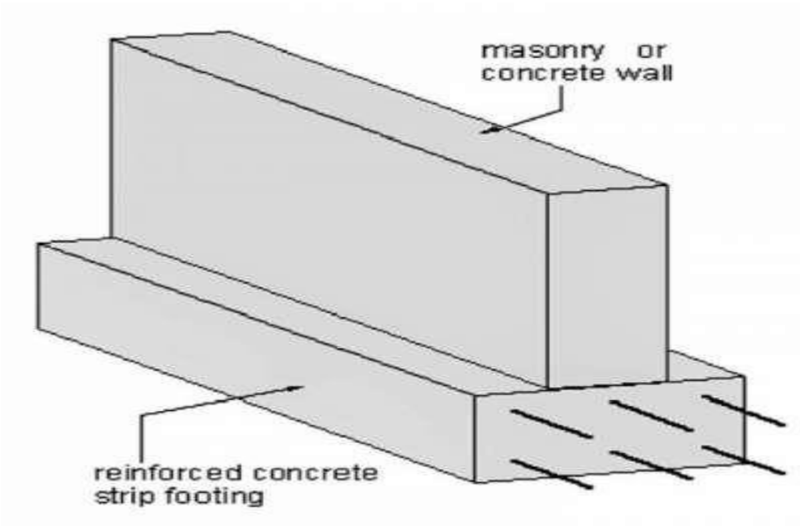


Figure: Wall or Strip footing

The wall footing is a continuous slab strip along the length of the wall. Stone, brick, reinforced concrete, etc. are used for the construction of wall foundations.

- On account of block walls, the footing comprises a few courses of bricks, the least course being generally double the expansiveness of the wall above.
- On account of stone masonry walls, the counterbalances could be 15 cm, with the statues of the course as 30 cm. Along these lines, the size of the footings is marginally more than that of the block divider footings.
- If the heap on the wall is substantial or the soil is of low bearing limit, this reinforced concrete foundation type can be given.

Wall footing is economical when:

- Loads to be transmitted are of small magnitude.
- It is placed on dense sand and gravel.

3. Combined Footing

The combined footing is very similar to the isolated footing. When the columns of the structure are carefully placed, or the bearing capacity of the soil is low and their footing overlaps each other, combined footing is provided. It is fundamentally a blend of different footings, which uses the properties of various balances in a single footing dependent on the necessity of the structure.

The foundations which are made common to more than one column are called *combined footings*. There are different types of combined footing, including slab type, slab and beam type, and rectangular, raft, and strap beam type. They may be square, tee-shaped, or trapezoidal. The main objective is the uniform distribution of loads under the entire area of footing, for this is necessary to coincide with the center of gravity of the footing area with the center of gravity of the total loads.

Combined foundations are economic when:

- The columns are placed close to each other.
- When the column is close to the property line and the isolated footing would cross the property line or become eccentric.
- Dimensions of one side of the footing are restricted to some lower value.

4. Cantilever or Strap Footing

Strap footings are similar to combined footings. The reasons for considering or choosing strap footing are identical to the combined one.

In *strap footing*, the foundation under the columns is built individually and connected by a strap beam. Generally, when the edge of the footing cannot be extended beyond the property line, the exterior footing is connected by a strap beam with the interior footing.

Figure: Cantilever or Strap Footing

5. Raft or Mat Foundation

Raft or Mat foundations are used where other shallow or pile foundations are not suitable. It is also recommended in situations where the bearing capacity of the soil is inadequate, the load of the structure is to be distributed over a large area, or the structure is subjected continuously to shocks or jerks.

A raft foundation consists of a reinforced concrete slab or T-beam slab placed over the entire area of the structure. In this type, the whole basement floor slab acts as the foundation. The total load of the structure is spread evenly over the entire area of the structure. This is called a raft because, in this case, the building seems like a vessel that floats on a sea of soil.

Raft foundations are economic when:

- The soil is weak and the load has to be spread over a large area.
- The structure includes a basement.
- Columns are closely placed.
- Other kinds of foundations are not feasible.
- Differential settlement is to be prevented.

Deep Foundations:

Several Types of Deep Foundations Are Discussed Below.

Types of Deep Foundation.

The followings are the types of deep foundations.

1. Pile Foundation

Pile is a common type of deep foundation. They are used to reduce cost, and when as per soil condition considerations, it is desirable to transmit loads to soil strata that are beyond the reach of shallow foundations.

The followings are the types of pile foundations.

1. Based on Function or Use
    1. Sheet Piles
    2. Load Bearing Piles
    3. End Bearing Piles
    4. Friction Piles
    5. Soil Compactor Piles
2. Based on Materials and Construction Method
    1. Timber Piles
    2. Concrete Piles
    3. Steel Piles
    4. Composite Piles

Pile is a slender member with a small cross-sectional area compared to its length. It is used to transmit foundation loads to deeper soil or rock strata when the bearing capacity of soil near the surface is relatively low. Pile transmits load either by skin friction or bearing. Piles are also used to resist structures against uplift and provide structures stability against lateral and overturning forces.

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Pile foundations are economic when

- Soil with great bearing capacity is at a greater depth.
- When there are chances of construction of irrigation canals in the nearby area.
- When it is very expensive to provide raft or grillage.
- When the foundation is subjected to a heavily concentrated load.
- In marshy places.
- When the topsoil layer is compressible in nature.
- In the case of bridges, when the scouring is more in the river bed.

It can again be classified based on its material and its mechanism of load transfer or function. Several types of pile foundations are shown in the following chart.

2. Pier Foundation

Pier is an underground structure that transmits a more massive load, which cannot be carried by shallow foundations. It is usually shallower than piles. The pier foundation is generally utilized in multi-story structures. Since the base region is determined by the plan strategy for the regular establishment, the single pier load test is wiped out. Along these lines, it is increasingly well-known under tight conditions.

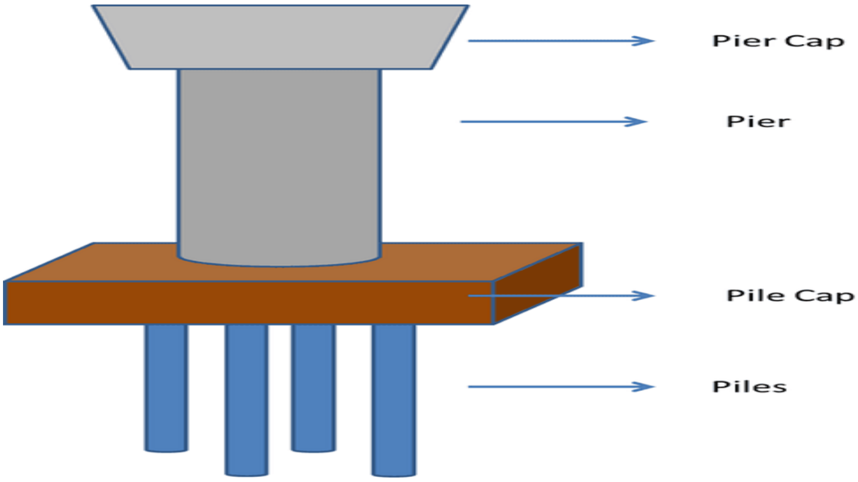


Figure: Pier Foundation

Pier foundation is a cylindrical structural member that transfers heavy load from the superstructure to the soil by end bearing. Unlike piles, it can only transfer load by bearing and by not skin friction.

Pier Foundation is economic when:

- Sound rock strata lie under a decomposed rock layer at the top.
- The topsoil is stiff clay that resists driving the bearing pile.
- When a heavy load is to be transferred to the soil.

Pier foundation has many advantages:

- It has a broad scope of assortment with regard to structure. There are different materials we can here to build a stylish view, and it stays in our spending limit.
- It sets aside cash and time as it doesn't require the broad removal of a ton of cement.
- Bearing limits can increment by under-reaming the base.

Along with the advantages, it has a few disadvantages as well:

- If one post or dock is harmed, it can prompt critical harm to the general establishment.
- It can be vitality wasteful if not protected appropriately.
- Floors must be intensely, vigorously protected, and shielded from critters.

3. Caisson Foundation

Caisson foundation is a watertight retaining structure used as a bridge pier, construction of the dam, etc. It is generally used in structures that require a foundation beneath a river or similar water bodies. The reason for choosing the caisson is that it can be floated to the desired location and then sunk into place.

Figure: Caisson Foundation

A caisson foundation is a ready-made hollow cylinder depressed into the soil up to the desired level and then filled with concrete, which ultimately converts to a foundation. It is mostly used as bridge piers. Caissons are sensitive to construction procedures and lack construction expertise.

There are several types of caisson foundations.

1. Box Caissons.
2. Floating Caissons.
3. Pneumatic Caissons.
4. Open Caissons.
5. Sheeted Caissons.
6. Excavated Caissons.

Caisson foundations are economic when:

- The pile cap requirement is to be minimized.
- Noise and vibration needed to be reduced.
- It has to be placed beneath water bodies.
- Highly lateral and axial loading capacity is required.

Masonry:

Masonry consists of building structures from single units that are laid and bound together with mortar. Brick, stone and concrete blocks are the most common materials used in masonry construction.

Masonry is a popular construction technique around the world, due to its many advantages. However, like with any construction method, there are also limitations. This article summarizes the pros and cons of masonry construction.

Reduce material and labour costs with professional design and project management services.ONTACT US

Advantages of Masonry Construction:

These general advantages apply for all types of masonry units (brick, stone or concrete blocks):

- Masonry is non-combustible, so improves fire protection for the building and its occupants. Fireplaces are commonly made of masonry for the same reason.
- Masonry offers a high resistance against rotting, pests, weather, and natural disasters such as hurricanes and tornadoes.
- Masonry structures provide an attractive rustic or elegant look for a home or building, depending on the material used and the workers' expertise.
- Being durable and resistant, mansory can withstand large amounts of compressive weight loads.
- Masonry units increase the thermal mass of a building.
- Masonry buildings have longer lifespans than any other building type.
- Using masonry in your construction improves its resale value.
- Masonry doesn't rot, and insects such as ants and termites can't destroy its structure.
- Using this method in construction costs less in terms of labor and materials as compared to using wood.

Disadvantage of Masonry Construction:

- Masonry construction involves heavy materials such as bricks, stone and concrete blocks. These cannot be transported in conventional vehicles, and in some cases they must be ordered from special catalogs, especially stones.
- The stability of masonry structures depends completely on their foundation. If any settling of the foundation occurs, cracks are likely and they must be repaired to prevent moisture infiltration and damage.
- Masonry activities cannot be done during heavy rain or freezing conditions, since mortar will be severely affected.
- Masonry construction requires a good amount of time and adequate project planning. Depending on the type or masonry, specialized manpower may be necessary.

Now that the general advantages and disadvantages of masonry have been established, let's discuss the pros and cons of the most commonly used materials: brick, stone and concrete blocks.

Brick Masonry

Advantages:

- Brick masonry does not require highly skilled labor, since the shape and size of the masonry units is uniform.
- Bricks are also lightweight (lower dead loads), easy to handle and transport, and cheaper that stones and concrete blocks.
- Brick walls are thinner, and units can be adhered with different types of mortar, depending on structural requirements.

- Openings for doors and windows are easily made with bricks, and costs are also reduced because the joints are thinner.

<u>Disadvantages</u>:

- Bricks have a low resistance against tension and torsion loads, making them more susceptible to seismic damage.
- Compared with stone and concrete blocks, bricks are also less strong and durable, and limited in sizes and colors.
- Plasterwork is required as finishing, which raises construction costs.

Stone Masonry:

<u>Advantages</u>:

- Stone masonry is the most durable, strong and weather resistant, thanks to the natural durability of the material.
- Stone is recommended for buildings with high foot traffic, since it does not bend or dent.
- One of the main advantages of stone is its aesthetic look, with a variety of colors, sizes and textures - the design possibilities are endless.
- Finally, stone masonry requires little maintenance and repairs, thanks to its durability.

<u>Disadvantages</u>:

- Stone walls are thick and heavy, reducing floor space.
- It also has a high self-weight, combined with low flexural strength, tensile strength and seismic resistance.
- Stone masonry is time-consuming and it requires skilled workers, since it cannot be altered, repaired or relocate easily.
- When using stone masonry, a careful installation will make the final structure safer for occupants.

Concrete Block Masonry:

Advantages:

- Concrete blocks are resistant against weather, pests, mold, and fire.
- Transporting concrete blocks can be quite expensive, but this material can be found locally in most cases.
- Concrete blocks are available in many sizes, finishes and colors.
- These units can also be manufactured to meet any set project requirements, and some concrete blocks are made using recycled materials.
- In addition, concrete blocks have good insulating properties against heat, sound and moisture.

Disadvantages:

- Large concrete blocks are heavy and difficult to handle, requiring more manpower.
- Concrete blocks also increase the amount of steel required in reinforced cement concrete structures. The price of concrete blocks can vary depending on the region, cement costs and availability.
- Plumbing issues_are harder to solve when they occur in a concrete masonry structure, since they can cause internal flooding.
- Concrete blocks must be cut open in this case, leading to material waste and expensive reparations.
- An effective drainage system is very important when dealing with concrete block masonry.

Cavity brick and block walls:

- Cavity brick walls started to be used in the 1930s but are invariably found in buildings put up after World War Two. They are still being used in new buildings.
- These walls have inner and outer skins with a cavity in between.
- Moisture that gets through the outer brick skin should drain down the cavity, leaving the inner wall dry.
- The two leaves are linked together with galvanised or stainless steel wall ties, designed to prevent water crossing the cavity.
- Concrete blocks were sometimes used for the internal leaf of the wall and sometimes blocks made to look like stone would be used on the outer leaf.

Insulating cavity walls:

Prior to the 1970s, cavity walls were built without insulation and are difficult-to-heat. In the 1970s, the inner leaf of cavity walls started to be built with a lightweight concrete block for insulation. Insulation standards increased again in the 1980s when the cavity was widened and insulation was added to the inner leaf.

Possible methods of insulation:

- Cavity wall fill
- Insulated render
- External overcladding
- Internal insulation using methods similar to those used for solid masonry walls

Cavity wall fill:

This should not be done in areas of high exposure as filling the cavity can increase the risk of moisture crossing to the inner leaf. Thermal bridging can also be a problem as the cavity fill will not insulate lintels, cills, balconies or joints with any concrete floors that bed into the wall. Condensation dampness may occur at these weak points as they will be much colder than the insulated walls.Suitable materials are

- Blown mineral wool fibre
- Various expanding foam products
- Expanded polystyrene (EPS) bead in a weak adhesive mix

The cavity should be checked to make sure it is at least 40mm wide and that the existing wall ties are not rusted or missing and there are no other materials (such as mortar) bridging the cavity. Site control is important as evidence suggests that cavity wall insulation is not always reaching all areas within the wall cavities.

Damp proof courses:

- Damp Proof Courses (DPCs) are found just below the ground floor (above the brick vents).
- They were probably made of slate though asphalt and bitumen felt was also used. More recently, DPCs have been made of reinforced plastic sheet.
- The purpose of these DPCs was to prevent rising damp.
- DPCs are also used at cills and lintels and where concrete floors penetrate the cavity wall.
- More recently, DPCs are also used around door and window openings.
- The purpose here is to prevent dampness from water running down the inside of the cavity and crossing to the inside leaf.
- Weep holes were sometimes provided to allow moisture to escape.

Mortar is a bonding agent which is generally produced by mixing cementing or binding material (lime or cement) and fine aggregate (sand, surki, sawdust, etc.) with water. Mortar is used to bind different building blocks like bricks, stones, etc. It can also add a decorative pattern in brick or stone masonry. Mortar is being used from the dawn of civilization. 2000 years ago, the Egyptians used lime mortars.

Properties Of Good Mortar:

It is always desirable to use the best mortar in constructions. Therefore, the properties of a good mortar must be investigated. Generally, good mortar possesses following properties-

- The main quality that mortar should possess is adhesion. Good mortar should provide good adhesion to building units (bricks, Stones etc).
- Mortar should be water resistant. It should have the capability of resisting the penetration of water.
- Deformability of mortar should be low.
- Mortar should be cheap.
- Mortar should be easily workable in the site condition.
- The mobility of mortar should be good. It helps the mortar to be paved thinly and evenly.
- It should possess high durability.
- To improve the speed of construction, good mortar should set quickly.
- Cracks should not be developed in the joint formed by mortar. It is desirable to last for long period of time without losing the appearance.

Mortar is produced by mixing a binding material (cement or lime) with fine aggregate (sand, surki, etc) with water. For construction purpose, different types of mortar are used. Depending upon the materials used for mortar mixture preparation, the mortar could be classified as follows.

1. Cement Mortar
2. Lime Mortar
3. Surki Mortar
4. Gauged Mortar
5. Mud Mortar

Cement Mortar

Cement mortar is a type of mortar where cement is used as binding material and sand is used as fine aggregate. Depending upon the desired strength, the cement to the sand proportion of cement mortar varies from 1:2 to 1:6.

Lime Mortar

Lime mortar is a type of mortar where lime (fat lime or hydraulic lime) is used as binding material and sand is used as fine aggregate. The lime to the sand proportion of cement mortar is kept 1:2. The pyramids at Giza are plastered with lime mortar.

Gauged Mortar

Gauged mortar is a type of mortar where cement and lime both are used as binding material and sand is used as fine aggregate. Basically, it is a lime mortar where cement is added to gain higher strength. The process is known as gauging. The cement to the lime proportion varies from 1:6 to 1:9. Gauged mortar is economical than cement concrete and also possess higher strength than lime mortar.

Surki Mortar

Surki mortar is a type of mortar where lime is used as binding material and surki is used as fine aggregate. Surki mortar is economic.

Mud Mortar

Mud mortar is a type of mortar where mud is used as binding material and sawdust, rice husk or cow-dung is used as fine aggregate. Mud mortar is useful where lime or cement is not available.

Mortar, a bonding agent between building materials, is mainly a mixture of water, fine aggregate (sand, surki, etc) and binding material like cement, lime etc. The applications of mortar in various construction phase have made it a very important civil engineering material.

Some of the numerous functions of mortar in construction are given below.

1. Mortar is used to bind together the bricks or stones in brick or stone masonry.
2. It is used to give a soft even bed between different layers of brick or stone masonry for equal distribution of pressure over the bed.
3. It is used to fill up the spaces between bricks or stones for making walls tight.
4. It is used in concrete as a matrix.
5. It is used in plastering works to hide the joints and to improve appearance.
6. It is used for molding and ornamental purpose.

Mortar mix is a binding material used for construction purposes. The most commonly used mortar ingredients to make different types of mortar are:

- Cement
- Lime
- Sand
- Surki

- Mud
- Water

For getting a good mortar mix, it is very important to use quality ingredients. Without good ingredients, it is not possible to get the desired quality of mortar mix. The properties of good mortar ingredients are given below.

Properties of Good Mortar Ingredients

Cement: It should be fresh and free from adulteration. To know more about the properties of good cement read >> Properties of Good Cement

Lime: Lime must be well slaked.

Sand: Sand should be sharp, angular and porous. It should be free from salts and other impurities. Read>> Function of Sand in Mortar

Surki: Surki should be perfectly pure and free from foreign matter. It should be sufficiently fine to pass through No. 8(US) sieve.

Mud: Mud should be free from adulteration.

Water: Water should be clean and free from salts and other impurities.

To produce the best mortar with the available ingredients some precautions are to be adopted carefully. The following factors must be considered to get the most out of the mortar mix.

Precautions Required while Using Mortar Mix

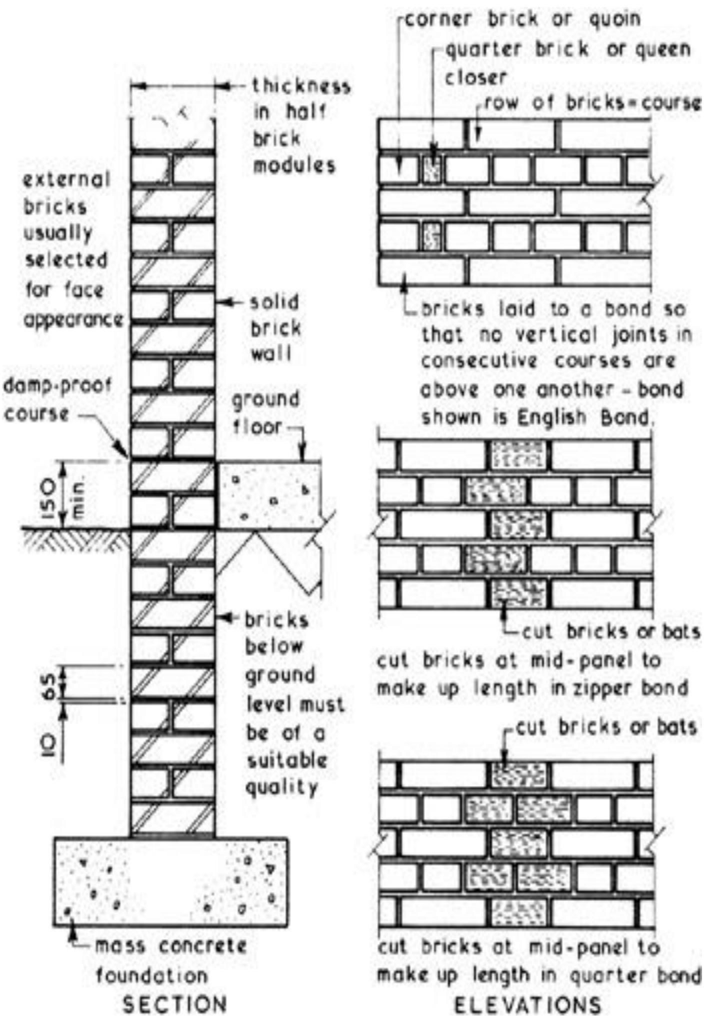
- Mortar should be mixed in small quantities so that it can be used conveniently before the mortar starts setting. The mortar which has set already should never be used. The followings are the maximum time limits for different kinds of mortar:
    - If mortar contains hydraulic lime (Class A lime) as an ingredient, it shall be used within four (04) hours of grinding.
    - If mortar contains surki or cinders an ingredient, it shall be used within twenty-four (24) hours of grinding.
    - In the case of cement mortar, the time limit is 90 minutes after adding water.

- In masonry construction work, usable bricks or stones should be soaked in water very thoroughly for at least for 12 hours before they are used in work with mortar. It will prevent the absorption of moisture from the mortar before it sets.
- Mortar should not contain excess water. It should be as stiff as it can be used without inconvenience.
- Fresh water should be used in mortar mix preparation. The water should be free from oils, dust, alkalies, etc.
- Use of seawater in mortar mixture should be avoided.
- The joints should be well filled with mortar.
- After casting, mortar works should be kept wet for a week or two. It will prevent the rapid drying of mortar, especially in hot weather.
- As frosty weather affects the setting of cement, the work should be stopped in frosty weather.

Brick and Block Walls:

Solid Brick Walls

Bricks ~ these are walling units within a length of 337.5 mm, a width of 225 mm and a height of 112.5 mm. The usual size of bricks in common use is length 215 mm, width 102 5 mm and height 65 mm and like blocks they must be laid in a definite pattern or bond if they are to form a structural wall. Bricks are usually made from clay (BS 3921, BS EN 772-3 and BS EN 772-7) or from sand and lime (BS 187) and are available in a wide variety of strengths, types, textures, colours and special shaped bricks to BS 4729.



Brick Bonding Principles

Typical Details ~

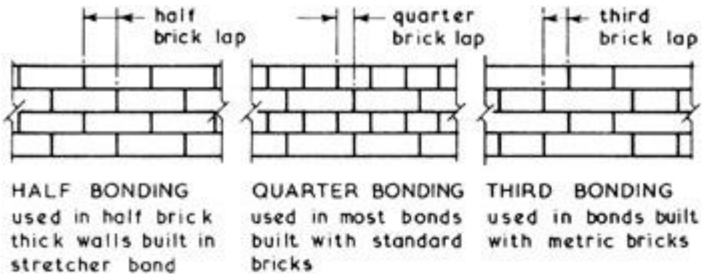
Bonding ~ an arrangement of bricks in a wall, column or pier laid to a set pattern to maintain an adequate lap.

Purposes of Brick Bonding ~

1. Obtain maximum strength whilst distributing the loads to be carried throughout the wall, column or pier.

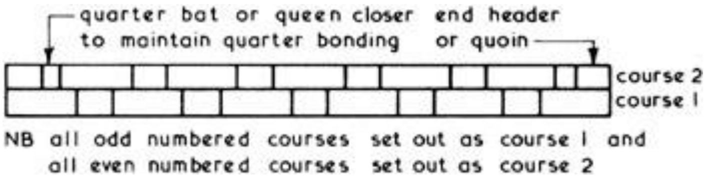
2. Ensure lateral stability and resistance to side thrusts.

3. Create an acceptable appearance.

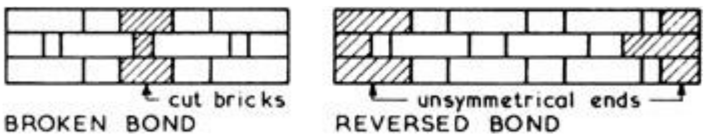


Simple Bonding Rules ~

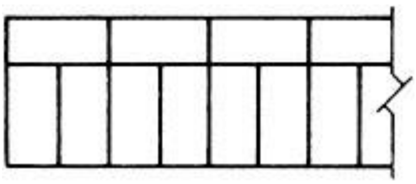
1. Bond is set out along length of wall working from each end to ensure that no vertical joints are above one another in consecutive courses.



2. Walls which are not in exact bond length can be set out thus



3. Transverse or cross joints continue unbroken across the width of wall unless stopped by a face stretcher.



Brick Bonding English Bond

English Bond ~ formed by laying alternate.

ding Construction Handbook, Sixth Edition

By Roger Greeno

Mortar ~ mixes for masonry should have the following properties:

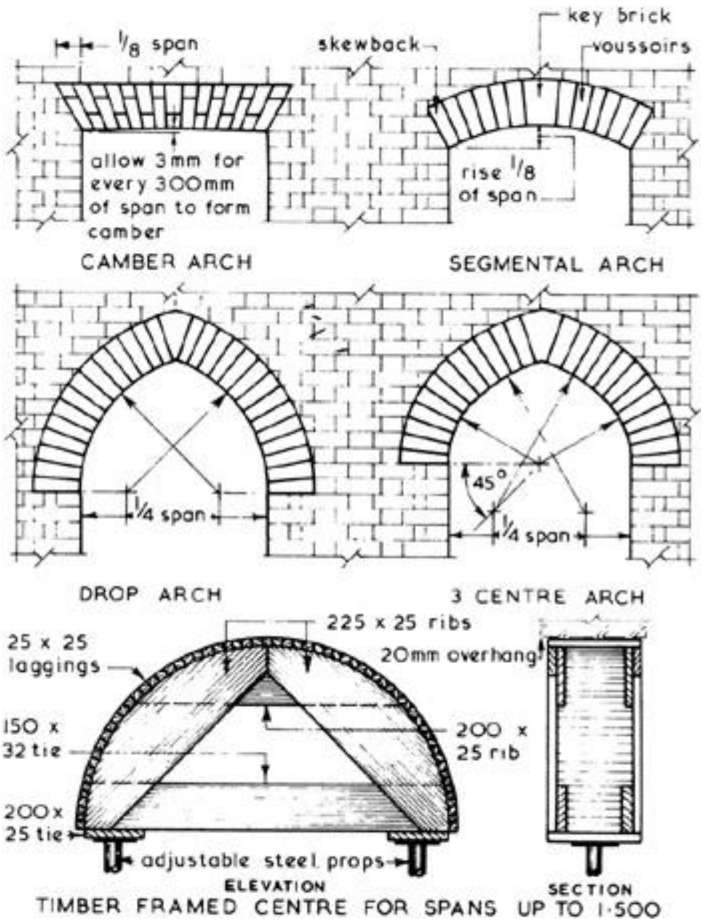
- Adequate strength
- Workability
- Water retention during laying
- Plasticity during application
- Adhesion or bond
- Durability
- Good

Arches and Openings

Arches

Arch Construction ~ by the arrangement of the bricks or stones in an arch over an opening it will be self supporting once the jointing material has set and gained adequate strength. The arch must therefore be constructed over a temporary support until the arch becomes self supporting. The traditional method is to use a framed timber support called a centre. Permanent arch centres are also available for small spans and simple formats.

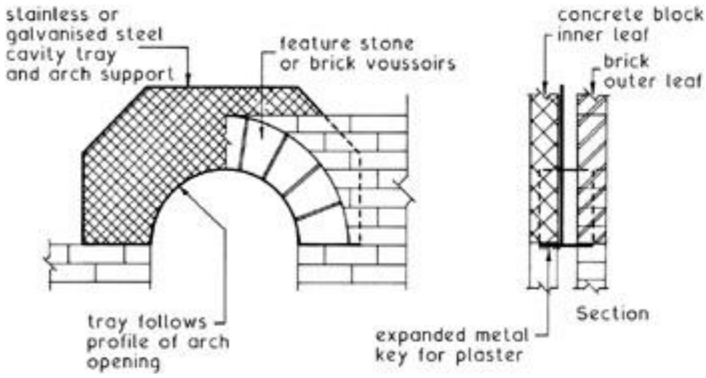
Typical Arch Formats ~



Arch Cavity Tray

The profile of an arch does not lend itself to simple positioning of a damp proof course. At best, it can be located horizontally at upper extrados level. This leaves the depth of the arch and masonry below the dpc vulnerable to dampness. Proprietary galvanised or stainless steel cavity trays resolve this problem by providing:

- Continuity of dpc around the extrados.
- Arch support/centring during construction.
- Arch and wall support after construction.



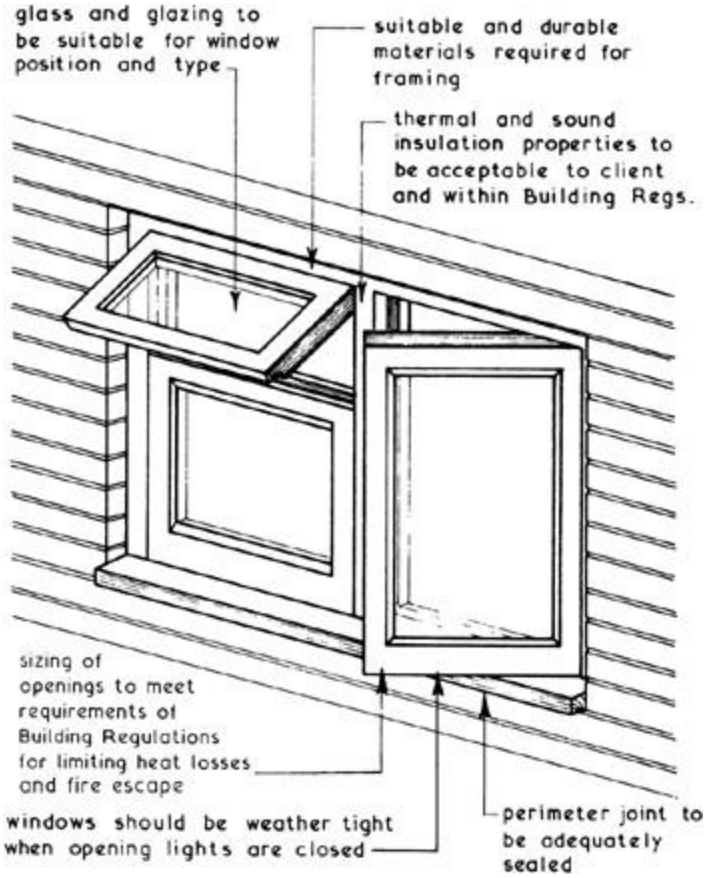
Standard profiles are made to the traditional outlines shown on the previous two pages, in spans up to 2 m. Other options may also be available from some manufacturers. Irregular shapes and spans can be made to order.

Note: Arches in semi-circular, segmental or parabolic form up to 2 m span can be proportioned empirically. For integrity of structure it is important to ensure sufficient provision of masonry over and around any arch, see BS 5628: Code of practice for use of masonry.

Alternative Arch Cavity Tray

Windows Performance Requirements

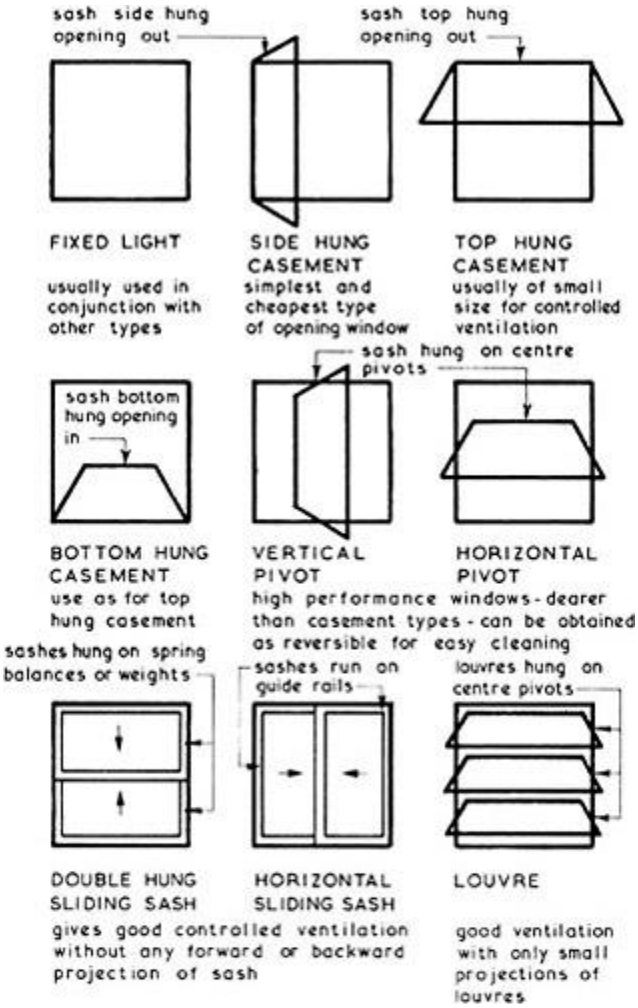
A window must be aesthetically acceptable in the context of building design and surrounding environment



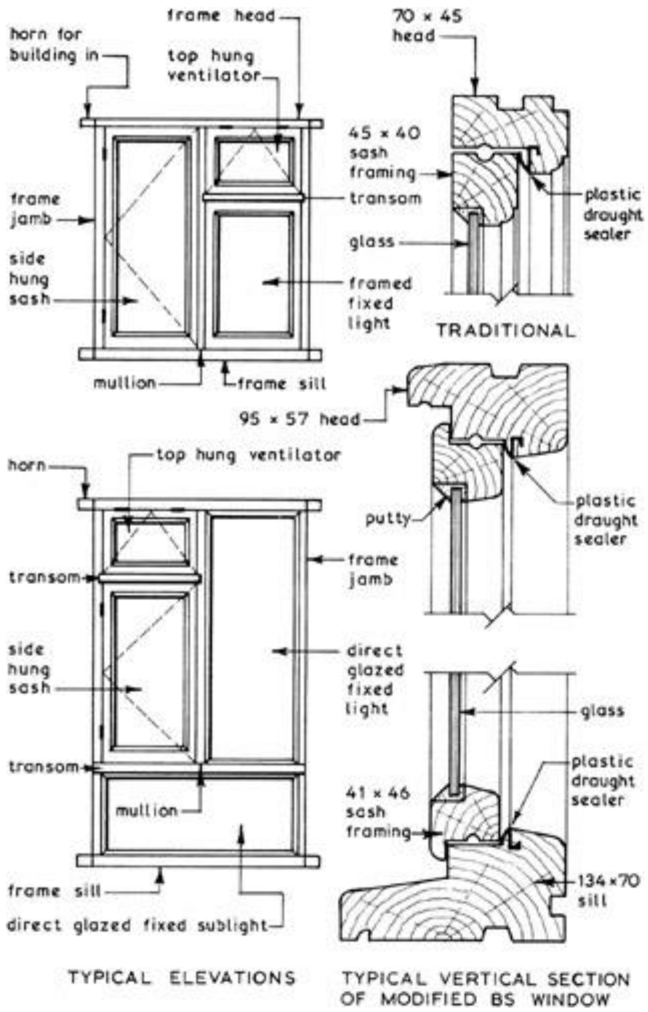
Windows should be selected or designed to resist wind loadings, be easy to clean and provide for safety and security. They should be sited to provide visual contact with the outside.

Habitable upper floor rooms should have a window for emergency escape. Min. opening area, 0.330 m^2. Min. height and width, 0.450 m. Max height of opening, 1.100 m above floor.

Windows Conventional Types

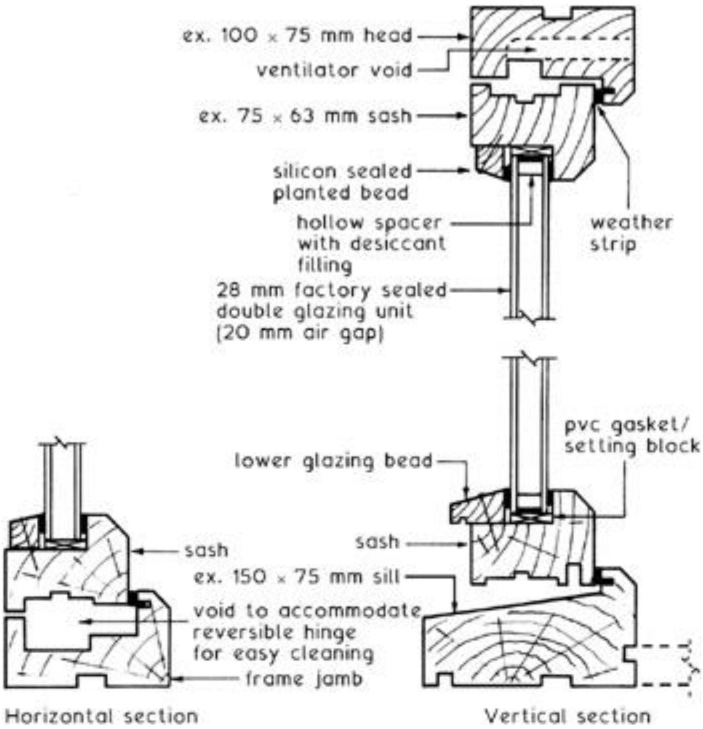


Timber Casement Windows



High Performance Timber Casement Windows

The standard range of casement windows used in the UK was derived from the English Joinery Manufacturer s Association (EJMA) designs of some 50 years ago. These became adopted in BS 644: Timber windows. Specification for factory assembled windows of various types. A modified type is shown on the preceding page. Contemporary building standards require higher levels of performance in terms of thermal and sound insulation (Bldg. Regs. Pt. L and E), air permeability, water tightness and wind resistance (BS ENs 1026, 1027 and 12211, respectively). This has been achieved by adapting Scandinavian designs with double and triple glazing to attain U values as low as 1 2 W/m ^{2}K and a sound reduction of 50dB.



Further refs:

- BS 6375: Performance of windows.
- BS 6375-1: Classification for weather tightness.
- BS 6375-2: Operation and strength characteristics.
- BS 7950: Specification for enhanced security performance. Horizontal section Vertical section

Metal Casement Windows

Metal Windows ~ these can be obtained in...

Chapter 5

FOUNDATIONS

5-1. GENERAL

Every structure consists of the following *two* parts:

(i) Foundations; and

(ii) Superstructures.

The lowest artificially prepared parts of the structures which are in direct contact with the ground and which transmit the loads of the structures to the ground are known as the *foundations* or *substructures.* The solid ground on which the foundations rest is called the *foundation bed* or *foundation soil* and it ultimately bears the load and interacts with the foundations of buildings. The lowermost portion of the foundation which is in direct contact with the sub-soil is called the *footing.*

The term *superstructure* is used to mean that part of the structure which is above ground level. A part of superstructure located between the ground level and the floor level is known as the *plinth.* Thus the term *plinth* is defined as the portion of the structure between the surface of the surrounding ground and level of the floor immediately above the ground.

For the purpose of convenience, the superstructure can be grouped in the following components:

(i) walls which are used to enclose or divide the floor space;

(ii) floors which are used to divide a building into different levels and thereby to provide more accommodation on a given plot of land;

(iii) doors, windows and ventilators which are in the form of openings in walls to permit light, air, passage, entry, ventilation, etc.;

(iv) vertical transportation structures like stairs, ramps, lifts, escalators, etc. which are used to provide access between various floors;

(v) roof structures which are used to give protection to the buildings from rain, snow, sun, etc.;

(vi) building finishes like plastering, pointing, painting, whitewashing, distempering, etc. which are used to give protective coverings to the various components of the buildings;

(vii) building services like water supply, drainage, electricity, acoustics, heating, air conditioning, fire detection, fire control, etc.

For any structure, its foundation forms the most important part and as it remains below the ground, it is not available for inspection. Hence the failures of foundation are not noticed till the structure is seriously affected by such failures. It becomes therefore necessary to exercise extreme care in the construction and design of foundations to avoid their failures in future.

5-2. OBJECTS OF FOUNDATIONS

The foundations are provided for the following *purposes*:

(i) to distribute the total load coming on the structure on a larger area so as to bring down the intensity of load at its base below the safe bearing capacity of sub-soil;

(ii) to support the structures;

(iii) to give enough lateral stability to the structures against various disturbing horizontal forces such as wind, rain, earthquake, etc.;

(iv) to prepare a level and hard surface for concreting and masonry work;

(v) to transmit the super-imposed loads through side friction and end bearing in case of deep foundations;

(vi) to distribute the non-uniform load of the superstructure evenly to the sub-soil;

(vii) to provide the structural safety against undermining or scouring due to animals, flood water, etc.;

(viii) to prevent or minimize cracks due to movement of moisture in case of weak or poor soils; etc.

5-3. ESSENTIAL REQUIREMENTS OF A GOOD FOUNDATION

Following are the *three* basic requirements to be fulfilled by a foundation to be satisfactory:

(1) Location: The foundation structure should be so located that it is able to resist any unexpected future influence which may adversely affect its performance. This aspect requires careful engineering judgement.

(2) Stability: The foundation structure should be stable or safe against any possible failure. The foundation base should be rigid enough to bring down the differential settlements to a minimum extent specially when the superimposed loads are unevenly distributed.

(3) Settlement: The foundation structure should not settle or deflect to such an extent so as to impair its usefulness or the stability of building or the adjoining structures. It is however difficult to define the objectionable amount of settlement or deflection.

The above *three* requirements are independent of each other and for the foundation structure to be satisfactory, all the *three* conditions should be simultaneously satisfied.

5-4. SHALLOW FOUNDATIONS

The foundations can broadly be classified into *two* categories: shallow and deep. If it is possible to construct foundations of a building at reasonable shallow depth, the foundations are termed as the *shallow foundations*. In such cases, a spread is given

5-6. SPECIAL FOUNDATIONS

The foundations of some important engineering structures require special treatment. Such structures have to be designed for heavy loads and ordinary methods of providing foundations may not be suitable for such structures. In such cases, special treatment is given to the foundations of such structures. These special foundations are as follows:

(1) Grillage foundations

(2) Raft foundations

(3) Inverted arches.

(1) Grillage foundations: In this method, the depth is limited to 1 m to 1.50 m and the width is increased considerably to bring the pressure on the soil within permissible limits. The superstructure rests on *two* perpendicular tiers of R.S.J. Fig. 5-11 and fig. 5-12 show typical grillage foundations for a steel stanchion and a wall respectively. Following points should be noted:

(i) The R.S.J. work should be thoroughly embedded in concrete so as to protect it from the atmospheric actions. The bed of concrete should have minimum thickness of 150 mm and at no other point, the depth of concrete should be less than 80 mm.

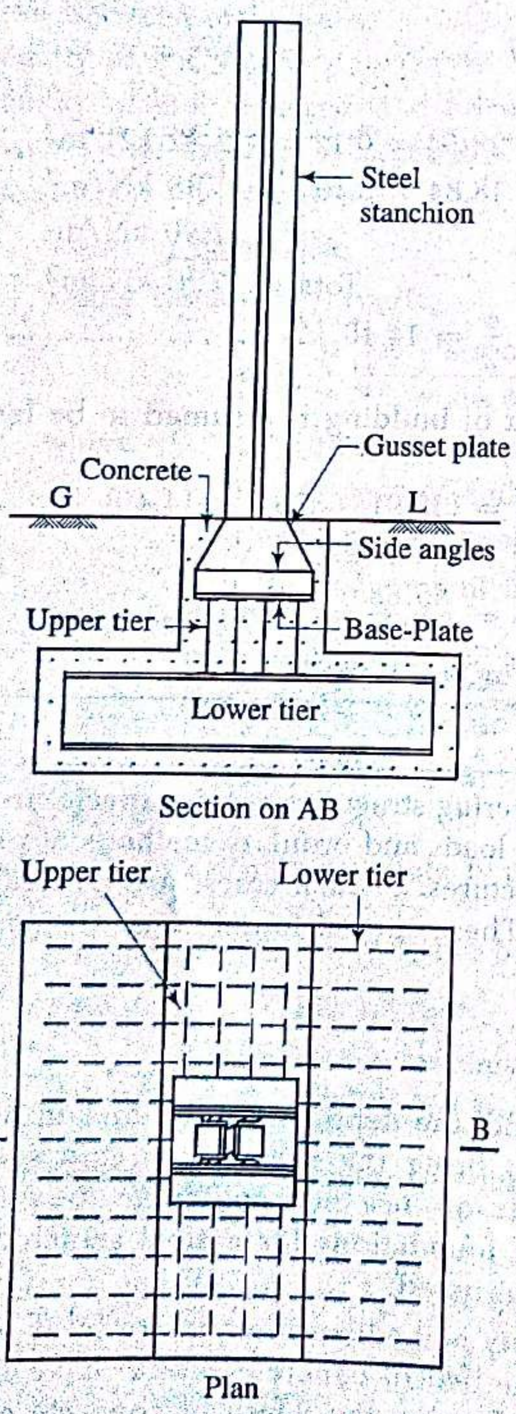
(ii) The concrete filling does not carry any load. But it maintains the beams in proper position and prevents them from the corrosion.

(iii) Each tier of R.S. joists should be designed to act independently.

(iv) The distance between the flange of R.S. joists should be equal to $1\frac{1}{2}$ to times the width of flange or 300 mm whichever is less. The tube or pip separators may be provided to maintain the R.S. joists in proper position.

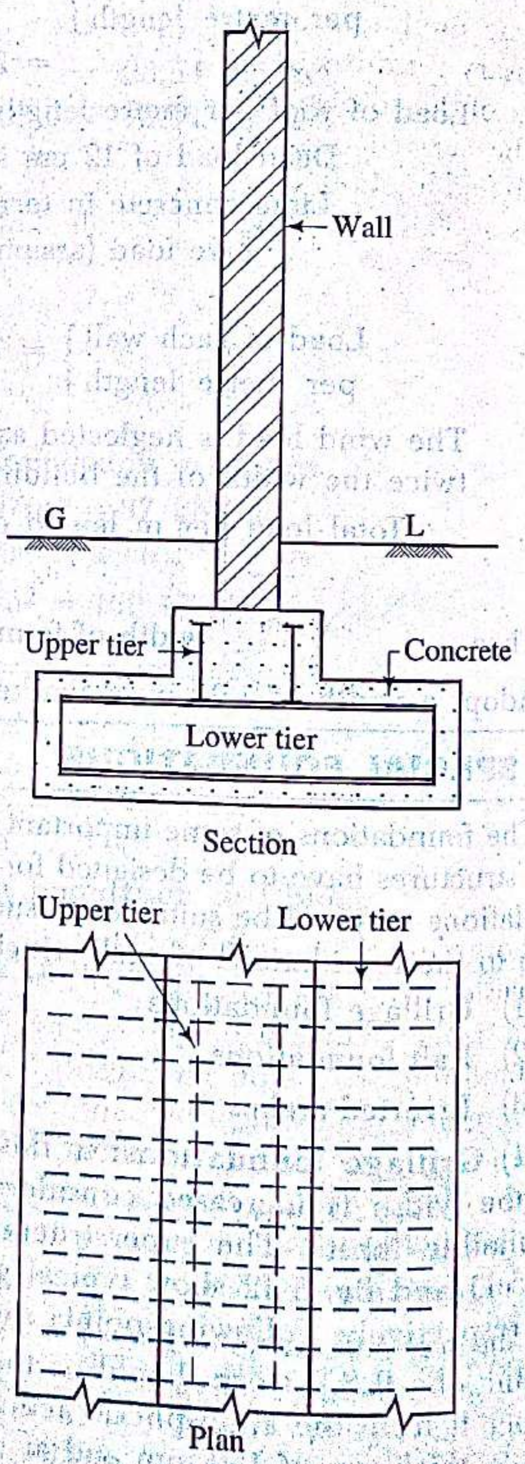
(v) It is possible to replace the R.S. joists by a number of reinforcement bars o steel of required diameter. This is termed as the *mat foundation.*

(vi) The steel grillage foundations are useful for structures having concentrate loads and hence, are employed for the foundations of the buildings such a theatres, factories, town halls, etc.



Grillage foundation for a steel stanchion

FIG. 5-11



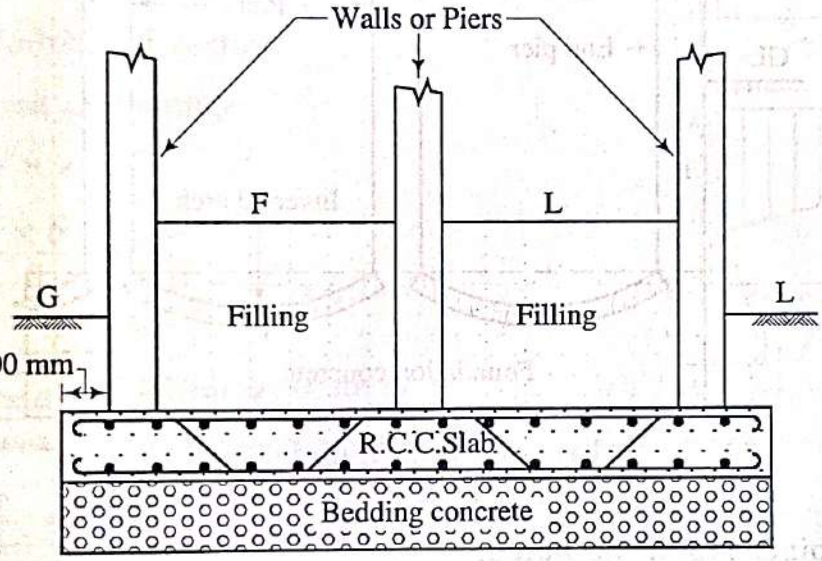
Grillage foundation for $2\frac{1}{2}$ bricks wall

FIG. 5-12

(vii) The temporary grillage foundations in the form of timber beams may be provided to timber columns or posts. They can also be designed for supporting light buildings in the soft soil and permanently water-logged areas. The loading on the soil is limited to 55 kN/m^2. The timber grillage takes the form of a platform of wooden planks arranged in two layers at right angles to each other. The *two* layers of planks are separated by rectangular sections of timber placed at a centre to centre distance of about 350 mm to 400 mm.

(2) Raft foundations: This method of increasing the bearing power of soil becomes very useful when the load coming on the soil is practically uniform, while the soil is of yielding nature. (e.g. soft clay or reclaimed soil).

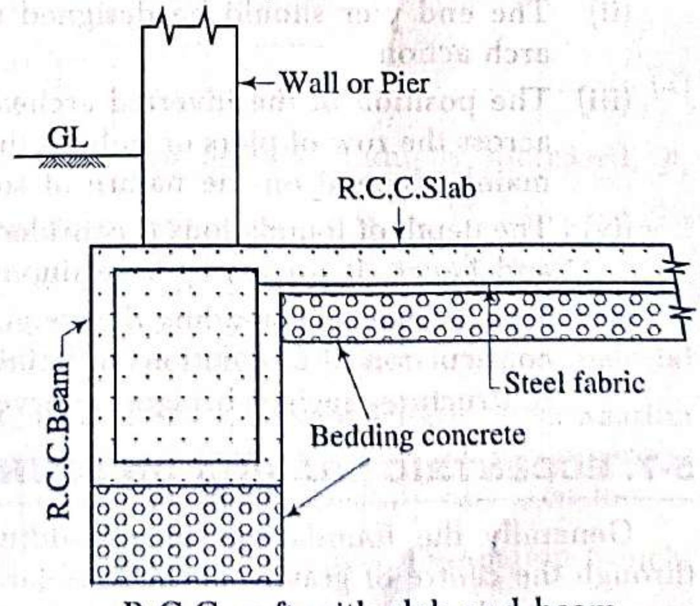
The method consists of providing an R.C.C. slab of suitable thickness and with necessary reinforcement. The raft is designed in such a way that the allowable bearing power of the soil is not exceeded. If required, beam and slab construction in R.C.C. can also be carried out. The raft is designed as an inverted R.C.C. roof with uniformly distributed load of the soil pressure and supported by walls, beams and columns. Fig. 5-13 shows an R.C.C. raft with slab only. Fig. 5-14 shows an R.C.C. raft with slab and beam.



R.C.C. raft with slab only
FIG. 5-13

Sometimes the design of the raft is so adjusted that the weight of the excavated earth is just equal to the total load of the building. Thus the loading on the soil remains practically the same after the construction of the building. This is known as a *floating foundation* and in such a case, the settlement is reduced to a minimum extent.

The design of raft foundations requires careful attention. Usually, the raft is so shaped and proportioned, wherever possible, that the centre of gravity of the imposed load is vertically under the centre of area of the bearing ground. Also, in cases where there is fear of



R.C.C. raft with slab and beam
FIG. 5-14

5-8. COMBINED FOOTING

A common footing provided for two or more columns is known as a *combined footing.* This type of construction becomes useful when an exterior column is situated near the boundary line of the plot and it is not possible to project its footing symmetrically on both the sides.

Following points are to be noted in case of combined footings:

(i) The shape of the combined footing should be so selected that the centres of gravity of the column loads and of soil reaction remain in the same vertical line. Usually a rectangular or a trapezoidal shape is selected.

(ii) The area of the combined footing should be equal to or greater than the ratio of the combined total load on the columns to the allowable bearing pressure on the soil.

(iii) The combined footing is treated as an inverted floor supported by columns and loaded by earth reactions.

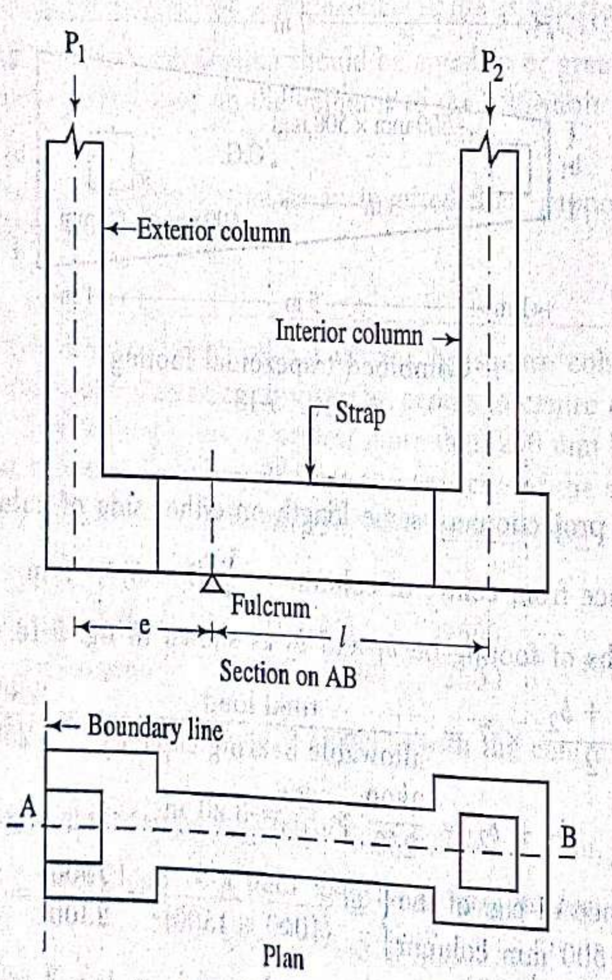
$$\therefore \quad b_2 = 2.286$$

$$\therefore \quad b_1 = (3.20 - 2.286) = 0.914 \text{ m.}$$

Fig. 5-18 shows the details of the combined trapezoidal footing.

5-9. CANTILEVER FOOTING

A cantilever footing consists in an eccentric footing for the exterior column, a concentric footing for the interior column and a strap or a cantilever beam joining these *two* footings as shown in fig. 5-19. Following points are to be noted in case of cantilever footings:



Cantilever footing
FIG. 5-19

(i) The strap joining the two footings need not touch the soil or rest on the ground.

(ii) The fulcrum is assumed at the point where shear force is equal to zero. At this section of zero shear, the reaction of the soil becomes equal to the load on the exterior column.

(iii) The cantilevers on either side of the fulcrum are designed for bending moments due to column loads.

(iv) Let e = Length of fulcrum from centre of exterior column

l = Length of fulcrum from centre of interior column

p_1 = Load on exterior column

p_2 = Load on interior column required to balance the load on exterior column

p = Safe allowable pressure on soil

b = Breadth of footing.

Then, $e \times p \times b = p_1$

$$\therefore \qquad e = \frac{p_1}{pb}$$

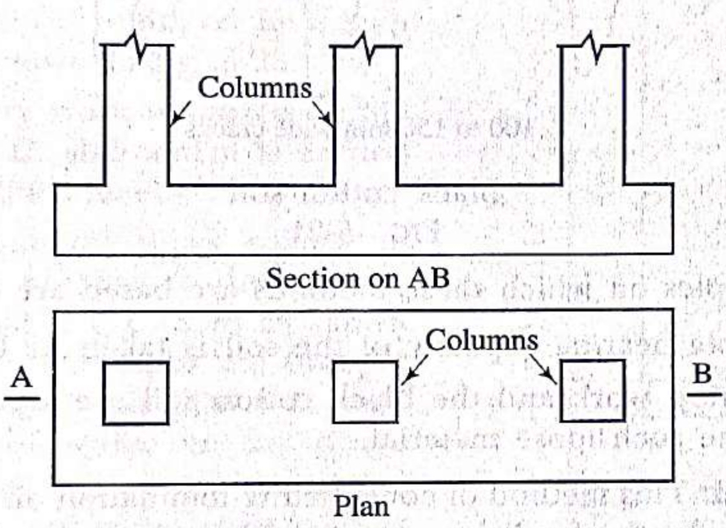
and $$p_2 = \frac{p_1 e}{l}$$

(v) If it is not possible to provide an interior column, a suitable anchorage should be provided in the form of a huge concrete block or tension piles.

(vi) The cantilever footing can be constructed either in R.C.C. or steel.

5-10. CONTINUOUS FOOTING

In this type of construction, the footings of two or three adjacent columns are made continuous by providing beams between the successive footings as shown in fig. 5-20.



Continuous footing
FIG. 5-20

This type of construction is cheaper than raft foundations and it is adopted to avoid differential or uneven settlement of the structure and to make the structure safe from earthquake disturbances.

5-11. FOUNDATIONS OF BLACK COTTON SOIL

This is a clayey or loose type of soil and it considerably swells and shrinks by variation in moisture contents. The variation in the volume of the soil is to the extent of 20 to 30 per cent of the original volume. The cracks formed in a black cotton soil are shown in fig. 5-21 and they are sometimes 100 mm to 150 mm in width and 2.50 m to 4.00 m in depth. As far as agriculture is concerned, this is an excellent type of soil. But from the structural view point, this is a very bad soil. Hence, extreme care should be taken when the foundations are to rest on this soil. The precautions to be taken to grant safety to the foundations on the black cotton soil are as follows:

(i) For important structures, the raft foundations should be adopted.

(ii) The black cotton soil should be completely removed, if possible and convenient.

(iii) The black cotton soil should not be allowed to come in direct contact with the foundation masonry.

5-12. STEPPED FOUNDATIONS

When the ground is sloping, it becomes uneconomical to provide foundations at the same level. In such cases, the correct levels of the sloping ground on which the building is to be constructed are taken and a longitudinal section is prepared accordingly. The stepped foundations are then provided as shown in fig. 5-24.

Following points should be noted:

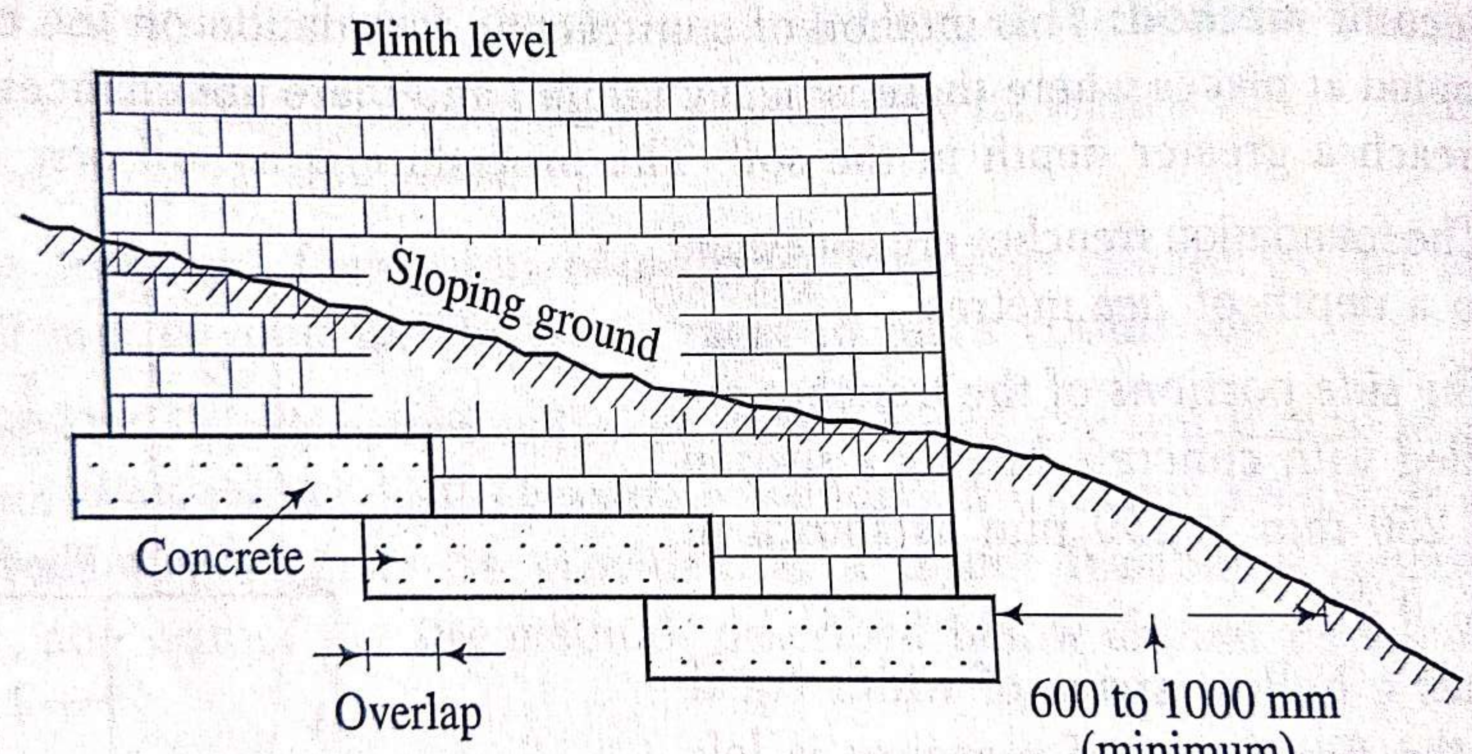
(i) The overlap between *two* layers of foundation concrete should be equal to the depth of foundation concrete or twice the height of the step, whichever is greater.

(ii) A minimum depth of 800 mm should be provided at all points so as to protect the foundations from weathering effects.

(iii) The depth of foundation concrete should be in even number of the masonry courses.

(iv) The distance of the sloping surface from the lower edge of the footing should not be less than 600 mm for rock and 1 m for soils.

(v) When footings are heavily loaded, it becomes necessary to carry out a slope stability analysis.



Stepped foundation
FIG. 5-24

5-17. CAUSES OF FAILURE OF FOUNDATIONS AND PREVENTIVE MEASURES

The main *causes* of failure of foundations are as follows:

(1) Unequal settlement of the sub-soil
(2) Unequal settlement of the masonry
(3) Withdrawal of moisture from the sub-soil
(4) Lateral pressure on the superstructure
(5) Horizontal movement of the earth
(6) Transpiration of trees and shrubs
(7) Atmospheric action.

We will now discuss each one in detail together with the measures to be taken to prevent such failures.

(1) Unequal settlement of the sub-soil: This occurs due to various reasons such as unequal distribution of load on the foundations, varying bearing power of the sub-soil, eccentricity of the load, etc. Due to unequal settlement of the sub-soil, the cracks are formed in the buildings, which in future, leads to serious defects.

Following are the measures to be adopted to prevent such failure:

(i) The foundations should rest on the rock or hard moorum.
(ii) The design of foundations should be appropriate to the nature of sub-soil.
(iii) It should be seen that the allowable bearing pressure on the soil is not exceeded, even under the worst conditions.
(iv) The proper attention should be given to the eccentricity of the load on the foundations and design should be accordingly modified.

(2) Unequal settlement of the masonry: The mortar used as the binding material in the masonry construction shrinks and gets compressed when loaded excessively before it has fully set. This may lead to the unequal settlement of the masonry and the measures to avoid such situation are as follows:

(i) The mortar to be used in the masonry should be stiff and in line with the workability desired.
(ii) The masonry work should be raised evenly.
(iii) The height of wall to be raised per day should be limited to one metre, if lime mortar is used and to 1.50 metres, if cement mortar is used.

(iv) The proper watering or curing for a period of at least 10 days should be done to the masonry work to ensure the development of adequate strength of the mortar joints.

(3) Withdrawal of moisture from the sub-soil: This occurs at places where there is considerable variation in the height of water table. When water table falls, the soil particles loose cohesion and hence, there is shrinkage of soil, resulting in the cracks to the buildings. The precaution to be taken to avoid such failure would be to drive piles upto the hard rock.

(4) Lateral pressure on the superstructure: The thrust of a pitched roof or arch action or wind action on the superstructure causes wall to overturn. The remedial measures to prevent this failure would be to provide a sufficient wide base and to design the foundations for the worst conditions.

(5) Horizontal movement of the earth: Very soft soil is liable to give way under the action of load, especially at places such as sloping ground, river banks, etc. Hence, in such cases, it is desirable to construct the retaining walls or to drive sheet piles to prevent the escape of the earth.

(6) Transpiration of trees and shrubs: The roots of trees planted near a building may extend upto the foundation level and may absorb the moisture. This effect is seen in the form of a depression on the ground and it may lead to cracks in the building. The remedial measures are as follows:

(i) The foundations should be taken sufficiently deep. A minimum depth of one metre is required for this purpose.

(ii) The fast growing and water-seeking trees should not be planted near the building with a minimum distance of 8 metres.

(7) Atmospheric action: The rain and sun are the main atmospheric agents to seriously affect the foundations of a building. The heavy rains or considerable variation in temperature or frost action may damage the foundations. The rain water may create pockets near the walls and while descending, it may carry certain chemicals and salts obtained from sewage, animal dung, etc. These chemicals and salts may react with the materials used for the foundation work and turn them into powder. The remedial measures to be taken are as follows:

(i) The foundations should be taken beyond the depth upto which rain water can reach.

(ii) Suitable underground drains should be provided to maintain the water table at a definite level.

(iii) After the masonry work is completed, the sides of trenches should be carefully filled with earth and well-consolidated. A gentle slope should be provided so as to keep rain water away from the wall.

5-18. METHOD OF SETTING OUT THE FOUNDATION TRENCHES

The setting out or *ground tracing* is a term applied to the process of laying down certain lines and marks on the ground before the excavation of foundation trenches is actually started. There are mainly *two* purposes of this process:

(i) The excavation of foundation trenches can be started immediately after this process is completed.

(ii) The lines and marks established by this process serve as a guide and provide checks in the construction of the foundation work.

Chapter 7

DEEP FOUNDATIONS (PILE FOUNDATIONS)

7-1. GENERAL

In case of deep foundations, the piles are used to transmit the load of structure to the soil. The term *pile foundations* is used to describe a construction for the foundation of a wall or a pier, which in turn is supported on the piles. The piles may be placed separately or they may be placed in the form of a cluster throughout the length of the wall. This construction is adopted when the loose soil extends to a great depth. The load of the structure is transmitted by the piles to hard stratum below or it is resisted by the friction developed on the sides of piles.

Piles are deep foundations. They are relatively long, slender members and are either driven into the ground or bored cast-in-situ. The pile foundations become one of the choices when shallow foundations are not able to meet the required objectives. Such situations are often faced by the construction engineer due to weak foundation soils, which are not in a position to withstand the load from the superstructure be meeting the desired criteria of satisfactory foundation, i.e., no shear failure of the foundation soil and not exceeding the allowable settlement.

The most important factor in a pile selection is the soil condition and the type of piles i.e., a driven pile or a cast-in-situ pile, selection will be governed by the soil type and its consistency if cohesive soil and its degree of compactness if cohesion less soil.

7-2. USES OF PILES

The situations which demand piles as foundations are as follows:

(i) The load coming from the structure is very heavy and the distribution of load on soil is uneven.

(ii) The subsoil water level is likely to rise or fall appreciably. This may be seasonal or occasional variation.

(iii) The pumping of subsoil water is too costly for keeping the foundation trench in dry condition.

(iv) The construction of raft or grillage foundations is likely to be very expensive or is practically impossible.

(v) The firm bearing stratum exists at a greater depth. The piles upto 20 metres depths are common and under exceptional circumstances, they may even be taken to 30 metres depth. The piles are considered to be long when their length exceeds 30 metres.

(vi) The timbering to excavations is too difficult to maintain the sides of the foundation trench.

(vii) The pile foundation is to be adopted for the structures in the area where canals, deep drainage lines, etc. are to be constructed in near future.

(viii) The structure is situated on sea-shore or river bed and the foundation is likely to be affected by the scouring action of water. Thus, the piles are useful for the marine structures.

(ix) The piles are also used as anchors. They may be designed to give lateral support or to resist an upward pressure or uplift pressure.

(x) The piles are used as *fender piles* in the construction of docks, piers and other marine structures. A fender pile protects the berthing ships from damage.

7-3. TYPES OF PILES

The piles are broadly classified into the following *two* categories:

(1) Load bearing piles

(2) Non-load bearing piles.

Each of the above category of piles will now be described in detail.

7-4. LOAD BEARING PILES

These piles bear the load coming from the structure. The piles are generally driven vertically or in near vertical position. When a horizontal force is to be resisted, the piles may be driven in an inclined position and such inclined piles are termed as the *batter piles.* The design of batter piles should be made by considering the fact that they will resist most, if not all, of the horizontal loading. If batter piles are used together with vertical piles, it may be assumed that part of the vertical load will be transferred to the batter piles also. The load bearing piles may resist the load by directly resting on a firm stratum or by friction developed at their sides. The former piles are known as the *bearing* or *sustaining piles* and the latter piles are known as the *friction* or *floating piles.*

(1) Bearing piles: These piles penetrate through the soft soil and their bottoms rest on a hard bed. Thus, they are end-bearing piles and act as columns or piers. The soft ground through which the piles pass also gives some lateral support and this increases the load carrying capacity of the bearing piles.

(2) Friction piles: When loose soil extends to a great depth, the piles are driven upto such a depth that the frictional resistance developed at the sides of the piles equals the load coming on the piles. Great care should be taken to determine the frictional resistance offered by the soil and suitable factor of safety should be provided in the design. The total frictional resistance of piles is obtained by multiplying frictional resistance of soil with the area of pile in contact with the soil. The circumference of pile when multiplied with the depth of penetration of pile in the ground will give the area of pile in contact with the soil. The total frictional resistance can be increased in the following ways:

(i) By increasing the diameter of the pile.

(ii) By driving the pile to a greater depth.

(iii) By making the surface of the pile rough.

(iv) By placing the piles closely.

(v) By grouping the piles.

7-5. MATERIALS USED IN CONSTRUCTION OF LOAD BEARING PILES

The materials which are used in the construction of load bearing piles are as follows:

(1) Cast-iron piles
(2) Cement concrete piles
(3) Sand piles
(4) Steel piles
(5) Timber piles
(6) Wrought-iron piles.

Each of the above materials which are used in the construction of load bearing piles will now be described in detail.

7-6. CAST-IRON PILES

The cast-iron piles are generally hollow. The inside diameter of pile is about 300 mm and thickness is about 25 mm. The length of pile is about 3 metres to 4 metres and with the help of suitable device, it can be extended to any desired length. As cast-iron is brittle, it is not possible to drive the piles into the ground by means of a hammer. Hence, special screws are provided at the bottom of piles and then, they are driven like a screw into the ground. These are known as the *cast-iron screw piles.*

(1) Advantages of cast-iron piles: Following are the *advantages* of the cast-iron piles:

(i) The cast-iron piles are useful for areas where the timber piles will be attacked and damaged by the insects or worms.

(ii) The cast-iron piles are suitable for heavy vertical pressure.

(iii) If shocks or vibrations would endanger the adjacent properties, the cast-iron piles are to be preferred.

(2) Disadvantages of cast-iron piles: Following are the *disadvantages* of the cast-iron piles:

(i) The cast-iron piles cannot be subjected to shocks or vibrations.

(ii) The cast-iron piles are unsuitable for works under sea water.

7-7. CEMENT CONCRETE PILES

The cement concrete possesses excellent compressive strength. With the advent of reinforced cement concrete, the R.C.C. piles are becoming more popular and they are fast replacing piles of other materials. The R.C.C. piles are divided into *two* groups:

(1) Cast-in-situ concrete piles
(2) Pre-cast concrete piles.

7-7-1. CAST-IN-SITU CONCRETE PILES

In this type of concrete piles, a bore is dug into the ground by inserting a casing. This bore is then filled with cement concrete after placing reinforcement, if any. The casing may be kept in position or it may be withdrawn. The former piles are known as the *cased cast-in-situ concrete piles* and the latter piles are known as the *uncased cast-in-situ concrete piles.* The various patented processes have been developed under both of the above categories. Some of them are briefly described below.

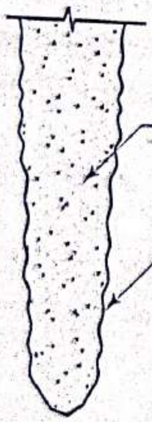
(1) Cased cast-in-situ concrete piles: It is possible to see that the casing is vertical, straight and undamaged. But as the casing is to be kept alongwith the pile, it will increase the cost of these piles. The casing protects the freshly placed concrete against ground pressures, intrusions and movements as the concrete sets. The shell lengths are easily adjusted on the job during the installation process to suit the changing subsoil conditions.

The examples of cased cast-in-situ concrete piles are:

(i) Raymond piles
(ii) Mac Arthur piles
(iii) Monotube piles
(iv) Cobi pneumatic mandrel piles
(v) BSP base-driven piles
(vi) Swage piles
(vii) Button-bottom piles.

(i) ***Raymond piles*** (fig. 7-1 and fig. 7-2): In 1897, A. A. Raymond developed a practical and economical way of placing cast-in-situ concrete piles and the system is known as the Raymond pile system. Following *two* types of Raymond piles are in common use:

(a) *Raymond standard concrete pile:* It consists of a thin corrugated steel shell closed at bottom. The shell is driven into the ground with a collapsible steel mandrel or core in it. When the desired depth is reached, the mandrel is collapsed and withdrawn. The shell is then inspected internally by using the light from a mirror or flashlight or droplight. If the shell is found to be damaged during driving, it is replaced by another shell. The concrete is then poured in the shell to finish up the pile as shown in fig. 7-1. The usual tip diameter is about 200 mm and spirally wound wires are provided at 80 mm pitch to serve as reinforcement.



Raymond standard concrete pile
FIG. 7-1

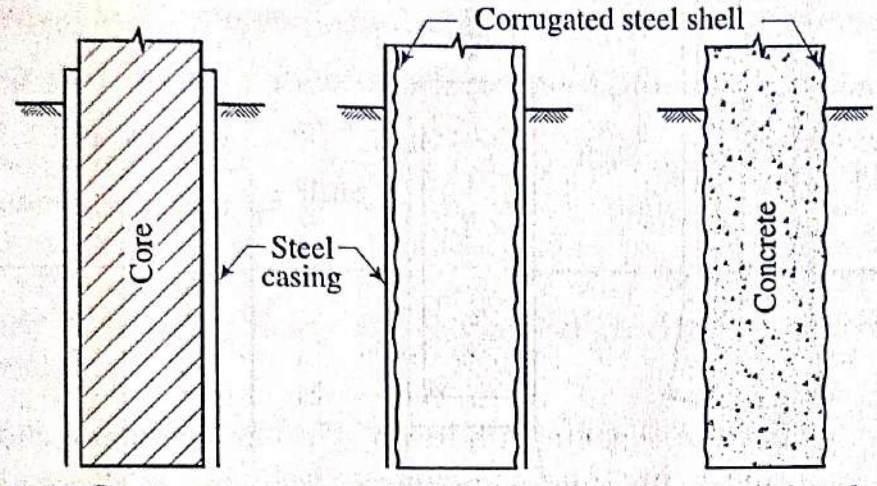
Raymond step-taper concrete pile
FIG. 7-2

(b) *Raymond step-taper concrete pile:* It consists of shell sections of suitable length. The bottom of first shell to be driven is closed by a flat steel plate. The diameter of pile increases in steps at the rate of 25 mm for each successive shell section. The required length of pile is obtained by joining the proper number of sections by screw connections as shown in fig. 7-2. The process of forming the pile is the same as that of standard concrete pile.

The *advantages* of this type of pile are:

(1) It grants on-the-job flexibility of length.
(2) It permits internal inspection after being driven.
(3) The steel shell left in position protects the fresh concrete filling.

(ii) ***Mac Arthur piles*** (fig. 7-3 to fig. 7-5): In this type of piles, a heavy steel casing with a core is driven into the ground as shown in fig. 7-3. When the desired depth is reached, the core is withdrawn and a corrugated steel shell is placed in the casing as shown in fig. 7-4. The last operation consists in filling and gradually compacting the concrete and withdrawing the casing. The completed pile with concrete core and the outer corrugated steel shell is shown in fig. 7-5.



Casing and core
FIG. 7-3

Casing and corrugated steel shell
FIG. 7-4

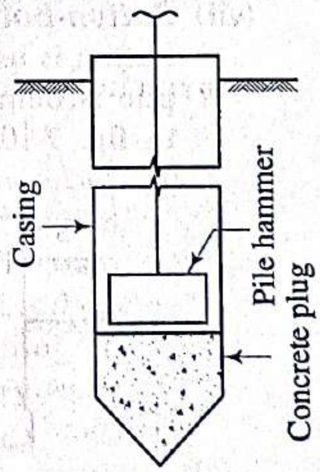
Completed pile
FIG. 7-5

(iii) ***Monotube piles:*** A monotube pile consists of a tapered fluted steel shell without mandrel. The pile shells are driven to the required depth and then, the interior of the shell is inspected. The shell is then filled with concrete and the excess shell, if any, is cut off. The extension of shell upto the required length is carried out by the welding.

The shells are rigid and watertight. These piles are suitable for a wide variety of soil conditions ranging from end-bearing to friction-load-carrying soils.

(iv) ***Cobi pneumatic mandrel piles:*** This pile consists of a corrugated steel shell and a Cobi mandrel. The four curved segments of the steel plate are supported by internal members and they are placed around a central expansible core to form a Cobi mandrel.

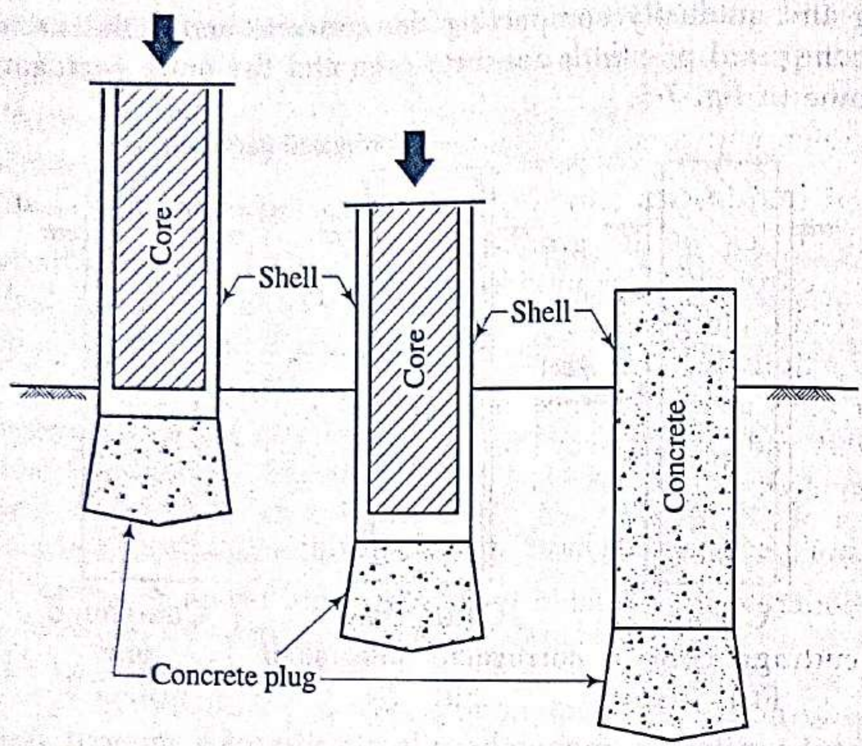
When in loose state, the diameter of mandrel is about 20 mm smaller than that of the shell diameter. The mandrel is placed in the shell and then nitrogen or air is forced into the mandrel at a pressure of about 9 kg/cm^2 or 0.90 N/mm^2. The mandrel thus becomes tight with the shell. Both are then lowered to the required depth. The valve of mandrel is then opened and nitrogen or air is allowed to escape. The mandrel collapses and it can then be easily withdrawn. The concrete is then laid in the shell.



BSP pile
FIG. 7-6

(v) ***BSP base-driven piles*** (fig. 7-6): This pile consists of a helically welded shell of steel plate. A concrete plug is provided at the bottom of the shell and driving is done by allowing pile hammer to fall on the concrete plug as shown fig. 7-6. The casing is driven to the desired depth and then it is filled with the concrete.

(vi) ***Swage piles*** (fig. 7-7 to fig. 7-9): In this type of piles, a pre-cast concrete plug of slight conical shape provided at the bottom of a steel shell. The *three* stages of forming these piles are shown in fig. 7-7 to fig. 7-9.

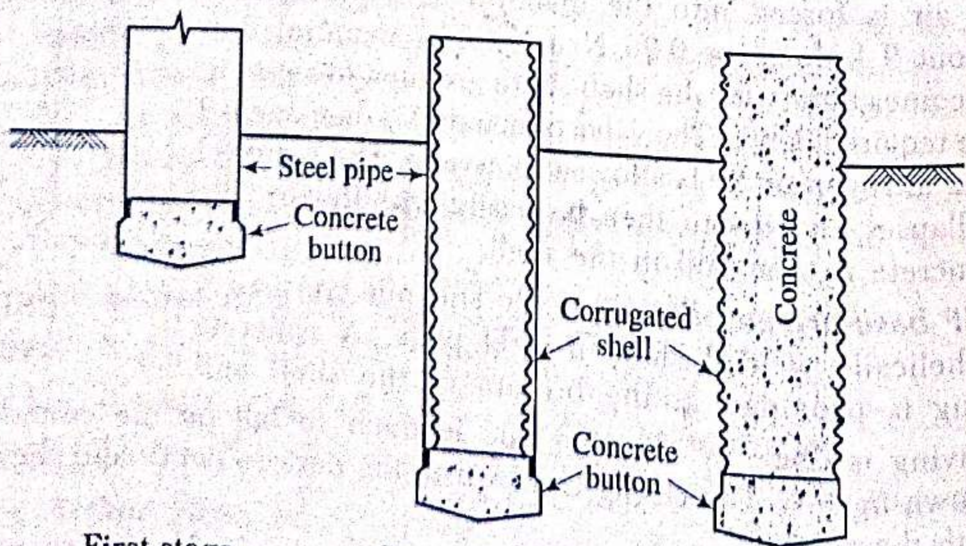


First stage Swage pile FIG. 7-7 | Second stage Swage pile FIG. 7-8 | Completed Swage pile FIG. 7-9

In the first stage, the shell and core are fixed at the top and driven on the top of concrete plug. In the second stage, the core reaches the top of concrete plug and the shell is forced round the taper of the plug forming a watertight joint.

The final stage consists in removing the core and filling the shell with concrete. These piles are used for hard soils or at places where it is desired to have watertight shells before concrete is placed in the shell.

(vii) ***Button-bottom piles*** (fig. 7-10 to fig. 7-12): In this type of piles, a concrete button is used at the bottom to provide an enlarged hole in the soil when the pile is being driven. The *three* stages of formation of these piles are shown in fig. 7-10 to fig. 7-12.



First stage Button-bottom pile FIG. 7-10 | Second stage Button-bottom pile FIG. 7-11 | Completed Button-bottom pile FIG. 7-12

In the first stage, the steel pipe is set on the concrete bottom. In the second stage, the pipe and button are driven upto the required depth and a corrugated steel shell is inserted inside the steel pipe. In the final stage, the pipe is withdrawn and concrete is laid after placing the reinforcement, if necessary.

(2) Uncased cast-in-situ concrete piles: These piles are comparatively cheap as no casing will be left in the ground. But great skill is required in this case to achieve the desired results. The uncased concrete piles are likely to be damaged from the subsoil pressure and ground movements which might result from the pile driving and from obstructions in the ground. It is essential to have close installation inspection in this type of piles as they cannot be inspected after they are installed and as they cannot be readily redriven, if heave or swelling occurs. However, these piles offer the following *advantages*:

(i) It is not necessary to have special handling equipment.

(ii) The concrete is not liable to damage from driving.

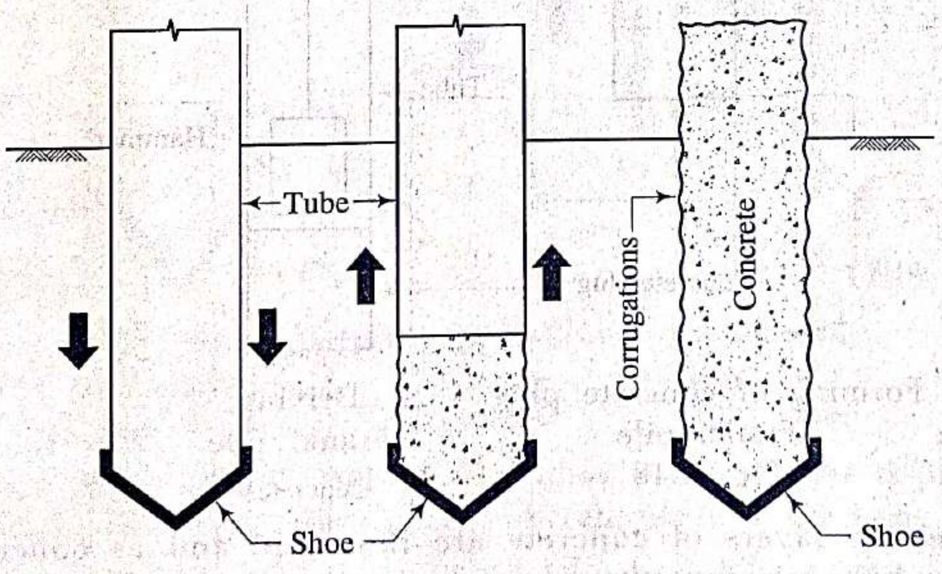
(iii) The cutting of excess lengths or building up short lengths is not required.

(iv) They do not require the storage space.

The examples of these piles are as follows:

(i) Simplex piles	(iv) Pedestal piles
(ii) Franki piles	(v) Pressure piles
(iii) Vibro piles	(vi) Under-reamed piles.

(i) ***Simplex piles*** (fig. 7-13 to fig. 7-17): In this type of piles, a steel tube fitted with cast-iron shoe is driven into the ground upto required depth as shown in fig. 7-13. The reinforcement, if necessary, is put up. The concrete is poured into the tube and the tube is slowly withdrawn, leaving the shoe into the ground as shown in fig. 7-14. The concrete is not tamped and the pile is completed as shown in fig. 7-15.

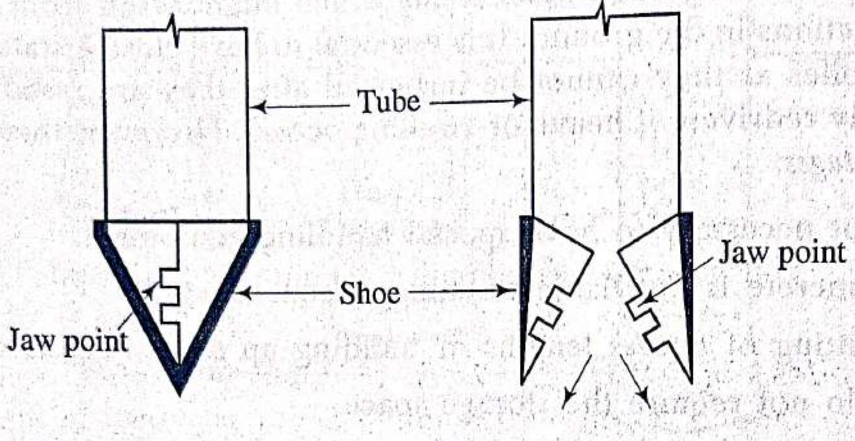


Tube driven Simplex pile
FIG. 7-13

Tube withdrawn Simplex pile
FIG. 7-14

Completed Simplex pile
FIG. 7-15

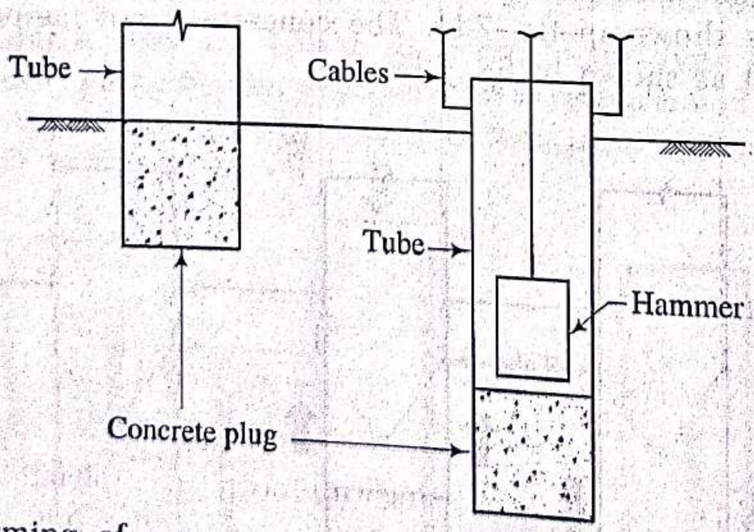
Such a pile is known as the *Simplex standard pile.* If tamping of concrete is done at regular intervals as the tube is withdrawn, it is known as the *Simplex tamped pile.* In case of Simplex alligator jaw pile, the cast-iron shoe is provided by alligator jaw point. When concrete is poured, the jaw opens and allows concrete to flow. The tube is slowly withdrawn. In this type of pile, the shoe does not remain in the ground. Fig. 7-16 and fig. 7-17 show respectively the jaw point in close and open positions.



Jaw point closed
FIG. 7-16

Jaw point opened
FIG. 7-17

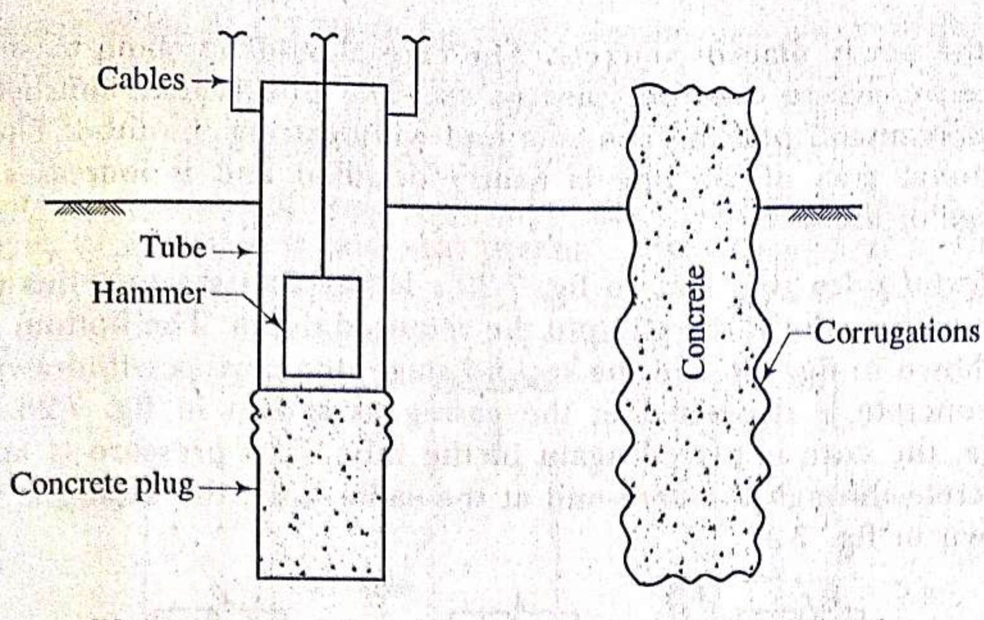
(ii) ***Franki piles*** (fig. 7-18 to fig. 7-21): In this type of piles, a plug of dry concrete is formed as shown in fig. 7-18. The plug is rammed by a hammer and in doing so, the plug drags the tube into the ground. When the required depth is reached, the tube is kept in position by cables as shown in fig. 7-19. Some quantity of concrete is then laid and rammed with such a pressure that the concrete plug is separated out from the tube as shown in fig. 7-20.



Forming of concrete plug
Franki pile
FIG. 7-18

Driving
Franki pile
FIG. 7-19

Successive layers of concrete are then laid and as concrete is being rammed, the tube is partly withdrawn. The completed pile is shown in fig. 7-21. The reinforcement, if necessary, is put up before withdrawal of tube commences. This pile has corrugated surface and hence, it possesses considerable frictional resistance.

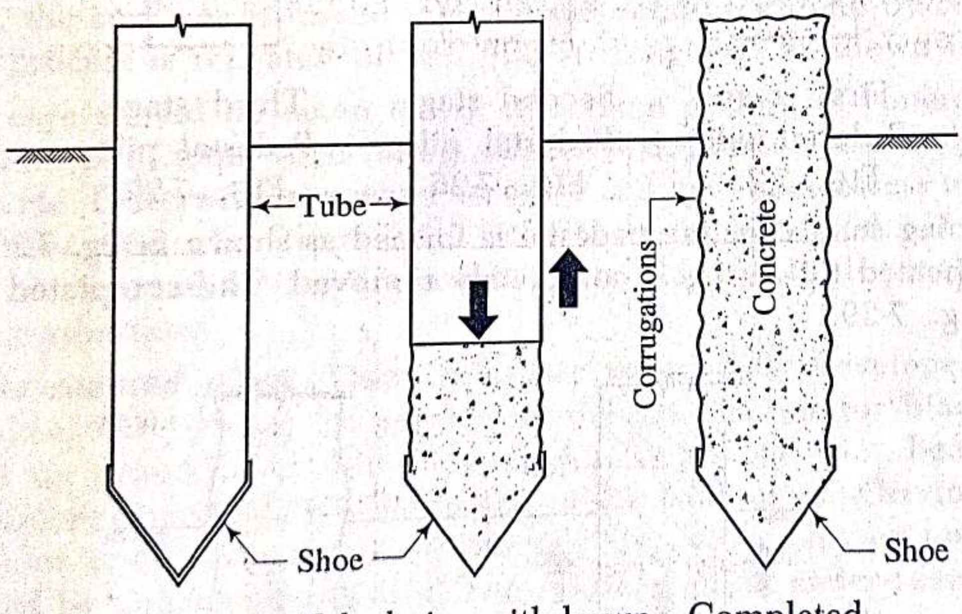


Plug separated Franki pile
Fig. 7-20

Completed Franki pile
Fig. 7-21

(iii) ***Vibro piles*** (fig. 7-22 to fig. 7-24): In this type of piles, a steel tube with a cast-iron shoe is driven upto required depth as shown in fig. 7-22. The tube is connected to the hammer by extracting links.

The tube is then filled with concrete and it is extracted by a succession of upward extracting and downward tamping blows as shown in fig. 7-23. This results in corrugations which provide a strong key for the pile with the surrounding ground. The reinforcement, if necessary, is put up before withdrawal of tube starts. The completed pile is shown in fig. 7-24.



Driving Vibro pile
FIG. 7-22

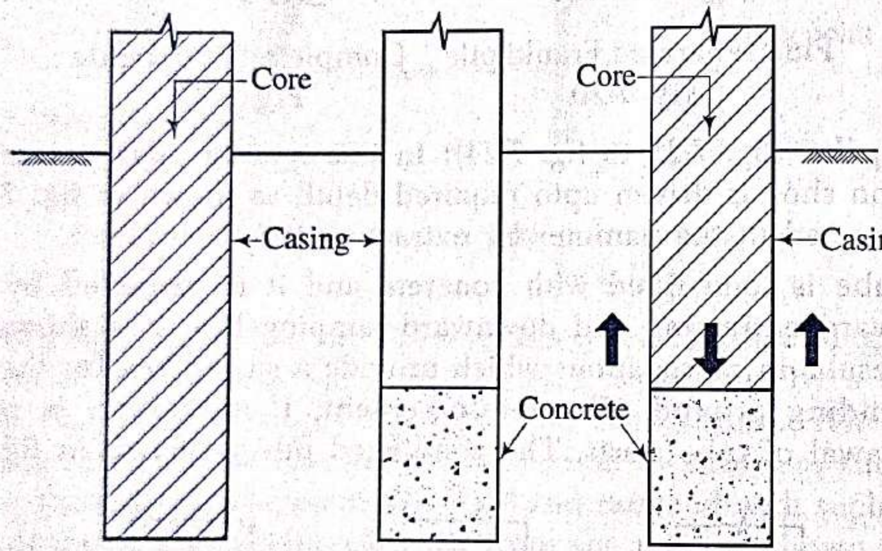
Tube being withdrawn Vibro pile
FIG. 7-23

Completed Vibro pile
FIG. 7-24

In case of the Vibro enlarged base piles, a bigger shoe is provided which results in the increase of area of concrete block at the base.

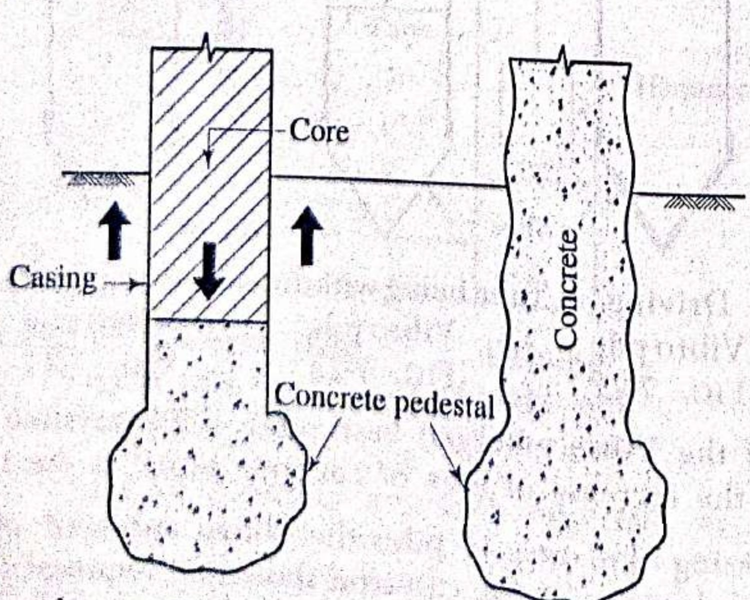
For increasing the area of pile, the Vibro enlarged piles are employed. The tube is driven with the cast-iron shoe upto required depth. The concrete is deposited in the tube upto ground level and no reinforcement is put up in the concrete. The tube is withdrawn and then, it is redriven with a new shoe on the newly placed concrete. The care should be taken to see that newly placed concrete does not start to set. The pile is then finished by placing reinforcement, pouring concrete and withdrawing the tube. Thus, the cross-sectional area of the pile is nearly doubled and it increases the bearing power of the pile.

(iv) ***Pedestal piles*** (fig. 7-25 to fig. 7-29): In the first stage of this pile, a casing tube with a core is driven upto the required depth. The bottom is made even as shown in fig. 7-25. In the second stage, the core is withdrawn and a layer of concrete is deposited in the casing as shown in fig. 7-26. In the third stage, the core is placed again in the tube. The pressure is applied on the concrete through the core and at the same time, the casing is withdrawn as shown in fig. 7-27.



First stage Pedestal pile FIG. 7-25 | Second stage Pedestal pile FIG. 7-26 | Third stage Pedestal pile FIG. 7-27

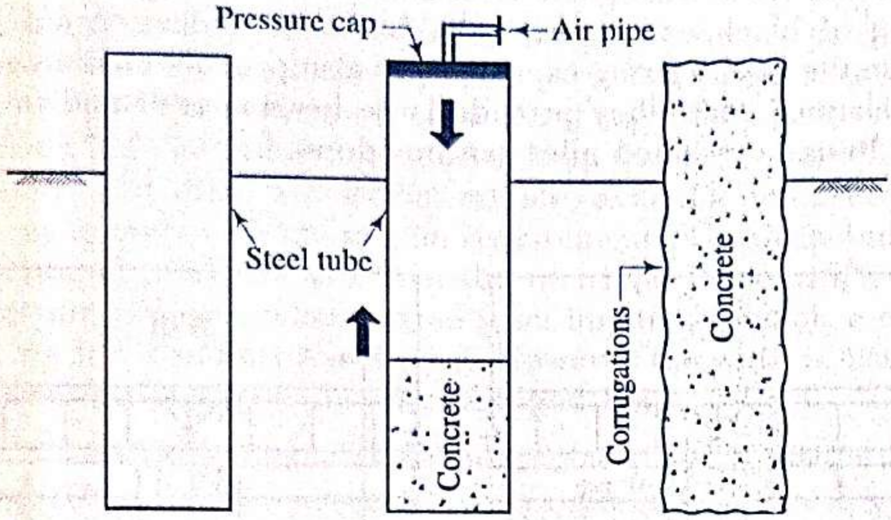
In doing so, a concrete pedestal is formed as shown in fig. 7-28. The process is repeated till casing is completely removed. The completed pile is shown in fig. 7-29.



Fourth stage Pedestal pile FIG. 7-28 | Completed Pedestal pile FIG. 7-29

(v) ***Pressure piles*** (fig. 7-30 to fig. 7-32): In the first stage of this pile, a hole is bored into the ground by means of an auger and as the boring proceeds, the hole is lined by a steel tube. When the tube reaches the required depth, the boring tool is withdrawn. The first stage is shown in fig. 7-30.

The reinforcement, if any, is then put up in the tube. In the second stage, a layer of concrete is laid and pressure cap is provided at the top of the tube as shown in fig. 7-31.



First stage Pressure pile FIG. 7-30

Second stage Pressure pile FIG. 7-31

Completed Pressure pile FIG. 7-32

The compressed air is then admitted through the air pipe and winch is applied to raise the tube. Thus, the tube is lifted slightly and at the same time, the concrete is forced into the surrounding ground by compressed air. The process is repeated till the pile is completed as shown in fig. 7-32.

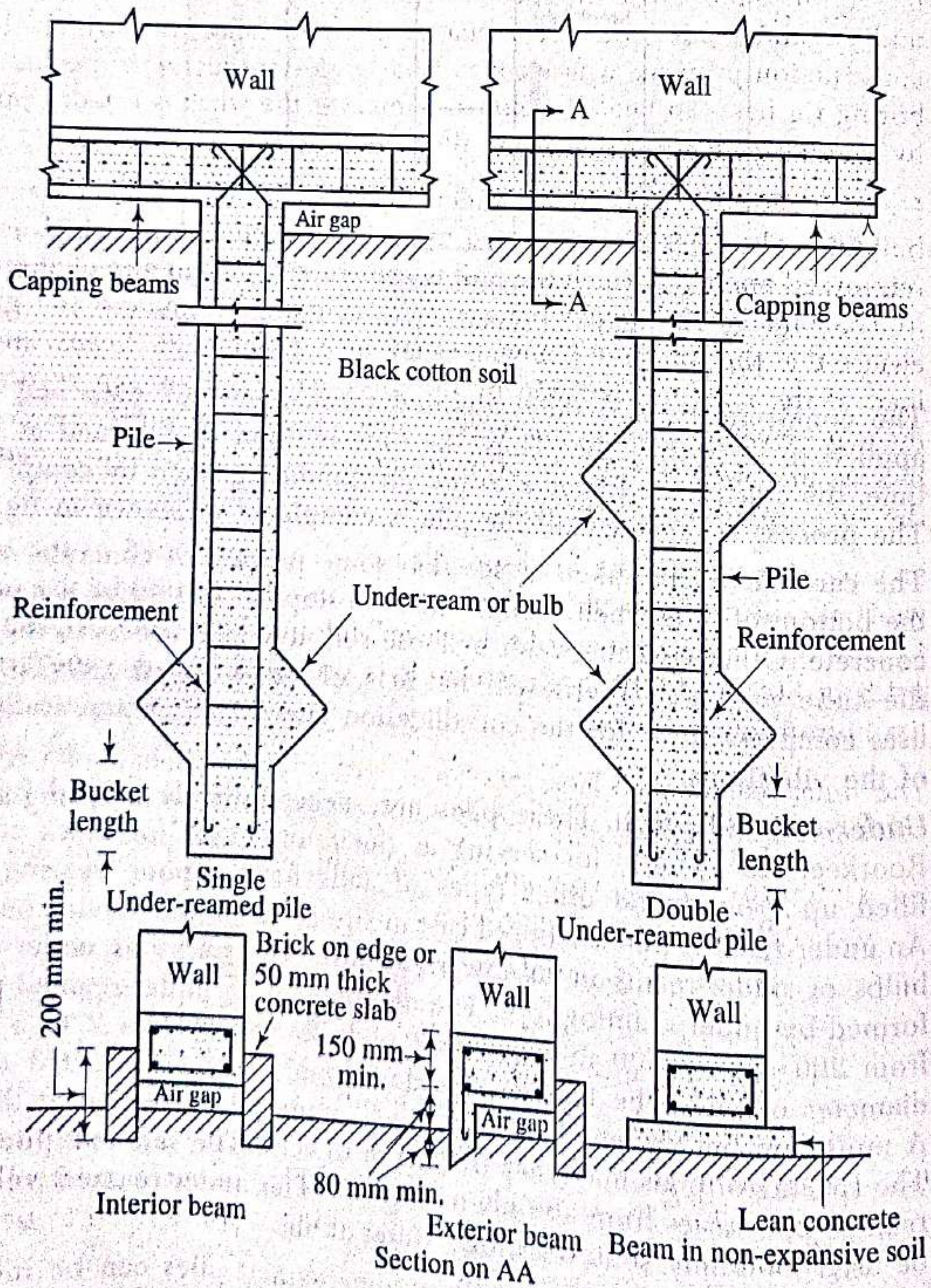
The care should be taken to see that some portion of concrete remains at the bottom of tube when lifting of tube is stopped to receive a new layer of concrete. Otherwise, the water or loose soil may gain access to the inside of the tube and also there will be loss of compressed air. This system uses compressed air for the consolidation and hence, it practically gets rid of the vibrations.

(vi) ***Under-reamed piles:*** These piles are successfully developed by C.B.R.I. Roorkee, U.P. (India) for serving as the foundations for black cotton soil, filled up ground and other types of soils having poor bearing capacity. An under-reamed pile is a bored cast-in-situ concrete pile having one or more bulbs or under-reams in its lower portion. The bulbs or under-reams are formed by under-reaming tool. The diameter of an under-reamed pile varies from 200 mm to 500 mm and that of bulb varies from 2 to 3 times the diameter of pile. The length of under-reamed piles is about 3 m to 8 m. A minimum bucket length of 300 mm is generally provided at the bottom. The spacing of piles may vary from 2 m to 4 m. The safe load for an under-reamed pile varies from 200 kN to 400 kN. The under-reamed piles can also be used for sandy soils with high water table.

The load carrying capacity of the under-reamed piles can be increased by adopting piles of large diameter or by extending the length of piles or by making more bulbs at the base.

A single under-reamed pile has only one bulb at the bottom. When the number of bulbs at the base is two or more, it is known as a *multi-under-reamed pile*. The vertical spacing between *two* bulbs varies from 1.25 to 1.50 times the diameter of bulb.

The appropriate under-reamed pile is selected by the considerations of pile length, stem diameter, bulb diameter and number of bulbs. But the most important factor affecting choice of an under-reamed pile is the site conditions. In case of black cotton soils, the bulbs of under-reamed piles, not only increase the load bearing capacity, but also provide anchorage against uplift. For reclaimed soils, they provide large bearing area and for heavier loads, the multi-under-reamed piles can be adopted.



Under-reamed piles
FIG. 7-33

The under–reamed piles are now being increasingly used under the following circumstances:

(a) taking the foundation through weaker strata into firm ground when the depth of such strata is rather shallow;

(b) providing anchorage against the uplift forces; and

(c) providing foundation through filled up soil deposits or reclaimed soils.

In India, the construction of under-reamed piles is mostly carried out manually. The equipment has been developed at the C.B.R.I., Roorkee. It is simple and light in weight. The basic tools are a spiral auger for boring, an under-reamer for making bulb and a boring guide to keep the hole vertical or at the desired inclination. The other accessories are also available to ensure work of better quality or to meet with the special requirements. For deep and large diameter under-reamed piles, the use is made of tripod hoist with winch. For large construction projects, where speed is an important factor, a mechanised pile boring rig has also been developed. However the work is usually carried out by manual process with the use of tripod basis.

Fig. 7-33 shows the details of under-reamed pile foundations provided for a building. The piles are connected by a rigid capping beam which is suitably reinforced and over which the wall is constructed. An air gap of about 80 mm to 120 mm height is kept between the capping beams and the ground to ensure that the soil from below does not heave against the beams and the full load of the structure is taken by the piles. Thus the air gap accommodates the soil movements without adversely affecting the superstructure. For interior beams, the brick on edge or 50 mm thick concrete slab is provided on both the sides to cover the air gap.

For exterior beams, the brick on edge or slab is provided to the inner face while the beam has a sharp edge penetrating the ground to the outer face. In case of non-expansive soils, however, the mass concrete of prop. 1:3:6 or 1:4:8 of 80 mm to 100 mm thickness is provided between the ground and the bottom of the beam.

The under-reamed piles have successfully proved to be a solution for constructing crack-free buildings. In addition to safety, they grant the following *advantages*:

(i) They prove to be economical to the tune of about 15 to 20 per cent over the conventional strip footings.

(ii) The quantity of materials required for these piles is less.

(iii) They do not require heavy excavation and hence the process can also be carried out in rainy season.

(iv) There is no back filling when these piles are adopted.

(v) It has been generally observed that an under-reamed pile becomes economical when it is taken to a hard strata at a relatively shallow depth and thus permitting the whole of the working load to be carried in end bearing.

(vi) There is freedom from vibrations and noise caused during the construction of standard piles.

Types of under-reamed piles: The under-reamed piles adopted currently can broadly be divided in the following *two* categories:

(i) Bored and cast–in–situ concrete piles

(ii) Bored compaction piles.

In case of former category, a bore of appropriate diameter is made generally using a spiral earth auger and the under-reaming is done at the appropriate depth by a collapsible tool known as the *under-reamer*. The bore along with the under-reamed cavity is then filled with concrete after placement of reinforcement cage.

In case of bored compaction piles, the concrete immediately after placement is compacted by driving a suitable core. The reinforcement cage itself is sometimes driven through the concrete to effect the necessary compaction.

The number of bulbs in bored compaction piles is generally limited to 2 and the normal minimum spacing is kept 1.5 times the under-ream diameter. The bored compaction piles are claimed to have higher load carrying capacity to the extent of about 50% as compared to the normal under-reamed piles of the same size.

The bored compaction piles suffer from the following *drawbacks*:

(a) There is danger of disturbing the concrete in lower depths after they have reached the initial set.

(b) There is possibility of side collapse of weak unlined soil and getting mixed with the concrete and thereby reducing the strength and integrity of concrete.

(c) This method may not work in subsoil water table without a liner being used.

(3) Advantages of cast-in-situ concrete piles: Following are the *advantages* of the cast-in-situ concrete piles:

(i) The light weight shells are used in the cast-in-situ concrete piles and these shells are easy to handle and to drive in the ground.

(ii) No extra reinforcement is necessary to resist the stresses developing during the handling or driving operations only. This fact makes them economical.

(iii) There is no wastage of material as the pile of required length is only constructed. Thus, it also eliminates the problems of lengthening or shortening of the pile.

(iv) The piles are sound in construction as they are not driven into the ground by a hammer. The danger of breaking a pile is also thus eliminated.

(v) If the need arises, the additional piles may be constructed quickly.

(vi) The extra cost of transport of pile is eliminated.

(4) Disadvantages of cast-in-situ concrete piles: Following are the *disadvantages* of the cast-in-situ concrete piles:

(i) It is difficult to maintain the reinforcement in correct position during construction of the pile.

(ii) For an unreinforced pile, a slight movement of earth may break the pile.

(iii) These piles cannot be constructed under water.

(iv) It is not possible to have a proper control over the composition and design of these piles.

(v) The dry ground may absorb the moisture from the wet concrete. The piles are then weakened.

(vi) The voids will remain in the piles if the concrete is not well-rammed and the reinforcement is displaced from its original position.

(vii) The concrete is poured from the top and as it falls on the reinforcement cage before it reaches the bottom, the complete segregation of the concrete takes place and hence the concrete produced will be of poor quality.

7-7-2. PRE-CAST CONCRETE PILES

(1) General: These piles are manufactured in the factory and then driven into the ground. A bore is dug into the ground by inserting steel shell. If shell is left in place, it is called *a shell pile.* If shell is removed it is called *a shell less pile.* The pre-cast concrete piles may be tapered or parallel-sided. They may be square, octagonal or round in shape. The square and octagonal piles are cast in horizontal forms and the round piles are cast in vertical forms. The size of the pile may be 300 mm to 500 mm and length may be as much as 18 metres or more. However, from the considerations of the handling and lifting, the diameter generally does not exceed 600 mm.

The reinforcement is usually provided in all the pre-cast concrete piles to take up the stress during driving and handling operations. The main or vertical reinforcement consists of steel bars 20 mm to 40 mm in diameter and lateral reinforcement consists of the steel bars 5 mm to 10 mm in diameter. The spacing of lateral ties or binders is about 100 mm for a length of one metre at top and bottom of pile and for the intermediate length, it is about 300 mm. A concrete cover of at least 50 mm is to be provided for the reinforcement.

Fig. 7-34 and fig. 7-35 show respectively a square pre-cast concrete pile and an octagonal pre-cast concrete pile. At the toe of the pile, a steel shoe is generally provided and it is secured with the pile in such a way that it becomes a part of the pile. The steel shoe protects the toe and helps the pile in penetrating into the ground during driving.

(2) Casting of the pre-cast concrete piles: *The casting of the pre-cast concrete piles* is carried out as follows:

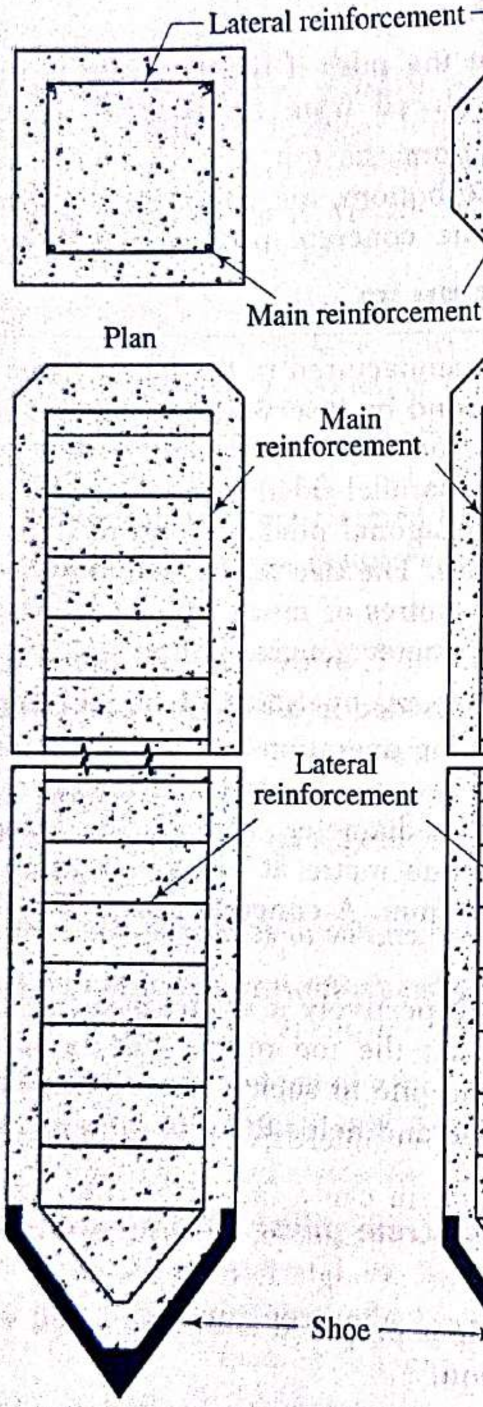
(i) The formwork for the pile is prepared and it is coated with the soap solution or oil to prevent adhesion.

(ii) The cage of reinforcement is prepared as per design and this cage is then placed in the formwork. The arrangement should be made to maintain a concrete cover of about 50 mm all round the reinforcement cage.

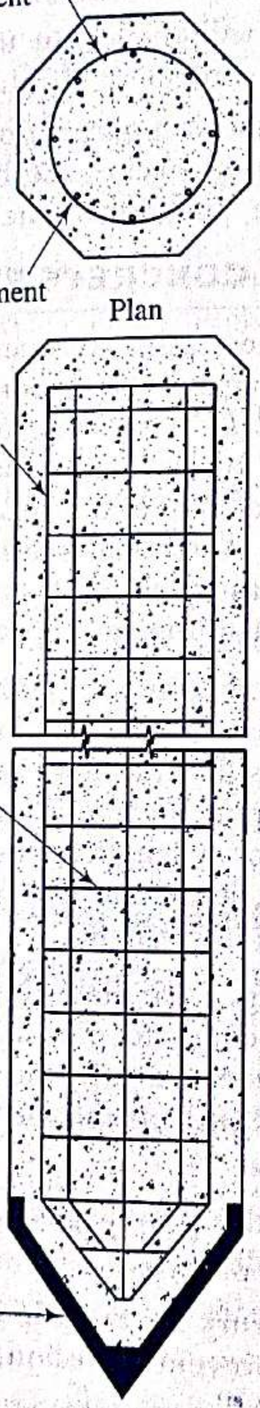
(iii) The concrete is prepared in the required proportion. The usual proportions are 1:1:2 and 1:2:4. The ends are constructed in a rich mix. The size of the coarse aggregate varies from 10 mm to 25 mm.

(iv) The concrete is laid in the formwork and well consolidated. The concrete should be laid continuously till the pile is completely filled up. The vibrators are generally used for consolidation of concrete. It should be seen that the concrete is tapped in such a way that all the edges and corners of the concrete remain unbroken, sharp and straight when the formwork is removed.

(v) The forms are removed after three days and the piles are kept in the same position for about 7 days or so. The piles are then shifted to a curing tank and after a period of about three or four weeks, they become ready for use.



Square pre-cast pile
FIG. 7-34



Octagonal pre-cast pile
FIG. 7-35

(3) Advantages and disadvantages of pre-cast concrete piles:

(i) *Advantages:* Following are the *advantages* of the pre-cast concrete piles:

(a) The position of reinforcement in pile is not disturbed from its original position.

(b) These piles can be driven under water. For ground water containing sulphates more than 5000 parts per million parts of water, the concrete in the cast-in-situ pile may not set and under such circumstances, the pre-cast concrete piles will be the feasible alternative.

(c) It is possible to have a proper control over the composition and design of these piles as they are manufactured in a workshop. It is possible to see that the pile concrete and pile shaft are of good quality and integrity.

(d) Any defect of casting such as hollows, etc. can be found out and repaired before driving the pile.

(e) Any number of piles can be manufactured at a convenient place and this may prove to be economical.

(f) These piles, when driven, are ready to take up the load. There is no wastage of time.

(g) These piles possess high resistance to biological and chemical actions of the ground.

(h) The driving of these piles is smooth in the sense that it does not develop any adverse effect on the adjacent already driven pile.

(ii) *Disadvantages:* Following are the *disadvantages* of the pre-cast concrete piles:

(a) These piles are heavy in weight and it is therefore difficult to transport, to handle and to drive them.

(b) The extra reinforcement is provided to resist the stresses developed during handling or driving operation. This fact makes the piles costly.

(c) The length of these piles is decided from trial bores. If additional length is required, it is to be made. A weak joint will be formed in this case. If the pile is too long, it is to be cut off which results in the wastage of material.

(d) If sufficient care is not taken, the piles may break during transport or driving.

(e) If piles are not available at a short notice, the delay of work would occur especially for emergency projects.

(f) The size and length of pile will depend on the available transport facilities.

(g) These piles require heavy pile driving equipments.

(h) The excessive driving can cause fine cracks in concrete. If the piles are driven from very soft to compact end bearing strata, the stresses produced at the pile tip could be as high as 80% of the stresses produced at the pile head. If excessive driving can cause chipping of the concrete at the pile head, the developments of many cracks at the pile tip cannot be ruled out.

(4) Underwater repairs of pre-cast concrete piles: If pre-cast concrete piles which are used for the marine structures are damaged, they can be repaired with success by any one of the following methods:

(i) By lowering a permanent jacket either of steel or pre-cast concrete around the pile and filling it with tremie grout.

(ii) By using an underwater-setting cement.

(iii) By using an underwater-setting epoxy.

(iv) By using a reinforced concrete jacket cast in a temporary form.

(v) By using shotcrete which is applied over wire mesh.

For methods (ii) and (iii), the cement or epoxy is mixed in a small batch, lowered under water in a sealed container and placed by a diver, usually by hand. It is important to note that the piles to be repaired are thoroughly cleaned of mud, etc., by using wire brush or underwater sandblasting. The piles which are repaired should be protected from erosion, wash, etc., until they have set. The period of completing the repairs will depend upon the type of material used and its time of set and it may vary from just few minutes to more elaborate methods such as clamps and forms.

The main *disadvantage* of the pre-cast concrete pile is its heavy weight. Hence the prestressed precast concrete piles have been developed. With the introduction of the prestressed technique, it has become possible to reduce the size of the pile and thereby making such piles of light weight. The prestressed concrete piles may be solid hollow with 200 mm to 300 mm diameter voids in the stem.

Following are the *advantages* of the prestressed pre-cast concrete piles:

(i) There is reduction in pick-up points. For instance, the square prestressed concrete piles of length 50 times the thickness can be handled with a single pick-up point and upto 60 times the thickness with *two* pick-up points.

(ii) They are light in weight and hence can be handled or transported easily and conveniently. It also results in less handling costs.

(iii) They are more durable in sea water because of the absence of cracks.

(iv) They can withstand extremely hard driving.

(v) They possess larger moment of inertia than the conventional pre-cast concrete piles of the same dimensions because the concrete is all in compression.

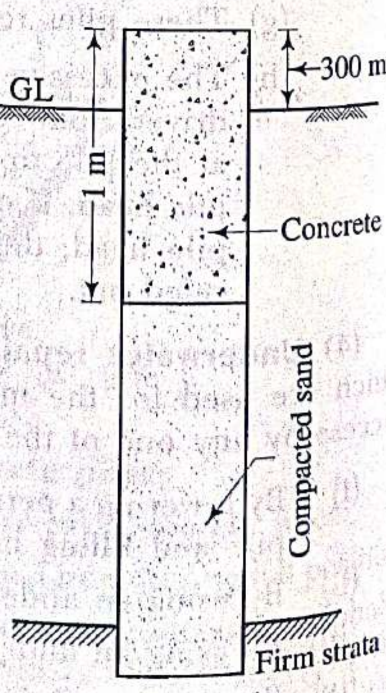
(vi) They possess more strength as compared to the normal pre-cast concrete piles.

7-8. SAND PILES

These piles are formed by making holes in the ground and then filling the holes by sand. If sand is kept confined, it possesses great crushing strength and becomes incompressible.

A bore of required diameter, usually 300 mm, is formed either by driving a wooden pile or by an auger or by forcing a pipe with closed end. The hole is then filled with sand and it is well-rammed until the sand in the hole does not escape. The sand to be used should be moist at the time of placing. The top of sand pile is filled with concrete to prevent the sand to come upwards due to lateral pressure.

Fig. 7-36 shows a typical sand pile. The sand piles are spaced at 2 metres to 3 metres, usually under the columns of the structure. A load test should be carried out to determine the bearing capacity of a sand pile. A properly constructed sand pile resting on a firm strata can take up a load of 1000 kN/m^2 or more. The dimensions of sand pile are determined from the load coming upon it and its length is kept about 12 times its diameter.



Sand pile
FIG. 7-36

Advantages of sand piles: Following are the *advantages* of the sand piles:

(i) These piles are economical for small buildings and for embankments of the roads.

(ii) The sand piles are easy to construct.

(iii) It is possible to use gravel in place of sand. Such piles are known as the *gravel piles.*

(iv) The sand piles can be used irrespective to any position of the water table.

Disadvantages of sand piles: Following are the *disadvantages* of the sand piles:

(i) The sand piles are not suitable for loose or wet soils or where there is danger of scour.

(ii) The sand piles cannot be adopted in regions subjected to frequent earthquakes.

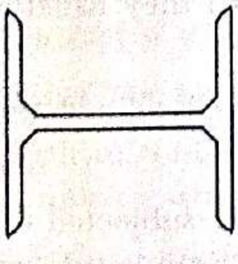
7-9. STEEL PILES

The steel piles are used as the load bearing piles in *three* different forms:

(1) H-beam piles
(2) Box piles
(3) Tube piles.

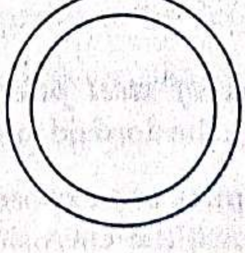
(1) H-beam piles: Fig. 7-37 shows the plan of a H-beam steel pile. These piles are usually of wide flange section and they are the most common variety of steel piles in general use. They are found very much suitable especially for trestle type structures in which the piles extend above ground level and work also as columns for the structure.

Since H-beam piles have small cross-sectional area, they can be easily driven in soils in which it will be difficult to drive ordinary displacement piles. They are also useful for deep penetration through soft soil and also under circumstances when ordinary displacement piles are likely to cause damage to adjoining structures. The driving of H-piles is very simple and the energy from a pile hammer is effectively transmitted to the lower portion of the pile.



H-beam pile
FIG. 7-37

Larssen box pile
FIG. 7-38



Tube pile
FIG. 7-39

(2) Box piles: The box piles are of various forms such as Algoma box pile, Dorman Lons box pile, Frodingham octagonal box pile, Larssen box pile, Rendhex box pile, etc. Fig. 7-38 shows the plan of a Larssen box pile. The various types of patented box piles are available. They may be rectangular or octagonal and formed by suitable combinations of steel sections. A box is formed and the pile is driven either with closed bottom or with open bottom.

In the latter case, it will be advisable to clean the box for the full depth. The box is then filled with concrete. A large volume of soil is displaced by a box pile and as a consequence, the end-resistance and the frictional resistance are built up rapidly. Hence, these piles are used when it is not possible to drive H-beam piles upto the hard strata. The shaft friction and end-friction depend respectively on the perimeter and cross-sectional area of the pile.

(3) Tube piles: Fig. 7-39 shows the plan of the tube pile. In this type of steel piles, the tubes or pipes of steel are driven into the ground. The pipes may be driven either with open end or with closed end. In the former case, the material inside the pipe is to be removed by suitable method. The concrete is then filled inside the tube piles. Because of their circular cross-section, these piles are easy to handle and easy to drive.

Advantages of steel piles: Following are the *advantages* of the steel piles:

(i) These piles can withstand easily the stresses due to driving.

(ii) These piles can be easily lengthened by the welding without causing any delay in the driving operations.

(iii) The extra lengths of these piles can be cut off easily and there is no wastage of material as the material thus removed has some value and it can be reused.

(iv) The bearing capacity of these piles is comparatively high. The allowable compressive stress on steel section is taken as about 60 N per mm^2 to 80 N per mm^2.

(v) These piles can resist the lateral forces and bulking in a better way.

(vi) These piles can be handled roughly without any serious damage.

(vii) In case of box piles and tube piles, it is possible to fill the hollow space with cement mortar instead of concrete. This will result in economy especially at places where the coarse aggregate is not available easily.

(viii) These piles can take up impact stresses. Hence, they are widely used in marine structures which are subjected to impact forces from the ships.

(ix) These piles are not damaged by sea insects and they usually last for a long period.

Disadvantage of steel piles: The corrosion is the only drawback of steel piles. But it should not be looked upon as a serious drawback.

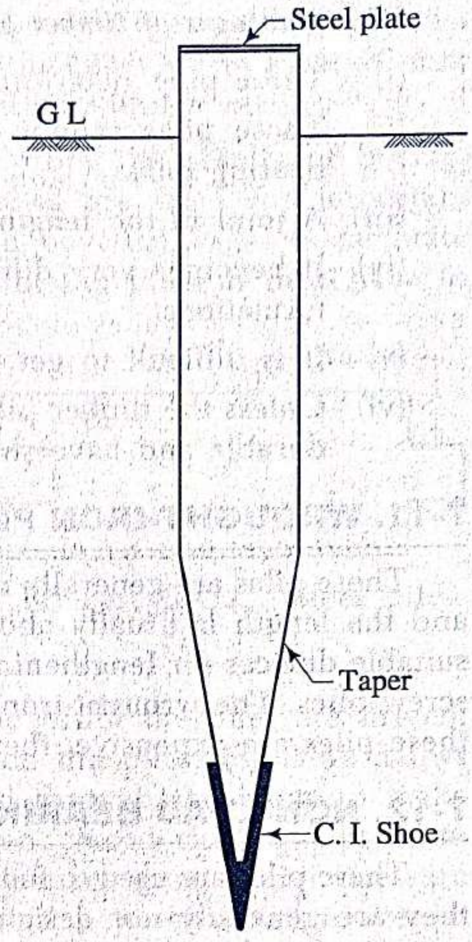
When steel piles are exposed to air or when they are subjected to alternative dry and wet conditions, the corrosion takes place. The corrosion is not a serious problem for lengths of piles below water level. To prevent corrosion, the steel piles may be coated with anti-corrosive paints or they may be encased with cement concrete.

7-10. TIMBER PILES

These piles are prepared from the trunks of trees and the use of timber as pile has been recorded since the beginning of the science of civil engineering. The wood to be used for timber piles should be free from knots, flaws, shakes and other defects. The common Indian timbers which are used as piles are: Babul, Chir, Deodar, Jarul, Poon, Sal, Semul, Teak and White Siris.

The timber piles may be circular or square. The diameter of circular timber piles varies from 300 mm to 500 mm and the side of a square timber pile is about 300 mm to 500 mm. The length of a timber pile should not exceed 20 times its top width. Otherwise it may fail by buckling.

Fig. 7-40 shows a timber pile. At the bottom, a cast-iron shoe is provided and at the top, a steel plate is fixed. If a group of timber piles is driven, the top of each member of the group is brought at the same level and then, a concrete cap is provided to have a common platform. The timber piles should be properly treated so as to make them durable.



Timber pile
FIG. 7-40

A timber pile with a single log of timber is known as the *simple timber pile*. When it is desired to have the length of timber pile exceeding that of one log of timber, the *built-up* or *spliced timber piles* are prepared. In case of built-up timber piles, suitable connecting joints with overlapping lengths are made at the junction of two piles and bolts or large nails are passed through them. When it is desired to increase the cross-sectional area of the pile, the *packaged timber piles* are made. In case of packaged timber piles, three or four logs are fitted in vertical plane and bolted together. Such packaged timber piles can also be extended in length by splicing. But it should be seen that the joints are staggered and do not fall in the same horizontal plane. The cementing effect in case of packaged timber piles can be obtained by the application of reliable water-resistant glues.

Advantages of timber piles: Following are the *advantages* of the timber piles:

(i) Where timber is available easily, these piles prove to be economical in cost.

(ii) These piles can be handled easily with little risk or danger of breakage.

(iii) The length of timber piles can be adjusted either by cutting or lengthening without much extra cost.

(iv) The skilled supervision is not required in the construction of timber piles.

(v) These piles can be removed easily, if necessary.

(vi) At present, the timber piles are generally used for the temporary work. This is due to the fact that the timber piles are light, flexible and can resist shocks to some extent.

(vii) These piles do not require heavy equipment for driving them into the ground.

(viii) The more popular sizes and lengths can be obtained on short notice.

(ix) These piles are elastic in nature and hence, they can be recommended for sites where the piles are likely to be subjected to unusual lateral forces.

Disadvantages of timber piles: Following are the *disadvantages* of the timber piles:

(i) These piles deteriorate due to the action of soil or salty water or insects.

(ii) These piles cannot take heavy loads and are unsuitable for use as end-bearing piles.

(iii) A joint in the lengthened timber pile is a source of weakness.

(iv) It becomes very difficult or even impossible to drive these piles into hard formations.

(v) It is difficult to get the timber pile of required size and length.

(vi) Unless the timber piles are suitably treated with a preservative, they are not durable and have short length of life.

7-11. WROUGHT-IRON PILES

These piles are generally made solid. The diameter varies from 80 mm to 200 mm and the length is usually about 4 metres to 6 metres. The wrought-iron piles have suitable devices for lengthening and sinking. These piles are mostly used for shafts of screw piles. The wrought-iron piles are most suitable for use under sea water. But as these piles are expensive, they are now replaced by the steel piles.

7-12. NON-LOAD BEARING PILES

These piles are used to function as the separating members below ground level and they are generally not designed to take any vertical load. However such piles are indeed to be designed to carry the horizontal earth pressure. Such piles are known as the *sheet piles* and they are used for the following purposes:

(i) To isolate foundations from the adjacent soils. This prevents escape of soil and passage of shocks and vibrations to adjoining structures.

(ii) To prevent underground movement of water. This becomes essential in the formation of a cofferdam which is a watertight enclosure required in the construction of foundations under water.

(iii) To prevent the transfer of machine vibrations to the adjacent structures.

(iv) To construct retaining walls in docks, wharfs and other marine works.

(v) To protect the river banks.

(vi) To retain the sides of foundation trenches.

(vii) To work as cutoff walls under dams.

(viii) To construct the caissons for water-intake supplies.

(ix) To confine the soil and thereby increase the bearing capacity of the soil.

(x) To protect the foundations of a structure from erosion by a neighbouring stream, river, sea, etc.

The materials which are employed in the construction of sheet piles are as follows:

(1) Concrete sheet piles

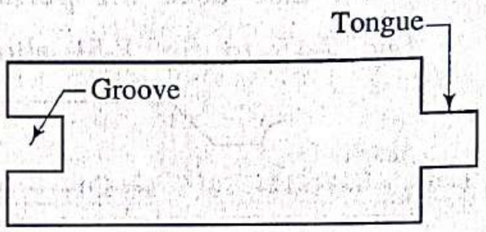
(2) Steel sheet piles

(3) Timber sheet piles.

(1) Concrete sheet piles: These piles are always pre-cast and the reinforcement is provided as per design. The piles are square or rectangular in cross-section and they are driven side by side so as to form a continuous wall. The width of pre-cast R.C.C. piles varies from 500 mm to 600 mm and the thickness varies from 20 mm to 60 mm. The reinforcement is in the form of vertical bars and hoops.

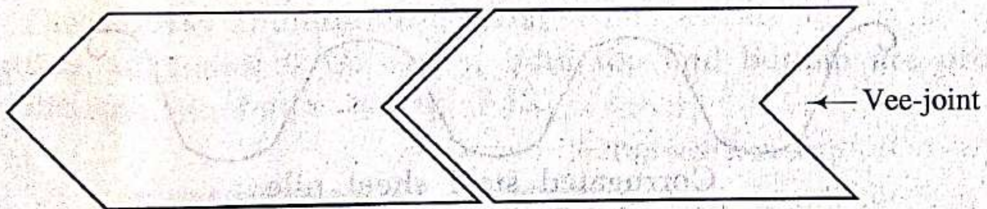
The length of piles is to be decided previously from the results of boring. At present, the pre-stressed pre-cast R.C.C. sheet piles are used for important works. The feet of the piles are shaped obliquely and bevelled so as to facilitate driving. The metal shoes are provided at the bottom of the piles, if they have to pass through hard strata.

The pre-cast R.C.C. sheet piles are used for the permanent works such as bulkhead, cutoff walls, retaining walls, wharf walls, etc. In order to make them watertight, they are placed in such a way that grooves are formed and these grooves are then filled by cement mortar in proportion 1:3 under pressure. Fig. 7-41 to fig. 7-44 show various shapes of the pre-cast R.C.C. sheet piles.

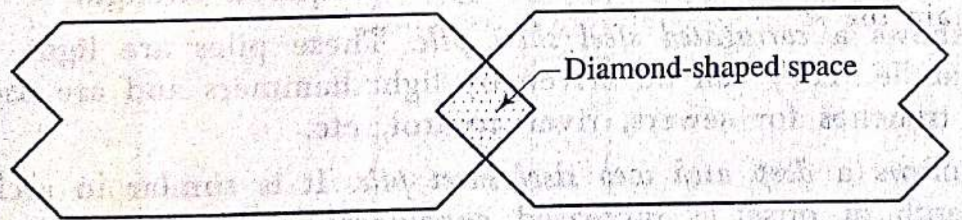


Pre-cast R.C.C. sheet pile
FIG. 7-41

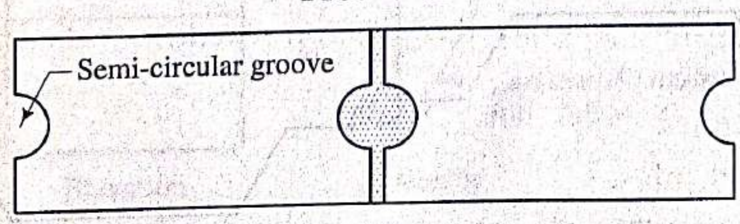
Fig. 7-41 shows the tongue and groove type of pile. After the piles are driven, the cement grout may be forced in the spaces between the piles. Fig. 7-42 shows the Vee-jointed pile. The cement grout may be forced through the joints to make them watertight. Fig. 7-43 shows the piles which when placed side by side form a diamond-shaped space. This space is filled by the cement grout under pressure after the piles are driven. Fig. 7-44 shows the piles with semi-circular grooves at their ends. The circular holes are therefore formed when such piles are placed side by side. These holes provide space for inserting water jets, if necessary. The cement grout under pressure is forced through the holes after the piles are driven.



Pre-cast R.C.C. sheet pile
FIG. 7-42



Pre-cast R.C.C. sheet pile
FIG. 7-43

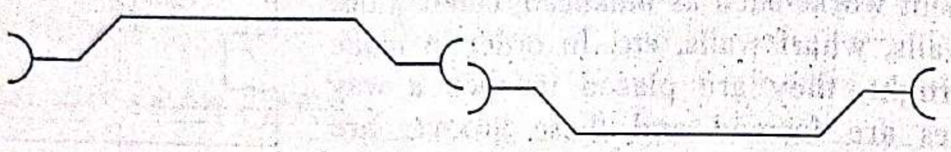


Pre-cast R.C.C. sheet pile
FIG. 7-44

(2) Steel sheet piles: The steel sheet piles are now commonly used. The various patented forms have been developed for the steel sheet piles. They are generally made from steel sheets 200 mm to 300 mm wide and 4 metres to 5 metres long with suitable interlocking arrangements so as to form fairly watertight joints.

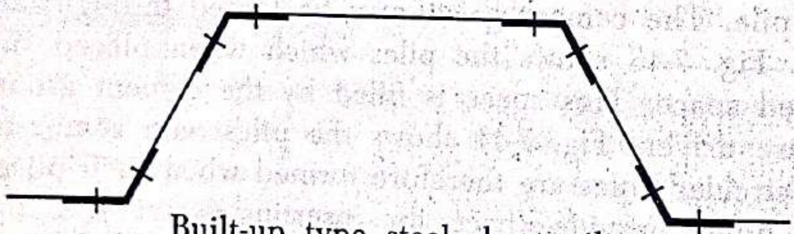
The steel sheet piles are strong and durable and can be easily driven and withdrawn without appreciable distortion. The steel sheet piles provide a fairly watertight enclosure and hence, they are widely used in the construction of cofferdams. They are also used for permanent works in the marine structures.

Fig. 7-45 to fig. 7-51 show some of the common forms of steel sheet piles.

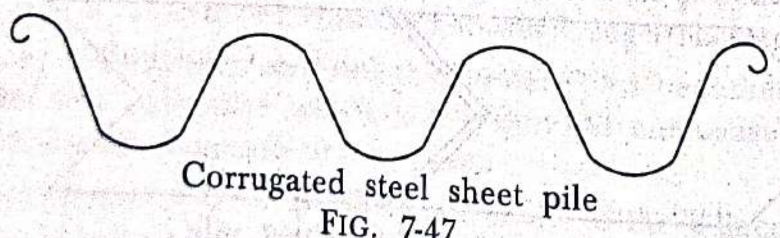


Arch web steel sheet pile
FIG. 7-45

Fig. 7-45 shows an *arch web steel sheet pile.* In this type of pile, the offsets are provided in the centre so as to increase the moment of inertia of the cross-section of the pile. These piles therefore offer greater resistance to bending.



Built-up type steel sheet pile
FIG. 7-46

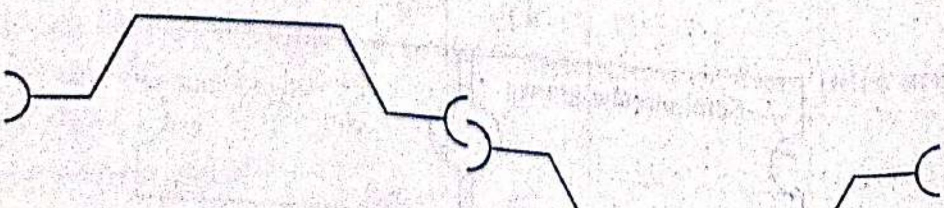


Corrugated steel sheet pile
FIG. 7-47

Fig. 7-46 shows a *built-up type* or *trough shaped steel sheet pile.* The steel plates and sections are combined to form a trough of required strength.

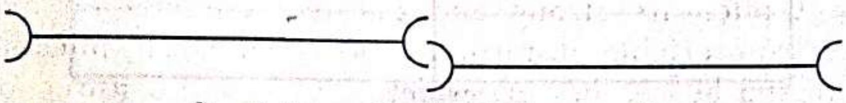
Fig. 7-47 shows a *corrugated steel sheet pile.* These piles are light, economical and easy to handle. They can be driven by light hammers and are used for light work such as trenches for sewers, river control, etc.

Fig. 7-48 shows a *deep arch web steel sheet pile.* It is similar to arch web type except that depth of offset is increased considerably. This type of pile is used where greater stiffness is required.



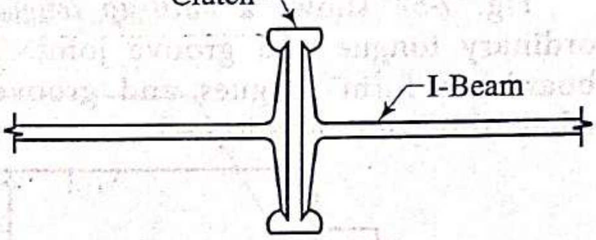
Deep arch web steel sheet pile
FIG. 7-48

Fig. 7-49 shows a *straight web steel sheet pile.* It is the simplest form of steel sheet pile. The width varies from 400 mm to 500 mm and the thickness varies from 10 mm to 12 mm. These piles are comparatively flexible and hence, they require bracing when horizontal thrust is more.



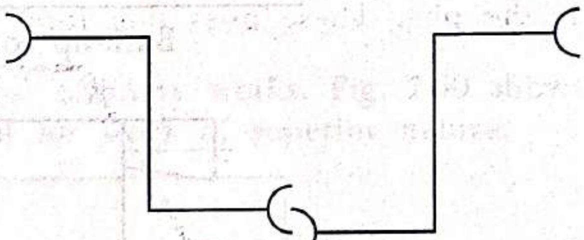
Straight web steel sheet pile
FIG. 7-49

Fig. 7-50 shows a *universal joist steel sheet pile.* These piles consist of I-beams connected by standard clutches or lockbars. The clutch is also of I-beam. But its flanges are curved so as to accommodate the flanges of I-beams as shown in the figure.



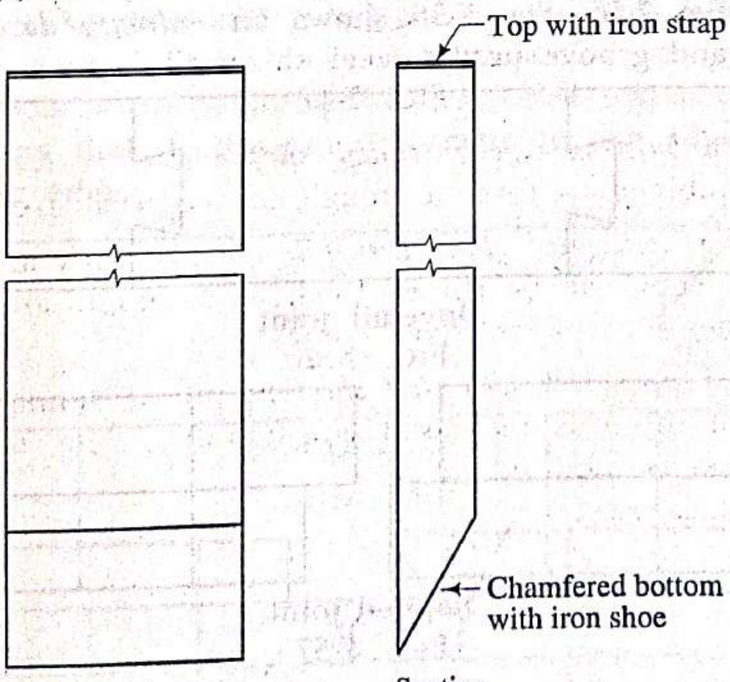
Universal joist steel sheet pile
FIG. 1-50

Fig. 7-51 shows a *Z-type steel sheet pile.* This section is difficult to roll and to drive. But it possesses the highest beam strength for its weight and therefore, such section is used for heavy work.



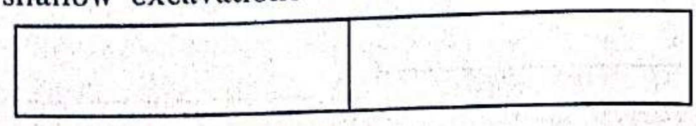
Z-type steel sheet pile
FIG. 1-51

(3) Timber sheet piles: The wooden sheet piles are commonly used for the temporary works such as cofferdams. They usually consist of wooden boards 80 mm to 150 mm thick, 200 mm to 300 mm wide and 2 metres to 4 metres long. The bottom is chamfered so as to form a cutting edge and if necessary, both top and bottom are provided with suitable iron fittings, as shown in fig. 7-52.



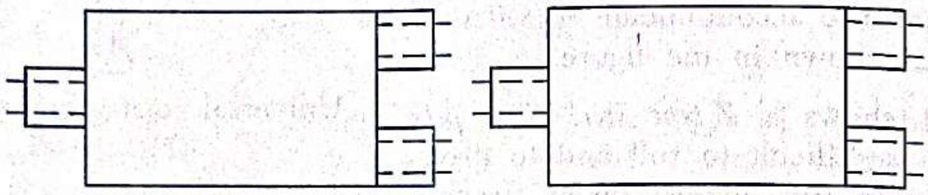
Timber sheet pile
FIG. 7-52

The various forms of joints adopted in case of timber sheet piles are illustrated in fig. 7-53 to fig. 7-62. Fig. 7-53 shows a *butt joint* which is formed by placing timber boards in a single line. It is also known as the straight, plain or square joint and it is used for shallow excavations where there is no trouble of ground water.

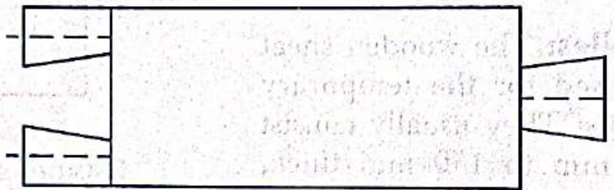


Butt joint
FIG. 7-53

Fig. 7-54 shows a *built-up tongue* and *groove joint.* This is a modified form of ordinary tongue and groove joint. The pieces of timber are attached to wooden boards to form tongues and grooves. There is practically no wastage of timber when this joint is adopted.



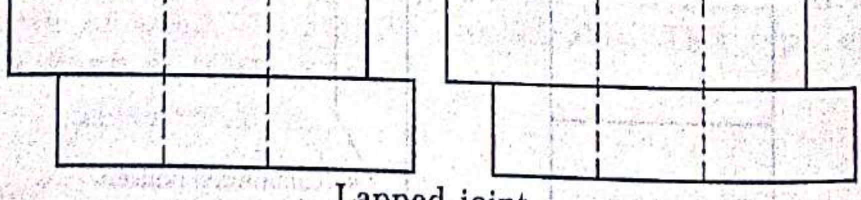
Built-up tongue and groove joint
FIG. 7-54



Built-up dovetail joint
FIG. 7-55

Fig. 7-55 shows a *built-up dovetail joint* and it is superior to ordinary dovetail joint as shown in fig. 7-56. Fig. 7-56 shows an *ordinary dovetail joint* and it is better than tongue and groove joint.

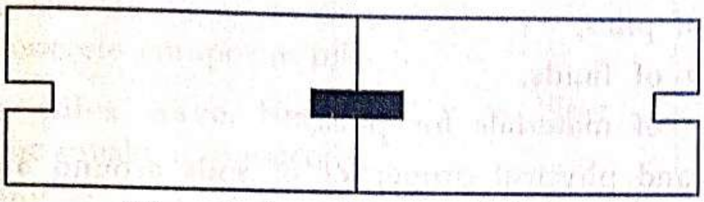
Dovetail joint
FIG. 7-56



Lapped joint
FIG. 7-57

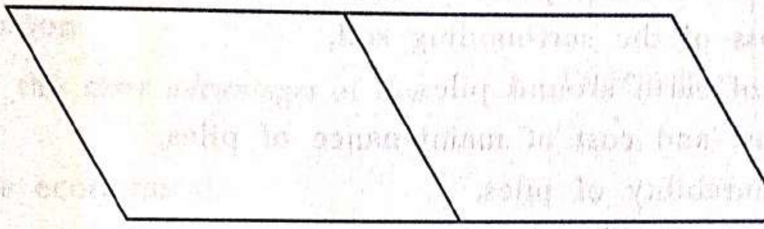
Fig. 7-57 shows a *lapped joint* and it is adopted when the wooden pile consists of *two* boards. These boards are spiked or bolted in such a way that an offset is formed with respect to one another.

Fig. 7-58 shows a *ploughed* and *tongued joint.* The *two* boards are cut at ends in such a way that when they are placed together, a groove is formed. After the boards are driven, a wooden piece is inserted in the groove. This joint requires more labour. But it forms an excellent joint.



Ploughed and tongued joint

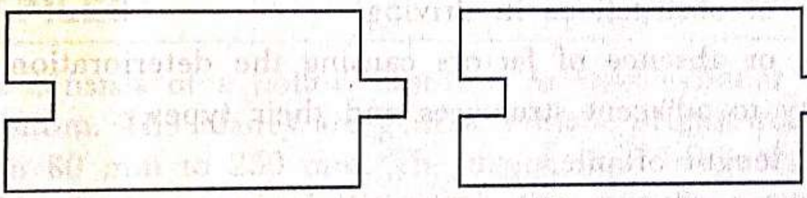
FIG. 7-58



Splayed joint

FIG. 7-59

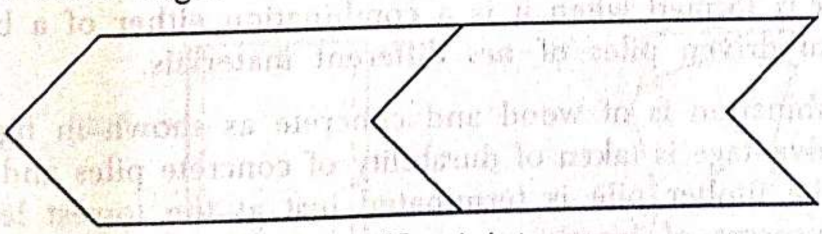
Fig. 7-59 shows a *splayed joint.* It is used for ordinary works. Fig. 7-60 shows an *ordinary tongued* and *grooved joint.* It is used for work of superior nature.



Tongued and grooved joint

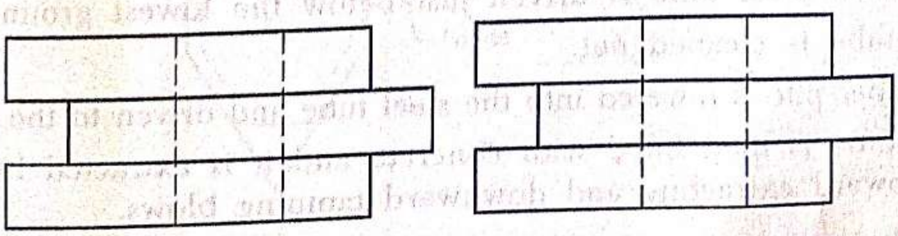
FIG. 7-60

Fig. 7-61 shows a *Vee joint* and it is used for ordinary works. Fig. 7-62 shows a *Wakefield joint.* It is used where more strength and watertightness are required. It consists of *three* boards which are spiked or bolted together. The middle board is placed in such way that the tongue is formed on one edge and the groove is formed on the other edge.



Vee joint

FIG. 7-61



Wakefield joint

FIG. 7-62

7-13. CHOICE OF TYPE OF PILE

Following are the important factors which are to be considered while making the selection of pile for a particular set of conditions:

(i) abrasion of piles,
(ii) availability of funds,
(iii) availability of materials for piles,
(iv) character and physical properties of soils around and below the piles,
(v) character, type, size and weight of the structure to be supported,
(vi) facilities for driving piles,
(vii) future loss of the surrounding soil,
(viii) heaving of earth around piles,
(ix) initial cost and cost of maintenance of piles,
(x) life or durability of piles,
(xi) maintenance of piles,
(xii) nature of loading on the pile,
(xiii) number of piles required,
(xiv) presence of ground water,
(xv) presence of obstructions in driving,
(xvi) presence or absence of factors causing the deterioration of piles,
(xvii) proximity to adjacent structures and their types,
(xviii) required length of pile,
(xix) resistance to uplift forces,
(xx) subsidence of surface near piles,
(xxi) water action on piles, and
(xxii) weight of pile.

7-14. COMPOSITE PILES

A *composite pile* is formed when it is a combination either of a bored pile and a driven pile or of driven piles of *two* different materials.

The usual combination is of wood and concrete as shown in fig. 7-63. In this combination, the advantage is taken of durability of concrete piles and the cheapness of timber piles. The timber pile is terminated just at the lowest level of ground water table. The process of forming a composite pile is as follows:

(i) A hollow steel tube is driven just below the lowest ground water level.
(ii) The tube is cleaned out.
(iii) A timber pile is lowered into the steel tube and driven to the required level.
(iv) The tube is then filled with concrete and it is extracted by a succession of upward extracting and downward tamping blows.

In the other commonly used form of composite pile, the steel or H-pile is provided at the lower end of a cast-in-situ concrete pile. This combination is recommended in cases where the designed length of the pile works out to be greater than that available for the cast-in-situ type concrete pile. The method of formation of this pile is more or less the same as that adopted for timber-concrete composite pile.

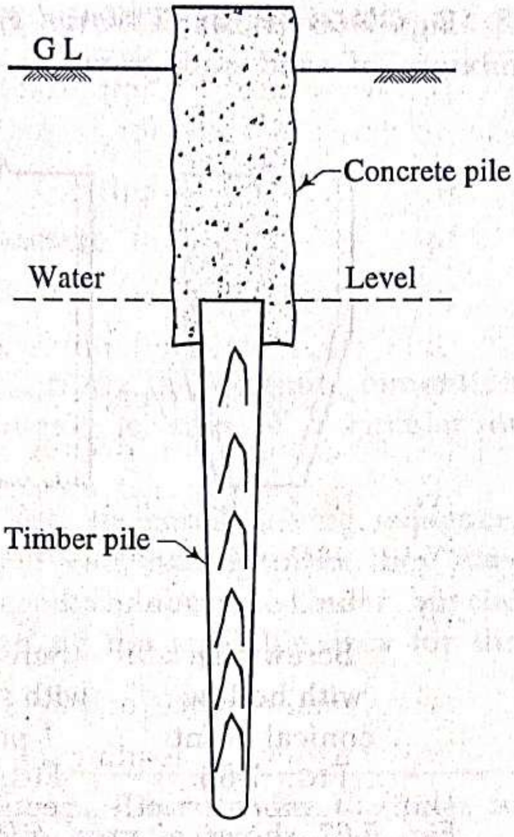
The composite piles have limited applications and they are usually recommended under special conditions only. The load bearing capacity of a composite pile is governed by the weaker of the materials used in its formation.

Following are the *three advantages* of the composite piles:

(i) They are economical.

(ii) They are easy to construct.

(iii) They are suitable for ground conditions in which other types of piles will be unsuitable.



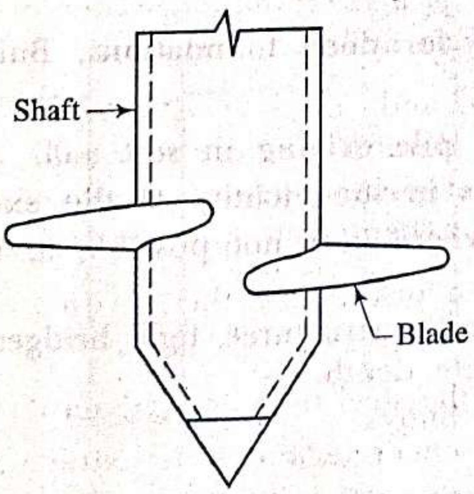
Composite pile
FIG. 7-63

7-15. SCREW PILES

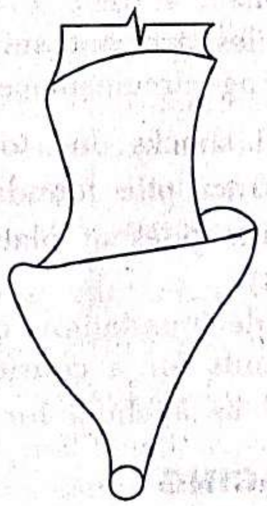
A *screw pile* consists of a hollow cast-iron or steel cylinder with one or more blades at the bottom. The blades are generally made of cast-iron. The diameter of shaft varies from 80 mm to 250 mm. The diameter of blade varies from 500 mm to 1500 mm. The bottom end of the screw pile may be provided with suitable design of point as shown in fig. 7-64 to fig. 7-67.

Fig. 7-64 shows a *screw pile with blunt point* and it is useful when ground to be penetrated consists of sand or clay.

Fig. 7-65 shows a *screw pile with gimlet point* which is useful when ground to be penetrated consists of gravel.

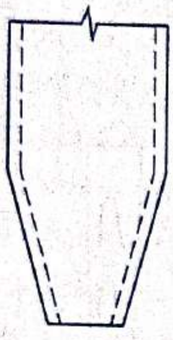


Screw pile with blunt point
FIG. 7-64

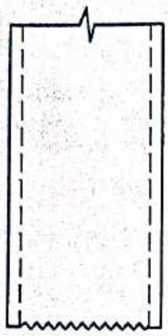


Screw pile with gimlet point
FIG. 7-65

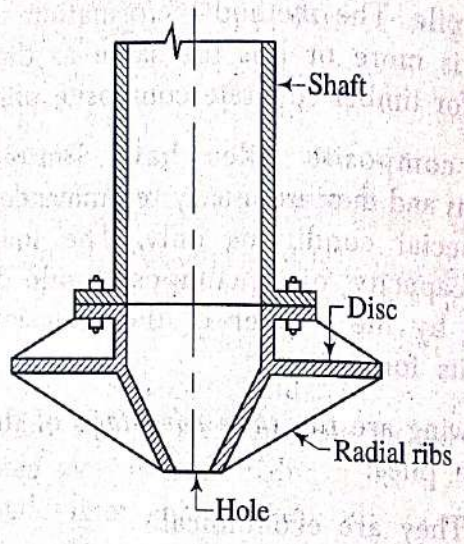
Fig. 7-66 shows a *screw pile with hollow conical point.* It is useful when a mixture of sand and gravel is to be penetrated.



Screw pile with hollow conical point
FIG. 7-66



Screw pile with serrated point
FIG. 7-67



Disc pile
FIG. 7-68

Fig. 7-67 shows a *screw pile with serrated point* and it is useful to drive piles through soft rock.

If a cast-iron disc is attached at the bottom of shaft in place of blade, it is known as a *disc pile.* The diameter of disc varies from 600 mm to 1200 mm. The disc is supported by a number of radial ribs as shown in fig. 7-68. A hole is provided at the bottom of pile to permit the water jet pipe to pass through during the sinking of the pipe by jetting of harder strata and tough soils. The disc piles are economical for light work on ground consisting of sand or sandy silt.

For driving screw piles, a capstan head is fitted to the upper end of the shaft. The capstan is a hollow sleeve pulled over by the pile head, its lugs gripping the pile. The torque is then applied to this capstan head either by manual labour or by rope or by a powered winch. It is advisable to use water jet to facilitate the driving of screw piles. As the screw descends, the new lengths of shaft are added by providing suitable joints.

The screw piles are not suitable for deep foundations. But they are useful under the following circumstances:

(i) To avoid shocks due to the pile driving in soft soil.
(ii) To construct pile foundations in the vicinity of the existing structures.
(iii) To provide piles at places where it is not possible to install heavy pile machinery.
(iv) To provide foundations of marine structures, light bridges, etc., where soft soil extends for a considerable depth.
(v) To serve as anchors for the buoys.

7-16. PILE SPACING

The centre to centre distance of successive piles is known as *pile spacing* and it has to be carefully decided by considering the following factors:

7-22. PULLING OF PILES

The piles are generally pulled out from their positions for the following reasons:

(i) To replace the piles damaged during the driving operations.

(ii) To reuse the existing piles when the structure above the pile is demolished or when the design of arrangement of piles is changed.

(iii) To prepare the data of the strata through which piles are to be driven by carrying out pulling tests.

(iv) To remove the piles which are driven temporarily, as in case of a cofferdam.

The methods employed for pulling of the piles will depend on the type of pile, equipment available, etc. It is found that the concrete piles cannot be pulled successfully without damage and therefore they cannot be reused. The steel piles, on the other hand, can be pulled out without damage and they can be reused at other places. The water jet or compressed air or a combination of both may be adopted to reduce the skin friction during pulling operations.

Following are the methods which are adopted most commonly:

(1) Use of double-acting steam hammers: The double-acting steam hammers are worked in a reverse way. It is necessary to apply a steady pull of 4 N/mm^2 in this method of pulling the piles.

(2) Use of pile extractors: In this method, the specially designed pile extractors are employed. The extractor can be put up into use immediately and it does not require any special fitting.

(3) Use of tongs: The piles can be pulled by specially designed tongs. It is suspended from a frame and with a pull of 50 N/mm^2 or so, the piles can be pulled out.

(4) Use of vibrators: It is possible to employ vibrators to pull out the piles. Due to vibrations, the soil surrounding the piles becomes loose and it facilitates the removal of the pile.

(5) Use of electricity: This method of pulling the piles is suitable for steel piles. A direct current voltage is applied to the steel pile for a short duration. The water present in the ground will be attracted towards the surface of steel pile and thus, it will lubricate the steel pile. The skin friction will thus be reduced, resulting in easy removal of the pile.

7-23. LOADS ON PILES

Following are the loads which are to be taken into account while designing a pile:

(i) direct vertical load to be transmitted by the pile;
(ii) impact stresses developed during the process of pile driving;
(iii) bending stresses developed due to curvature of the pile;
(iv) bending stresses developed due to eccentricity of loads coming on the pile;
(v) stresses developed during handling operations;
(vi) lateral forces due to wind, waves, currents of water, etc.;
(vii) forces due to impact of ships, in case of marine structures;
(viii) impact forces due to the ice sheets or bergs;
(ix) forces due to the uplift pressure, if any;
(x) earthquake forces; etc.

7-24. CAUSES OF FAILURES OF PILES

Following are the most common causes of failures of piles:

(i) absence of statistical data regarding the nature of strata through which the piles are to be driven;
(ii) actual load coming on the pile being more than the designed load;
(iii) attack by insects, etc. on wooden piles, causing thereby decay of the timber piles;
(iv) bad workmanship in case of the cast-in-situ cement concrete piles;
(v) breakage due to overdriving especially in case of the timber piles;
(vi) buckling of piles due to removal of side support, inadequate lateral support, etc.;
(vii) damage due to abrasion resulting from the absence of suitable protective covering;
(viii) improper choice of the method of driving the pile;
(ix) improper choice of the type of pile;
(x) improper classification of soils;
(xi) insufficient reinforcement or misplacement of reinforcement in case of the R.C.C. piles;
(xii) lateral forces not being taken into the design of the pile;
(xiii) misinterpretation of the results obtained during the test-loads;
(xiv) presence of soft strata just below the tips of piles;
(xv) wrongful use of pile formula for determining its load bearing capacity; etc.

Some of the predominant causes of failures of the R.C.C. piles can be enlisted as follows:

(i) early removal of concrete forms to expose green concrete to the attack of salts;
(ii) improperly designed concrete mix;
(iii) insufficient concrete cover to the reinforcement;
(iv) poor workmanship such as inadequate vibration;
(v) use of aggregates that react with the type of cement selected or the outside environment to produce serious cracking;
(vi) use of wrong type of cement for the corrosive environment; etc.

Chapter 10

STONE MASONRY

10-1. DEFINITION

In a very strict sense, the term *masonry* is used to indicate the art of building the structures in stones. But broadly speaking, the term *masonry* is used to indicate the art of building the structures in either stones or bricks. The former type is called the *stone masonry* and the latter type is called the *brick masonry*.

It is to be noted that the masonry work by itself is one of the most important traditional technology. Even though new principles of construction and new materials of construction are adopted in the building construction processes, the masonry has got as such the highest importance in the building industry.

The masonry is used for the construction of foundations, walls, columns and other similar components of a structure. The basic *advantage* of the masonry for the load bearing structures is that it performs a variety of functions like:

(i) affording architectural effect,

(ii) granting fire and weather protection,

(iii) providing acoustic and thermal insulation,

(iv) subdividing space,

(v) supporting loads, etc.

The topic of stone masonry will be discussed in this chapter and that of brick masonry in the subsequent chapter.

10-2. MATERIALS REQUIRED FOR STONE MASONRY

For stone masonry, the following *two* materials are required:

(1) Stones

(2) Mortar.

(1) Stones: Depending upon the availability, the stones are selected. The stones to be used in the work should be hard, durable, tough and free from any defect such as shake, vent, mottle, etc. Table 10-1 shows some varieties of stones which are commonly used in India along with their classification, qualities and uses.

(2) Mortar: The mortar is required to keep the stones in position. It is prepared by mixing lime or cement with sand and after adding water, it is placed in the joints. The type of mortar to be used will depend on the strength required, load coming on the structure, resistance desired for weathering agencies, etc. The usual varieties are: lime mortar, cement mortar, cement-lime mortar and lime-cement mortar.

TABLE 10-1
COMMON BUILDING STONES OF INDIA

No.	Stone	Classification	Qualities	Uses	Localities
1.	Basalt and trap	Igneous	Hard and tough; difficult to work. its sp. gr. is 3 and compressive strength varies from 150 to 185 N/mm^2. Its weight varies from 18 to 29 kN per m^3.	Road metal, for rubble masonry, foundation work, etc.	Maharashtra, Bihar, Gujarat, Bengal and M.P.
2.	Chalk	Sedimentary	Pure white limestone; soft and easy to form powder.	In preparing glazier's putty; as colouring material in manufacture of portland cement.	Same as limestone.
3.	Gneiss	Metamorthic	Splits into thin slabs; easy to work. Its sp. gt. is 2.69 and compressive strength is 206 N/mm^2.	Street paving, rough stone masonry work, etc.	Madras, Mysore, Bihar, A.P., Maharashtra, Bengal, Kerala and Gujarat.
4.	Granite	Igneous	Hard, durable and available in different colours, highly resistant to natural forces, can take nice polish. Its sp. gr. varies from 2.6 to 2.7 and compressive strength varies from 75 to 127 N/mm^2. Its weight is about 26 to 27 kN per m^3.	Steps, sills, facing work, walls, bridge piers, columns, road metal, ballast, etc. It is unsuitable for carving.	Kashmir, Madras, Punjab, Rajasthan, U.P., M.P., Mysore, Maharashtra, Assam, Bengal, Bihar, Orissa, Kerala and Gujarat.
5.	Kankar	Sedimentary	Impure limestone.	Road metal, manufacture of hydraulic lime, etc.	North and Central India.
6.	Laterite	Metamorphic	Porous and spongy structure; easily quarried in blocks; contains high percentage of oxide of iron; available in different colours. Its compressive strength varies from 1.8 to 3.1 N/mm^2.	Building stone, road metal, rough stone masonry work, etc.	Bihar, Orissa, Mysore, M.P., Maharashtra, Kerala, A.P. and Madras.

TABLE 10-1 (Continue)
COMMON BUILDING STONES OF INDIA

No.	Stone	Classification	Qualities	Uses	Localities
7.	Limestone	Sedimentary	Consists of carbonate of lime; easy to work. Its sp. gr. varies from 2.00 to 2.75 and compressive strength is 54 N/mm^2.	Floors, steps, walls, road metal, manufacture of lime in blast furnaces, etc.	Maharashtra, Rajasthan, Punjab, Gujarat, Andaman Islands, Bengal, Bihar, A.P., Himachal Pradesh, M.P., and U.P.
8.	Marble	Metamorphic	Can take good polish and available in different colours. Its sp. gr. is 2.65 and compressive strength is 71 N/mm^2.	Flooring, facing work, columns, steps, ornamental work, etc. It can take nice polish. It can easily be sawn and carved.	Rajasthan, Maharashtra, Gujarat, A.P., Mysore, M.P. and U.P.
9.	Murum	Metamorphic	Decomposed laterite, deep brown or red in colour.	Blindage for metal roads, for fancy paths and garden walls.	Same as laterite.
10.	Quartzite	Metamorphic	Hard, brittle, crystalline and compact; difficult to work and dress.	Retaining walls, road metal, concrete aggregate, pitching, rubble masonry, facing of buildings, etc.	Bengal, A.P., Himachal Pradesh, Madras, U.P., Mysore, Gujarat, Punjab and Rajasthan.
11.	Sandstone	Sedimentary	Consists of quartz and other minerals, easy to work and dress and available in different colours. Its sp. gr. varies from 2.65 to 2.95 and compressive strength is 64 N/mm^2. Its weight is about 20 to 22 kN per m^3.	Steps, facing work, columns, flooring, walls, road metal, ornamental carving, etc.	A.P., M.P., Punjab, Rajasthan, Maharashtra, Gujarat, Andaman Islands, Bengal, Bihar, Himachal Pradesh, Kashmit, Madras and U.P.
12.	Slate	Metamorphic	Black colour and splits along natural bedding planes; non-absorbent. Its sp. gr. is 2.89 and compressive strength varies from 75 to 207 N/mm^2.	Roofing work, sills, damp-proof courses, etc.	U.P., M.P., Bihar, Madras, Rajasthan and Mysore.

In cement-lime mortar, a portion of cement is replaced by hydrated lime. It spreads more easily under the trowel and produces a more plastic material.

In lime-cement mortar, a portion of lime is replaced by cement. It makes the mortar stronger, more plastic and workable. Also the mortar sets earlier.

The choice of mortar and its composition will be governed by several factors like type of masonry, situation of structure, intensity of load, degree of exposure to weather, type of bond, durability desired and some other special requirements like fire resistance, insulation, rate of hardening, etc.

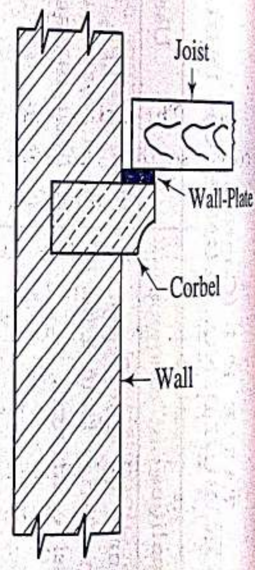
10-3. SOME DEFINITIONS

The meanings, attached to some technical terms used in the masonry, are given below for ready reference. Some of these terms are common in stonework as well as in brickwork. The remaining definitions for brick masonry are given in the chapter on *Brick Masonry*. These technical terms are as follows:

(1) Natural bed: The building stones are obtained from rocks. These rocks have a distinct plane of division along which the stones can easily be split. This plane represents the *natural bed* and in stone masonry, the general rule to be observed is that the direction of natural bed should be perpendicular or nearly so to the direction of the pressure.

(2) Sill: The bottom surface of a door or a window opening is known as a *sill* and the sill stones are so dressed that they prevent the entry of water to the interior of the building.

(3) Corbel: A *corbel* is a projecting stone which is usually provided to serve as support for roof truss, beam, weather shed, etc., as shown in fig. 10-1. The corbels are generally moulded and given ornamental treatment. The corbels should extend at least two-third of their length into the wall.



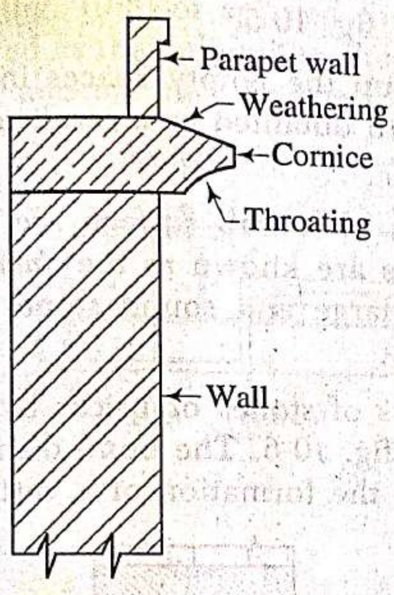
Corbel
FIG. 10-1

(4) Course: A layer of stones or bricks is known as a *course* and its thickness is generally equal to the thickness of a stone or a brick plus the thickness of one mortar joint.

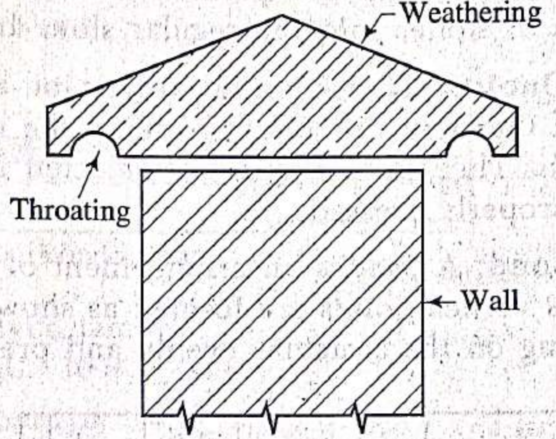
(5) Cornice: A *cornice* is a course of stone provided at the top of wall as shown in fig. 10-2. It is generally moulded and given ornamental treatment. It is weathered and throated to dispose off rain water. In order to prevent the overturning of the cornice, sufficient bearing and extra weight at the top in the form of a parapet wall should be provided.

(6) Coping: A *coping* is a course of stone which is laid at the top wall so as to protect the wall from rain water. This course is generally provided at the top of a compound wall or a parapet wall and it is suitably weathered and throated as shown in fig. 10-3. Sometimes the term coping is used to refer to cutting of the stones by means of feathers, plugs and wedges.

(7) Weathering: The upper surface of stones used for sill, cornice and coping is dressed in a sloping way so that the water may flow off easily. This is termed as the *weathering*. See fig. 10-2 and fig. 10-3. The term weathering is sometimes used to denote the wearing of stone surfaces by the action of weather.



Cornice
FIG. 10-2

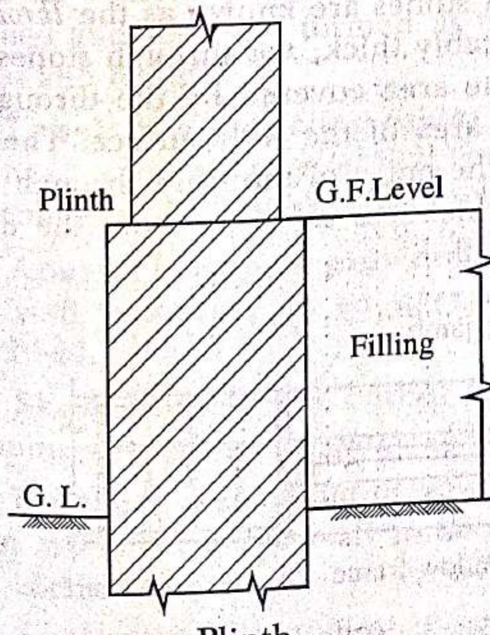


Coping
FIG. 10-3

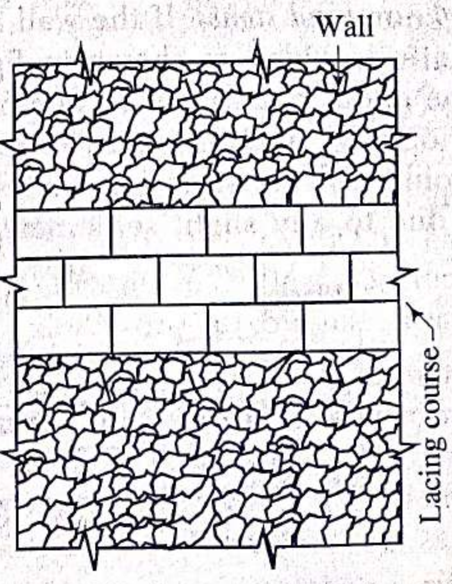
(8) **Throating:** A groove is provided on the underside of sill, cornice and coping so that the rain water can be discharged clear of the wall surface. This is known as the *throating*. See fig. 10-2 and fig. 10-3.

(9) **Plinth:** The projecting course at ground floor level is known as the *plinth* as shown in fig. 10-4. It is also 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. It is sometimes moulded and given ornamental treatment. The offset at plinth level is sometimes omitted for the architectural purpose.

(10) **String course:** The horizontal course provided at suitable levels between the plinth and the cornice is termed as a *string course*. It breaks the monotony of a plane surface and it is sometimes moulded and given architectural treatment. The string course is suitably weathered and throated so as to throw off the rain water clear of the wall surface.



Plinth
FIG. 10-4



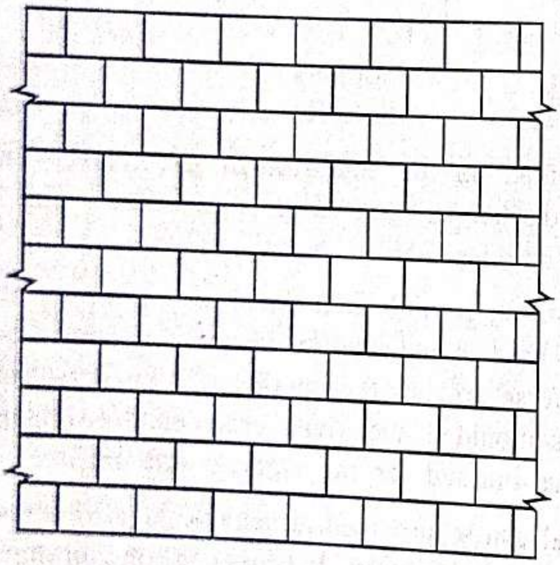
Lacing course
FIG. 10-5

(11) Lacing course: The horizontal course provided to strengthen a wall of irregular small stones is known as a *lacing course.* It may be in the form of either ashlar masonry or coursed rubble masonry or brick masonry. See fig. 10-5.

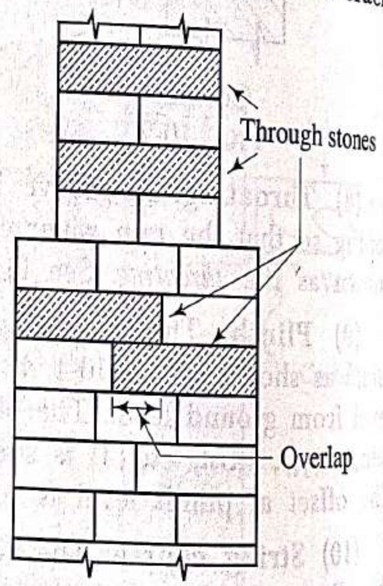
(12) Spalls: The chips of stones used to fill up the empty spaces in the stone masonry are known as the *spalls* or *snecks.* They are obtained as a result of reducing big blocks of stones into the regular stone blocks.

(13) Quoins: The external corners or angles of a wall surface are called the *quoins* and the stones or bricks forming the quoins are known as the *quoin stones* or *quoin bricks.* The quoin stones are selected from large and sound stones and their beds are properly dressed.

(14) Bond: A *bond* is an arrangement of layers of stones or bricks by which no continuous vertical joints are formed as shown in fig. 10-6. The bond distributes the load coming on the structure evenly and prevents the formation of a vertical crack.

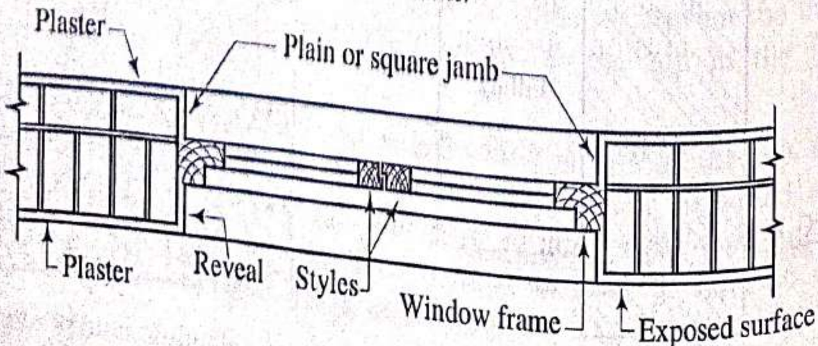


Bond
FIG. 10-6



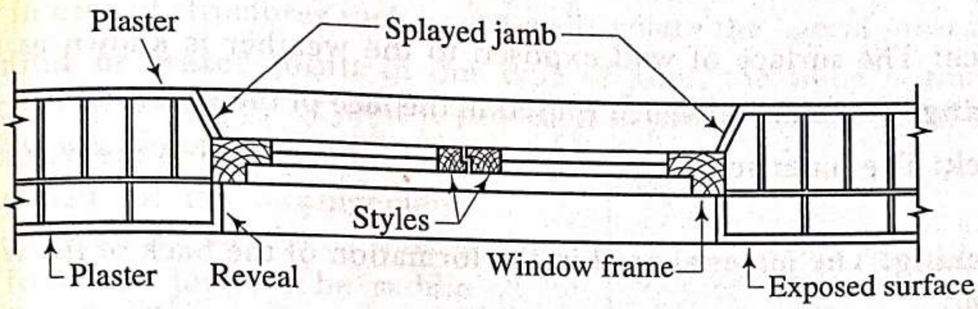
Through stone
FIG. 10-7

(15) Through stone: In stonework, some stones at regular intervals are placed right across the wall as shown in fig. 10-7. Such stones are known as the *through stones* or *throughs* or *bond stones.* If the wall is considerably thick, *two* through stones with an overlap are provided as shown in fig. 10-7. The area covered by the through stones should be about one-fourth to one-half of the area of the wall surface. The through stones should be non-porous so as to prevent the entry of moisture through the wall. They should also be strong and of sufficient thickness so as to avoid the danger of fracture due to any slight settlement of the wall.

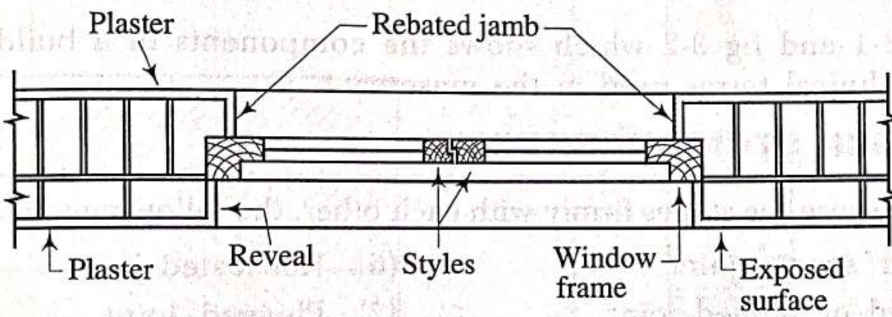


Plain jamb
FIG. 10-8

(16) **Jambs:** The sides of the openings such as doors, windows, etc. are known as the *jambs* and they are constructed similar to quoins. The jambs may be either plain or square (fig. 10-8) or splayed (fig. 10-9) or rebated (fig. 10-10). The splayed jambs are preferred as they allow the shutters to open up at an obtuse angle and thus permit more light and air into the room.



Splayed jamb
FIG. 10-9



Rebated jamb
FIG. 10-10

(17) **Reveals:** The exposed vertical surfaces at right angles to the door or window frames are known as the *reveals* as shown in fig. 10-8, fig. 10-9 and fig. 10-10.

(18) **Heads:** The horizontal stones provided at the top of openings for doors, windows, etc. are known as the *heads* or *lintels*. A bearing of 150 mm to 200 mm should be given on either side of the opening.

(19) **Stoolings:** The horizontal seatings which are provided to receive jambs and mullions are called the *stoolings* and they are formed at the ends of sills, transomes and heads.

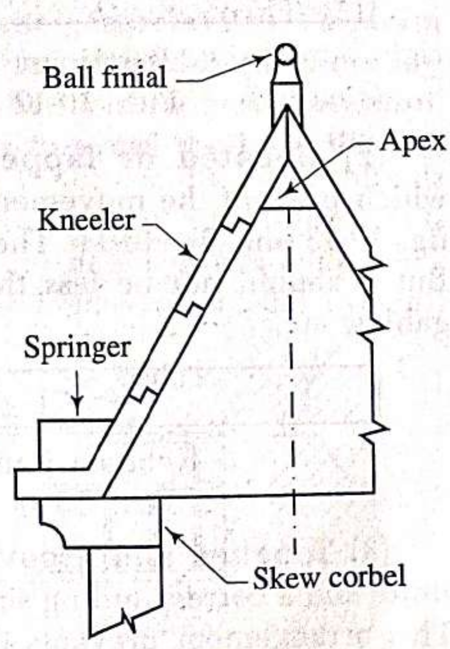
(20) **Label:** The projecting course from an arch or window head is known as a *label*. It is usually moulded and is sometimes known as a *drip stone*.

(21) **Apex:** The coping provided at the summit of a gable wall is known as an *apex* or *summit stone*. See fig. 10-11.

(22) **Skew corbel:** The corbel provided below a gable coping is known as a *skew corbel*. See fig. 10-11.

(23) **Kneeler:** The coping between apex and skew corbel in case of a gable wall is known as a *kneeler*. See fig. 10-11.

(24) **Springer:** The coping provided at the foot of the gable wall is known as a *springer*. See fig. 10-11.



Gable wall
FIG. 10-11

(25) Finial: The ornamental finish to an apex or summit stone is termed as a *finial.*

(26) Buttress: A *buttress* is a sloping or a stepped pier and it is provided to work as lateral support of the wall.

(27) Pilaster: A right-angled columnar projection from a wall or a pier is known as a *pilaster.*

(28) Face: The surface of wall exposed to the weather is known as the *face.*

(29) Facing: The material which is used in the face of the wall is known as the *facing.*

(30) Back: The inner surface of wall which is not exposed to the weather is known as the *back.*

(31) Backing: The material used in the formation of the back of the wall is known as the *backing.*

(32) Hearting: The portion of a wall between facing and backing is known as the *hearting.*

Refer fig. 3-1 and fig 3-2 which shows the components of a building indicating some of the technical terms used in the masonry.

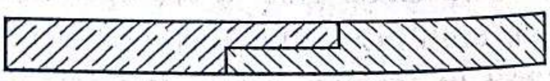
10-4. JOINTS IN STONE MASONRY

In order to secure the stones firmly with each other, the following joints are provided:

(1) Butt or square joint
(2) Rebated or lapped joint
(3) Tongued and grooved joint
(4) Tabled joint
(5) Saddled or water joint
(6) Rusticated joint
(7) Plugged joint
(8) Dowelled joint
(9) Cramped joint.

(1) Butt or square joint: In this type of joint, the square surface of one stone is placed against that of another as shown in fig. 10-12. This is the most common joint and is extensively used for ordinary work.

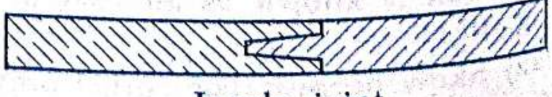
Butt joint
FIG. 10-12



Rebated joint
FIG. 10-13

(2) Rebated or lapped joint: In this type of joint, the rebates are provided which prevent the movements of stones. The *two* such forms of rebates are shown in fig. 10-13 and fig. 10-14. The length of the rebate depends on the nature of the work. But it should not be less than 70 mm. This joint is used for arch work, coping on gables, etc.

Rebated joint
FIG. 10-14



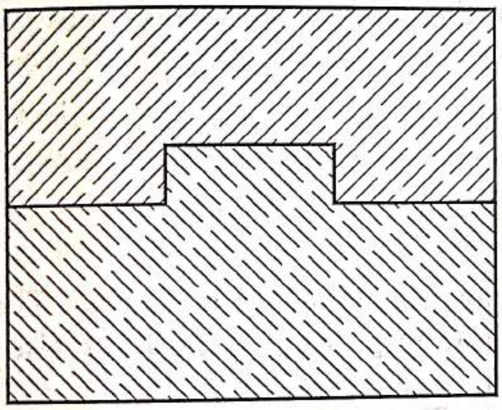
Joggle joint
FIG. 10-15

(3) Tongued and grooved joint: In this type of joint, a projection is kept on one stone and a corresponding sinking is provided in the other stone as shown in fig. 10-15. This arrangement prevents the sliding of one stone over the other. This joint is also known as a *joggle joint* and is rarely used as it involves a great deal of labour and thus becomes expensive. For the end portions of ashlar masonry, the mortar joggled joints are sometimes provided. The cement grout is poured in the joggles formed by means of a hammer and a punch.

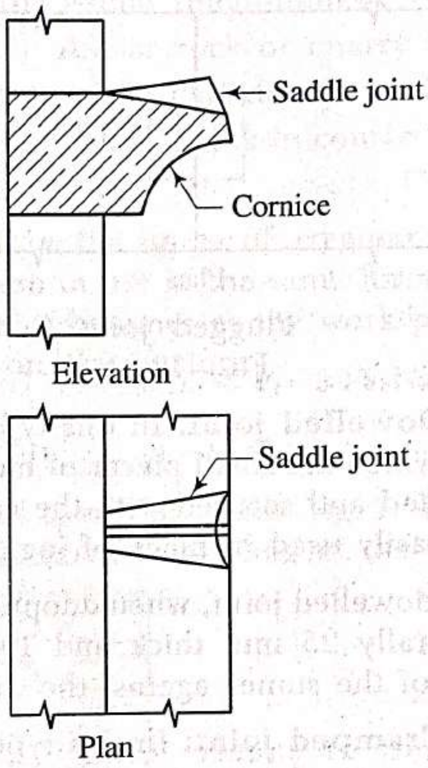
(4) **Tabled joint:** In this type of joint, a joggle is formed in the bed of the stone to prevent lateral movement. See fig. 10-16. The depth of projection is about 40 mm and the width of projection is about one-third the breadth of the stone. This type of joint is used in case of structures such as sea-walls where the lateral pressure is heavy.

(5) **Saddled or water joint:** In this type of joint, the stone is rounded off as shown in fig. 10-17. This type of joint is provided to protect the joints of the cornices and such other weathered surfaces.

With the help of this arrangement, any water moving on the weathered surface is diverted from the joints. The saddle is generally bevelled backwards from the front edge so as to make it inconspicuous.

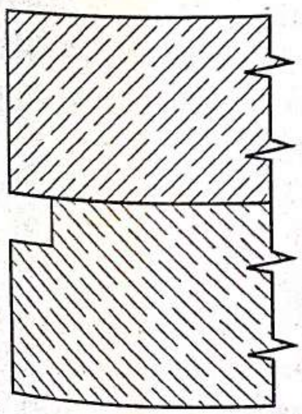


Tabled joint
FIG. 10-16

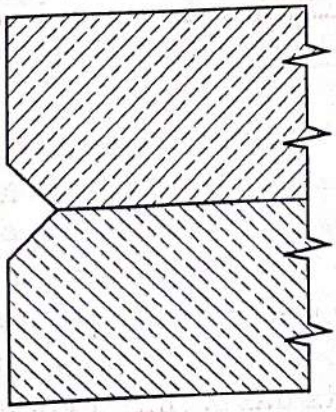


Saddled joint
FIG. 10-17

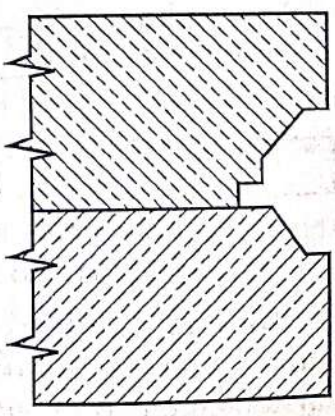
(6) **Rusticated joint:** Sometimes the margins or edges of stones used for plinth, quoin, outer walls of lower storeys, etc., are sunk below the general level. The term *rusticated* is used to indicate such masonry. The *three* forms of rusticated joints are shown in fig. 10-18, fig. 10-19 and fig. 10-20. The channelled joint is more common. In this joint, the sinking is made on the lower joint so as to avoid the possibility of entry of water through the mortar joints.



Channelled joint
FIG. 10-18

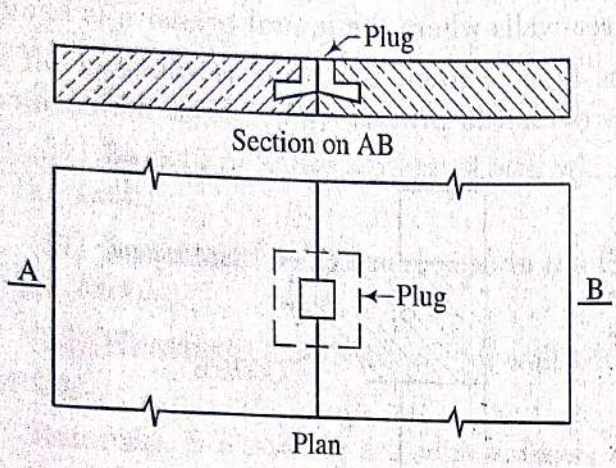


Vee joint
FIG. 10-19

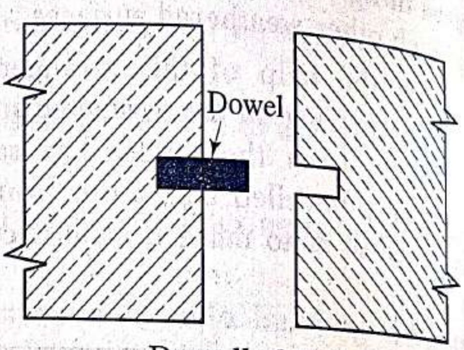


Vee and channelled joint
FIG. 10-20

(7) Plugged joint: In this type of joint, the dovetail shaped mortices are provided in the sides of adjacent stones as shown in fig. 10-21. When stones are placed in position, the molten lead is poured in the joint, which, when cooled, connects the stones firmly. The cement grout is sometimes used in place of the molten lead. This joint is used for copings, cornices, etc.



Plugged joint
FIG. 10-21



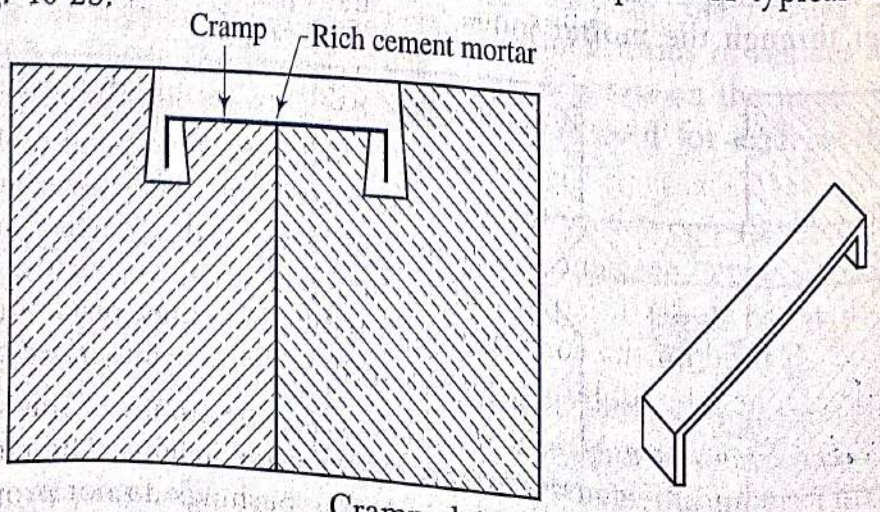
Dowelled joint
FIG. 10-22

(8) Dowelled joint: In this type of joint, a hole is cut into each stone and loose dowels, which are small pieces of hard stone, slate, gunmetal, brass, bronze or copper, are inserted and secured with the cement as shown in fig. 10-22. The dowelled joint can be easily used in place of joggled joints.

The dowelled joint, when adopted for columns, is known as a *bed plug*. The dowels are generally 25 mm thick and 100 mm to 150 mm long. This joint also ensures stability of the stones against the displacement.

(9) Cramped joint: In this type of joint, the cramps are used instead of dowels. The cramps are the pieces of non-corrosive metals such as gunmetal, copper, etc. and their ends are turned down to a depth of about 40 mm to 50 mm. The length, width and thickness of the cramps vary from 200 mm to 300 mm, 25 mm to 50 mm and 5 mm to 10 mm respectively. The holes made on the stones should be of dovetail shape as shown in fig. 10-23.

It prevents the tendency of the joint to be pulled apart. The cramps are placed in position, grouted and covered with cement, lead or asphalt. A typical cramp is also shown in fig. 10-23.



Cramped joint
FIG. 10-23

10-5. CLASSIFICATION OF STONE MASONRY

The stone masonry is classified under *two* categories as shown below:

Stone masonry

Rubble masonry
- (i) Coursed rubble
- (ii) Uncoursed rubble
- (iii) Random rubble
- (iv) Dry rubble
- (v) Polygonal rubble
- (vi) Flint rubble

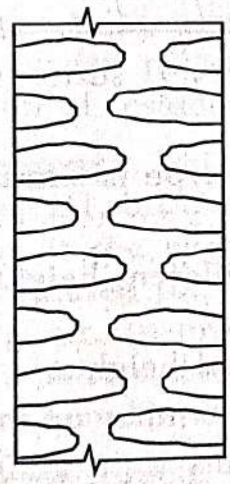
Ashlar masonry
- (i) Ashlar fine
- (ii) Ashlar rough-tooled
- (ii) Ashlar rock or quarry faced
- (iv) Ashlar chamfered
- (v) Ashlar block-in-course

(1) Rubble masonry: In this type of construction, the stones of irregular sizes are used. The stones, as obtained from quarry, are taken in use in the same form or they are broken and shaped in suitable sizes by means of hammer as the work proceeds. The strength of rubble masonry mainly depends on *three* factors:

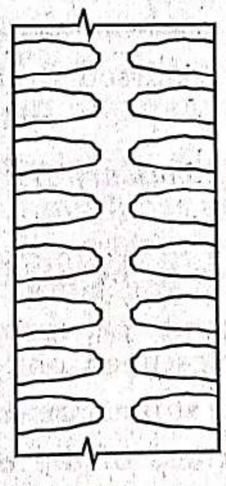
(i) the quality of mortar,

(ii) the use of long through stones at frequent intervals, and

(iii) the proper filling of the mortar between the spaces of stones. Fig. 10-24 shows good filling of the mortar and fig. 10-25 shows bad filling of the mortar.



Good filling
FIG. 10-24

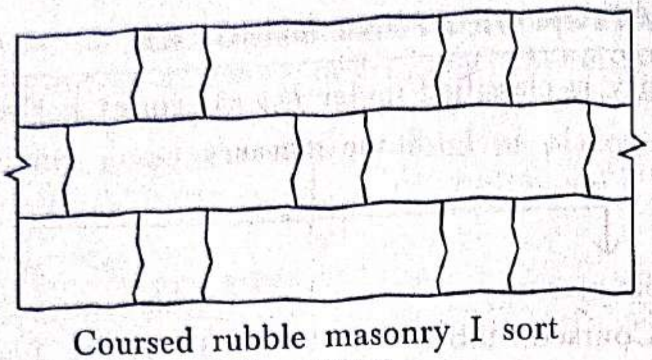


Bad filling
FIG. 10-25

The different types of the rubble masonry will now be briefly described.

(i) ***Coursed rubble masonry*** (fig. 10-26 to fig. 10-28)**:** In this type of rubble masonry, the heights of stones vary from 50 mm to 200 mm. The stones are sorted out before the work commences. The masonry work is then carried out in courses such that the stones in a particular course are of equal heights. This type of masonry is used for the construction of public buildings, residential buildings, etc. The coursed rubble masonry is further divided into *three* categories:

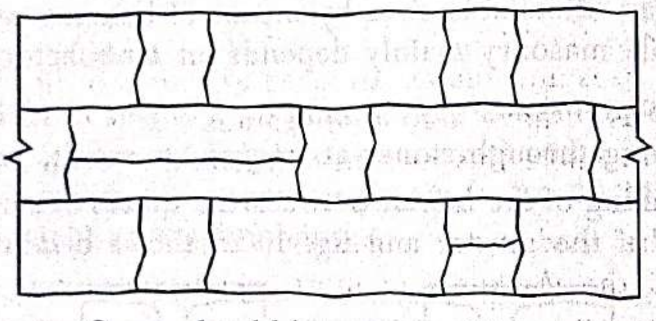
(a) *Coursed rubble masonry I sort:* In this type, the stones of the same heights are used and the courses are also of the same heights. The face stones are dressed by means of a hammer and the bushings do not project by more than 40 mm. The thickness of mortar joint does not exceed 10 mm.



Coursed rubble masonry I sort
FIG. 10-26

(b) *Coursed rubble masonry II sort:* It is similar to I sort except the following:

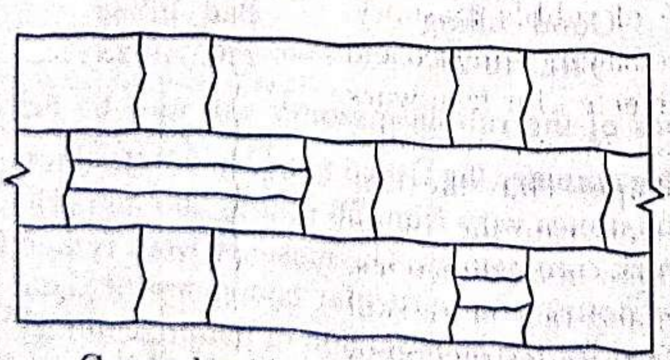
(1) The stones to be used are of different heights.
(2) The courses need not be of equal heights.
(3) Only *two* stones are to be used to make up the height of one course.
(4) The thickness of the mortar joints is 12 mm.



Coursed rubble masonry II sort
FIG. 10-27

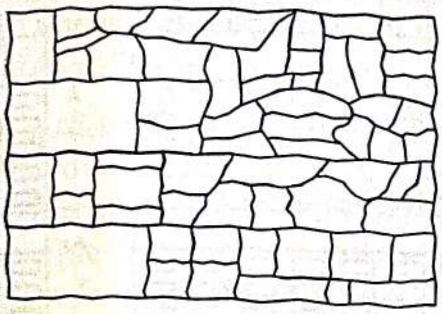
(c) *Coursed rubble masonry III sort:* This type is similar to I sort except the following:

(1) The stones to be used are of different heights, the minimum being 50 mm.
(2) The courses need not be of equal heights.
(3) Only *three* stones are to be used to make up the height of one course.
(4) The thickness of the mortar joints is 16 mm.

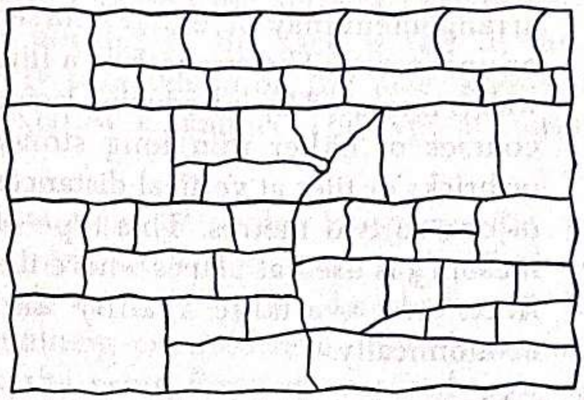


Coursed rubble masonry III sort
FIG. 10-28

(ii) ***Uncoursed rubble masonry*** (fig. 10-29): In this type of rubble masonry, the stones are not dressed. But they are used as they are available from the quarry, except knocking out some corners. The courses are not maintained regularly. The larger stones are laid first and the spaces between them are then filled up by means of spalls or snecks as shown in fig. 10-29. The wall is brought to a level every 300 mm to 500 mm. This type of rubble masonry, being cheaper, is used for the construction of compound walls, godowns, garages, labour quarters, etc.



Uncoursed rubble masonry
FIG. 10-29

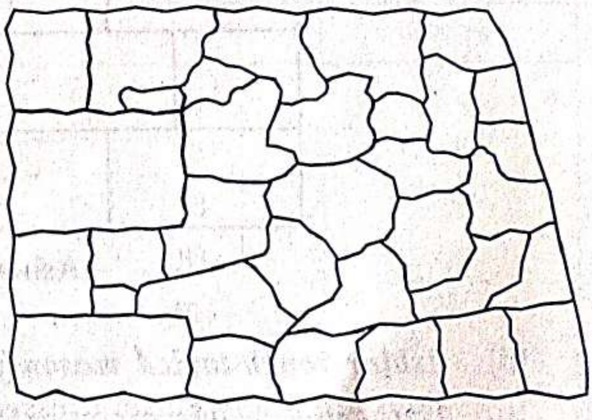


Random rubble masonry
FIG. 10-30

(iii) ***Random rubble masonry*** (fig. 10-30)**:** In this type of rubble masonry, the stones of irregular sizes and shapes are used as shown in fig. 10-30. The stones are arranged so as to have a good appearance. It is to be noted that more skill is required to make this masonry structurally stable. If the face stones are chisel-dressed and the thickness of mortar joints does not exceed 6 mm, it is known as the *random rubble masonry I sort.* If the face stones are hammer-dressed and the thickness of mortar joints does not exceed 12 mm, it is known as the *random rubble masonry II sort.* This type of masonry is used for the construction of residential buildings, compound walls, godowns, etc.

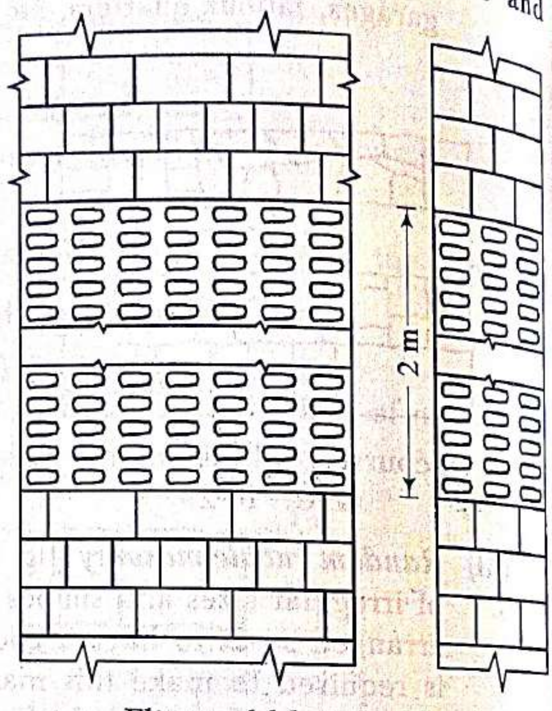
(iv) ***Dry rubble masonry:*** This is just similar in construction to the coursed rubble masonry III sort except that no mortar is used in the joints. This type of construction is the cheapest, but it requires more skill in construction. It is extensively used for compound walls, pitching on bridge approaches, retaining walls, etc. In order to prevent the displacement of stones and to make the work more stable, the *two* courses at top and about 500 mm length at the ends are sometimes built in mortar.

(v) ***Polygonal rubble masonry*** (fig. 10-31)**:** In this type of rubble masonry, the stones are hammer-dressed and the stones selected for face work are dressed in an irregular polygonal shape. Thus the face joints are seen running in an irregular fashion in all directions. It is to be noted that more skill is required in the construction of this type of masonry. As the stones are of irregular shape, it is difficult to adjust them with regard to stability and appearance of the work as a whole.



Polygonal rubble masonry
FIG. 10-31

(vi) *Flint rubble masonry* (fig. 10-32): In this type of rubble masonry, the stones used are flints which are irregularly shaped nodules of silica. The width and thickness vary from 80 mm to 150 mm and the length varies from 150 mm to 300 mm. The stones are extremely hard. But they are brittle and therefore they break easily. The face arrangement may be either coursed or uncoursed. The strength of a flint wall is increased by introducing lacing courses of either thin long stones or bricks or tiles at vertical distances of one to two metres. This type of masonry is used at places where the flints are available readily and economically.

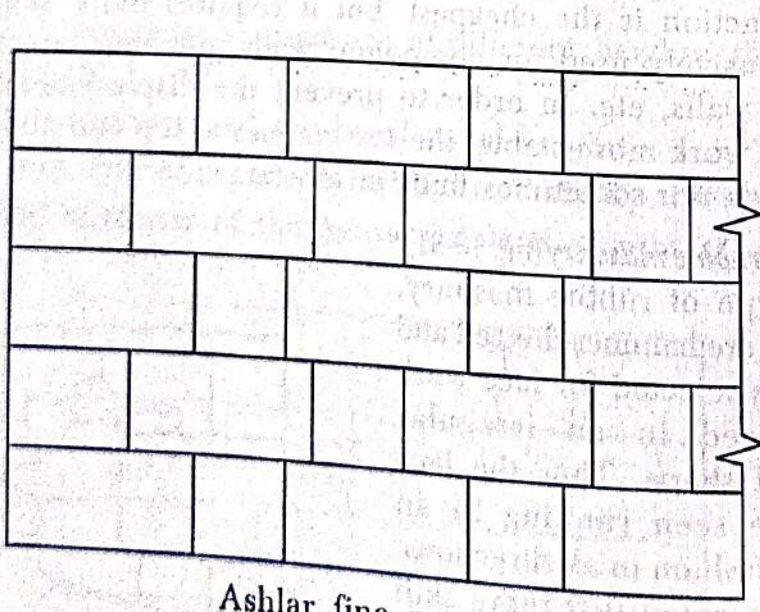


Flint rubble masonry
FIG. 10-32

(2) **Ashlar masonry:** In this type of construction, the square or rectangular blocks of stones are used. The courses are not necessarily of the same height. The height of stones varies from 250 mm to 300 mm. The length of stones should not exceed *three* times the height and the depth into the wall should be at least equal to half the height.

Following are the different types of ashlar masonry:

(i) *Ashlar fine masonry* (fig. 10-33): In this type of ashlar masonry, the beds, sides and faces are finely chisel-dressed. The stones are arranged in proper bond and the thickness of the mortar joints does not exceed 3 mm. This type of construction gives perfectly smooth appearance, but it is costly in construction.



Ashlar fine masonry
FIG. 10-33

(ii) *Ashlar rough-tooled masonry:* In this type of ashlar masonry, the beds and sides are finely chisel-dressed. But the face is made rough by means of tools. A strip, about 25 mm wide and made by means of a chisel, is provided around the perimeter of every stone exposed for view. The thickness of mortar joints does not exceed 6 mm. This type of work is also known as the *bastard ashlar.*

(iii) ***Ashlar rock or quarry faced masonry:*** In this type of ashlar masonry, a strip about 25 mm wide and made by means of a chisel, is provided around the perimeter of every stone exposed for view as in case of rough-tooled ashlar. But the remaining portion of the face is left in the same form as received from quarry. Only projections on the face, known as the *bushings*, exceeding 80 mm are removed by a hammer. This type of construction gives massive appearance.

(iv) ***Ashlar chamfered masonry:*** In this type of ashlar masonry, the strip is provided as above. But it is chamfered or bevelled at an angle of 45 degrees by means of chisel for a depth of about 25 mm. Another strip 12 mm wide is then provided on the remaining exposed face of the stone and the surface inside this strip is left in the same form as received from quarry. The large bushings projecting more than 80 mm are removed by a hammer. A neat appearance of the grooved joints is obtained with the help of this type of construction.

(v) ***Ashlar block-in-course masonry:*** This type of ashlar masonry occupies an intermediate position between the rubble masonry and the ashlar masonry. The faces of the stones are generally hammer-dressed and the thickness of mortar joints does not exceed 6 mm. The depth of courses varies from 200 mm to 300 mm. This type of construction is used for heavy engineering works such as retaining walls, sea-walls, etc. and in some cases, it may also be adopted for theatres, railway stations, temples, bridges, public buildings, etc.

10-6. SAFE PERMISSIBLE LOADS ON STONE MASONRY

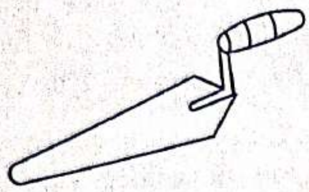
It should be remembered that the strength of stone masonry depends on *three* factors i.e. type of masonry, type of mortar and type of stone.

Table 10-2 gives the safe approximate permissible loads on different types of stone masonry.

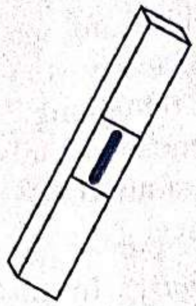
TABLE 10-2
SAFE PERMISSIBLE LOADS ON STONE MASONRY

No.	Description of masonry	Safe permissible load in	
		t/m^2	kN/m^2
1.	Coursed rubble (granite) in lime mortar	55	540
2.	Coursed rubble (granite) in cement mortar	88	863
3.	Random rubble (granite) in lime mortar	33	324
4.	Random rubble (granite) in cement mortar	88	863
5.	Ashlar (granite) in lime mortar	164	1609
6.	Ashlar (granite) in cement mortar	220	2158
7.	Ashlar block-in-course	132	1295
8.	Stone masonry in limestone and sandstone	20 to 100	196 to 981

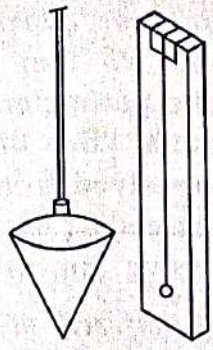
10-7. TOOLS USED IN STONE MASONRY



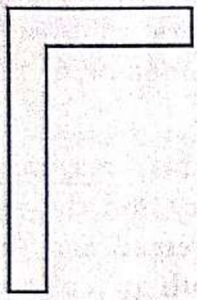
Trowel
FIG. 10-34



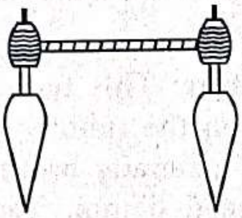
Spirit level
FIG. 10-35



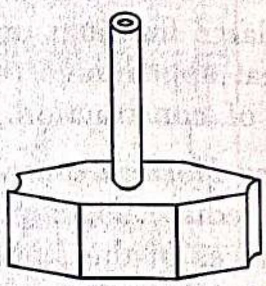
Plumb rule and bob
FIG. 10-36



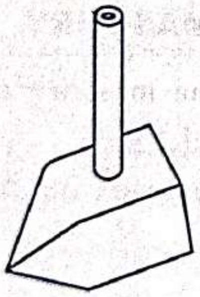
Square
FIG. 10-37



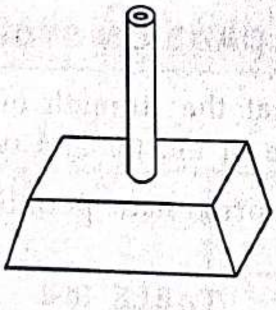
Line and pins
FIG. 10-38



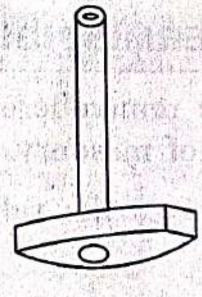
Spall hammer
FIG. 10-39



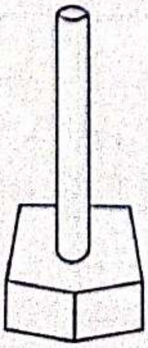
Scabbling hammer
FIG. 10-40



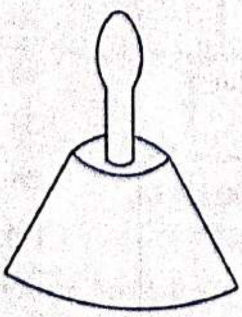
Mash hammer
FIG. 10-41



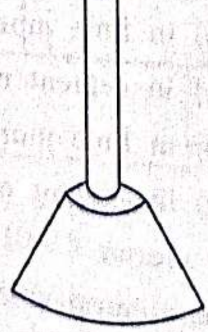
Waller's hammer
FIG. 10-42



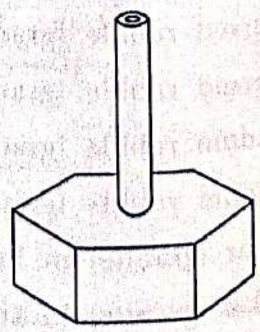
Club hammer
FIG. 10-43



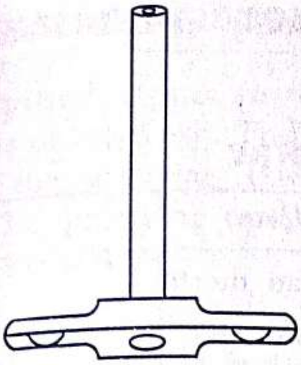
Mallet
FIG. 10-44



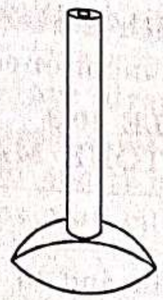
Dummy
FIG. 10-45



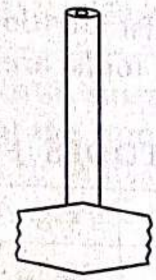
Axe
FIG. 10-46



Ordinary pick
FIG. 10-47

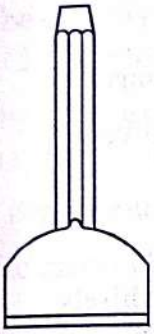


Scabbling pick
FIG. 10-48



Serrated pick
FIG. 10-49

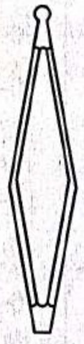
Crow bar
FIG. 10-50



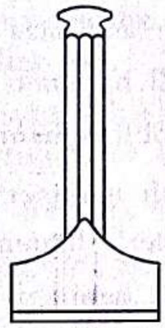
Pitching tool
FIG. 10-51

Punch
FIG. 10-52

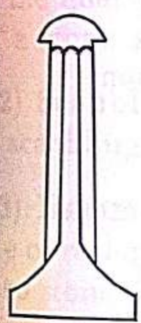
Point
FIG. 10-53



Gauge
FIG. 10-54

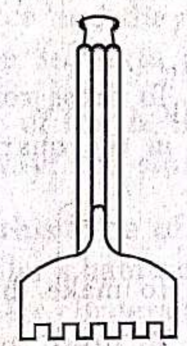


Broad tool
FIG. 10-55

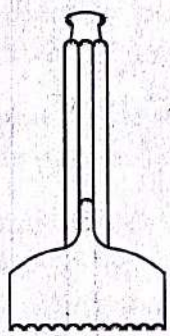


Boaster
FIG. 10-56

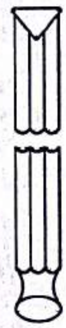
Wood handled chisel
FIG. 10-57



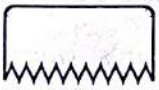
Claw chisel
FIG. 10-58



Tooth chisel
FIG. 10-59

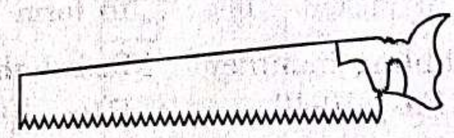


Jumper
FIG. 10-60

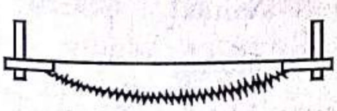


Drag
FIG. 10-61

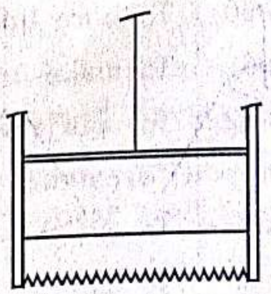
Gad
FIG. 10-62



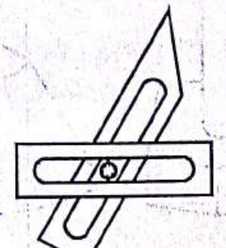
Hand saw
FIG. 10-63



Cross cut saw
FIG. 10-64



Frame saw
FIG. 10-65



Bevel
FIG. 10-66

Chapter 11

BRICK MASONRY

11-1. GENERAL

The bricks are obtained by moulding clay in rectangular blocks of uniform size and then by drying and burning these blocks. As bricks are of uniform size, they can be properly arranged and further, as they are light in weight, no lifting appliance is required for them. The bricks do not require dressing and the art of laying bricks is so simple that the brickwork can be carried out even with the help of unskilled labourers. Thus, at places where stones are not easily available, but there is plenty of clay suitable for the manufacture of bricks, the stones are replaced by bricks.

The mortar to be used for the brick masonry should have the same characteristics as the mortar used in the stone masonry. The mud mortar is sometimes used in brick masonry where low strength bricks are available and where the superimposed loads are not heavy.

In this chapter, the topic of brick masonry will be discussed in detail.

11-2. SIZE AND WEIGHT OF BRICKS

The bricks are prepared in various sizes. The custom in the locality is the governing factor for deciding the size of a brick. Such bricks which are not standardised are known as the *traditional bricks.*

If bricks are large, it is difficult to burn them properly and they become too heavy to be placed with a single hand. On the other hand, if bricks are small, more quantity of mortar is required. Hence the BIS has recommended the bricks of uniform size. Such bricks are known as the *modular bricks* and the actual size of a modular brick is 190 mm × 90 mm × 90 mm. With mortar thickness, size of such a brick becomes 200 mm × 100 mm × 100 mm and it is known as the nominal size of the modular brick. Thus the nominal size of brick includes the mortar thickness.

It is found that the weight of 1 m^3 of brick earth is about 1800 kg. Hence the average weight of a brick will be about 3 to 3.50 kg.

11-3. SOME DEFINITIONS

The definitions of common terms in stonework and brickwork are already given in the previous chapter on the stone masonry. The remaining definitions pertaining specifically to the brickwork only are mentioned below:

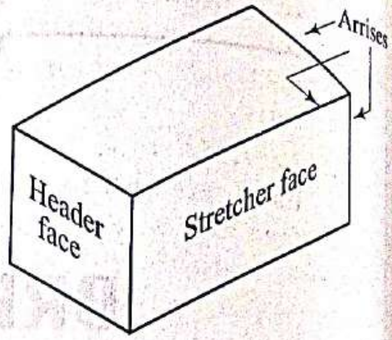
(1) **Stretcher:** This is a brick laid with its length parallel to the face or front or direction of a wall. The course containing stretchers is called a *stretcher course.* See fig. 11-1 and fig. 11-2.

(2) **Header:** This is a brick laid with its breadth or width parallel to the face or front or direction of a wall. The course containing headers is called a *header course*. See fig. 11-1 and fig. 11-2.

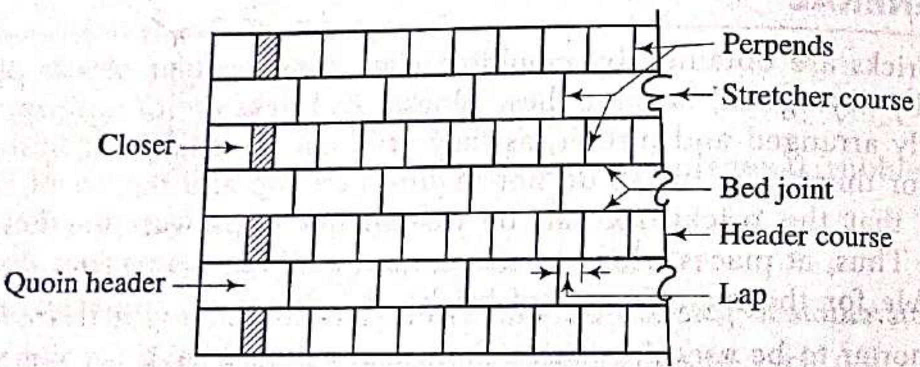
(3) **Arrises:** The edges formed by the intersection of plane surfaces of brick are called the *arrises* and they should be sharp, square and free from damage. See fig. 11-1.

(4) **Bed:** The lower surface of the brick when laid flat is known as the *bed*.

(5) **Bed joint:** The horizontal layer of mortar upon which the bricks are laid is known as a *bed joint*. See fig. 11-2.



Definitions
FIG. 11-1



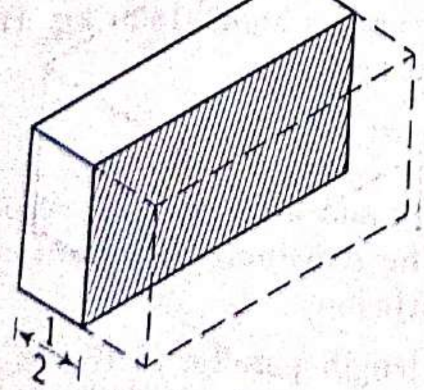
Definitions
FIG. 11-2

(6) **Perpends:** The vertical joints separating the bricks in either length or cross directions are known as the *perpends* and for a good bond, the perpends in alternate courses should be vertically one above the other. See fig. 11-2.

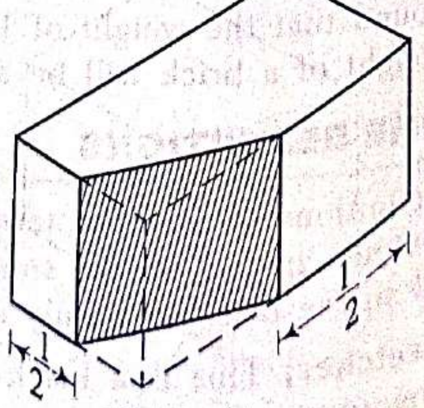
(7) **Lap:** The horizontal distance between the vertical joints in successive courses is termed as a *lap* and for a good bond, it should be one-fourth of the length of a brick. See fig. 11-2.

(8) **Closer:** A piece of brick which is used to close up the bond at the end of brick courses is known as a *closer* and it helps in preventing the joints of successive courses to come in a vertical line. Generally the closer is not specially moulded. But it is prepared by the mason with the edge of the trowel. Following are the *types* of closers:

(i) *Queen closer* (fig. 11-3): This is obtained by cutting the brick longitudinally in *two* equal parts. It can also be made from *two* quarter bricks, known as the *quarter closers*, to minimize the wastage of bricks. A queen closer is generally placed near the quoin header to obtain the necessary lap.



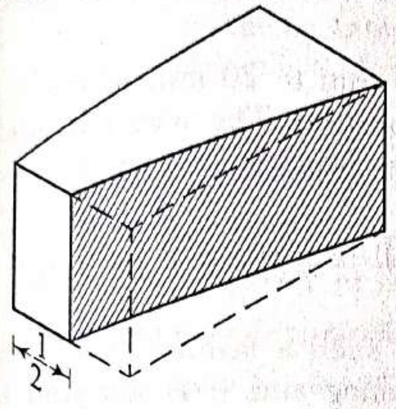
Queen closer
FIG. 11-3



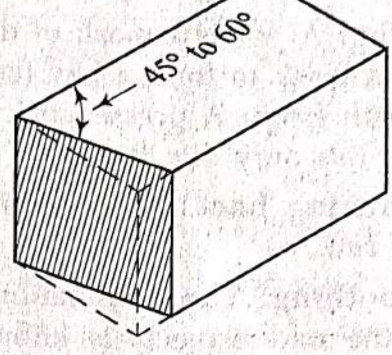
King closer
FIG. 11-4

(ii) *King closer* (fig. 11-4)**:** 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 the mortar joints.

(iii) *Bevelled closer* (fig. 11-5)**:** This is obtained by cutting a triangular portion of half the width but of full length. A bevelled closer appears as a closer on one face and as a header at the other face. It is used for the splayed brickwork.



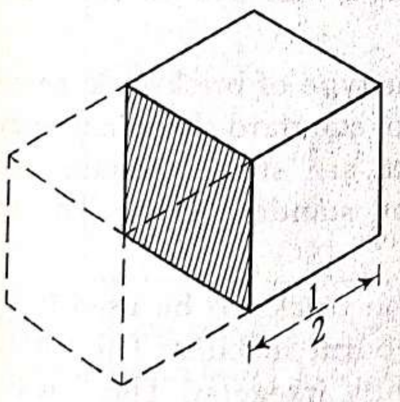
Bevelled closer
FIG. 11-5



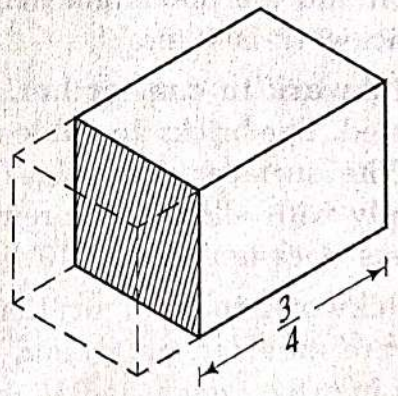
Mitred closer
FIG. 11-6

(iv) *Mitred closer* (fig. 11-6)**:** This is obtained by cutting a triangular portion of the brick through its width and making an angle of 45° to 60° with the length of the brick. It is used at corners, junctions, etc.

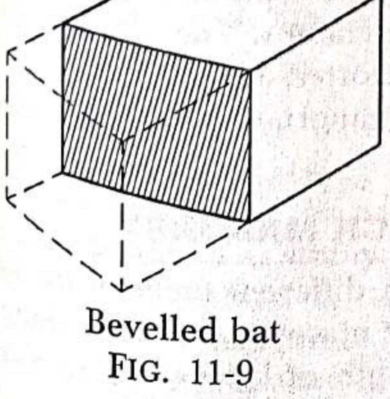
(9) Bat: This is a piece of brick, usually considered in relation to the length of a brick and accordingly known as *half bat* (fig. 11-7) or *three-quarter* bat (fig. 11-8). A bevelled bat may be formed as shown in fig. 11-9.



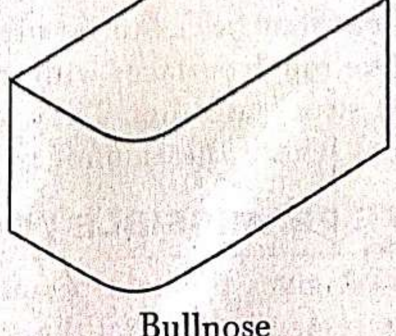
Half bat
FIG. 11-7



Three-quarter bat
FIG. 11-8



Bevelled bat
FIG. 11-9



Bullnose
FIG. 11-10

(10) **Bullnose:** A brick moulded with a rounded angle is termed as a *bullnose* and it is used for a rounded quoin. A connection which is formed when a wall takes a turn is known as a *quoin.* The centre of the curved portion is situated on the long centre-line of the brick. Fig. 11-10 shows a bullnose brick.

(11) **Cownose:** A brick moulded with a double bullnose on end is termed as a *cownose.*

(12) **Squint quoin:** A brick which is cut or moulded such that an angle other than a right angle is formed in plan is known as a *squint quoin.*

(13) **Frog:** A *frog* is a mark of depth about 10 mm to 20 mm which is placed on the face of a brick to form a key for holding the mortar. The wire cut bricks are not provided with frogs. A pressed brick as a rule has frogs on both the faces. A hand-made brick has only one frog.

(14) **Racking back:** The termination of a wall in a stepped fashion is known as the *racking back.*

(15) **Toothing:** The termination of a wall in such a fashion that each alternate course at the end projects is known as the *toothing* and it is adopted to provide adequate bond, when the wall is continued horizontally at a later stage.

11-4. TYPES OF BRICK MASONRY

The brickwork is classified according to the quality of mortar, quality of bricks and thickness of mortar joints. The types of brickwork are as follows:

(1) **Brickwork in mud:** In this type of brickwork, the mud is used to fill up the joints. The mud is prepared by intimately mixing sand with clay. The thickness of the mortar joints is 12 mm. This type of brickwork is adopted in case of the cheapest construction and the maximum height upto which a wall can be constructed in this type of brickwork is 4 m.

(2) **Brickwork in c.m. or l.m. I class:** In this type of brickwork, cement or lime mortar is used. The bricks are table-moulded and of standard shape and they are burnt in kilns. The surfaces and edges of the bricks are sharp, square and straight. They comply with all the requirements of a good standard brick. The thickness of mortar joints does not exceed 10 mm.

(3) **Brickwork in c.m. or l.m. II class:** The bricks to be used in this type of brickwork are moulded on ground and they are burnt in kilns. The surface of these bricks is somewhat rough and shape is also slightly irregular. The bricks may have hair cracks and their edges may not be sharp and uniform. These bricks are commonly used at places where the brickwork is to be provided with a coat of plaster. The thickness of mortar joints is 12 mm.

(4) **Brickwork in c.m. or l.m. III class:** This type of brickwork is same as II class except that bricks to be used are burnt in clamps. These bricks are not hard and they have rough surfaces with irregular and distorted edges. These bricks give dull sound when struck together. They are used for unimportant and temporary structures and at places where the rainfall is not heavy.

11-5. SAFE PERMISSIBLE LOADS ON BRICK MASONRY

Table 11-1 gives the safe permissible loads on different types of bricks masonry. It should be remembered that the strength of brick masonry primarily depends on the quality of bricks and the basic compressive strength of bricks.

The strength of bricks in one country varies from region to region depending upon the nature of soil available for manufacture of bricks and the technique adopted for moulding and burning of the bricks. It is therefore essential to determine the compressive strength of brick units before designing the brick masonry structures.

TABLE 11-1

SAFE PERMISSIBLE LOADS ON BRICK MASONRY

No.	Description of masonry	Safe permissible load	
		t/m^2	kN/m^2
1.	Brick masonry in mud	14	140
2.	Brick masonry in c.m. I class	88	880
3.	Brick masonry in l.m. I class	44 to 55	440 to 550
4.	Ordinary brickwork in c.m.	44 to 65	440 to 650
5.	Ordinary brickwork in l.m.	22 to 40	220 to 400

TABLE 11-2

REDUCTION COEFFICIENTS FOR ISOLATED BRICK PILLARS

Ratio of $\frac{\text{effective height}}{\text{least dimension}}$	Reduction coefficient
6	nil
7	0.9
8	0.8
9	0.7
10	0.6
11	0.5
12	0.4

For isolated brick pillars, a reduction coefficient for safe permissible load should be applied as shown in table 11-2, if the ratio of effective height to the least dimension exceeds 6. It is desirable that this ratio should not exceed 12.

11-6. TOOLS USED IN BRICK MASONRY

The tools employed by a mason are: trowel, spirit level, plumb rule and bob, square, line and pins, club hammer, axe, boaster, hand saw, bevel, straight edge and gauge rod.

A *straight edge* is a piece of wood about one metre long and of section 80 mm × 15 mm. It is used for checking the alignment of brickwork. A *gauge rod* is similar to straight edge except that its section is about 100 mm × 20 mm and it may be as long as the height of a storey. The levels of different courses including mortar joints, sills, etc. are marked on the gauge rod and it is used to confirm that the courses are maintained at correct levels. The remaining tools are already mentioned in table 10-3 of stone masonry chapter.

11-7. BONDS IN BRICKWORK

The bricks being of uniform size can be arranged conveniently in a variety of forms. Some of the rules to be observed for getting a good bond are as follows:

(i) The amount of lap should be minimum one-fourth brick along the length of the wall and one-half brick across the thickness of the wall.

(ii) The bricks should be of uniform size to get uniform lap.

(iii) The stretchers should be used in the facing. The hearting should be carried out with headers only.

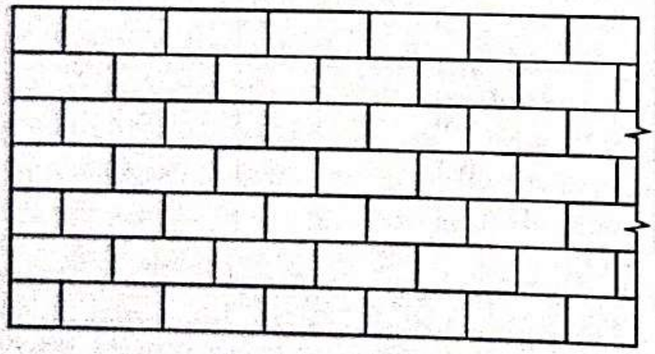
(iv) The use of brickbats should be discouraged except under special circumstances.

(v) The vertical joints in the alternate courses should be along the same perpend.

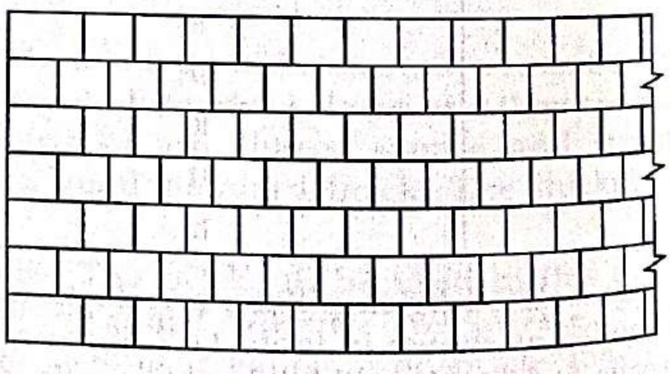
The various types of bonds with their patented names have been constructed. Following are the types of bonds in brickwork:

(1) Stretcher bond
(2) Header bond
(3) English bond
(4) Flemish bond
(5) Garden-wall bond
(6) Raking bond
(7) Dutch bond
(8) Brick-on-edge bond
(9) English cross bond
(10) Facing bond.

(1) Stretcher bond (fig. 11-11): In this type of bond, all the bricks are arranged in the stretcher courses. Fig. 11-11 shows the elevation of a wall with the stretcher bond. The stretcher bond is useful for one-brick partition walls as there are no headers in such walls. As this bond does not develop proper internal bond, it should not be used for walls having thicknesses greater than that of one-brick wall.



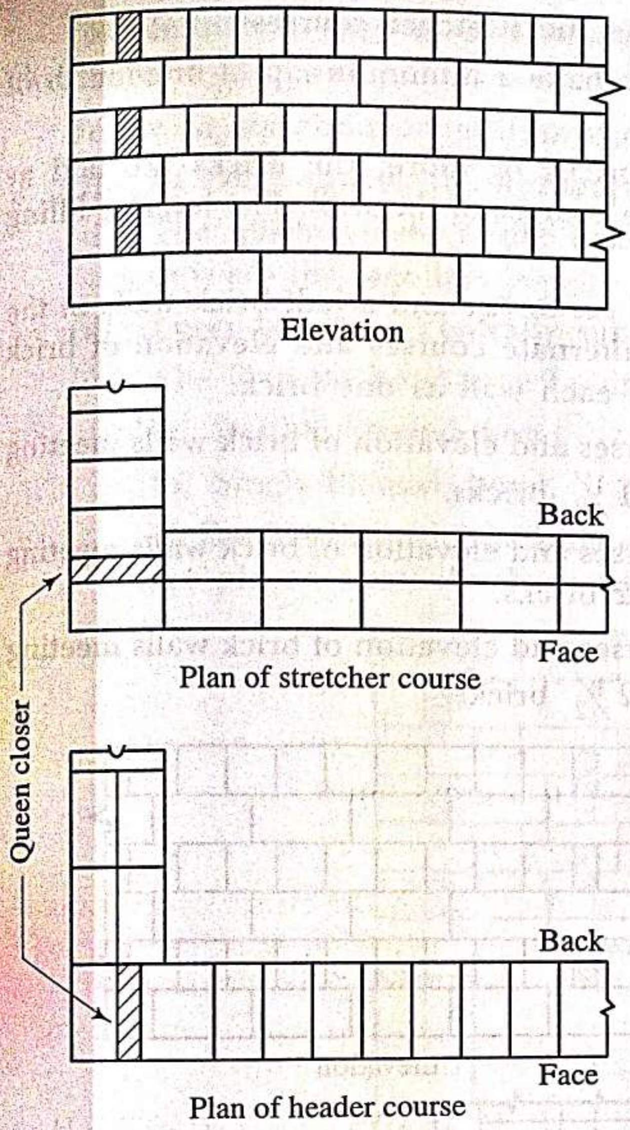
Stretcher bond
FIG. 11-11



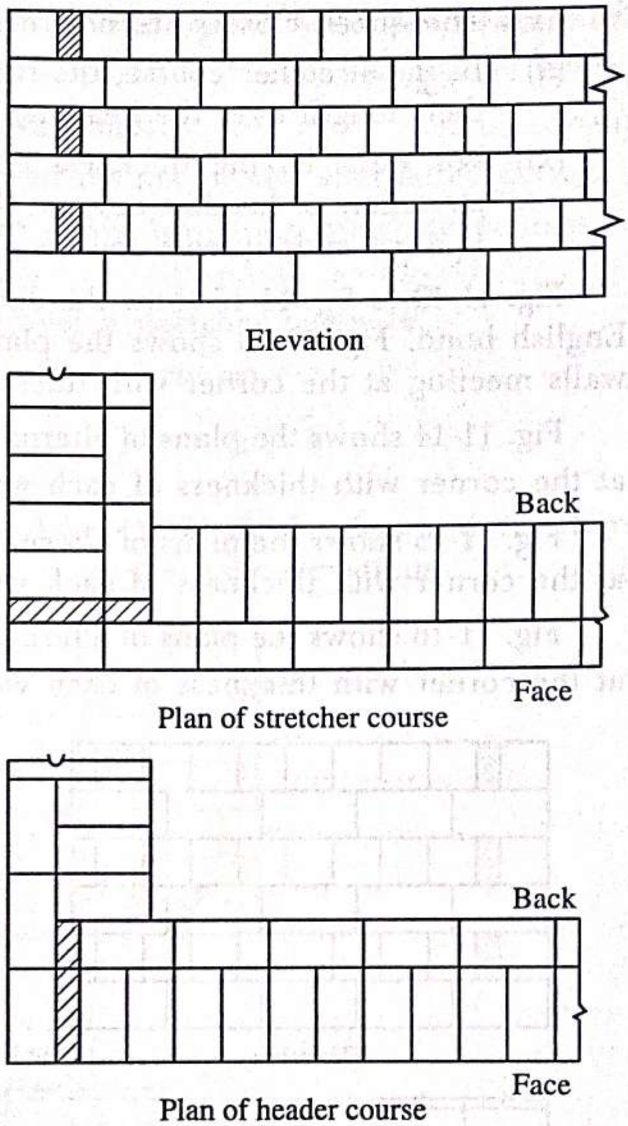
Header bond
FIG. 11-12

(2) Header bond (fig. 11-12): In this type of bond, all the bricks are arranged in header courses. Fig. 11-12 shows the elevation of a wall with the header course. The overlap is usually kept equal to half the width of brick and it is achieved by using three-quarter brickbats in each alternate courses as quoins. This bond does not have strength to transmit pressure in the direction of the length of the wall. Hence it is not suitable for load bearing walls. However this bond is used for curved surfaces in brickwork because stretchers, if used for curved surfaces, would project beyond the face of the wall.

(3) English bond (fig. 11-13 to fig. 11-16): This type of bond is generally used in practice. It is considered as the strongest bond in brickwork. Following are the features of an English bond:



English bond–1 brick wall
FIG. 11-13



English bond–1 $\frac{1}{2}$ bricks wall
FIG. 11-14

(i) The alternate courses consist of stretchers and headers.

(ii) The queen closer is put next to the quoin header to develop the face lap.

(iii) Each alternate header is centrally supported over a stretcher.

(iv) If the wall thickness is an even multiple of half-brick, the same course shows headers or stretchers in both the front and the back elevations. But if the wall thickness is an uneven multiple of half-brick, a course showing stretcher on the face shows header on the back and vice versa.

(v) The bricks in the same course do not break joints with each other. The joints are straight.

(vi) In this bond, the continuous vertical joints are not formed except at certain stopped ends.

(vii) The number of mortar joints in the header course is nearly double than that in the stretcher course. Hence care should be taken to make the header joints thinner; otherwise the face lap disappears quickly.

(viii) A header course should never start with a queen closer as it is liable to get displaced in this position.

(ix) The queen closers are not required in the stretcher courses.

(x) In the stretcher course, the stretchers have a minimum lap of one-fourth of their length over the headers.

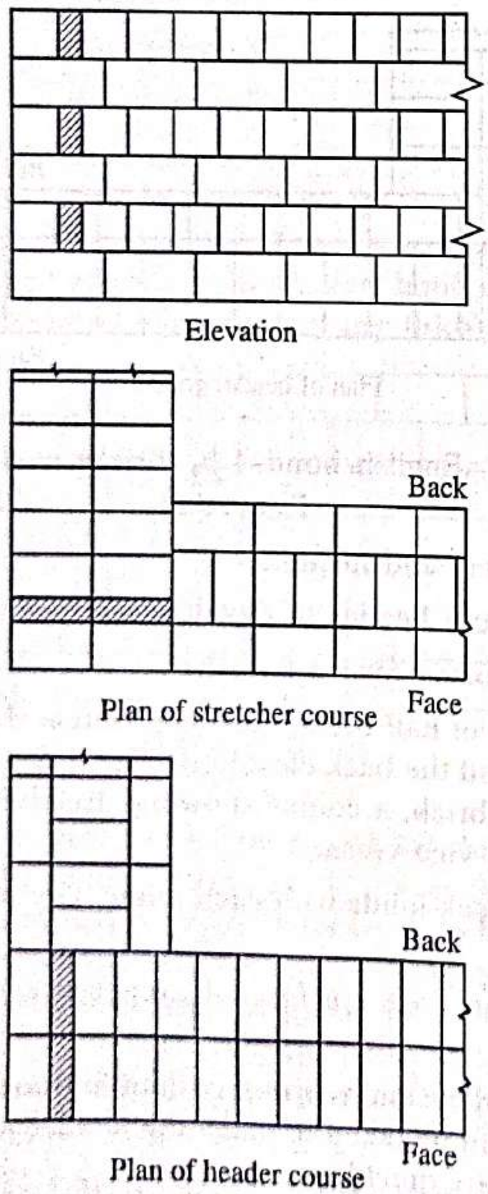
(xi) For walls having thickness of *two* bricks or more, the bricks are laid as stretchers or headers only on the face courses of the wall. The interior filling is done entirely with the headers.

Fig. 11-13 to fig. 11-16 show the details of *one* to *two* and a half brick walls in the English bond. Fig. 11-13 shows the plans of alternate courses and elevation of brick walls meeting at the corner with thickness of each wall as one brick.

Fig. 11-14 shows the plans of alternate courses and elevation of brick walls meeting at the corner with thickness of each wall as $1\frac{1}{2}$ bricks.

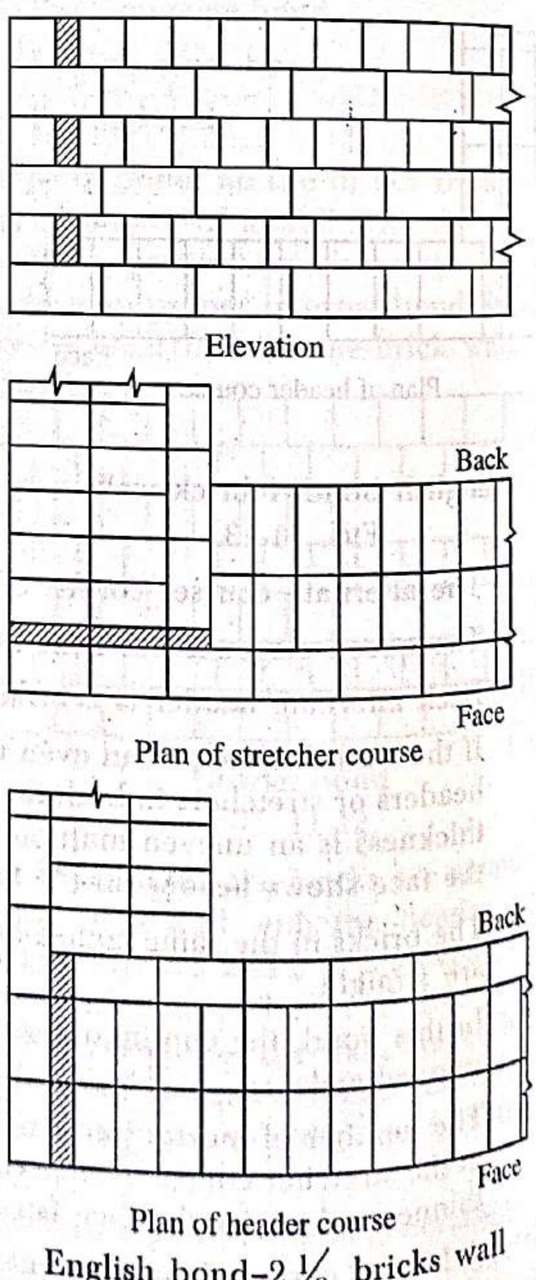
Fig. 11-15 shows the plans of alternate courses and elevation of brick walls meeting at the corner with thickness of each wall as 2 bricks.

Fig. 11-16 shows the plans of alternate courses and elevation of brick walls meeting at the corner with thickness of each wall as $2\frac{1}{2}$ bricks.



English bond–2 bricks wall

FIG. 11-15



English bond–$2\frac{1}{2}$ bricks wall

FIG. 11-16

(4) **Flemish bond** (fig. 11-17 to fig. 11-20): In this type of bond, the headers are distributed evenly and hence, it creates a better appearance than the English bond.

Following are the peculiarities of a Flemish bond:

(i) In every course, the headers and stretchers are placed alternatively.

(ii) The queen closer is put next to the quoin header in alternate courses to develop the face lap.

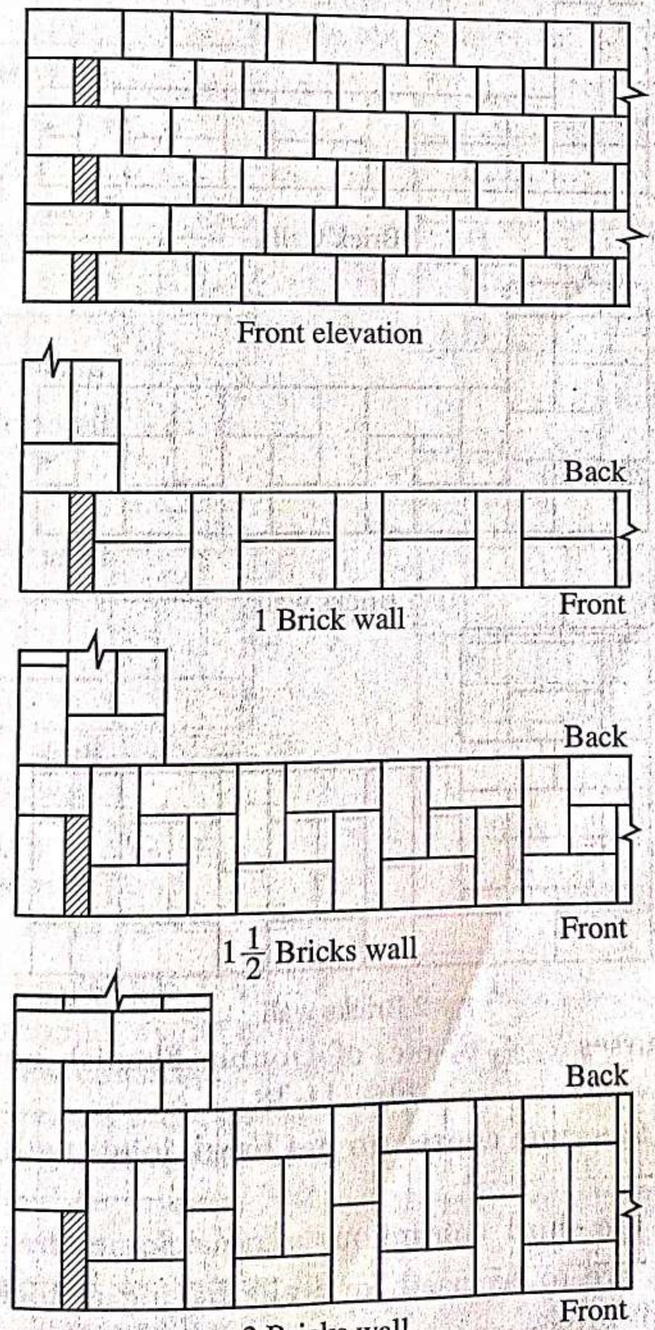
(iii) Every header is centrally supported over a stretcher below it.

(iv) The Flemish bond may be divided into *two* groups:

(a) Double Flemish bond

(b) Single Flemish bond.

In Double Flemish bond (fig. 11-17 and fig. 11-18), the headers and stretchers are placed alternatively in front as well as the back elevations.

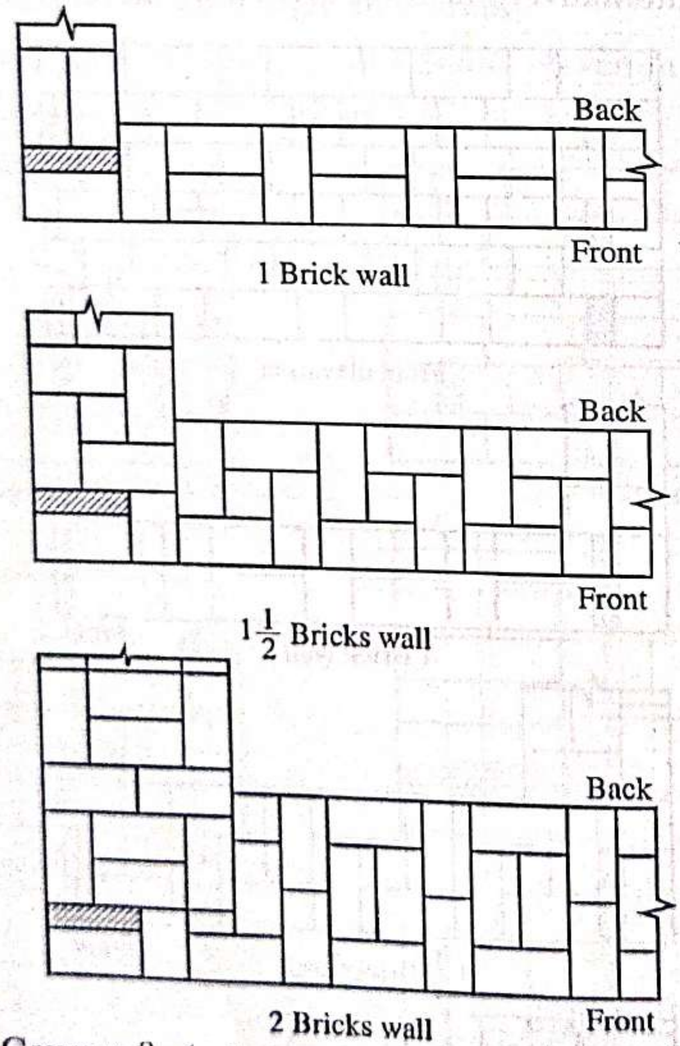


Courses 1, 3, 5, etc. of Double Flemish bond

FIG. 11-17

For this type of bond, the half bats and three-quarter bats will have to be used for walls having thickness equal to odd number of half bricks. For walls of thickness equal to even number of half bricks, no bats will be required and a stretcher or a header will come out as a stretcher or a header in the same course in front as well as back elevations. This bond gives better appearance than the English bond. But it is not so strong as the English bond as it contains more number of stretchers.

In Single Flemish bond (fig. 11-19 and fig. 11-20), the face elevation is of Flemish bond and the filling as well as backing are of the English bond. Thus, in this type of bond, an attempt is made to combine the strength of the English bond with the appearance of the Flemish bond. This type of bond is used when expensive bricks are used for the face work. But in order to construct this bond, a wall of minimum thickness $1\frac{1}{2}$ bricks is required.



Courses 2, 4, 6, etc. of Double Flemish bond

FIG. 11-18

(v) The bricks in the same course do not break joints with each other. The joints are straight.

(vi) In this bond, the short continuous vertical joints are formed.

(vii) The brickbats are to be used for walls having a thickness equal to uneven number of half-brick.

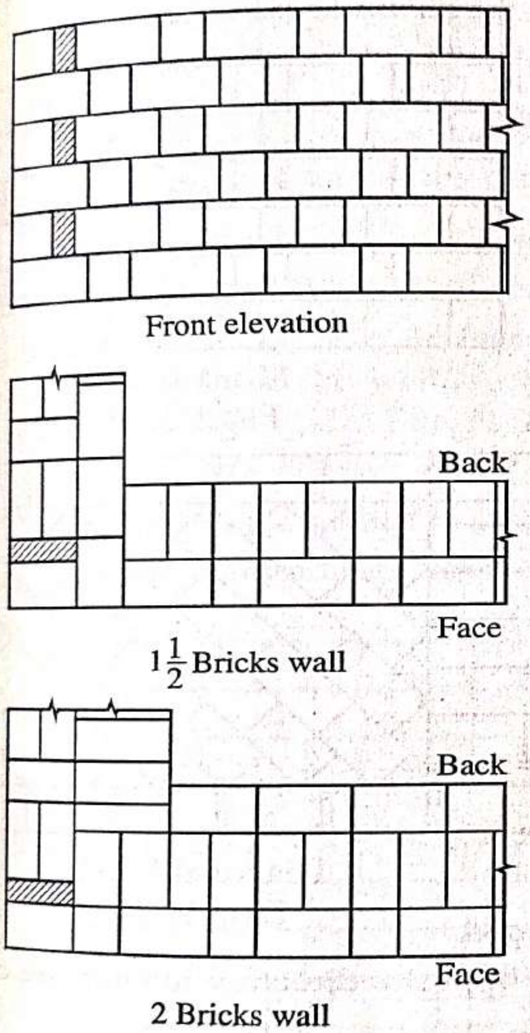
The comparison of English bond and Flemish bond can be made with respect to the following aspects:

(a) The English bond is found to possess more strength than the Flemish bond for walls having thickness greater than 1 ½ bricks.

(b) The Flemish bond grants more pleasing appearance than the English bond.

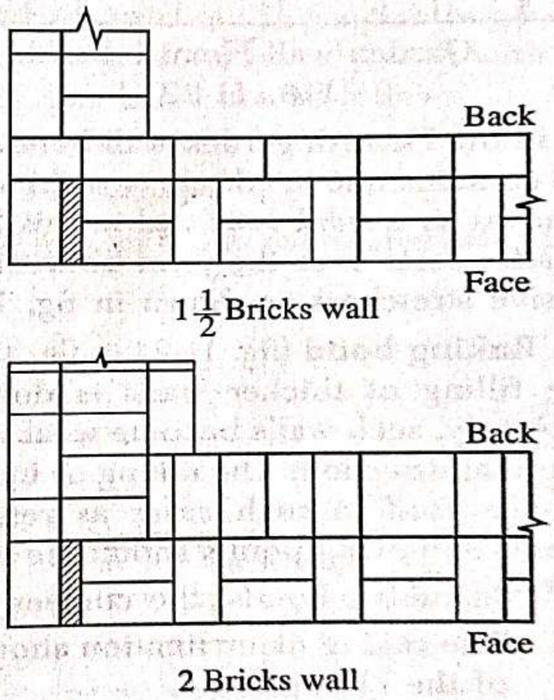
(c) It is possible to make use of broken bricks in the form of brickbats in case of the Flemish bond. However more mortar will be required.

(d) The construction with the Flemish bond requires greater skill as compared to the English bond.



Courses 1, 3, 5, etc. of Single Flemish bond

FIG. 11-19

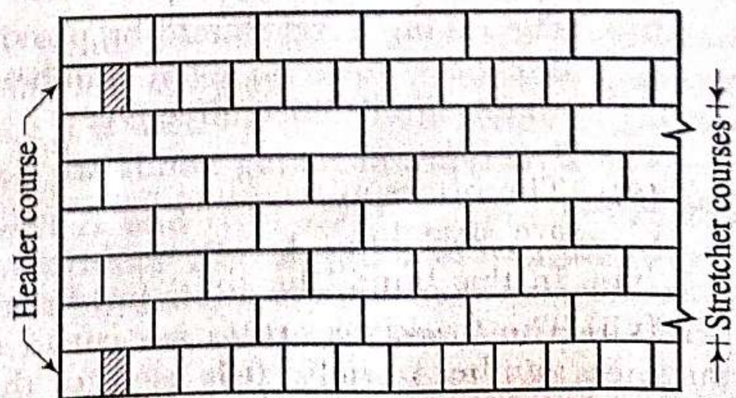


Courses 2, 4, 6 etc. of Single Flemish bond

FIG. 11-20

(5) **Garden-wall bond** (fig. 11-21 to fig. 11-23): This type of bond, as the name suggests, is used for the construction of the boundary walls, compound walls, garden walls, etc. The wall is one-brick wall and its height does not exceed *two* metres. The wall may be constructed either in the English bond or the Flemish bond as shown in fig. 11-21 and fig. 11-22 respectively.

In the English garden-wall bond (fig. 11-21), one header course is provided

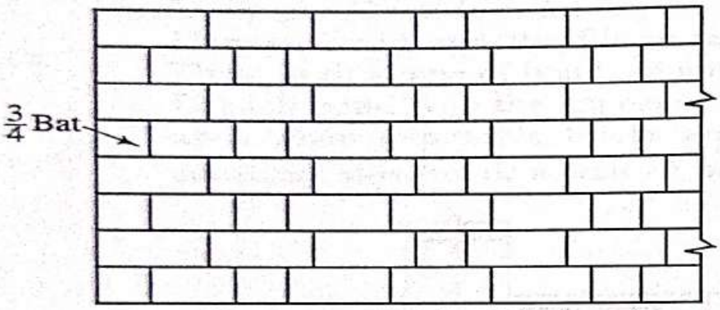


Garden-wall English bond

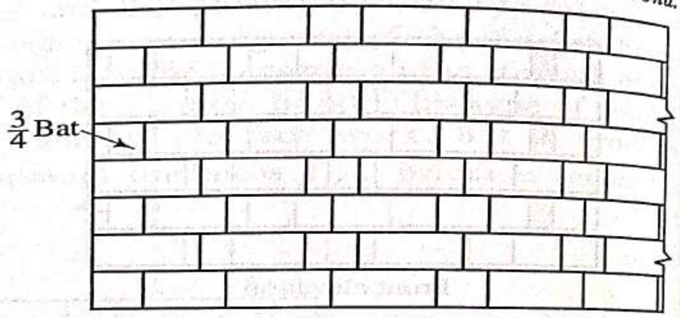
FIG. 11-21

to *three* or *five* stretcher courses. The quoin headers are placed in alternate courses and a quoin closer is placed next to the quoin header in a header course to develop the necessary lap.

In the Flemish garden-wall bond (fig. 11-22), each course contains one header to *three* or *five* stretchers. A three-fourth brickbat is placed next to quoin header in every alternate course to develop the necessary lap. A header is placed centrally over each middle stretcher. This type of bond is also known as the *Scotch bond* or *Sussex bond*.



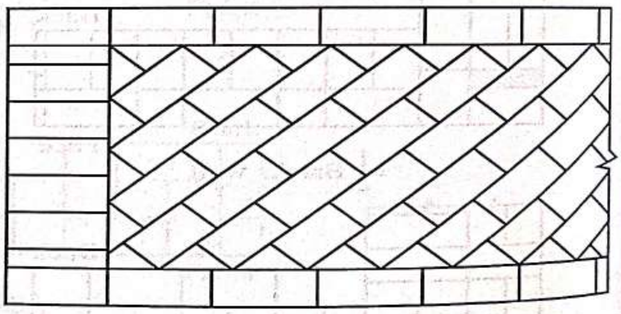
Garden-wall Flemish bond
FIG. 11-22



Monk bond
FIG. 11-23

If, in the Flemish garden-wall bond, each course contains one header to two stretchers, it is known as a *monk bond* and in this bond, the header rests over the joint between two successive stretchers as shown in fig. 11-23.

(6) Raking bond (fig. 11-24 to fig. 11-26): As the filling of thicker walls is done by headers only, such walls become weak in the longitudinal direction. The raking or inclined bonds are used in such cases as remedial measures. Following points should be noted:



Diagonal bond
FIG. 11-24

(i) In raking bonds, the courses are inclined.

(ii) The raking or inclination should be in opposite direction in alternate courses of the raking bond.

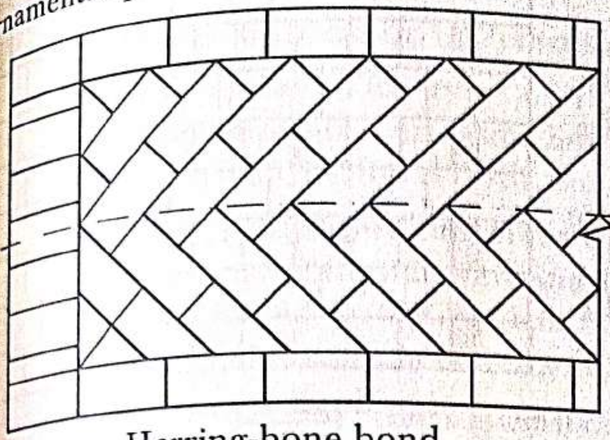
(iii) The successive courses of the raking bonds should not be provided. Generally a course with raking bond is provided at regular interval of *four* to *eight* courses in the height of a wall.

(iv) The raking bond should be provided in the stretcher course of a wall having thickness equal to even number of half-brick. This arrangement makes a raking bond more effective.

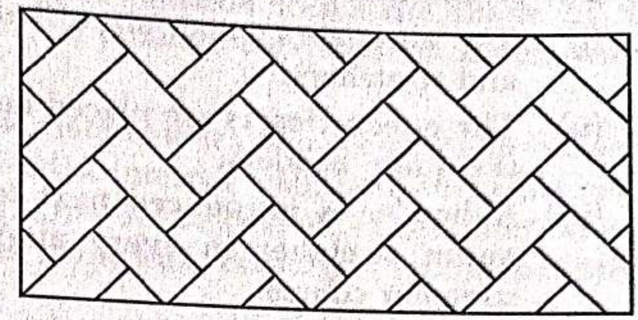
The *three* types of raking bonds are – diagonal bond, herring–bone bond and zig-zag bond.

In *diagonal bond* (fig. 11-24), the bricks are laid diagonally. The angle of inclination is so selected that there is minimum breaking of the bricks. The triangular pieces of bricks required near the sides are cut to shape. This bond is useful for walls having thickness of 2 to 4 bricks. It is used for the construction of the footings of high walls.

In *herring-bone bond* (fig. 11-25), the bricks are laid at an angle of 45° from the centre in both the directions. This bond is useful for walls having thickness of more than *four* bricks. It is also used for ornamental finish to the face work and for making ornamental panels in the flooring of bricks.



Herring-bone bond
FIG. 11-25



Zig-zag bond
FIG. 11-26

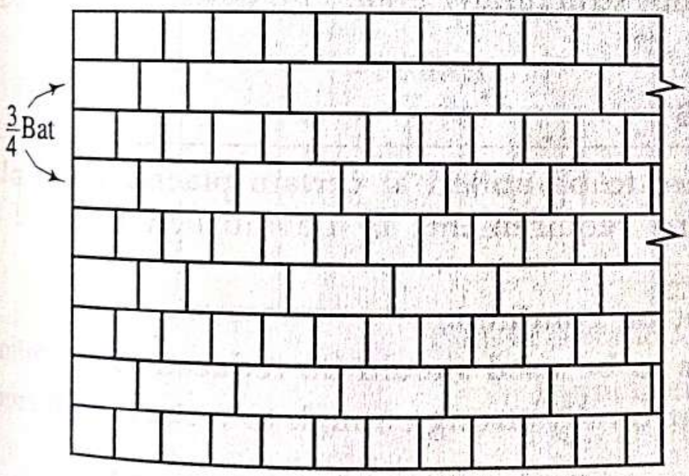
In *zig-zag bond* (fig. 11-26), the bricks are laid in a zig-zag fashion. It is commonly used for making ornamental panels in the flooring of bricks.

(7) **Dutch bond** (fig. 11-27)**:** This is a modified form of the English bond and by this bond, the corner of the wall is strengthened. The elevation of a wall with Dutch bond is shown in fig. 11-27. The *peculiarities* of this bond are as follows:

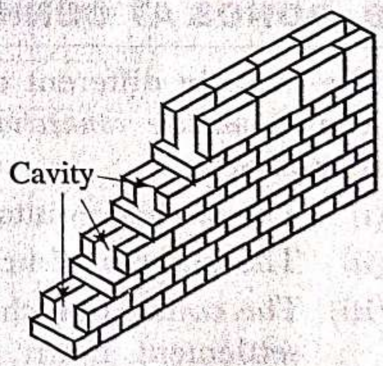
(i) The alternate courses are of headers and stretchers.

(ii) The quoin of a stretcher course is a three-quarter bat.

(iii) A header is introduced next to the three-quarter bat in every alternate stretcher course.



Dutch bond
FIG. 11-27



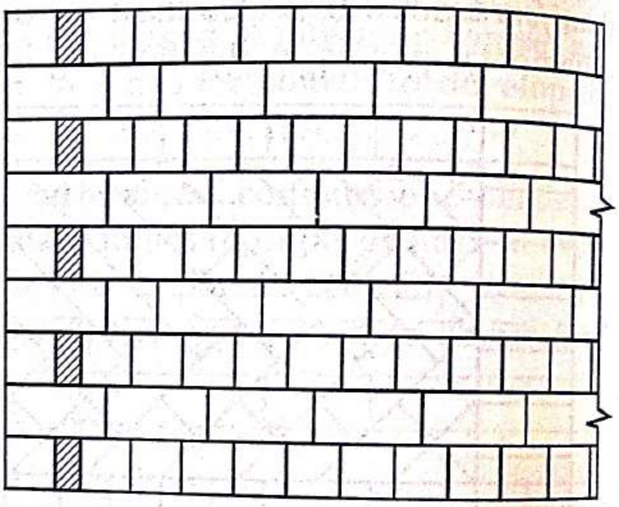
Silvercock's bond
FIG. 11-28

(8) **Brick on-edge bond:** In this type of bond, the bricks are laid on edge instead of bed. This bond is economical as it consumes less number of bricks and less quantity of mortar. It is however not strong and hence it is used for the construction of garden walls, compound walls, partition walls, etc.

In this bond, the bricks are laid as headers and stretchers in alternate courses in such a way that the headers are laid on bed and the stretchers are laid on edge. Thus a continuous cavity is formed as shown in fig. 11-28. This bond is also referred to as the *silvercock's bond.*

(9) **English cross bond** (fig. 11-29)**:** This is another modified form of the English bond and it is used to add beauty in the appearance of the wall. The elevation of a

wall with English cross bond is shown in fig. 11-29. It is also known as the *St. Andrews cross bond.*



English cross bond
FIG. 11-29

The *peculiarities* of this bond are as follows:

(i) The alternate courses are of headers and stretchers.

(ii) The queen closers are placed next to the quoin headers.

(iii) A header is introduced next to the quoin stretcher in every alternate stretcher course.

(10) Facing bond: In this type of bond, a header course is placed after several stretcher courses. It is used under the following circumstances:

(i) If the facing and backing bricks vary in size and shape, the facing bond is adopted. The least common multiple of the thickness of facing and backing bricks decides the distance between the successive header courses. For instance, if the nominal thickness of facing bricks is 100 mm and that of backing bricks is 80 mm, the header course is provided at a vertical interval of 800 mm.

(ii) If the facing bricks are expensive and if it is desired to economise, the facing bond is adopted. A header course is placed after every *three* or *five* stretcher courses.

It is found that the facing bond is not structurally good and hence the distribution of load is not uniform.

11-11. DEFECTS IN BRICK MASONRY

The brick masonry may develop the defects mainly due to the following *four* reasons:

(1) Corrosion of embedded fixtures;

(2) Crystallization of salts from bricks;

(3) Shrinkage on drying; and

(4) Sulphate attack.

(1) Corrosion of embedded fixtures: The iron or steel fixtures like pipes, holdfasts, etc. which are embedded in the brick masonry may get corroded in presence of dampness. The metal expands in volume due to corrosion and it leads to the cracking of brickwork. To avoid this defect, these fixtures should be embedded in dense mortar with a cover of 15 mm to 25 mm.

(2) Crystallization of salts from bricks: This defect is developed when bricks containing excessive soluble salts are used in the masonry work. When such bricks come in contact with water, the soluble salts are dissolved and fine whitish crystals are seen on the surface of brickwork. This phenomena is known as the *efflorescence* and it presents an ugly appearance. The brushing and washing of the effected surface from time to time may be adopted as a remedy for this defect.

(3) Shrinkage on drying: The brickwork normally swells with the absorption of water and subsequently shrinks when the water evaporates due to atmospheric heat, etc. The cracks in the masonry joints are developed in the process of shrinkage. This defect can be minimized by using good quality bricks and by protecting masonry from moisture penetration.

(4) **Sulphate attack:** The sulphate salts present in brick react with alumina of cement in case of cement mortar and with hydraulic lime in case of lime mortar. Due to this reaction, there is increase in the volume of mortar and it leads to the chipping and spalling of bricks. This defect is prominent at locations where the brickwork is exposed like boundary walls, parapets, etc. or where it is likely to be in contact with moisture like manholes, retaining walls, etc. To prevent this defect, the materials should be chosen in such a way that the entry of water into the body of brickwork is checked.

11-13. COMPARISON OF BRICKWORK AND STONEWORK

The brickwork is superior to the stonework in the following respects:

(i) At places where stones are not easily available but where there is plenty of clay, the brickwork becomes cheaper than stonework.

(ii) The cost of construction works out to be less in case of brickwork than the stonework as less skilled labour is required in the construction of brickwork.

(iii) No complicated lifting devices are necessary to carry the bricks as they can be easily moved by the manual labour.

(iv) The bricks resist fire better than the stones and hence in case of a fire, they do not easily disintegrate.

(v) The bricks of good quality resist the various atmospheric effects in a better way than the stones.

(vi) In case of brickwork, the mortar joints are thin and hence the structure becomes more durable.

(vii) It is easy to construct connections and openings in case of brickwork than in case of stonework.

(viii) It is possible to mould the bricks into any desired shape at a reasonable cost. The moulding of stones is very expensive.

(ix) The brick walls of small thickness, say 100 mm or 200 mm, can be easily constructed. The minimum thickness of a stone wall will usually be 300 mm.

(x) The bricks are of regular size and shape and hence it grants the facility of maintaining proper bond. On the other hand, the stones are to be dressed and placed in position which results in extra labour and more time.

(xi) The first class bricks possess all the qualities required for a good construction and hence the brick masonry has now practically replaced the stone masonry.

The brickwork is inferior to the stonework in the following respects:

(i) The brickwork is less water-tight than the stonework. The bricks absorb moisture from the atmosphere and dampness can enter the building.

(ii) The brickwork does not create a solid appearance in relation to the stonework and hence, for public buildings and monumental structures, the stonework is found to be more useful than the brickwork.

(iii) The stonework is stronger than the brickwork.

(iv) It is possible to develop better architectural effects by the stonework.

(v) The stonework is cheaper at places where the stones are easily available and hence its usage is generally restricted to the hilly areas or stone districts.

(vi) The stones of good quality offer attractive texture and hence no finishing will be required. On the other hand, the plastering will have to be carried out to conceal the defects in the brick masonry and to serve as a protective layer.

(vii) The stone possesses high crushing strength and hence the stone masonry is adopted in the construction of piers, docks, dams and other marine structures. The brickwork, on the other hand, is considered unsuitable in all such places.

11-14. COMPOSITE MASONRY

Sometimes the facing and backing of a wall are constructed with different classes of masonry or of different materials. This is known as the *composite masonry*. Following are the usual combinations:

(i) facing of ashlar masonry and backing of rubble masonry or brickwork,

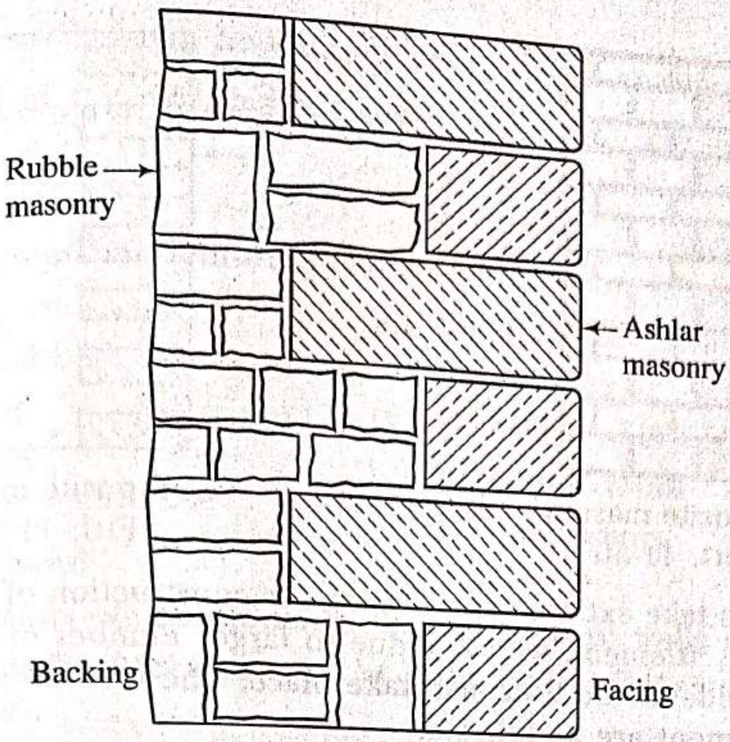
(ii) facing of stone slabs and backing of concrete or brickwork,

(iii) facing of brickwork and backing of rubble masonry,

(iv) facing of brickwork and backing of cement concrete, and

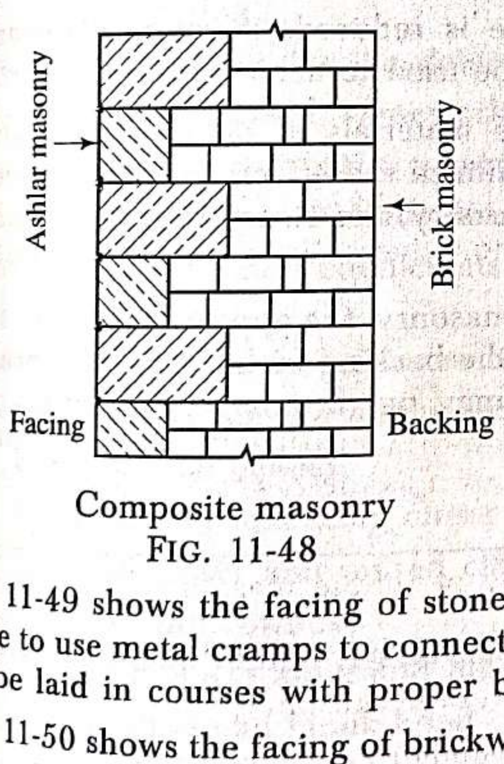
(v) facing of brickwork and backing of hollow cement concrete blocks.

Fig. 11-47 to fig. 11-51 show the different forms of the composite masonry. Fig. 11-47 shows the facing of ashlar masonry and backing of rubble masonry. The rubble masonry is generally cheap while the ashlar masonry gives pleasing and attractive appearance.

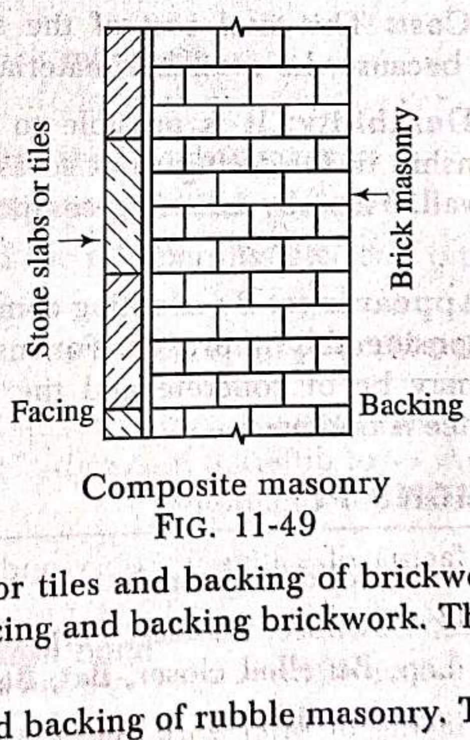


Composite masonry
FIG. 11-47

Fig. 11-48 shows the facing of ashlar masonry and backing of brickwork. It is preferable to use the height of ashlar as a multiple of brick thickness plus the masonry joints so as to obtain the coursed masonry work. The alternate courses of ashlar may be headers and the header bricks should be used under each projecting course of ashlar.



Composite masonry
FIG. 11-48

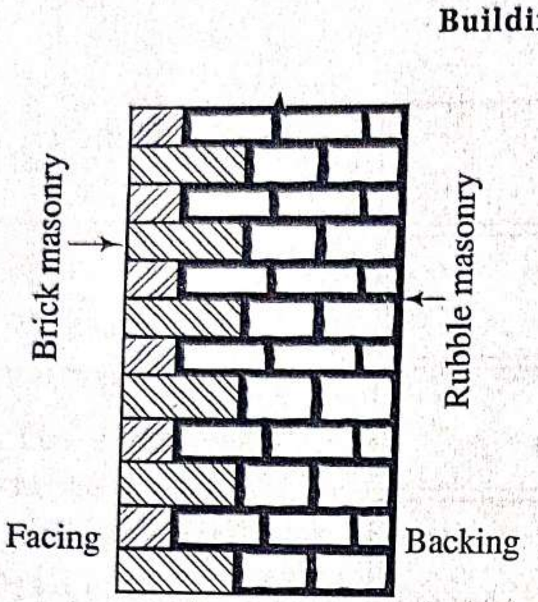


Composite masonry
FIG. 11-49

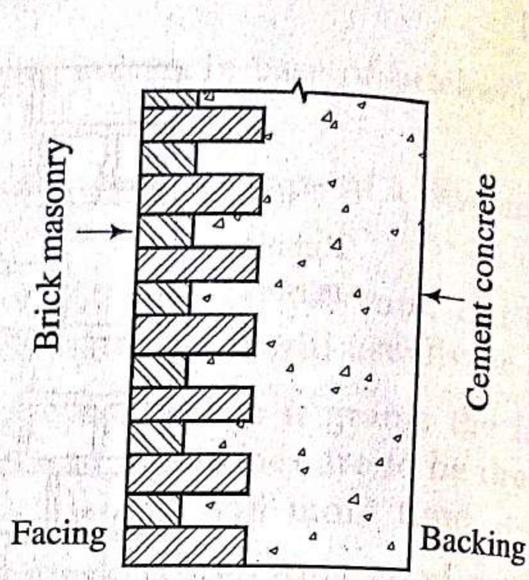
Fig. 11-49 shows the facing of stone slabs or tiles and backing of brickwork. It is desirable to use metal cramps to connect the facing and backing brickwork. The bricks should be laid in courses with proper bond.

Fig. 11-50 shows the facing of brickwork and backing of rubble masonry. This type of composite masonry is generally used at places where rubble stone is available in large quantities. The facing of the wall is done in bricks laid in courses and each alternate brick course consists of quoin header.

Fig. 11-51 shows the facing of brickwork and backing of cement concrete. The solid cement concrete wall can also be replaced by cement concrete blocks which may either be solid or hollow.



Composite masonry
FIG. 11-50



Composite masonry
FIG. 11-51

It is necessary to take extreme care during the construction of composite masonry. Otherwise unequal settlement, which is due to larger number of mortar joints in the inside than the outside of the wall, will take place. The measures adopted to prevent such unequal settlement are as follows:

(i) By using large number of through stones for stone composite masonry.

(ii) By providing metal cramps, dowels, lead plugs, etc. between facing and backing of the wall.

(iii) By constructing the backing or hearting portion in rich cement mortar.

(iv) By carrying up the facing and backing portions of the wall simultaneously.

Following are the *advantages* of composite masonry:

(1) Cost: The total cost of the structure is reduced, if composite masonry is adopted because the available materials can be used to achieve optimum economy.

(2) Durability: It is possible to provide materials of better quality and good workmanship in the facing work so as to minimize the effects of atmospheric agents on the wall. Thus, by adopting composite masonry, the structure can be made more durable.

(3) Appearance: By adopting composite masonry, the appearance of the structure can be considerably improved. For instance, the backing or hearting of a bridge or a culvert may be of concrete and the facing may be of stonework. Thus a massive appearance is obtained.

12-15. CAVITY WALLS

A *cavity wall* or a *hollow wall* consists of *two* separate walls, called *leaves* or *skins*, with a cavity or a gap in between them. The *two* leaves of the cavity wall may be of equal thickness or unequal thickness. The former arrangement is adopted for non-load bearing wall and in the latter arrangement, the internal leaf may be made thicker than the external leaf to meet with the structural requirements.

12-15-1. REASONS OF PROVIDING A CAVITY OR A HOLLOW SPACE IN A WALL

Following are the *reasons* of providing a cavity in a wall:

(1) **Prevention of dampness:** When cavity wall construction is adopted, there is considerable decrease in the penetration of dampness from outside to inside of the building.

(2) **Heat insulation:** The air in the cavity acts as a non-conductor of heat and hence the uniform temperature is maintained inside the building.

(3) **Sound insulation:** The considerable portion of external noise is not allowed to enter the inside of a building by adopting cavity wall construction.

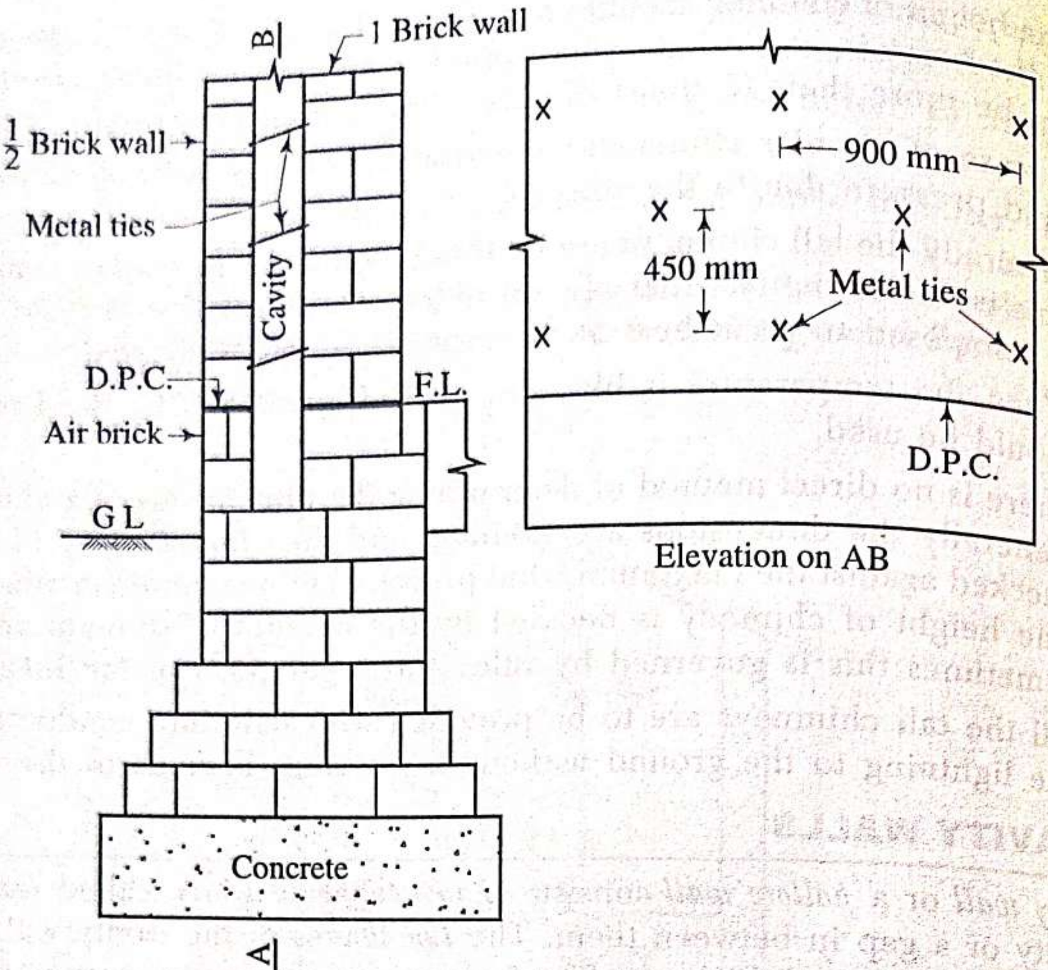
(4) **Load on foundation:** Due to less solid thickness of wall, the loads on foundation are considerably reduced.

(5) **Efflorescence:** The construction of a cavity wall results in the reduction of nuisance of efflorescence to a great extent.

(6) **Economical:** In addition to above-mentioned advantages, it is found that the construction cost of a cavity wall is about 20% less than the construction cost of a corresponding solid wall.

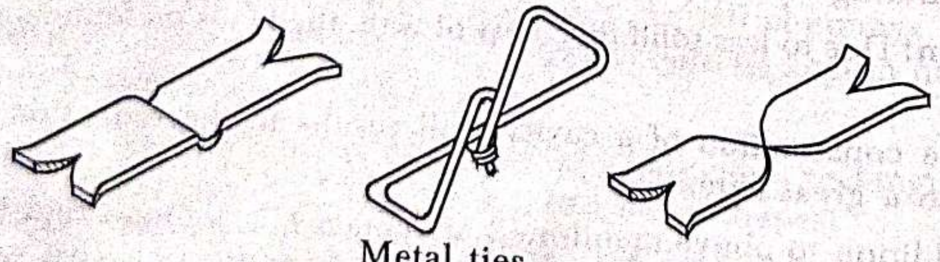
12-15-2. DETAILS OF CONSTRUCTION OF CAVITY WALL

A cavity wall is constructed of *two* leaves–inner and outer with a hollow space in between them as shown in fig. 12-31.

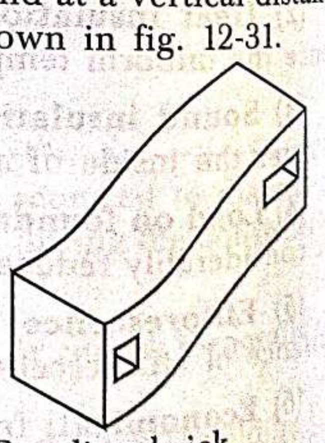


Cavity wall
FIG. 12-31

The width of cavity varies from 50 mm to 100 mm and it stands vertically. The outer wall is generally of ½ brick thickness and the inner wall may be of ½ or 1 brick thickness. The *two* portions of the wall are connected by means of metal ties or specially prepared bonded bricks. The metal ties and a bonding brick are shown in fig. 12-32 and fig. 12-33 respectively. The metal ties are generally of wrought iron or mild steel and they are coated with tar or galvanised so as to have protection against rust. Where corrosion is heavy, the metal ties of copper or bronze may be adopted. The metal ties are placed at a horizontal distance of 900 mm and at a vertical distance of 450 mm. The arrangement of ties is kept staggered as shown in fig. 12-31.



Metal ties
FIG. 12-32



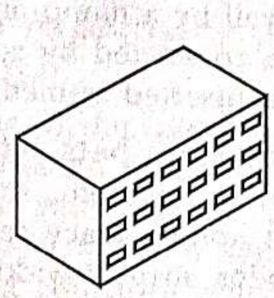
Bonding brick
FIG. 12-33

The outer wall is generally constructed in stretcher bond. But it may be constructed in the Flemish bond or English garden-wall bond or Flemish garden-wall bond by using bats for headers. As far as possible, there should be no intimate contact between the *two* leaves of the cavity wall.

12-15-3. FEATURES OF A CAVITY WALL

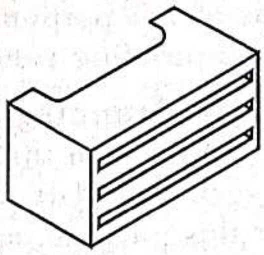
Following are the *features* of a cavity wall:

(1) **Ventilation:** It is necessary to provide enough ventilation to the hollow space of the cavity wall. This is achieved by providing openings at top and bottom of the wall so that a free current of air is established. The openings are to be fitted with gratings so that entry of rats and other vermins to the hollow space is prevented. Sometimes, the *air bricks*, as shown in fig. 12-34 and fig. 12-35, are used for this purpose.



Terra-cotta air brick

FIG. 12-34



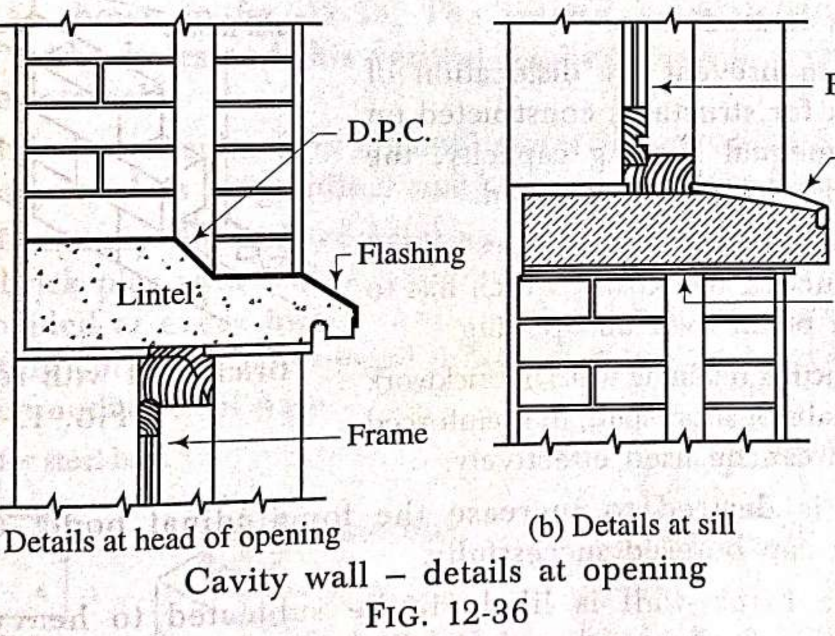
Cast-iron air brick

FIG. 12-35

(2) **Shape and slope of ties:** The metal ties which are used to connect the outer and inner portions should be so shaped and placed that water from outer portion does not pass along the inner portion. They should thus be sloped away from the inner portion as shown in fig. 12-31.

(3) **Construction at openings:** In the plan, the cavity is discontinued at the openings such as doors, windows, etc. The jambs of openings for doors and windows are constructed solid either in brickwork or with layers of slates or tiles. If metal windows are to be used, specially prepared metal frames can be used for this purpose.

Fig. 12-36 (a) shows the details at head of opening when a common R.C.C. lintel is provided. An inclined flexible D.P.C. is provided to act as a bridge over the cavity. The D.P.C. should extend lengthwise beyond the frame for a distance of about 150 mm on either side. Fig. 12-36(b) shows the details at the window sill.



(a) Details at head of opening (b) Details at sill

Cavity wall – details at opening

FIG. 12-36

(4) **Base:** The cavity may be started from the top of foundation concrete and the hollow space, upto a level of about 100 mm to 300 mm below the damp-proofing course at plinth level, may be filled with plain cement concrete of proportion 1:2:4. But, as the cavity below damp-proof course does not serve any purpose, the brickwork upto a level of 100 mm to 300 mm below the damp-proofing course at plinth level may be constructed solid as shown in fig. 12-31. The increased thickness of wall will also be helpful in supporting the load to be carried by the wall.

(5) **Construction at the top:** It is necessary to take adequate steps at top to prevent the entry of dampness to the inside portion of the wall. The cavity may be constructed upto the coping of the parapet wall or alternatively, it may be closed at the bottom of parapet wall by a damp-proofing course. In case of a pitched roof, the tops of *two* portions are connected by solid brickwork to support the roof truss and damp-proofing course is inserted immediately below this solid portion.

(6) **Dropping of mortar, bats, etc.:** During construction of a cavity wall, it should be seen that mortar, bats, etc., do not fall in the hollow space. The presence of such materials in the hollow space seriously affects the working of a cavity wall. For this purpose, a wooden strip of width slightly less than that of the hollow space, is supported on ties and it is raised as the work proceeds. Also, some bricks at the bottom are left out and bats, etc. falling in the cavity are removed from these holes. When the work is completed, this bottom portion is sealed by filling it with bricks. It should also be seen that the vermins or mosquitoes do not find access in the cavity.

(7) **Design:** The outside portion of a cavity wall should be treated only as protecting skin and not as a member of a load-bearing wall. The inside portion shou[ld] have sufficient thickness to carry safely the loads coming on it.

Chapter 20

FORMWORK

20-1. GENERAL

When concrete is placed, it is in a plastic state. It requires to be supported by temporary supports and casings of the desired shape till it becomes sufficiently strong to support its own weight. This temporary casing is known as the *formwork* or *forms* or *shuttering*. The term *moulds* is sometimes used to indicate formwork of relatively small units such as lintels, cornices, etc. For circular work such as arch, dome, etc., the term *centering* is generally used.

In the early days, the job of formwork was carried out by the carpenter with available timber and nails as best as possible with the approach of rule of thumb. The formwork techniques have also developed side by side along with the growth in the development of concrete construction. With the technological advancement and introduction of new materials of formwork, more rational approach is being made in the design of formwork.

In this chapter, the salient features and other relative items of the formwork will be discussed.

20-2. REQUIREMENTS OF FORMWORK

Following are the requirements of a good formwork:

(1) Easy removal	(5) Rigidity
(2) Economy	(6) Smooth surface
(3) Less leakage	(7) Strength
(4) Quality	(8) Supports.

Each requirement of formwork will now be briefly discussed.

(1) Easy removal: The design of formwork should be such that it can be removed easily with least amount of hammering. This will also prevent the possible injury to the concrete which has not become sufficiently hard. Further, if the removal of formwork is easy, it can be made fit for re-use with little expenditure.

The operation of removing the formwork is commonly known as the stripping and when the stripping takes place, the components of the formwork are removed and then re-used for another part of the structure. Such forms whose components can be re-used several times are known as the *panel forms.*

Sometimes the forms are prepared for individual non-standard members and structures. Such forms do not have repeatable elements.

In some cases, the formwork cannot be stripped from the structure and it forms part of the structure itself. All such forms are known as the stationary forms.

(2) **Economy:** It is to be noted that the formwork does not contribute anything to the stability of the finished structure and hence, it will be desirable to bring down its cost to a minimum consistent with safety. The various steps such as reduction in number of irregular shapes of forms, standardising the room dimensions, use of component parts of commercial sizes, putting the formwork in use again as early as possible, etc. may be taken to effect economy in the formwork. The formwork should be constructed of that material which is easily available at low cost and which can safely be re-used for severaltimes.

(3) **Less leakage:** The formwork should be so arranged that there is minimum of leakage through the joints. This is achieved by providing tight joints between adjacent sections of the formwork.

(4) **Quality:** The forms should be designed and built accurately so that the desired size, shape and finish of the concrete is attained.

(5) **Rigidity:** The formwork should be rigid enough so as to retain the shape without any appreciable deformation. For visible surface in the completed work, the deflection is limited to 1/300 of span and that for hidden surface, it is limited to 1/150 of span. It should be noted that a rigid formwork will be robust and stiff enough to allow repeated use.

(6) **Smooth surface:** The inside surface of formwork shouldbe smooth so as to turn out a good concrete surface. This is achieved by applying crude oil or soft soap solution to the inside surface of formwork. This also makes the removal of formwork easy.

(7) **Strength:** The formwork should be sufficiently strong enough to bear the dead load of wet concrete as well as the weights of equipments, labour, etc. required for placing and compacting the concrete. This requires careful design of the formwork. The over-estimation of loads results in expensive formwork and the under-estimation of loads results in the failure of formwork. The loads on vertical forms are to be assessed from various considerations such as density of concrete, dimensions of section, concrete temperature, slump of concrete, reinforcement details, stiffness of forms, rate of pouring of concrete, etc.

(8) **Supports:** The formwork should rest on sound, hard and non-yielding supports.

20-3. COST OF FORMWORK

The cost of formwork plays a significant role in the cost of concrete. It varies from 30% to 40% of the cost of concrete for ordinary structures and may go as high as 50% to 60% for special structures such as dams, bridges, etc.

The *four* components contributing to the total cost of formwork are as follows:

(i) cost of formwork material;
(ii) cost of erecting, placing and removal of formwork;
(iii) cost of joining material such as nails, wires, etc.; and
(iv) cost of labour for fabrication of formwork.

In general, it can be stated that careful watch should be kept on the cost of formwork and all attempts should be made to bring down the cost of formwork to a minimum so as to achieve overall economy in the concrete work.

20·4. MATERIALS USED FOR PREPARING FORMWORK

The usual materials which are employed in the preparation of formwork are steel and timber. The formwork is also sometimes prepared from aluminium, pre-cast concrete or fibre glass for cast-in-situ members involving curved surfaces.

(1) **Steel formwork:** The steel is used for formwork when it is desired to re-use the formwork several times. The initial cost of steel formwork is very high. But it proves to be economical for large works requiring many repetitions of the formwork. The erection and removal of steel formwork are simple and it presents a smooth surface on removal.

Following are the *advantages* of steel formwork over timber formwork:

(i) It can be re-used several times, nearly ten times more than timber formwork.

(ii) It does not absorb water from the concrete and hence, the chances of the formation of honey-combed surface are brought down to the minimum level.

(iii) It does not shrink or distort and hence, it is possible to achieve higher degree of accuracy and workmanship by its use as compared to the timber formwork.

(iv) It is easy to install and to dismantle and hence, there is saving in the labour cost.

(v) It gives excellent exposed concrete surfaces requiring no further finishing treatment. The surface obtained by the use of timber formwork invariably requires plastering for getting the desired finish of the concrete surface.

(vi) It possesses more strength and is more durable than the timber formwrok.

(vii) The design calculations for the steel formwork system can be made precisely because of the known characteristics of steel.

(2) **Timber formwork:** When formwork is required for small works requiring less repetitions, the timber is preferred to steel. The timber formwork is cheap in initial cost and it can be easily adopted or altered for a new use. The timber to be used as formwork should be well-seasoned, free from loose knots, light in weight and easily workable with nails without splitting.

Following facts in connection with the timber formwork should be remembered:

(i) The timber is to receive wet concrete. Hence, the timber formwork should be neither too dry nor too wet. If it is too dry, the timber will swell and get distorted when wet concrete is placed on it. This will affect the workability of concrete and honeycomb surface will appear on removal of the formwork. On the other hand, if it is too wet, the timber will shrink in hot weather resulting in gaps in the formwork through which concrete will flow out. Hence, the ridges will be formed on the concrete surface. It is found that a moisture content of about 20% is appropriate for the timber formwork.

(ii) The dimensions of components of the timber formwork will depend upon the loads to be carried and the availability of timber sections. But generally, the latter is the governing factor as the former can be adjusted by suitable spacing of the supports.

(iii) The minimum nails should be used in timber formwork and the nail heads should be kept projecting so as to facilitate easy removal.

(iv) The timber formwork proves to be economical for buildings with minimum number of variations in the dimensions of the rooms. Thus, the cutting of timber pieces is brought down to the minimum.

(v) It is the common practice to support formwork for slab in buildings with the timber ballies which are cut to approximate sizes with wedges below them for final adjustments. It leads to the formation of weak points which are seldom prevented from displacement. The timber ballies are generally not straight and they do not transmit the load axially.

The idea of using plywood as the formwork is becoming popular at present because it affords the following *advantages* over the timber formwork:

(i) The plywood formwork can be re-used several times as compared to ordinary timber formwork. Under normal conditions, the plywood formwork can be used for 20 times to 25 times and the timber formwork can be used for 10 times to 12 times.

(ii) The plywood formwork gives surfaces which are plain and smooth and hence, they may not require any further finishing treatment.

(iii) It is possible to cover up more area by using large size panel and hence, there is considerable reduction in the labour cost of fixing and dismantling of formwork.

20-5. FORMWORK FOR COLUMN FOOTINGS

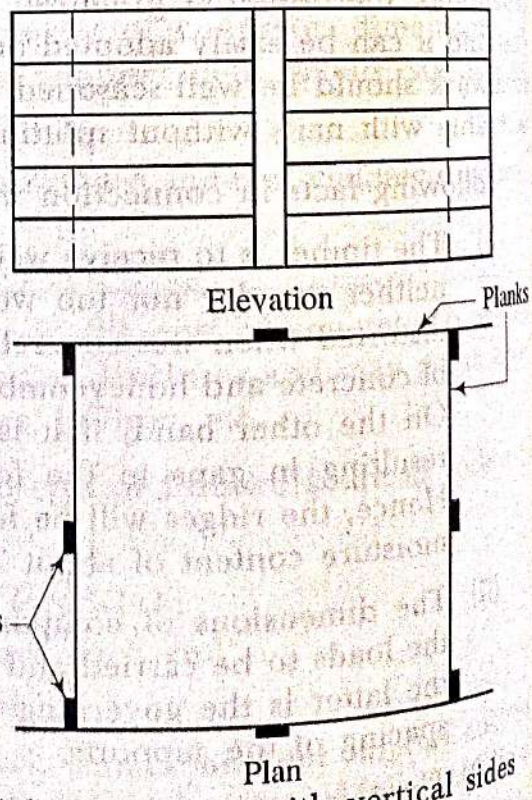
Depending upon the shape of the column footing, the formwork of suitable shape is to be provided to receive the concrete. The usual shape is square or rectangular and it is accompanied by vertical sides or steps or sloping sides.

Fig. 20-1 shows a column footing with vertical sides. A box of required dimensions is prepared from planks and one side of the box is made about 300 mm longer than the other. Suitable braces are provided to make the box rigid and strong.

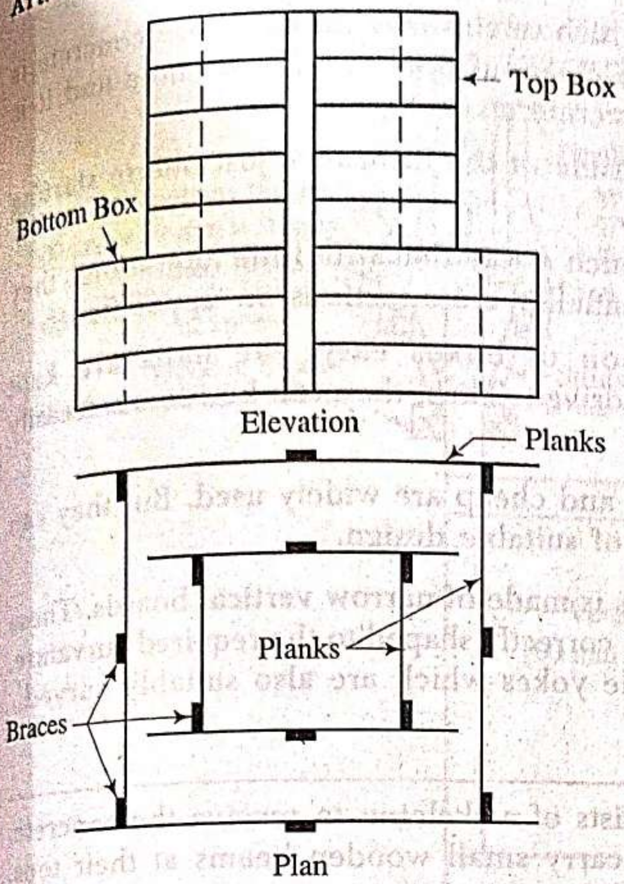
For further security, the opposite sides may be connected by wire fixed on nails before concrete is placed in the formwork. The wire will remain in the concrete when formwork is removed.

Fig. 20-2 shows a column footing with steps. It is just similar to above. The bottom box is filled with concrete and after a short time, the top box is placed on the surface of the wet concrete.

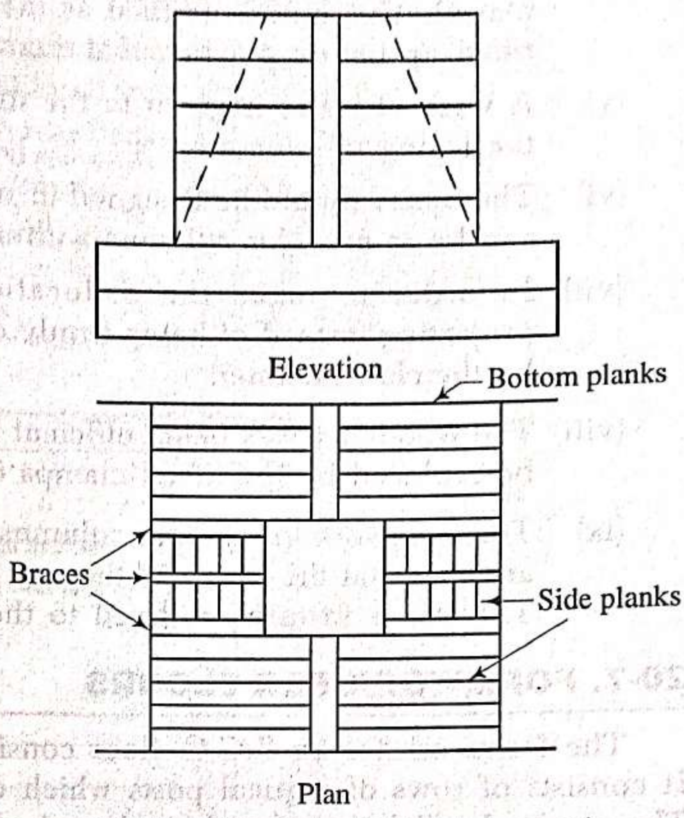
Fig. 20-3 shows a column footing with the sloping sides. The bottom planks are of required vertical sides and after placing footing reinforcement, the box of side planks is placed on the bottom planks and both are suitably connected. Sometimes, the concrete is placed upto the top of bottom planks before the box of side planks is placed in position.



Column footing with vertical sides
FIG. 20-1



Column footing with steps
FIG. 20-2



Column footing with sloping sides
FIG. 20-3

20-6. FORMWORK FOR COLUMNS

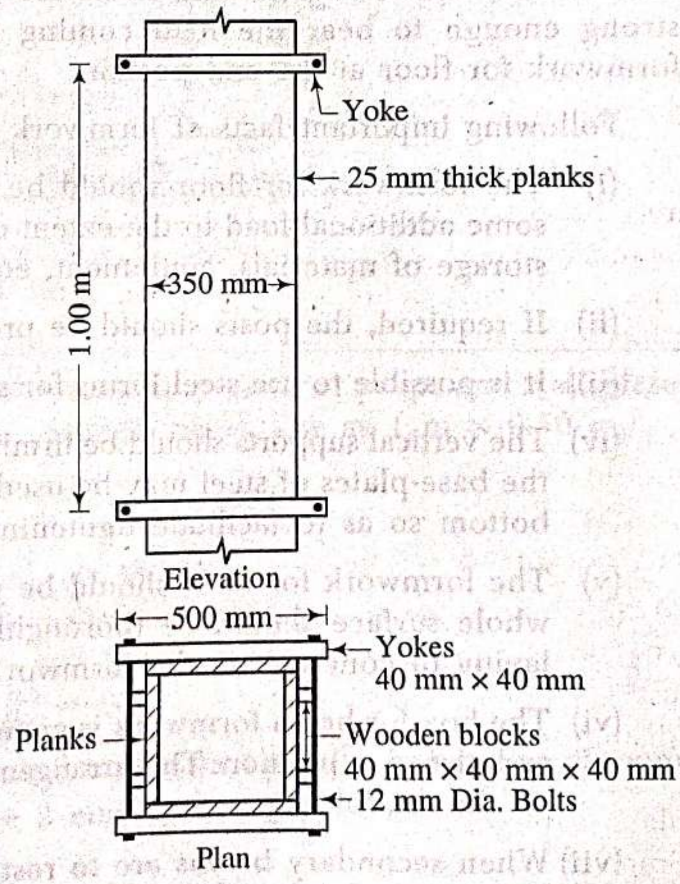
The column formwork consists of a box prepared from *four* separate sides. The *four* sides of the box are held in position by wooden blocks, bolts and yokes. Fig. 20-4 shows the details of formwork for an R.C.C. column of section 300 mm × 300 mm. The important features of the formwork for R.C.C. columns are:

(i) The formwork should be designed to resist the high pressure resulting from the quick filling of the concrete.

(ii) The spacing of yokes is about one metre. But it should be carefully determined by working out the greatest length of the formwork which can safely resist the load coming on the formwork.

(iii) Depending upon the shape of the column, the box can be suitably prepared.

(iv) A hole is generally provided at the bottom of the formwork



Formwork for column
FIG. 20-4

of column to remove the debris which might have fallen before concrete is placed. This hole is termed as the cleanout hole or washout hole and it is filled up before placing of the concrete starts.

(v) A wash of water is given to the inside of the formwork just before starting the laying of concrete.

(vi) The boxes should be designed in such a way that with little alterations, they can be re-used for columns with smaller cross-sections on upper floors.

(vii) In order to make the dislocation of boxes easy, the nails are kept projecting instead of being firmly driven. Thus, they can be removed easily by the claw hammer.

(viii) The wooden yokes being efficient and cheap are widely used. But they can be replaced by the metal clamps of suitable design.

(ix) The formwork for circular columns is made of narrow vertical boards. These are known as the *staves* and they are correctly shaped to the required curvature. The staves in turn are fixed to the yokes which are also suitably curved.

20-7. FORMWORK FOR FLOORS

The formwork for an R.C.C. floor consists of a skeleton to receive the concrete. It consists of rows of vertical posts which carry small wooden beams at their tops. The planks for slab are placed on these beams.

The boxes for beams are prepared from *two* sides and one bottom. The vertical posts are suitably supported by lateral supports. The laterals, tapering blocks, base-beams, wooden blocks and struts are provided to make the formwork for floor strong enough to bear the load coming upon it. Fig. 20-5 shows the details of formwork for floor at the end portion.

Following important facts of formwork for the floors should be remembered:

(i) The formwork for floor should be designed for the weight of concrete plus some additional load to the extent of about 30 per cent to provide for labour, storage of materials, equipment, etc.

(ii) If required, the posts should be provided with the diagonal braces.

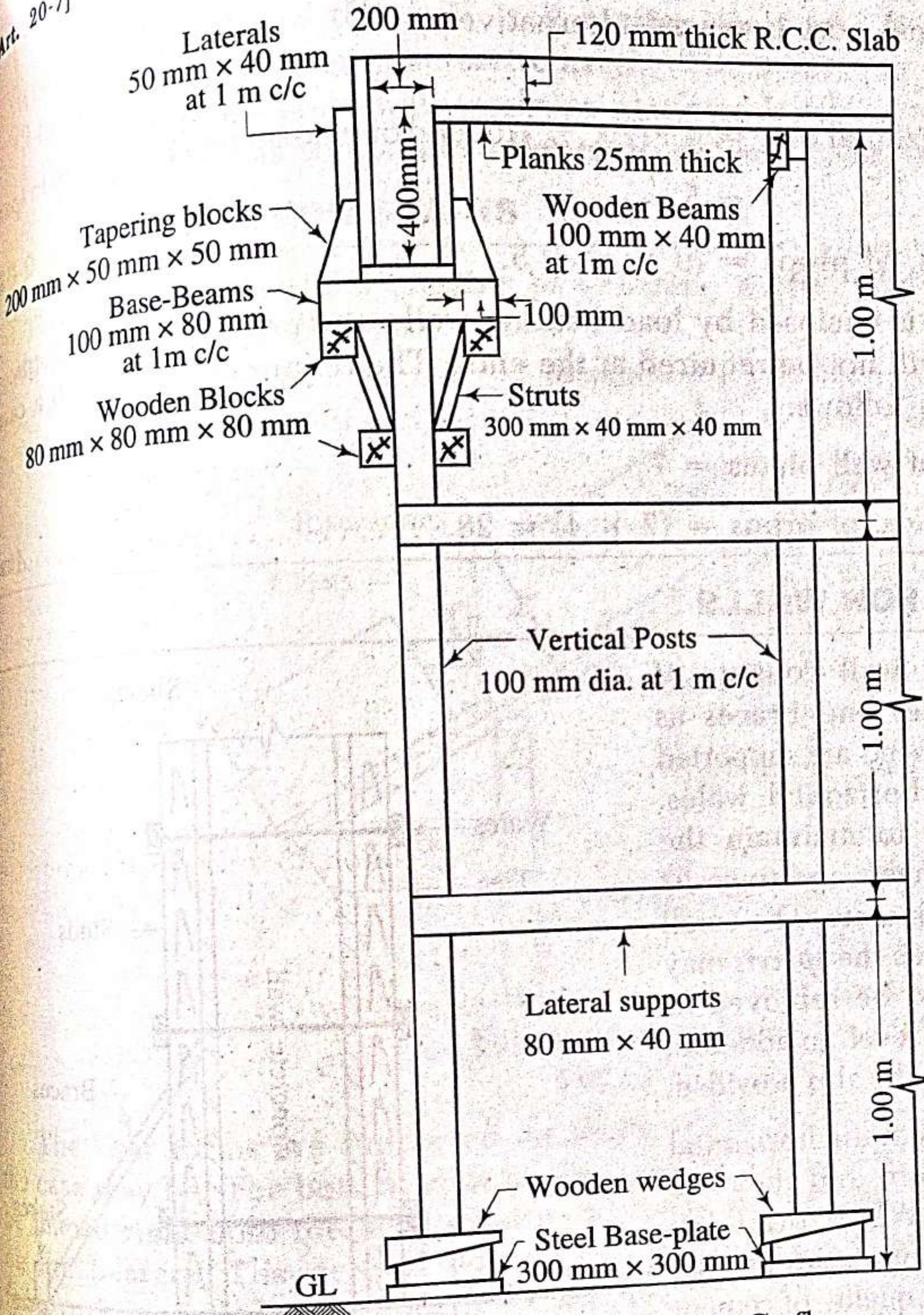
(iii) It is possible to use steel forms for slab, the other components being of wood.

(iv) The vertical supports should be firmly supported at the bottom. For this purpose, the base-plates of steel may be used. The wooden wedges are provided at the bottom so as to facilitate tightening or loosening of the post.

(v) The formwork for floor should be given necessary slope as required and the whole surface should be thoroughly cleaned with water before starting the laying of concrete on the formwork.

(vi) The box for beam formwork is generally prepared at ground level and hoisted and placed in position. This arrangement will avoid the construction of formwork on the scaffolding.

(vii) When secondary beams are to rest on the main beams, suitable openings at the correct positions are provided in main beams to receive the formwork of secondary beams.



Formwork for an R.C.C. floor
FIG. 20-5

20-12. REMOVAL OF FORMWORK

The operation of removing the formwork is commonly known as the *stripping*. The forms which can be conveniently re-used are known as the *panel forms*. The forms which cannot be re-used because of their non-standard shapes or which are meant for structures which do not require stripping are known as the *stationary forms*.

The formwork is to be removed only when the concrete has become sufficiently hard so that removal of formwork will not damage the structure. The length of time for which formwork should be kept in position depends on the following factors:

(i) amount and nature of dead load;

(ii) character and quality of concrete;

(iii) shape, span and situation of structure; and

(iv) temperature of the atmosphere.

In general, it may be mentioned that the formwork which is used merely to retain the concrete can be removed within 2 to 3 days as in case of sides of a concrete beam. But when the formwork is required to carry the whole weight of concrete, it becomes necessary to keep the formwork in position for a longer period. Thus, the formwork in case of floors and bottoms of beams is to be removed at least after 10 days and 21 days respectively. For slabs and beams, projecting in the form of cantilevers, the formwork should only be removed after making construction of the necessary counter-weight to balance the cantilever action. In general, it may be stated that the formwork should be kept as long as possible because it would assist the curing.

The quality of cement used in the preparation of concrete also greatly affects the period for which the formwork is to be kept in position. When rapid hardening cement is used, the formwork can be removed after 3 to 4 days and in case of high-alumina cement, this period is reduced to few hours only.

Chapter 14

SCAFFOLDING, SHORING AND UNDERPINNING

14-1. GENERAL

In the normal activities of the building construction, it becomes necessary to have some type of temporary structure or support so as to proceed with the work. These temporary arrangements take up the form of scaffolding, shoring and underpinning.

In this chapter, the salient features of scaffolding, shoring and underpinning will be discussed.

14-2. SCAFFOLDING

Definition: When the height above floor level exceeds about 1.50 m a temporary structure, usually of timber, is erected close to the work to provide a safe working platform for the workers and to provide a limited space for the storage of plant and building materials. The temporary framework is known as a *scaffolding* or simply a *scaffold* and it is useful in construction, demolition, maintenance or repair works.

14-3. COMPONENT PARTS OF A SCAFFOLDING

An ordinary scaffolding consists of the following parts:

(1) **Standards:** These are the vertical members of the framework and they are either supported on the ground or drums or embedded into the ground.

(2) **Ledgers:** These are the horizontal members parallel to the wall.

(3) **Putlogs:** These are the transverse pieces which are placed on the ledgers and which are supported on the wall at one end. They are at right angles to the wall.

(4) **Transoms:** These are putlogs, but their both ends are supported on the ledgers.

(5) **Braces:** These are the diagonal or cross pieces fixed on the standards.

(6) **Bridle:** This is a piece which is used to bridge an opening in a wall and it supports one end of the putlog at the opening.

(7) **Guard rail:** This is a rail provided like a ledger at the working level.

(8) **Toe board:** This is a board placed parallel to the ledgers and supported between the putlogs. It is provided to work as a protective measure on the working platform.

(9) **Raker:** This is an inclined support.

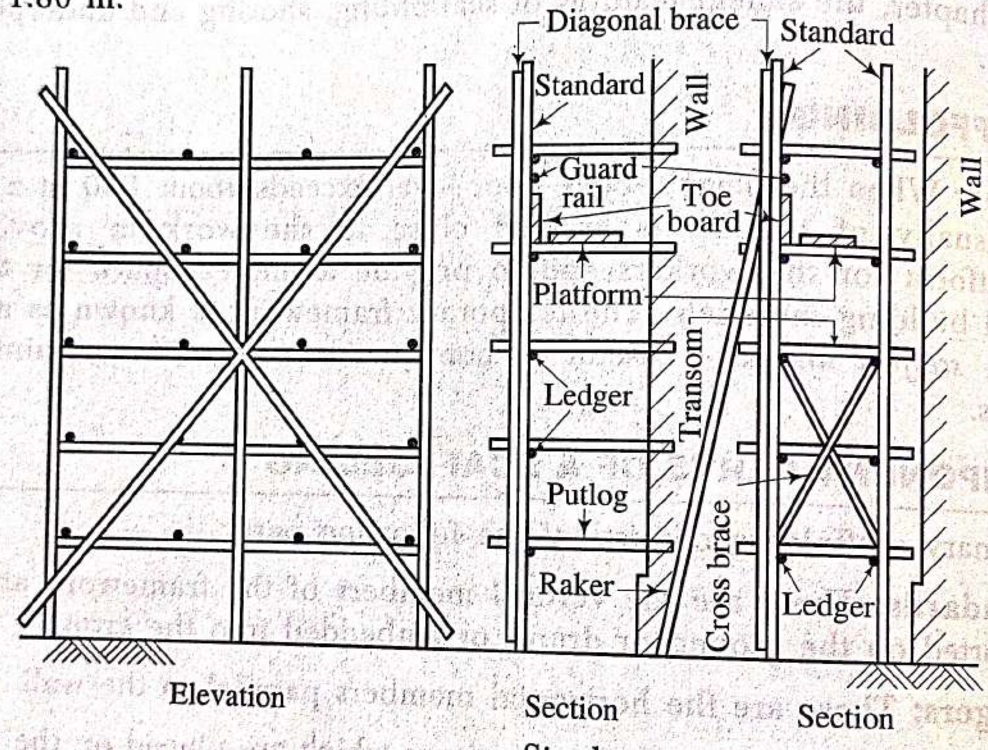
The various members of a scaffold are secured by means of devices such as nails, bolts, rope, etc.

14-4. TYPES OF SCAFFOLDING

Following are the types of scaffolding:

(1) Single scaffolding or bricklayer's scaffolding
(2) Double scaffolding or mason's scaffolding
(3) Cantilever or needle scaffolding
(4) Suspended scaffolding
(5) Trestle scaffolding
(6) Steel scaffolding
(7) Patented scaffolding.

(1) Single scaffolding or bricklayer's scaffolding (fig. 14-1 and fig. 14-2): This is the most common type of scaffolding and is widely used in the construction of brickwork. It consists of a single row of standards placed at a distance of about 1.20 m from the wall. The distance between the successive standards is about 2 m to 2.50 m. The ledgers are then fixed to the standards at a vertical distance of about 1.20 m to 1.80 m.



Scaffolding
FIG. 14-1

Single scaffolding
FIG. 14-2

Double scaffolding
FIG. 14-3

The putlogs, with one end on the ledger and the other end on the wall, are then placed at a horizontal distance of about 1.20 m to 1.80 m. The braces, guard rail and toe board are fixed as shown in fig. 14-1 and fig. 14-2. This type is also sometimes known as the *putlog scaffolding.*

(2) Double scaffolding or mason's scaffolding (fig. 14-3): This scaffolding is stronger than the single scaffolding and it is used in the construction of stonework. The framework is similar to the single scaffolding except that *two* rows of standards are provided. The distance between the face of the wall and the first row of standard is about 200 mm to 300 mm and the distance between the *two* rows is about one metre. The rakers and cross braces may be provided to make the scaffolding more strong as shown in fig. 14-3. This type is also sometimes known as an *independent scaffolding.*

(3) **Cantilever or needle scaffolding** (fig. 14-4 and fig. 14-5): This type of scaffolding is useful under the following circumstances:

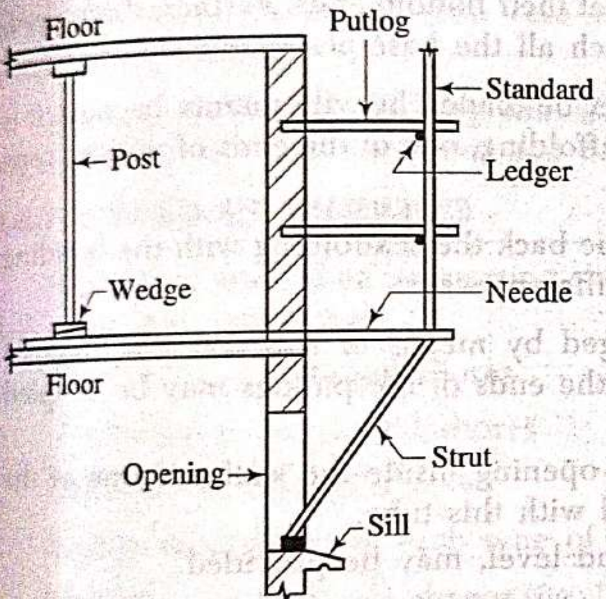
(i) The proper hard ground is not available for the standards to rest.

(ii) It is desired to keep the road or pavement near the face of wall, clear of obstruction caused by the scaffolding.

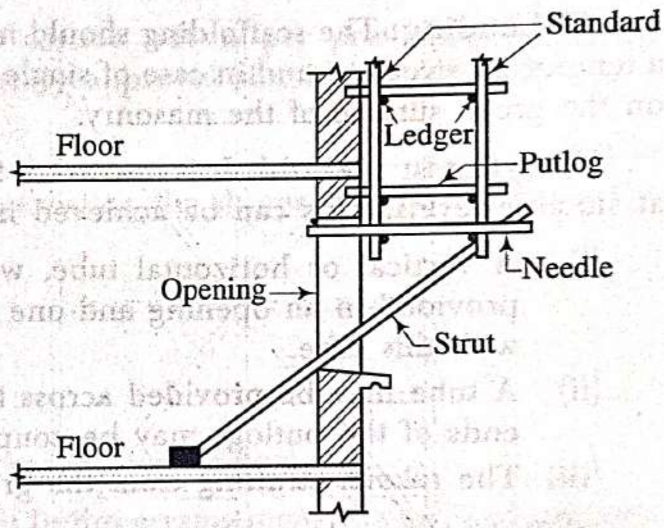
(iii) The construction work is to be carried out for upper parts of a multi-storeyed building.

In this type of scaffolding, the general framework may be of single scaffolding type or of double scaffolding type. But the standards are supported by a series of needles or ties which are taken out at floor levels or through openings or through holes kept in the masonry.

Fig. 14-4 shows a cantilever scaffolding of putlog type. The needles are supported at the floor levels and strutted through projections such as sills, cornices, string courses, etc. The inner end of the needle projects sufficiently inside and is well strutted between the floors as shown.



Cantilever scaffolding
FIG. 14-4



Cantilever scaffolding
FIG. 14-5

Fig. 14-5 shows a cantilever scaffolding of independent type. The needles are passing through the openings and are strutted on the floors through the openings as shown. The suitable timber blocks should be interposed at the ends of struts on the floor levels.

(4) **Suspended scaffolding:** This is a very light type of scaffolding and can be used only for the maintenance works such as painting, pointing, whitewashing, distempering, etc. The working platform is suspended from the roofs by means of ropes, wires or chains and arrangements are made such that the platform can be raised or lowered. This type of scaffolding does not create any obstruction on the ground and it is the most effective as it always provides the optimum level for working.

(5) **Trestle scaffolding:** In this type scaffolding, the working platform is supported on movable contrivances such as ladders, tripods, etc., mounted on wheels. This type of scaffolding is useful for minor repairs or painting work inside the rooms and the maximum height upto which this type of scaffolding can be adopted is about 5 m from the supporting surface.

(6) **Steel scaffolding:** In place of timber, the steel tubes can be effectively used for the scaffolding work. The diameter of the tubes is about 40 mm to 50 mm and the thickness is about 5 mm. The tubes are available in standard lengths with special couplings and set-screws. The *advantages* of steel scaffolding are manifold. The scaffolding can be used upto any height; it is strong and more durable; it can be easily erected and dismantled; it possesses high scrap value and it is resistant to fire. However the *disadvantages* are that the initial cost is high, it requires skilled labour and it also requires periodical painting.

(7) **Patented scaffolding:** Now-a-days, the various patented scaffoldings made of steel, with special types of couplings and frames, are available. Usually the working platform is supported on a bracket which can be adjusted to any suitable height.

14-5. POINTS TO BE ATTENDED TO IN SCAFFOLDING

Following important points should be carefully attended to in the scaffolding work:

(1) **Bedding of standards:** If standards are not resting on the firm ground, the base-plates of suitable size should be provided at their bottom ends. Further, if required, a timber sole plate may be provided on which all the base-plates rest.

(2) **Loading:** The scaffolding should never be loaded heavily mainly because it is a temporary structure and in case of single scaffolding, one of the ends of putlogs rests on the green surface of the masonry.

(3) **Tying-in scaffold:** It is necessary to tie back the scaffolding with the building at suitable levels. This can be achieved in different ways:

(i) A vertical or horizontal tube, wedged by means of a reveal pin, may be provided in an opening and one of the ends of the putlogs may be coupled with this tube.

(ii) A tube may be provided across the opening inside the wall and one of the ends of the putlogs may be coupled with this tube.

(iii) The rakers, strutting from the ground level, may be provided.

(4) **Raising:** As the work proceeds, the standards are suitably lengthened and fresh ledgers and putlogs are inserted. The working platforms are then shifted to new levels.

(5) **Finishing:** After the scaffolding is removed, the holes of putlogs in the wall should be immediately filled up.

(6) **Spacing of standards:** The loading on the scaffolding decides the spacing of standards. It is less for heavy loading and more for light loading. The maximum spacing is about 3 m.

(7) **Miscellaneous structures:** The scaffolding of special types should be built for miscellaneous structures such as chimneys, towers, domes, etc.

14-6. SHORING

Definition: Sometimes the structures are to be temporarily supported. This is achieved by what is known as the *shoring*. It is essential for structures which have become unsafe due to unequal settlement of foundations or due to removal of the adjacent building or due to any other reason. For safe structures, the shoring is required to prevent movements when certain additions and alterations are being carried out. The circumstances under which the shoring is required can be summarised as follows:

Chapter 15

DAMP-PROOFING, WATER-PROOFING AND TERMITE-PROOFING

15-1. GENERAL

In this chapter, the following *three* important treatments to be given to the buildings to control damp, water leakage and termites will be discussed:

(1) Damp-proofing

(2) Water-proofing

(3) Termite-proofing.

15-2. DAMP-PROOFING

Meaning of the term damp-proofing: One of the basic requirements in case of all the buildings is that the structure should remain dry as far as possible. If this condition is not satisfied, it is likely that the building may become unhabitable and unsafe from structural point of view. Hence, in order to prevent the entry of damp into a building, the courses, known as the *damp-proofing courses*, are provided at various levels of entry of damp into a building.

At present, practically all the buildings are given the treatment of damp-proofing. Thus the provision of damp-proofing courses prevents the entry of moisture from walls, floors and basement of a building. The treatment given to the roofs of a building for the same purpose is known as the *water-proofing* and it is discussed in this chapter

15-2-1. CAUSES OF DAMPNESS

The dampness in a building is a universal problem and the various *causes* which are responsible for the entry of dampness in a structure are as follows:

(1) **Rising of moisture from the ground:** The ground on which the building is constructed may be made of soils which easily allow the water to pass. Usually the building materials used for the foundations, absorb moisture by capillary action. Thus the dampness finds its way to the floors through the substructure.

(2) **Action of rain:** If the faces of wall, exposed to heavy showers of rain, are not suitably protected, they become the sources of entry of dampness in a structure. Similarly the leaking roofs also permit the rain water to enter a structure.

(3) **Exposed tops of walls:** The parapet walls and compound walls should be provided with a damp-proof course on their exposed tops. Otherwise the dampness entering through these exposed tops of such walls may lead to serious results.

(4) **Condensation:** The process of condensation takes place when warm humid air is cooled. This is due to the fact that cool air can contain less invisible water vapour than warm air. The moisture is deposited on the walls, floors and ceilings. This is the main source causing dampness in badly designed kitchens.

(5) Miscellaneous causes of dampness: There are various miscellaneous causes of dampness as mentioned below:

(i) If the structure is located on a site which cannot be easily drained off, the dampness will enter the structure.

(ii) The orientation of a building is also an important factor. The walls obtaining less sunshine and heavy showers of rain are liable to become damp.

(iii) The newly constructed walls remain damp for a short duration.

(iv) Very flat slope of a roof may also lead to the penetration of rain water which is temporarily stored on the roof.

(v) The dampness is also caused due to bad workmanship in construction such as defective rain water pipe connections, defective joints in the roofs, improper connections of walls, etc.

Thus the important sources of dampness can be summarised as follows:

(i) defective junctions between roof slab and parapet wall;

(ii) defective roof covering of the pitched roofs;

(iii) faulty eaves and valley gutters;

(iv) improper rain water pipe connections;

(v) inadequate roof slope;

(vi) moisture from wet ground below foundation;

(vii) splashing rain water;

(viii) unprotected tops of walls, parapets and compound walls; etc.

15-2-2. EFFECTS OF DAMPNESS

The building materials such as bricks, timber, concrete, etc., have a moisture content which is not harmful under normal circumstances. The rise in moisture content of these materials beyond a certain level from where it becomes visible or when it causes deterioration, leads to the real dampness. In absolute terms, the moisture content of different materials may be the same. But the acceptable limit differs from material to material. For instance, the presence of 10 per cent by weight of water in timber is not harmful. But the same level could saturate a brick or cause deterioration of plaster.

The structure is badly affected by dampness. The prominent effects of dampness are as follows:

(i) A damp building gives rise to breeding of mosquitoes and creates unhealthy conditions for those who occupy it.

(ii) The metals used in the construction of the building are corroded.

(iii) The unsighty patches are formed on the wall surfaces and ceilings.

(iv) The decay of timber takes place rapidly due to dry-rot in a damp atmosphere.

(v) The electrical fittings are deteriorated and it may lead to leakage of electricity and consequent danger of short circuiting.

(vi) The materials used as floor coverings are seriously damaged.

(vii) It promotes and accelerates the growth of termites.

(viii) It results in softening and crumbling of the plaster.

(ix) The materials used for wall decoration are damaged and it leads to difficult and costly repairs.

(x) The continuous presence of moisture in the walls may cause efflorescence which may result in disintegration of stones, bricks, tiles, etc. and the strength of wall is then reduced.

(xi) The floorings get loosened because of reduction in the adhesion when moisture enters through the floor.

(xii) The dampness combined with warmth and darkness breeds germs of dangerous diseases such as tuberculosis, rheumatism, etc. and the occupants may also become asthmatic.

15-2-3. REQUIREMENTS OF AN IDEAL MATERIAL FOR DAMP-PROOFING

Following are the requirements of an ideal material for the damp-proofing:

(i) The material should be durable. As a matter of fact, the damp-proof course should remain effective during the useful life of the building.

(ii) The material should be such that it remains steady and does not allow any movement in itself.

(iii) The material should be perfectly impervious.

(iv) The material should be capable of resisting safely the loads coming on it.

(v) The material should be flexible so that it is capable of accommodating the structural movements without any fracture.

(vi) The material should be dimensionally stable.

(vii) The material should be reasonably cheap.

(viii) The material should be such that it is possible to carry out leak-proof jointing work.

(ix) The material should be free from deliquescent salts like sulphates, chlorides and nitrates.

15-2-4. MATERIALS USED FOR DAMP-PROOFING

Following are the materials which are commonly used for the damp-proofing:

(1) **Hot bitumen:** This is a flexible material and is placed on the bedding of concrete or mortar. This material should be applied with a minimum thickness of 3 mm.

(2) **Mastic asphalt:** This is a semi-rigid material and it forms an excellent impervious layer for damp-proofing. The good asphalt is a very durable and completely impervious material. It can withstand only very slight distortion. It is liable to squeeze out in very hot climates or under very heavy pressure. It should be laid by experienced men of the specialist firms.

(3) **Bituminous felts:** This is a flexible material. It is easy to lay and is available in rolls of normal wall width. It is laid on a layer of cement mortar. An overlap of 100 mm is provided at the joints and full overlap is provided at all corners. The laps may be sealed with bitumen, if necessary. The bitumen felt can accommodate slight movements. But it is liable to squeeze out under heavy pressure and it offers little resistance to sliding. The material is available in rolls and it should be carefully unrolled, especially in cold weather.

(4) **Metal sheets:** The sheets of lead, copper and aluminium can be used as the membranes of damp-proofing.

The lead is a flexible material. The thickness of lead sheets should be such that its weight is not less than 200 N/m^2. The lead can be dressed to complex shapes without fracture and it possesses high resistance to sliding action. It is impervious to moisture and it does not squeeze out under ordinary pressure. It resists ordinary atmospheric corrosion. The surfaces of lead coming in contact with lime and cement are likely to be corroded and hence the metal should be protected by a coating of bitumen or of bitumen paint of high consistency.

The copper is a flexible material. It possesses higher tensile strength than that of lead. It is impervious to moisture and it does not squeeze out under ordinary pressure. It possesses high resistance to sliding action. The external walls, especially of stones, are likely to be stained when a damp-proof course of copper is adopted. The surfaces of copper coming in contact with mortars are likely to be affected. But, for normal use, the metal does not require any protective coating.

The aluminium sheets can also be used for damp-proofing. But they should be protected with a layer of bitumen.

(5) **Combination of sheets and felts:** A lead foil is sandwiched between asphalt or bituminous felt. This is known as the *lead core* and it is found to be economical, durable and efficient.

(6) **Stones:** The *two* courses of sound and dense stones such as granites, slates, etc. laid in cement mortar with vertical breaking joints can work as an effective damp-proofing course. The stones should extend for full width of the wall. Sometimes the stones can be fixed, as in case of roof surfaces, on the exposed faces of the wall, etc.

(7) **Bricks:** The dense bricks, absorbing water less than 4.50% of their weight, can be used for damp-proofing at places where the damp is not excessive. The joints are kept open. Such bricks are widely used when a damp-proofing course is to be inserted in an existing wall.

(8) **Mortar:** The mortar to be used for bedding layers can be prepared by mixing 1 part of cement and 3 parts of sand by volume. A small quantity of lime is added to increase the workability. For plastering work, the water-proof mortar can be prepared. It is prepared by mixing 1 part of cement, 2 parts of sand and pulverised alum at the rate of 120 N per m^3 of sand. In the water to be used, 0.75 N of soft soap is dissolved per litre of water and this soap water is then added to the dry mix. The mortar thus prepared is used to plaster the surfaces. Alternatively some patented water-proofing material such as Pudlo, Cido, Dempro, etc. may be added to the cement mortar.

(9) **Cement concrete:** A cement concrete layer in the proportion 1:2:4 is generally provided at the plinth level to work as a damp-proofing course. The depth of cement concrete layer varies from 40 mm to 150 mm. It stops the rise of water by capillary action and it is found to be effective at places where the damp is not excessive.

(10) **Plastic sheets:** The material is made of black polythene having thickness of about 0.50 mm to 1 mm with usual width of wall and it is available in roll lengths of 30 m. This treatment is relatively cheap but it is not permanent.

15-2-5. GENERAL PRINCIPLES OF DAMP-PROOFING

It should be remembered that when a damp-proof course is found to be ineffective, the fault usually lies in its position or location rather than the defects in the material. The general principles to be observed in case of all the damp-proofing methods are as follows:

(i) The damp-proofing course may be horizontal or vertical.

(ii) The horizontal damp-proofing course should cover the full thickness of the wall excluding rendering.

(iii) At junctions and corners of a wall, the horizontal damp-proofing course should be laid continuous.

(iv) The mortar bed which is prepared to receive the horizontal damp-proofing course should be even and levelled and free from projections so that the damp-proofing course is not damaged.

(v) The damp-proofing courses should be laid so as to make a continuous protection.

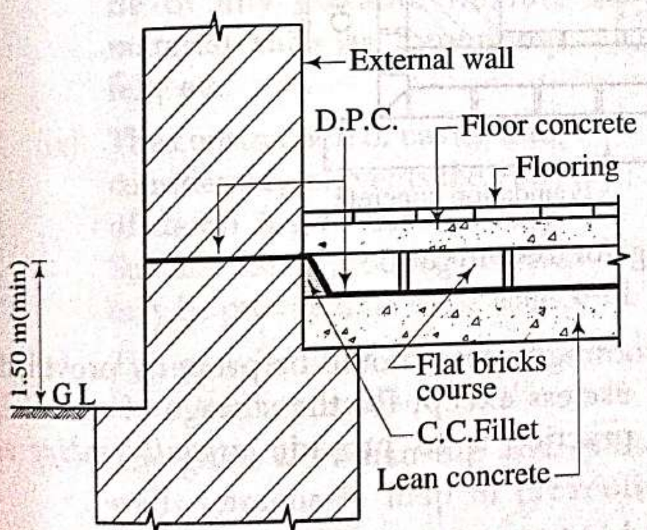
(vi) The damp-proofing course should not be kept exposed on the wall surface. Otherwise it is likely to be damaged by carpenters, tile layers, etc. during the finishing work.

(vii) When a horizontal damp-proofing course i.e. that of a floor is continued to a vertical face, a cement concrete fillet of about 75 mm radius should be provided at the junction.

15-2-6. METHODS OF DAMP-PROOFING

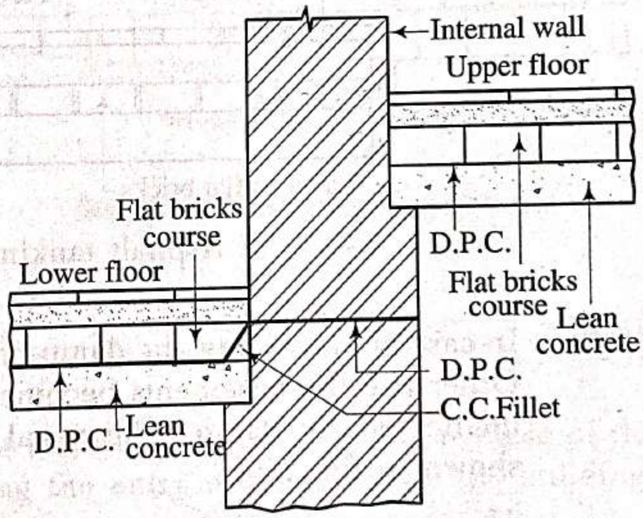
There are various methods of damp-proofing and depending upon the nature of surface, situation of the structure and amount of dampness, the proper method is selected. Following are the methods or measures adopted to prevent entry of dampness:

(i) It 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. 15-1. The material should be flexible and it should be stepped vertically through the wall to meet the damp-proofing course of the solid floor.



Damp-proofing of an external wall

FIG. 15-1

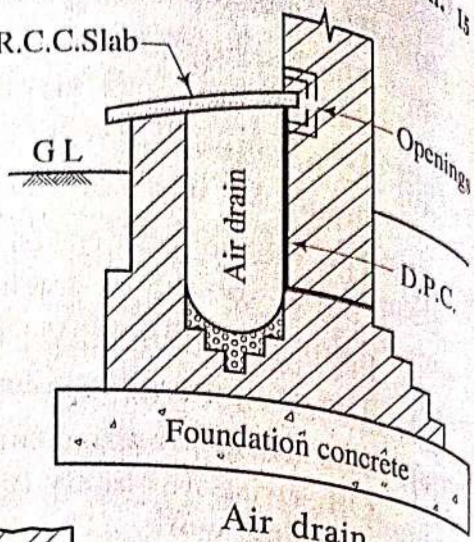


Damp-proofing of an internal wall

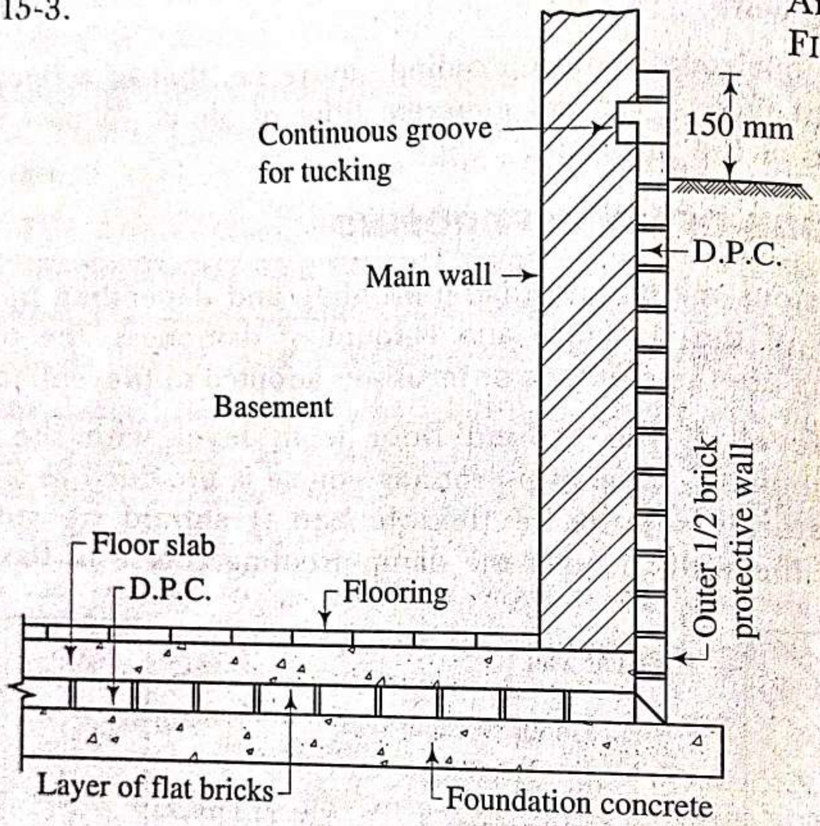
FIG. 15-2

(ii) If *two* ground floors at different levels are connected by an internal wall, the damp-proofing course may be provided as shown in fig. 15-2. It should be noted that the damp-proofing course on the internal wall is in level with the lower floor level.

(iii) In order to prevent the rising of moisture from the adjacent ground, the *air drains* may be provided as shown in fig. 15-3. An air drain is a narrow hollow space which is constructed parallel to the external wall. The width of air drain is about 200 mm to 300 mm. The openings with gratings are provided at regular intervals for the passage of air. The wall forming the air drain rests on the foundation concrete of the main wall and is carried about 150 mm above the ground level. The top of air drain is covered either by an R.C.C. slab or a stone and necessary arrangements are provided for the inspection of the air drain. The vertical and horizontal damp-proofing courses are provided as shown in fig. 15-3.



Air drain
FIG. 15-3



Asphalt tanking for basement
FIG. 15-4

(iv) In case of basements, the damp-proofing course should be properly provided. Otherwise the basements become useless except for the storage of materials unaffected by damp. The usual practice is to provide *asphalt tanking* as shown in fig. 15-4.

The important facts to be observed in case of asphalt tanking are as follows:

(a) The layer of asphalt should be continuous.

(b) The vertical end of asphalt layer may end in a horizontal damp-proofing course, if necessary.

(c) The vertical damp-proofing course should be taken above ground level for a minimum distance of 150 mm.

(d) The sequence of construction should be: inner wall, asphalt layer and protective wall. The reverse sequence may also be adopted but with less success.

(d) The damp-proof membrane, usually bituminous felt, is inserted immediately after the cut is made.

(e) The cycle of cutting the slot and inserting the damp-proof membrane is repeated till the entire length of wall is completed.

(f) The removed bricks are relaid and the surface is finished with plaster or pointing.

The above method of providing damp-proof course in an existing wall proves to be speedy, easy and economical. After the layer is laid, the height of exposed wall between the damp-proof layer and floor or ground level should be treated with suitable paint.

Chapter 17

ARCHES

17-1. GENERAL

The openings for doors, windows, ventilators, cupboards, wardrobes, etc., are invariably required in a wall. These openings are bridged by the provision of either an arch or a lintel. Thus the arch as well as the lintel are structural members which are designed to support the loads of the portion of wall above the openings and to transmit such loads to the ends of walls or piers or jambs or columns over which they are supported.

In this chapter, the various aspects of arches will be discussed and the topic of lintel will be described in the next chapter.

17-2. DEFINITION

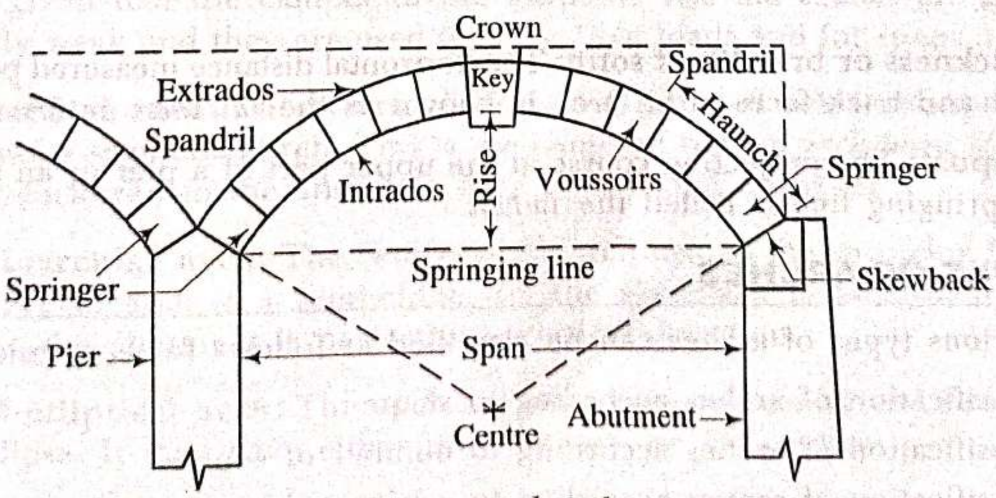
An *arch* is a structure which is constructed to span across an opening. It generally consists of small wedge-shaped units which are joined together with mortar. However the arches made of steel and R.C.C. are built in single units without the use of wedge-shaped units and they are used for the bridge construction.

17-3. TECHNICAL TERMS

Fig. 17-1 shows the various elements of a segmental arch. The definitions of technical terms used in connection with the archwork are as follows:

(1) **Intrados:** This is the inner curve of the arch.

(2) **Soffit:** This is the inner surface of the arch. Sometimes the terms, intrados and soffit are treated as synonymous.



Segmental arch

FIG. 17-1

(3) **Extrados or back:** This is the external curve of an arch.

(4) **Voussoirs:** These are the wedge-shaped units forming the courses of an arch.

(5) **Skewback:** This is the inclined or splayed surface on the abutment. It is prepared to receive the arch and from it, springs the arch.

(6) **Springer:** This is the first voussoir at springing level on either side of an arch and it is immediately adjacent to the skewback.

(7) **Crown:** This is the highest point of the extrados.

(8) **Key:** This is the wedge-shaped unit at the crown of an arch. It is sometimes made prominent by making it of a larger section and projecting it below and above the outlines of an arch.

(9) **Abutment:** This is the end support of an arch.

(10) **Piers:** These are the intermediate supports of an arcade.

(11) **Springing points:** These are the points from which the curve of an arch springs.

(12) **Springing line:** This is the imaginary horizontal line joining the two springing points.

(13) **Span:** This is the clear horizontal distance between the supports.

(14) **Rise:** This is the clear vertical distance between the highest point on the intrados and the springing line.

(15) **Centre:** This is the geometrical centre of the curve of an arch.

(16) **Ring:** This is the circular course forming an arch.

(17) **Depth or height:** This is the perpendicular distance between the intrados and extrados.

(18) **Spandril:** This is the irregular triangular space formed between the extrados and the horizontal line drawn tangent to the crown.

(19) **Haunch:** This is the lower half portion of the arch between the crown and the skewback.

(20) **Arcade:** This is a row of arches supporting a wall above and being supported by the piers.

(21) **Thickness or breadth of soffit:** The horizontal distance measured perpendicular to the front and back faces of an arch is known as the *thickness* or *breadth of soffit*.

(22) **Impost:** The projecting course at the upper part of a pier or an abutment to stress the springing line is called the *impost*.

17-4. TYPES OF ARCHES

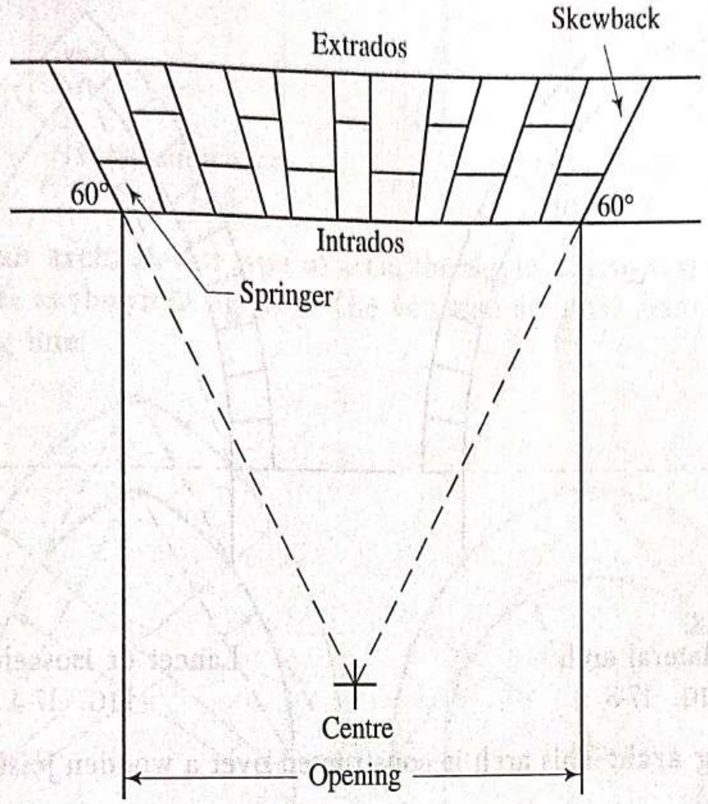
The various types of arches can be classified as follows for convenience:

(1) Classification of arches according to shape
(2) Classification of arches according to number of centres
(3) Classification of arches according to workmanship
(4) Classification of arches according to materials of construction.

17-4-1. CLASSIFICATION OF ARCHES ACCORDING TO SHAPE

According to shape, the arches are classified as follows:

(1) **Flat arch:** The apparent shape of this arch is flat and usually the skewback forms an angle of 60° with the horizontal as shown in fig. 17-2.



Flat arch
FIG. 17-2

Thus an equilateral triangle is formed with one side as intrados. The depth of a flat arch is invariably made equivalent to some courses of masonry. The intrados is given a slight rise or camber of about 10 mm to 15 mm per metre width of the opening so as to allow for slight settlement of the arch. The extrados is kept perfectly horizontal or sometimes, in order to prevent it from becoming hollow when arch settles, it is given half the camber of the intrados. The flat arches are found to be comparatively weak and they are used only for light loads and for spans upto 1.50 m.

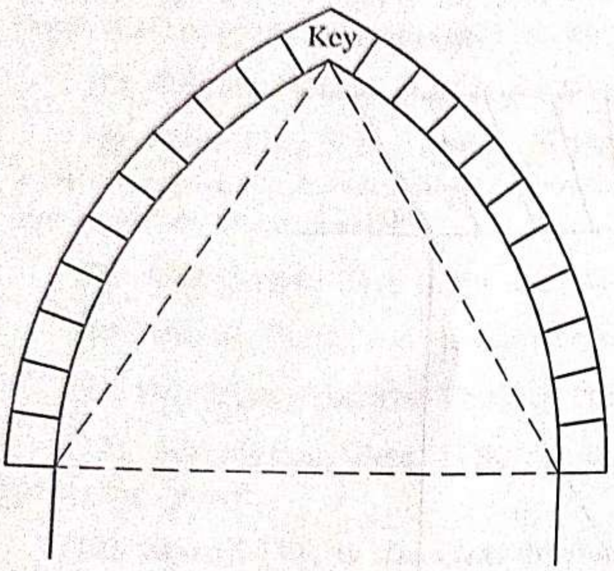
(2) **Segmental arch:** The centre of the arch is situated below the springing line. Fig. 17-1 shows a segmental arch. This is the common type of arch used for buildings. The thrust transferred to the abutment is in an inclined direction.

(3) **Semi-circular arch:** The centre of the arch lies on the springing line and the shape of curve of arch is a semi-circle. As the skewback is horizontal, the thrust transferred to the abutment is perfectly in vertical direction.

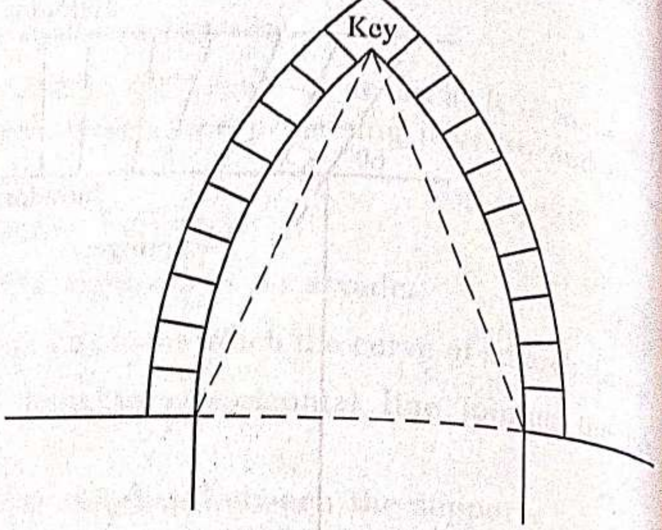
(4) **Semi-elliptical arch:** This arch has more than one centre and its shape is that of a semi-ellipse. It may have either three centres or *five* centres.

(5) **Inverted arch:** This arch is constructed to increase the bearing power of the soil and is already discussed in chapter 5.

(6) Pointed arch: This type of arch consists of *two* curves which are meeting at the apex of a triangle. The triangle formed may be equilateral or isosceles as shown in fig. 17-3 and fig. 17-4 respectively. The latter type is known as the *Lancet arch*. The centres of the arch may be on or below the springing line and they may be in between or outside the springing points. In equilateral arch, the centres will be on the springing points.



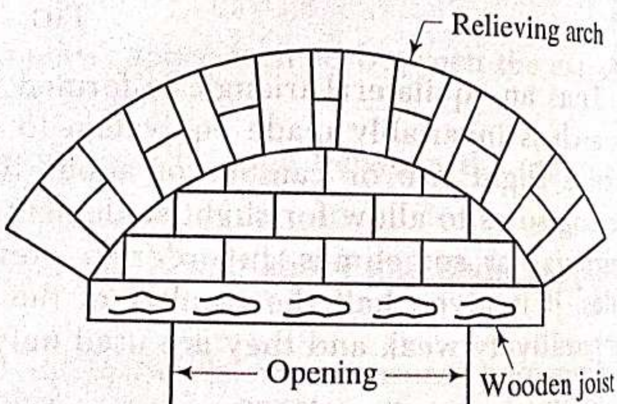
Equilateral arch
FIG. 17-3



Lancet or isosceles arch
FIG. 17-4

(7) Relieving arch: This arch is constructed over a wooden joist or a flat arch as shown in fig. 17-5.

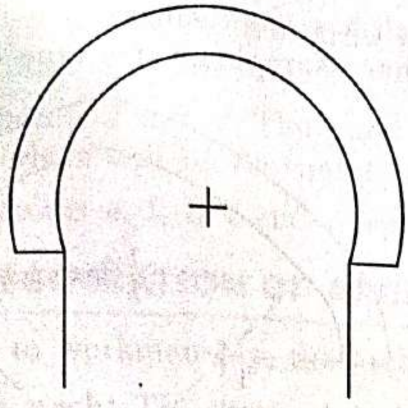
Thus it relieves the joist or flat arch from carrying the load. The ends of a relieving arch should be kept sufficiently inside the solid wall or there should be enough cover beyond the end of joist, opening or portion to be strengthened by the relieving arch. Thus the span of the relieving arch will be equal to the clear span of the opening plus twice the bearing of wooden joist which is being relieved from taking the load. The relieving arch makes it possible to replace the existing decayed or damaged wooden lintel without disturbing the stability of the existing structure.



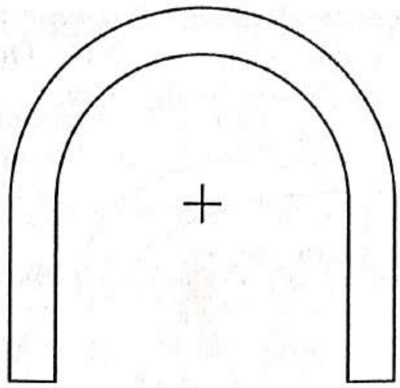
Relieving arch
Fig. 17-5

(8) Horse-shoe arch: This arch has the shape of a horse-shoe as shown in fig. 17-6 and it is mainly adopted from architectural considerations. The shape of the arch includes more than a semi-circle.

(9) Stilted arch: This type of arch has a semi-circular shape attached at the tops of *two* vertical portions as shown in fig. 17-7. The springing line of arch passes through the tops of vertical portions.

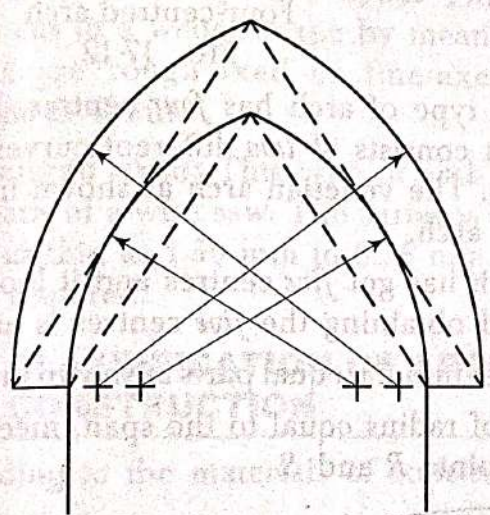


Horse-shoe arch
FIG. 17-6

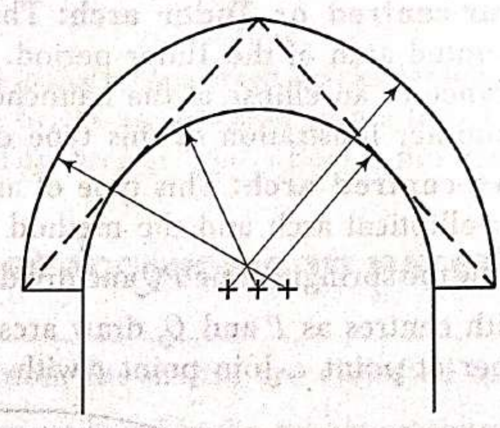


Stilted arch
FIG. 17-7

(10) **Venetian arch:** In this type of arch, the depth at crown is more than that at the springing line as shown in fig. 17-8. The venetian arch has *four* centres, all located on the springing line.



Venetian arch
FIG. 17-8



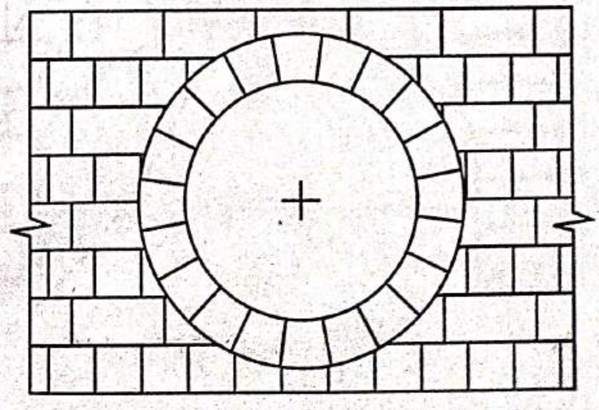
Florentine arch
FIG. 17-9

(11) **Florentine arch:** This type of arch is similar to the venetian arch except that the intrados has the shape of a semicircular curve as shown in fig. 17-9. There are *three* centres for a florentine arch, all located on the springing line.

17-4-2. CLASSIFICATION OF ARCHES ACCORDING TO NUMBER OF CENTRES

According to number of centres, the arches are classified as follows:

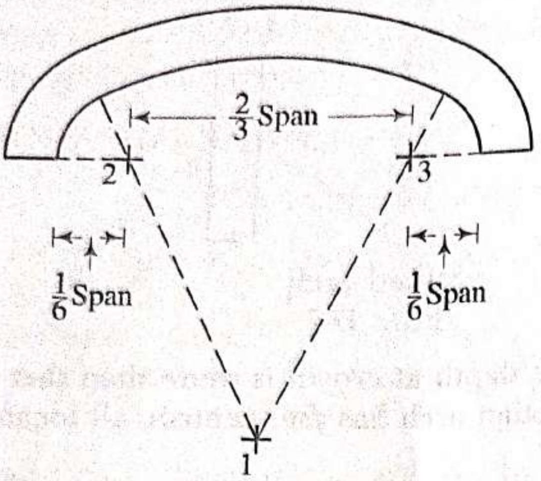
(1) **One-centred arch:** This type of arch has *one* centre only. The flat, segmental, semi-circular, horse-shoe and stilted arches are one-centred. Sometimes the circular windows are used to have an architectural effect. For this purpose, a bull's eye arch, as shown in fig. 17-10, is adopted.



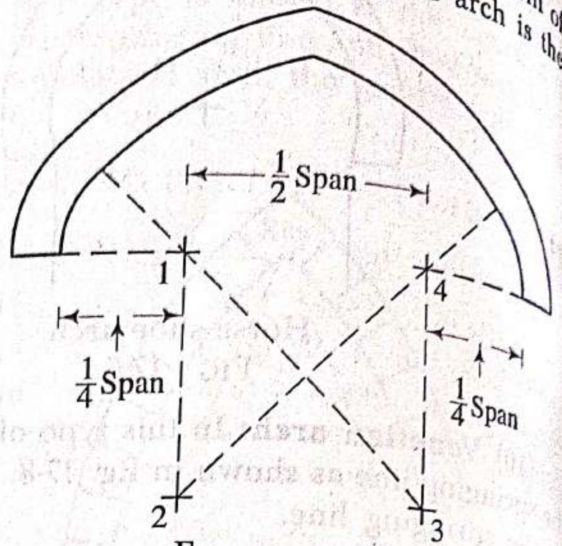
Bull's eye arch
FIG. 17-10

(2) **Two-centred arch:** This type of arch has *two* centres. A pointed arch is a good example of this type of arch.

(3) **Three-centred arch:** This type of arch has *three* centres. It is in the form of a semi-ellipse as shown in fig. 17-11. The other example of this type of arch is the florentine arch as shown in fig. 17-9.



Three-centred arch
FIG. 17-11



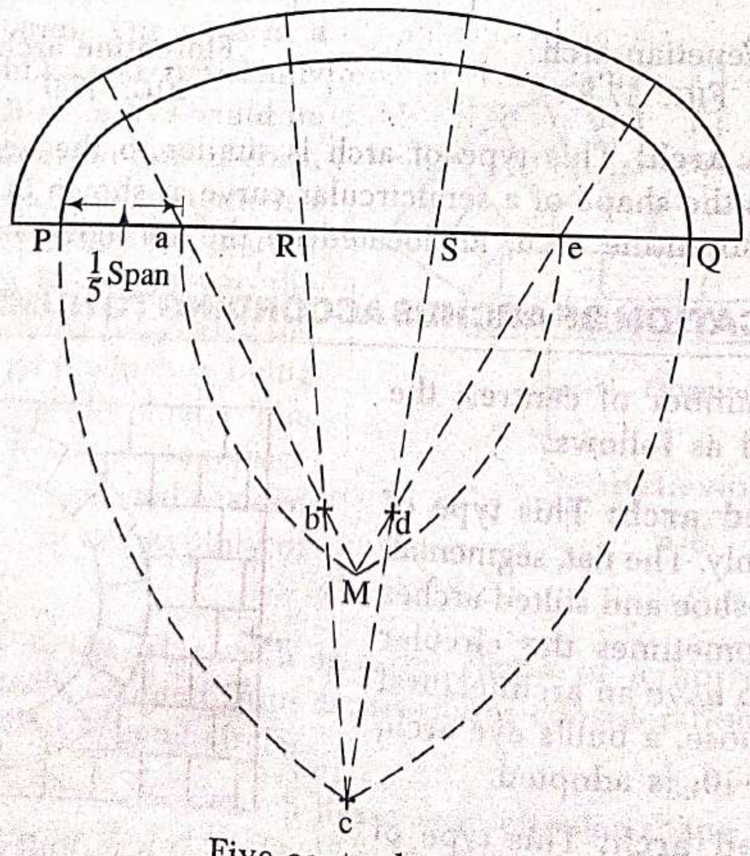
Four-centred arch
FIG. 17-12

(4) **Four-centred or Tudor arch:** This type of arch has *four* centres. Fig. 17-12 shows a pointed arch of the Tudor period. It consists of *two* different curves and has the appearance of an ellipse at the haunches. The venetian arch as shown in fig. 17-8 provides another illustration of this type of arch.

(5) **Five-centred arch:** This type of arch has got *five* centres and it looks nearly like a semi-elliptical arch and the method of obtaining the *five* centres is as follows:

(i) Draw the springing line *PQ* and divide it into *five* equal parts as shown in fig. 17-13.

(ii) With centres as *P* and *Q*, draw arcs of radius equal to the span, meeting each other at point *c*. Join point *c* with points *R* and *S*.



Five-centred arch
FIG. 17-13

(iii) With centres as *a* and *e*, draw arcs of radius equal to *three* divisions meeting each other at point *M*.

(iv) Join points *a* and *M*. The point of intersection of lines *aM* and *cR* is point *b*. Similarly *d* will be the point of intersection of lines *eM* and *cS*.

(v) The points *a*, *b*, *c*, *d* and *e* represent *five* centres of the arch.

17-4-3. CLASSIFICATION OF ARCHES ACCORDING TO WORKMANSHIP

According to workmanship, the arches are classified as follows:

(1) **Rough arch:** This type of arch is constructed from ordinary uncut bricks. As the bricks are rectangular in shape, the mortar joints become wider at the extrados than at the intrados. In order to prevent the thick end of mortar to become too large, such arches are constructed in rings of half-bricks. A rough arch is used where appearance is of secondary importance or when it is intended to plaster the face of the arch.

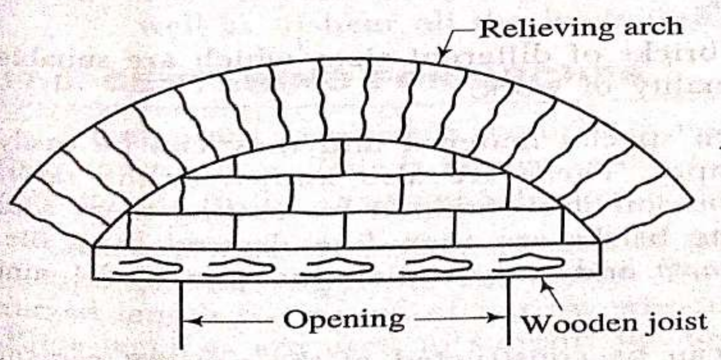
(2) **Axed or rough-cut arch:** This type of arch is constructed from bricks which are cut to a wedge-shape by means of an axe. According to class of the work, the bricks are rough-axed or fine-axed. The thickness of mortar joints varies from 3 mm to 6 mm.

(3) **Gauged arch:** This type of arch is constructed from bricks which are finely cut by means of a wire saw. The surfaces of bricks are finished with a file. The mortar joints are as thin as 1.50 mm to 0.75 mm. This arch is used where a fine finish of the surface is required.

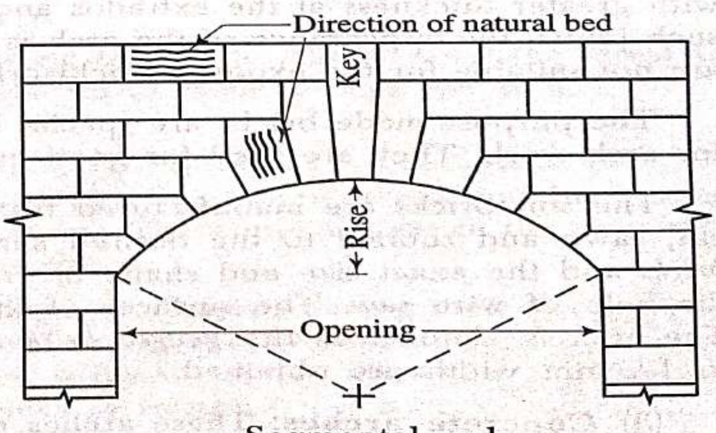
17-4-4. CLASSIFICATION OF ARCHES ACCORDING TO MATERIALS OF CONSTRUCTION

According to the materials of construction, the arches are classified as follows:

(1) **Stone arches:** These arches can be constructed in the rubble masonry or ashlar masonry. The rubble masonry arch is comparatively weak and hence it is used for inferior type of work. The span of rubble masonry stone arch is limited to about 1 m or so. Fig. 17-14 shows a stone relieving arch in rubble masonry.



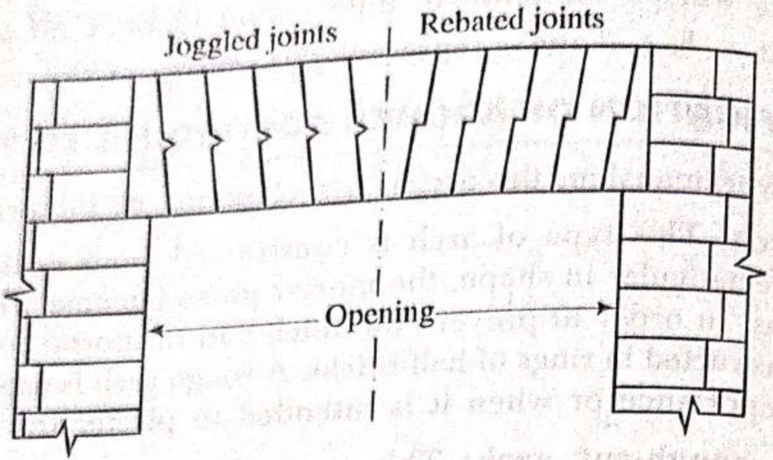
Relieving arch
FIG. 17-14



Segmental arch
FIG. 17-15

The stone arches in ashlar masonry are constructed from the wedge-shaped stones. A segmental arch in ashlar masonry is shown in fig. 17-15.

In order to strengthen flat stone arches in ashlar masonry, the rebated or joggled joints are sometimes provided as shown in fig. 17-16.



Flat arch
FIG. 17-16

The number of voussoirs required and their corresponding sizes can be worked out by setting out the arch on a level platform. The size of keystone can then also be known.

It should always be remembered that the stones should be laid or fixed with their natural bedding planes normal to the direction of pressure. This is due to the fact that thrust in an arch is passed from voussoir to voussoir and hence the natural bedding planes should be parallel to the radiating centre-line of the voussoir as shown in fig. 17-15.

(2) **Brick arches:** These arches can be constructed from ordinary bricks or purpose-made bricks or soft bricks.

The ordinary bricks are not cut to the shape of voussoirs and hence the rough brick arches are formed. For getting the arch curve, the joints are made wedge-shaped with greater thickness at the extrados and smaller thickness at the intrados. Due to such joints, the appearance of the arch is spoiled and hence the rough brick arches are not suitable for the exposed brickwork.

The purpose-made bricks are special bricks of different sizes which are suitable for arch work. They are used for good quality of work.

The soft bricks are manufactured from special material and they can be easily cut, sawn and rubbed to the desired shapes. These are also known as the *rubber bricks* and the exact size and shape of voussoir are obtained by cutting them with the help of wire saw. The surfaces of the bricks are then fine dressed by a file. The arch is known as the *gauged brick arch* and truly radial thin joints of 1 mm to 1.5 mm width are obtained.

(3) **Concrete arches:** These arches can be constructed of the pre-cast cement concrete blocks or monolithic concrete. The blocks are similar to stones and are prepared by casting cement concrete in specially prepared moulds. The monolithic concrete arches are constructed from cast-in-situ concrete and are suitable for big spans. Hence they are employed in the construction of culverts and bridges.

17-5. STABILITY OF AN ARCH

An arch transmits the super-imposed load to the abutments or piers or side walls through the combined action of friction between the surfaces of voussoirs and the cohesion of mortar. Every element of an arch remains in compression and it has also to bear the transverse shear. Following are the *four* ways of failure of an arch:

(1) **Crushing of the masonry:** In this case, the compressive stress or thrust exceeds the safe crushing strength of the materials and the arch fails due to crushing of the masonry. The measures to avoid failure of arch due to this reason are as follows:

(i) The material used for construction should be of adequate strength.

(ii) The size of voussoirs should be properly designed to bear the thrust transmitted through them.

(iii) The height of voussoirs should not be less than one-twelfth of the span. If the span exceeds 6.50 m, the thickness of arch ring may be increased by about 20% of the thickness at the crown.

(iv) If necessary, the voussoirs of variable heights may be provided i.e. less height near crown and more height at skewback.

(2) **Rotation of some joint about an edge:** To prevent the rotation of joint, the line of resistance should be kept within intrados and extrados. The line of thrust should also be made to cross the joint away from the edge so as to prevent the crushing of that edge. It should fall within middle-third portion of the arch height.

(3) **Sliding of voussoir:** To safeguard against the sliding of adjacent voussoirs due to transverse shear, the voussoirs of greater height should be provided. It should also be seen that the angle between the line of resistance of the arch and the normal to any point is less than the angle of internal friction.

(4) **Uneven settlement of abutment or pier:** The secondary stresses in the arch are developed due to the uneven settlement of the supports of arch and to avoid such conditions, the following *precautions* should be taken:

(i) The arch should be symmetrical so that unequal settlements of the *two* abutments or abutment and pier are minimized.

(ii) The supports of arch should be strong enough to take or resist the thrust as well as to bear all the loads transferred to them through the arch.

17-6. CENTERING FOR ARCHES

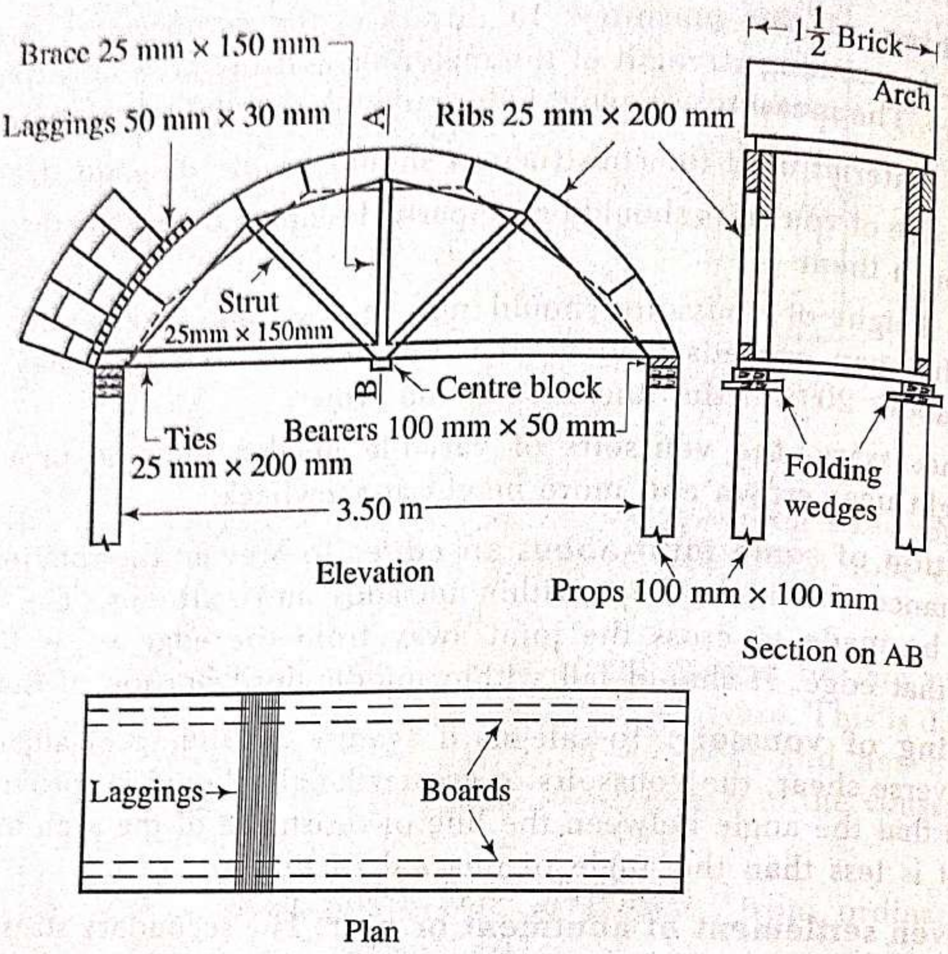
A temporary structure is required to support brick, stone or concrete arches during their construction. This is known as the *centering*. The upper surface of the centering corresponds to the shape of intrados of the arch.

The centering for arches consists of *two* parallel boards having their upper edges shaped to the required curvature. The boards are connected through their curved length by means of narrow wooden strips which are known as the *laggings*. These laggings are used to support the bricks or stones.

The centering is supported by props at each end. The boards are prepared from *two* ribs whose thickness varies from 25 mm to 40 mm and whose width varies from 200 mm to 300 mm. The struts and braces are provided to strengthen the ribs and horizontal ties are provided at the lower ends of the ribs to prevent them from spreading.

The ties are generally 25 mm to 50 mm thick and 200 mm to 250 mm wide. The bearers support the ribs and a pair of folding wedges is provided at the top of each prop to tighten or to loosen the centering.

Fig. 17-17 shows an arch centering for a span of 3.50 m and of width equal to 1½ bricks thickness.



Arch centering
FIG. 17-17

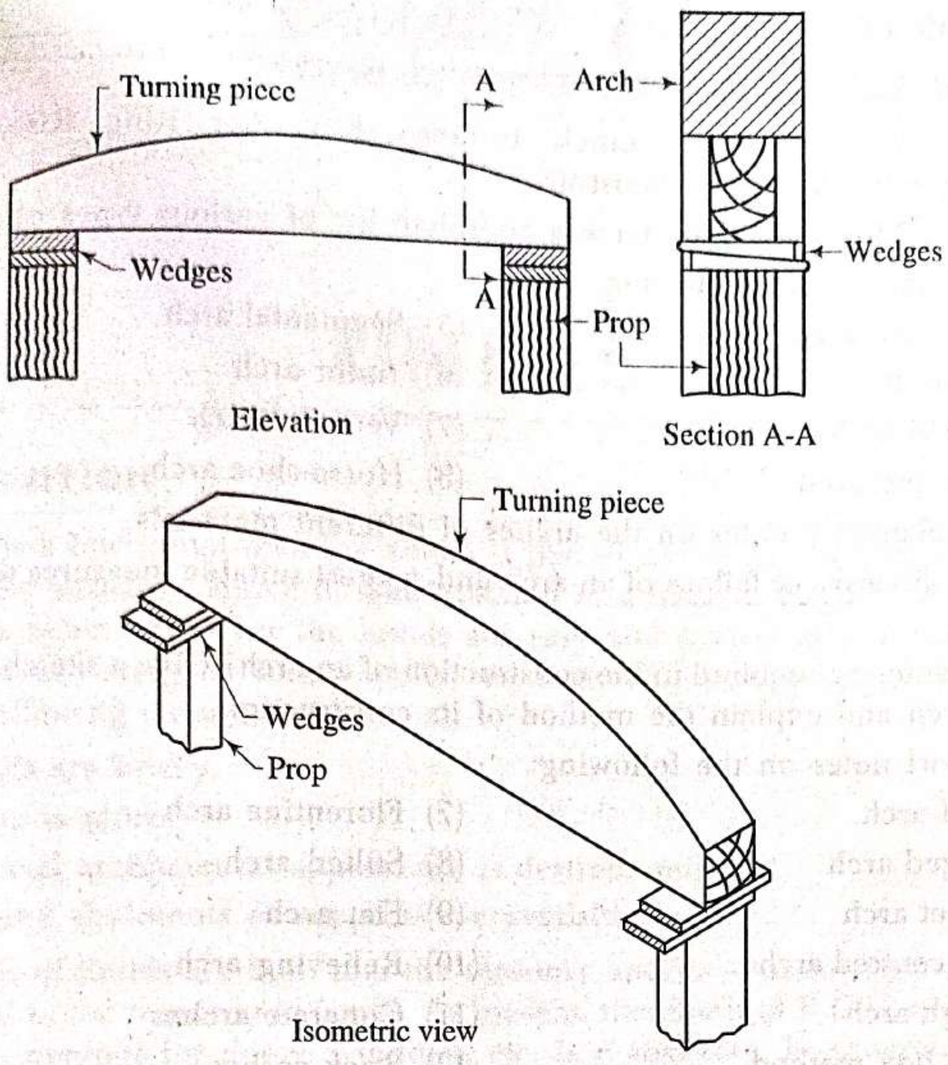
Following points should be noted in connection with the arch centering:

(i) The length of laggings and the distance between the boards depend on the width of an arch. For rough and axed arches, the laggings are provided 20 mm apart. But for gauged work, they are closely spaced.

(ii) The laggings should be kept 10 mm to 12 mm back from the face of archwork so that they will not form an obstruction to the line and plumb rule observed by the masons during construction.

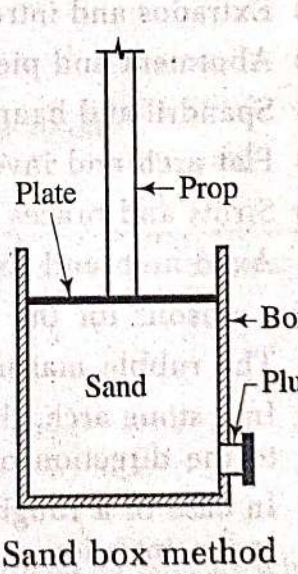
(iii) A thick wooden plank can be used as centering for arch of thickness one-half brick. The plank is shaped to the curvature of the arch and it is supported on the props. Fig. 17-18 shows the elevation, section and isometric view of centering with *turning piece.* The thick wooden plank with horizontal bottom and the upper surface shaped to the underside of the soffit is known as the *centre* or *turning piece.* Its width is normally 100 mm and it is supported on vertical timber posts known as the *props.* The wooden wedges are provided to tighten or loosen the centering.

(iv) For small spans, the single ribs may be provided on either side and laggings, bearers and folding wedges may be provided as usual.



Centering with turning piece
FIG. 17-18

(v) The centering for arch should be removed after the arch has developed sufficient strength. For small spans, the removal of centering is done by slightly loosening the folding wedges. But when the span exceeds 7 m or so, a method known as the *sand box method*, is adopted to avoid shocks. A box is filled with sand and a hole is provided at the bottom of box. The hole is plugged to retain sand. The bottom of prop rests on a plate which is provided at the top surface of sand as shown in fig. 17-19. When it is desired to lower the centering, the plug is taken out and the sand is allowed to come out of the box. The prop is thus lowered gradually.



Sand box method
FIG. 17-19

(vi) The construction of centering for an arch depends on the span of arch, rise of arch, form of arch curve and the materials of which arch is constructed.

Chapter 19

STAIRS

19-1. GENERAL

A *stair* is defined as a sequence of steps and it is provided to afford the means of ascent and descent between the floors or landings. The apartment or room of a building, in which the stair is located, is known as a *staircase* and the opening or space occupied by the stair is known as a *stairway.*

The other means of transportation between the floors of a building, apart from stairs, are lifts, ramps and moving stairs. In this chapter, the salient features of stairs will be discussed.

19-2. TECHNICAL TERMS

The definitions of technical terms used in connection with the stairs are as follows:

(1) **Baluster:** This is the vertical member which is fixed between string and handrail to give support to the handrail as shown in fig. 19-1.

(2) **Balustrade or barrister:** The combined framework of handrail and balusters is known as the *balustrade* or *barrister.*

(3) **Flight:** This is defined as an unbroken series of steps between the landings.

(4) **Going:** This is the horizontal distance between the faces of two consecutive risers as shown in fig. 19-2.

(5) **Handrail:** The inclined rail over the string is known as a *handrail* as shown in fig. 19-1. It is generally moulded and some forms of handrails are shown in fig. 19-3. The handrail serves as a guard rail and it should be provided at a convenient height so as to give grasp to the hand during ascent and descent.

(6) **Headroom:** The vertical distance between the nosings of one flight and the bottom of flight immediately above is known as the headroom and it should be of sufficient value so as not to cause any difficulty to the persons using the stair. See fig. 19-29.

(7) **Landing:** The horizontal platform between *two* flights of a stair is known as the *landing.* A landing facilitates change of direction and provides an opportunity for taking rest during the use of a stair.

(8) **Newel post:** This is the vertical member which is placed at the ends of flights to connect the ends of strings and handrails as shown in fig. 19-1.

(9) **Nosing:** The projecting part of the tread beyond the face of riser is known as a *nosing* as shown in fig. 19-2. The term *line of nosings* is used to denote an imaginary line parallel to the strings and tangential to the nosings. It is useful in the construction of handrails. The undersurface of the handrail should coincide with the line of nosings.

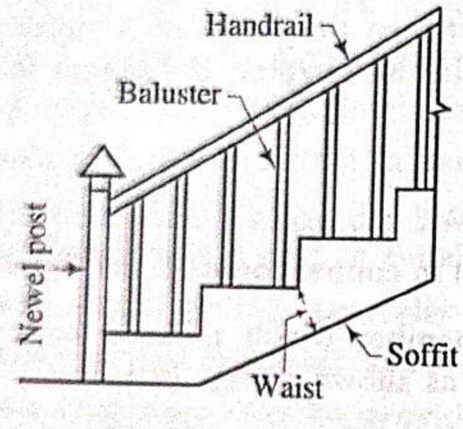
(10) **Pitch:** The angle of inclination of the stair with the floor is known as a *pitch*. It also indicates the angle which the line of nosings makes with the horizontal.

(11) **Rise:** This is the vertical distance between *two* successive treads as shown in fig. 19-2.

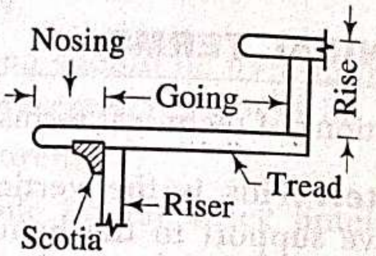
(12) **Riser:** The vertical or front member of the step, which is connected to the treads, is known as a *riser* as shown in fig. 19-2.

(13) **Run:** The total length of a stair in a horizontal plane is known as the *run* and it includes the lengths of landings also.

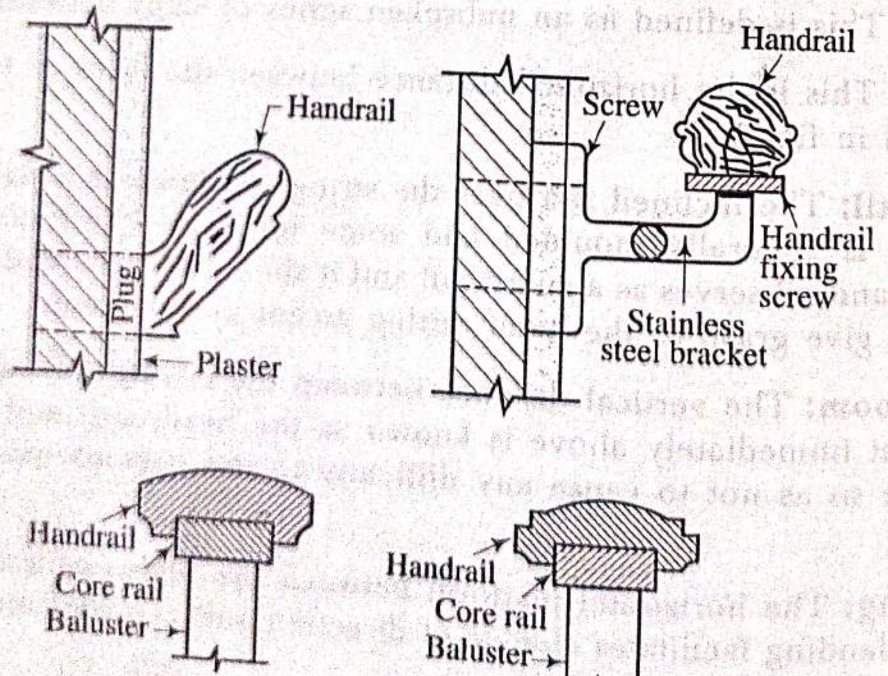
(14) **Scotia:** This is an additional finish or moulding provided to the nosing or tread as shown in fig. 19-2 to improve the elevation of the step and to provide strength to the nosing.



Stair
FIG. 19-1



Step
FIG. 19-2



Handrails
FIG. 19-3

(15) Soffit: The under surface of a stair is known as the *soffit* as shown in fig. 19-1. It is generally covered with ceiling or finished with plaster.

(16) Step: A combination of tread and riser is known as a *step* as shown in fig. 19-2. Following are the common types of steps:

(i) ***Bullnose step:*** This is generally provided at the bottom of flight. It projects in front of the newel post and its end forms a circular quadrant in plan as shown in fig. 19-4.

(ii) ***Commode step:*** This step has a curved riser and tread as shown in fig. 19-4.

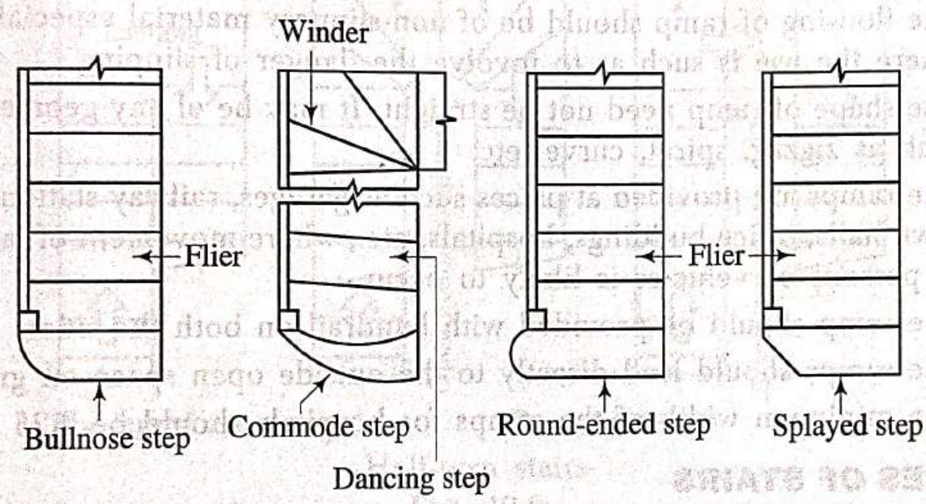
(iii) ***Dancing or balancing step:*** These steps do not radiate from a common centre as shown in fig. 19-4.

(iv) ***Flier:*** This is an ordinary step of rectangular shape in plan as shown in fig. 19-4.

(v) ***Round-ended step:*** This step is similar to a bullnose step except that its end or ends are semi-circular in plan as shown in fig. 19-4.

(vi) ***Splayed step:*** This step has one end or both ends splayed in plan as shown in fig. 19-4.

(vii) ***Winder:*** This is a tapering step and it is used to change the direction of a flight as shown in fig. 19-4. The winders radiate from a common centre.



Types of steps
FIG. 19-4

(17) String: The inclined member of a stair which supports the ends of steps is known as a *string*. There are *two* types of string:

(i) a cut or open string

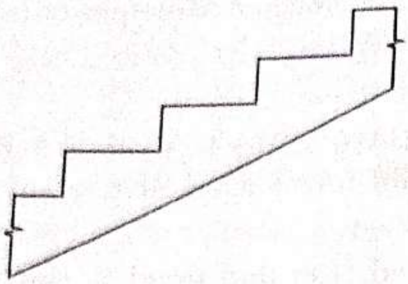
(ii) a closed or housed string.

In the cut or open string, the upper edge is cut away to receive the ends of steps as shown in fig. 19-5. In the closed or housed string, the ends of steps are housed between straight parallel edges of the string as shown in fig. 19-6.

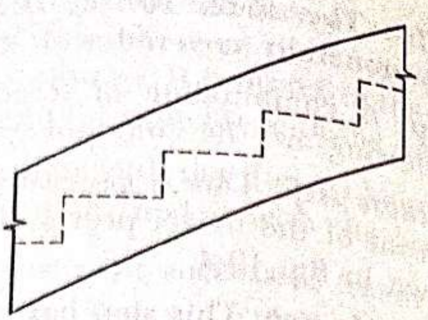
(18) Tread: The horizontal upper portion of a step is known as a *tread*.

(19) Waist: The thickness of structural slab in case of an R.C.C. stair is known as a *waist* as shown in fig. 19-1.

(20) Walking line: The approximate line of movement of people on a stair during ascending or descending is known as a *walking line* and it is situated at a distance of about 450 mm from the centre of handrail.



Cut or open string
FIG. 19-5



Closed or housed string
FIG. 19-6

19-3. RAMPS

A *ramp* is a sloping surface and it is adopted as a substitute for stair for easy connection between the floors. The important features of the ramps are as follows:

(i) The usual slope of ramp is 1 in 15. But a slope of 1 in 10 is desirable. This indicates that the ramp requires more space. For instance, a total length of 45 m of ramp will be required to connect a floor height of 3 m with slope as 1 in 15.

(ii) The flooring of ramp should be of non-slippery material especially at places where the use is such as to involve the danger of slipping.

(iii) The shape of ramp need not be straight. It may be of any geometrical shape such as zigzag, spiral, curve, etc.

(iv) The ramps are provided at places such as garages, railway stations, stadiums, town halls, office buildings, hospitals, etc., where movement of large number of persons or vehicles is likely to occur.

(v) The ramp should be provided with handrail on both the sides.

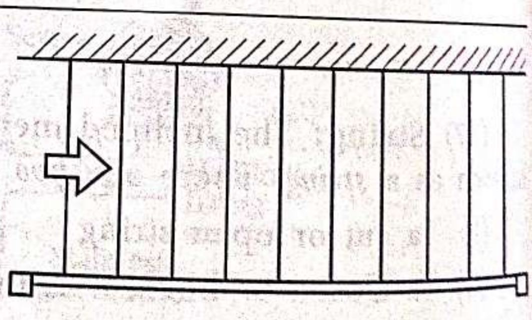
(vi) The ramps should lead directly to the outside open space on ground level.

(vii) The minimum width of the ramps for hospitals should be 2.25 m.

19-4. TYPES OF STAIRS

The stairs are classified as follows:

(1) Straight stairs
(2) Turning stairs
(3) Circular or helical or spiral stairs
(4) Geometrical stairs.



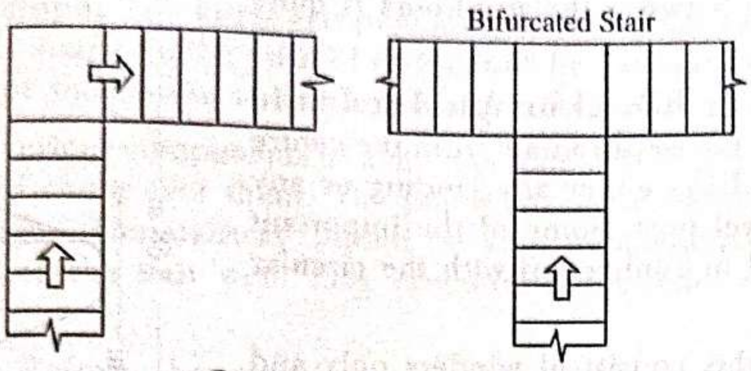
Straight stair
FIG. 19-7

(1) Straight stairs: In case of a straight stair, all steps lead in one direction only as shown in fig. 19-7.

This type of stair may consist of one or more flights and they are used when the space available for staircase is long but narrow in width.

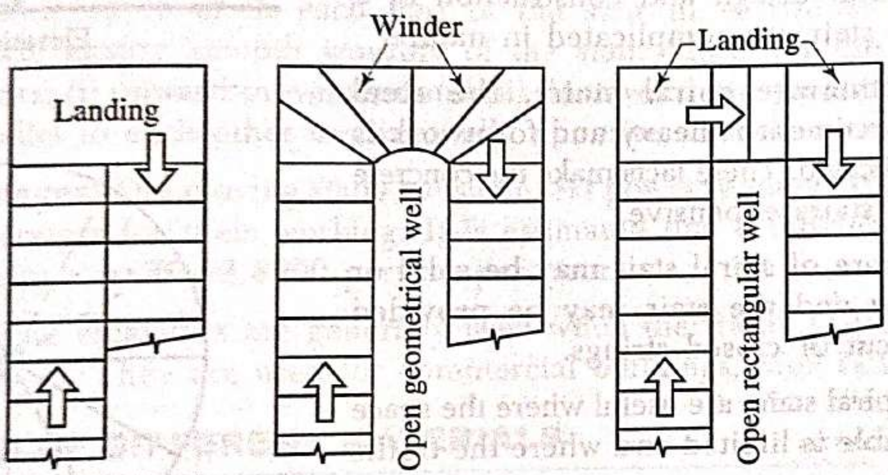
(2) Turning stairs: In case of turning stairs, the flights take turn. The usual types of turning stairs are described below.

(i) ***Quarter-turn stairs:*** A stair turning through one right angle is known as a *quarter-turn stair*. If a quarter-turn stair is branched into *two* flights at a landing, as shown in fig. 19-8, it is known as a *bifurcated stair*. This type of stair is commonly used in the public buildings near their entrance hall. The stair has a wider flight at the bottom which bifurcates into *two* narrower flights at the landing – one turning to the left and the other to the right.



Quarter-turn stairs
FIG. 19-8

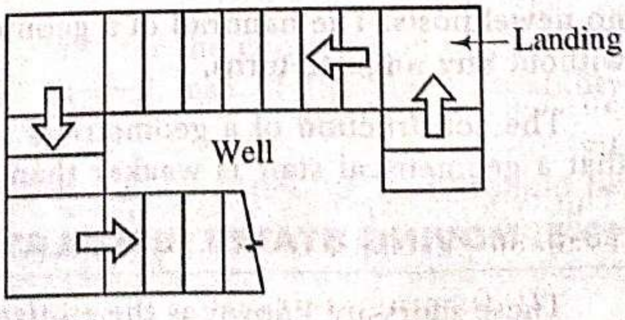
(ii) ***Half-turn stairs:*** A stair turning through *two* right angles is known as a half-turn stair. A *half-turn stair* may be of dog-legged type or open newel type as shown in fig. 19-9.



Half-turn stairs
FIG. 19-9

In case of a *dog-legged stair*, the flights run in opposite directions and there is no space between them in plan. These stairs are useful where total width of space available for the staircase is equal to twice the width of steps. Its name is derived from its appearance in the sectional elevation.

In case of an *open newel stair,* there is a well or hole or opening between the flights in plan. This well may be rectangular or of any geometrical shape and it can be used for fixing lift. These stairs are useful where available space for staircase has a width greater than twice the width of steps.



Three-quarter-turn stair
FIG. 19-10

(iii) ***Three-quarter-turn stairs:*** A stair turning through *three* right angles is known as a *three-quarter-turn stair* as shown in fig. 19-10.

In this case, an open well is formed. This type of stair is used when the length of the staircase is limited and when the vertical distance between the *two* floors is quite large.

(3) Circular or helical or spiral stairs: In this type of stair, the steps radiate from the centre and they do not have either any landing or any intermediate newel post. Some of the important facts to be noted in connection with the circular stairs are:

(i) The flights consist of winders only and they may be continued through any desired number of turns.

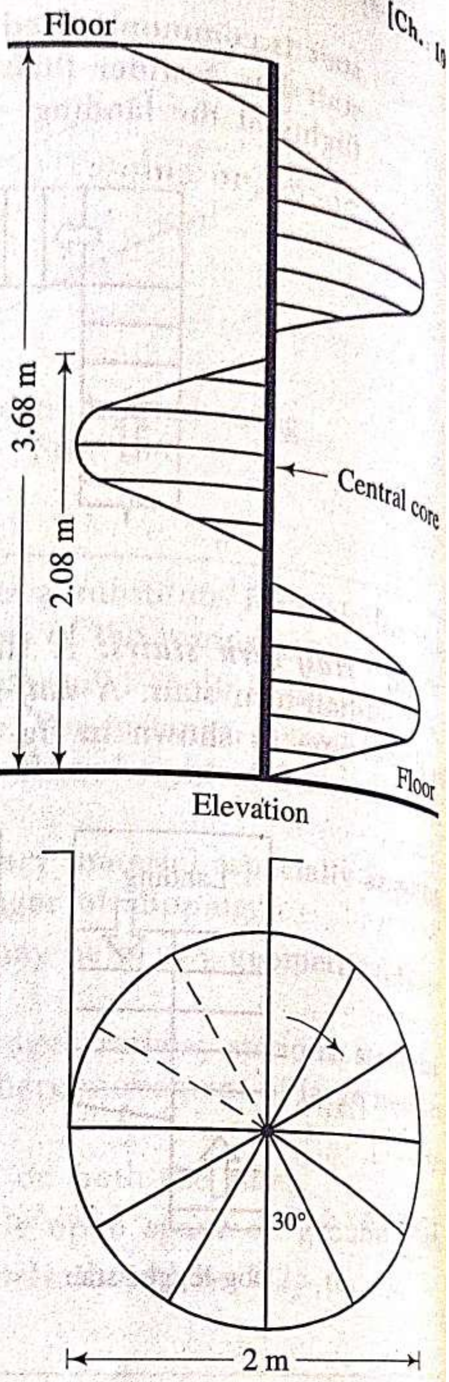
(ii) A spiral stair may be constructed of cast-iron, mild steel or concrete. Usually the structural design and construction of a spiral stair are complicated in nature.

(iii) For concrete spiral stairs, the steel reinforcement is heavy and formwork is complicated. These facts make the concrete spiral stairs expensive.

(iv) The core of spiral stair may be solid or hollow and the stair may be provided with cut or closed strings.

(v) The spiral stairs are useful where the space available is limited and where the traffic is less.

Fig. 19-11 shows the details of a circular stair. The height of floor and rise are respectively 3.68 m and 160 mm. The steps radiate at an angle of 30° from the core. The headroom is 2.08 m and width of stair is 2 m. The handrail is not shown.



Spiral stair
FIG. 19-11

(4) Geometrical stairs: These stairs have any geometrical shape and they require no newel posts. The handrail of a geometrical stair continues without interruption and without any angular turns.

The construction of a geometrical stair requires considerable skill and it is found that a geometrical stair is weaker than a corresponding open newel stair.

19-5. MOVING STAIRS (ESCALATORS)

These stairs are known as the *escalators* or *ever-moving flights* of electrically-operated stairs. These escalators are kept in motion by a revolving drum. A few steps at top and bottom are kept level though moving individually. The only thing a person has to do is to occupy a step of the escalator for his upward or downward motion. The important features of the escalators are as follows:

(1) **Essential parts:** An escalator consists essentially of the *three* parts: steel trussed framework, handrails and an endless belt with steps. The accurately prepared tracks are attached to the steel trusses and the steps move on these tracks.

(2) **Speed and slope:** The usual accepted speed of the moving stair is 450 mm per second. A moving stair is in the form of an inclined bridge between *two* successive floors and its pitch or inclination to the horizontal is kept 30°.

(3) **Design:** The various components of a moving stair should be carefully designed for the loads likely to come over them. The important factor affecting the design is the floor-to-floor height. The stairway should be kept independent by providing a structural frame around the stair well. This structural frame takes the load of floor, handrail, etc.

(4) **Location:** Before the position of a moving stair in a building is decided, a careful study of flow of traffic should be made or if it is a new structure, the moving stairs should be located at points where the traffic is likely to be the heaviest.

(5) **Installation:** The various parts of a moving stair are prepared in the workshop and they are then brought on site for installation. The process of installation should be carefully done so as to fit each part of the stair in its proper position. This arrangement will ensure smooth working of the stair. Moreover the escalators are arranged in pairs: (i) upward movement and (ii) downward movement. The units may be placed parallel to each other or diagonally opposite to each other.

(6) **Advantages:** The moving stairs consume less power, possess large capacity and require no operators for their working. It is estimated that a moving stair of width 1.20 m can carry a traffic of 8000 persons per hour.

(7) **Uses:** The escalators are generally used when the traffic of persons is heavy between the floors. They are used for commercial buildings, tube railways, etc.

19-6. STAIRS OF DIFFERENT MATERIALS

Following are the materials which are commonly used in the construction of stairs:

(1) Stone stairs
(2) Wooden or timber stairs
(3) Brick stairs
(4) Metal stairs
(5) R.C.C. stairs.

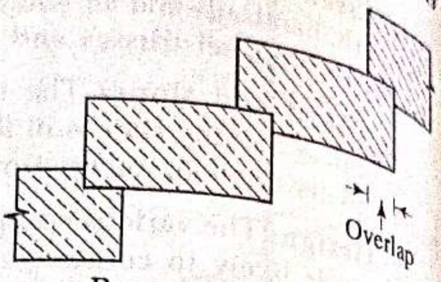
The choice of the type of material to be adopted for the construction of stair will depend on the availability of funds, qualities desired, use of the stair, durability expected, architectural effect required, etc.

(1) **Stone stairs:** The stones to be used for the construction of stairs should be hard and non-absorbent and they should possess enough resistance to the action of fire. These stairs are used for warehouses, workshops, etc. They are widely used at places where the ashlar stones are readily available.

(i) ***Construction:*** A stone step may be constructed in any one of the following ways:

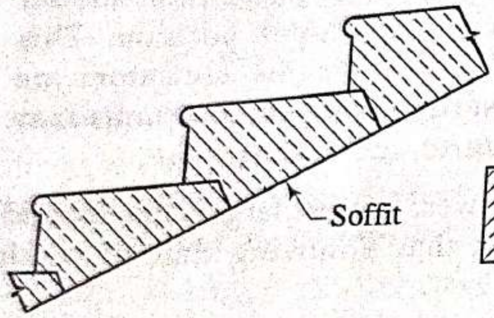
(a) *Rectangular step with rebated joint:* In case of a rectangular step, the arrangement is made as shown in fig. 19-12. The overlap is about 25 mm to 40 mm.

This arrangement results in considerable saving in labour of cutting and dressing stones.

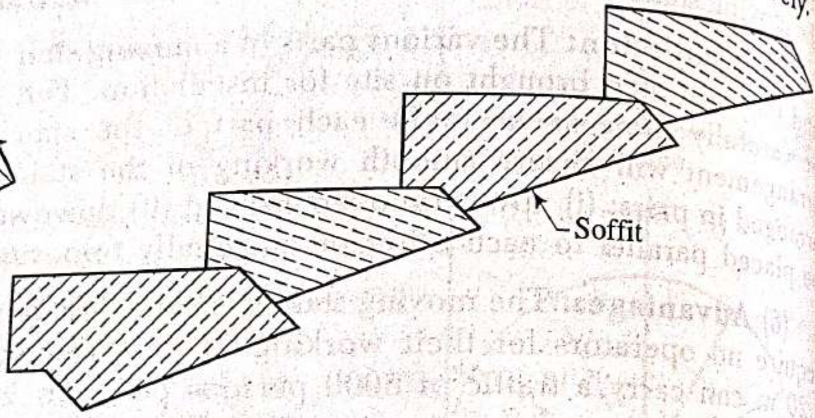


Rectangular stone step
FIG. 19-12

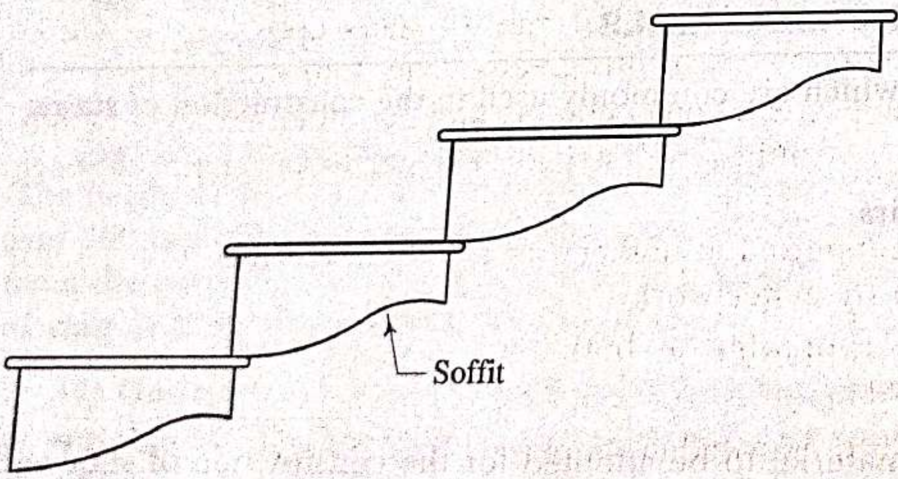
(b) *Spandril step:* In this arrangement, the steps are triangular in shape and they are cut in such a way so as to obtain aci plain soffit as shown in fig. 19-13. This arrangement is used where the headroom is desired. The soffit affords a nice appearance and the weight of steps is also reduced. The ends of spandril steps which are built into the wall should be square so as to provide a horizontal seating or bearing. The soffit can also be made broken or moulded as shown in fig. 19-14 and fig. 19-15 respectively.



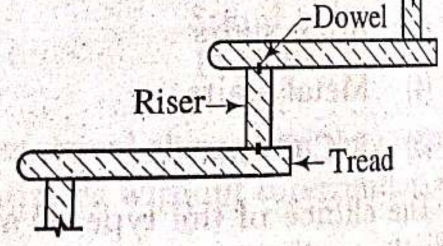
Spandril step with plain soffit
FIG. 19-13



Spandril step with broken soffit
FIG. 19-14



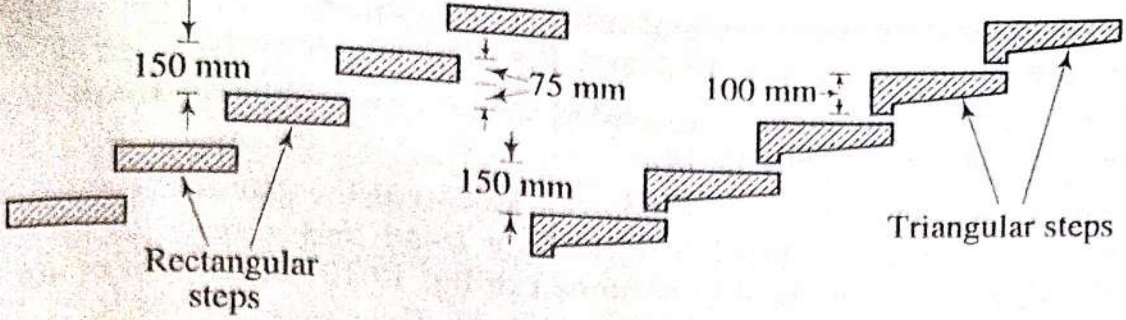
Spandril step with moulded soffit
FIG. 19-15



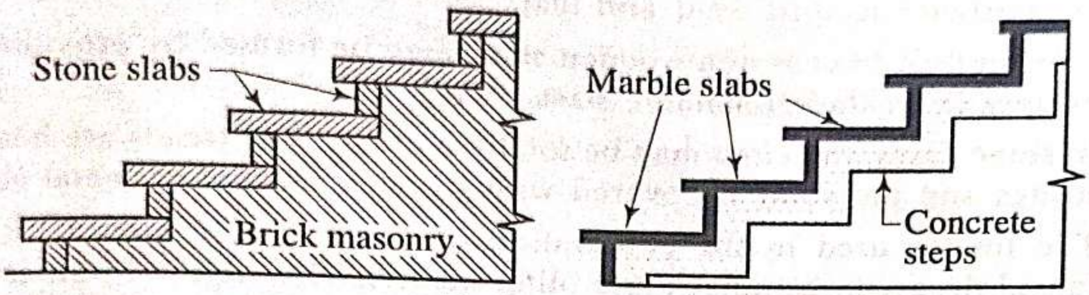
Tread and riser of stone step
FIG. 19-16

(c) *Tread and riser step:* In this arrangement, the treads and risers of stones are provided as in case of timber steps. The stone slab treads and risers are connected by dowels as shown in fig. 19-16.

(d) *Cantilever tread slab step:* In this arrangement, the steps are formed of treads only. For this purpose, only thick stone slabs are used without any riser. The steps may either be rectangular or triangular in shape as shown in fig. 19-17.



Cantilever tread slab step
FIG. 19-17



Built-up step
FIG. 19-18

(e) *Built-up step:* These steps are in the form of treads and risers of thin sawn stone slabs. They are placed over brick or concrete steps as shown in fig. 19-18. The thickness of stone slab may vary from 20 mm to 50 mm. This arrangement is generally adopted for marble steps to give an ornamental covering to the step.

(ii) ***Support and fixing:*** A stone step may be supported and fixed in any one of the following *four* ways:

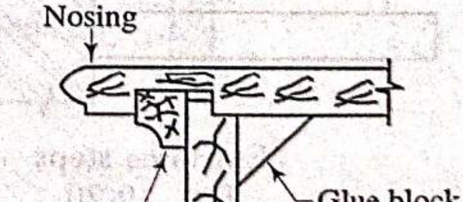
(a) The step may be supported and fixed at both the ends in a wall. The bearing in wall should be at least 100 mm for stairs upto 1.20 m width and 200 mm for stairs having width greater than 1.20 m.

(b) The step may be supported at one end only and the other end may be left unsupported. Such a cantilevered step should not have length of more than 1.20 m.

(c) The step may be supported at one end in a wall and at the other end, it may be supported by a steelwork.

(d) The step may be supported at both the ends on a steelwork.

(2) **Wooden or timber stairs:** As wooden stairs are light in weight, they are mostly used for residential buildings. The main objection to the provision to a wooden stair is that it is easily attacked by fire and thus, in case of a fire, the occupants of upper floors cannot escape. But if a wooden stair is constructed from good quality timber such as teak and if its thickness is about 45 mm, it becomes sufficiently fire-proof and it allows enough time for the occupants of upper floors to escape. Fig. 19-19 shows a wooden stair. The important factors to be considered in case of a wooden stair are as follows:



Wooden stair
FIG. 19-19

(i) The *string* supporting the ends of wooden steps may be a cut string or a close string as shown in fig. 19-5 and fig. 19-6 respectively.

(ii) The *scotia blocks* may be provided to give an additional finish to a wooden step as shown in fig. 19-19.

(iii) The small triangular wooden blocks, known as the *glue blocks*, may be provided at the inner angle formed between a tread and a riser, to give additional strength to a wooden step as shown in fig. 19-19. These blocks are glued and placed at about 80 mm distance.

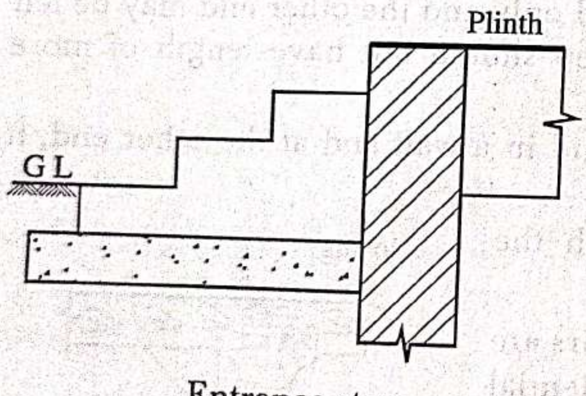
(iv) A metal strip may be provided on the nosing of a wooden step to increase its resistance against wear and tear.

(v) The landing, in case of a wooden stair, may be formed by providing wooden bearers or beams of suitable sizes.

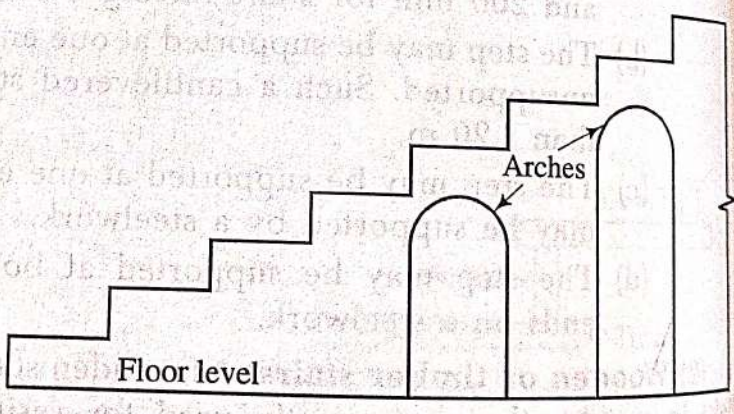
(vi) In some cases, the *risers* may be totally omitted. The treads are housed in the strings and the soffit is covered with wooden battens or metal sheets.

(vii) The timber used in the preparation of wooden stair should be free from fungal decay, insect attack and other defects. The edges of timber should be finished smooth and the pieces of timber having abnormal light weight should not be used.

(3) Brick stairs: These stairs are now not frequently used. The entrance steps form a typical brick stair as shown in fig. 19-20. A brick stair may be made of solid construction or arches may be provided as shown in fig. 19-21. The latter arrangement reduces the total quantity of brickwork and gives some additional space which can be used for making cupboards, etc. In case of a brick stair, the treads and risers are generally made equal to length of $1\frac{1}{2}$ bricks and height of *two* layers of bricks respectively. The treads and risers of a brick stair are finished with suitable flooring material.



Entrance steps
FIG. 19-20



Brick stair
FIG. 19-21

(4) Metal stairs: The external fire-escape stairs are generally made of metal. The common metals, used for the construction of stairs, are cast-iron, bronze and mild steel. Thus the metal stairs are widely used in factories, workshops, godowns, etc. The important features of a metal stair are as follows:

(i) The stringers are usually of channel section.

(ii) The tread and riser of a step may be of one unit as shown in fig. 19-22.

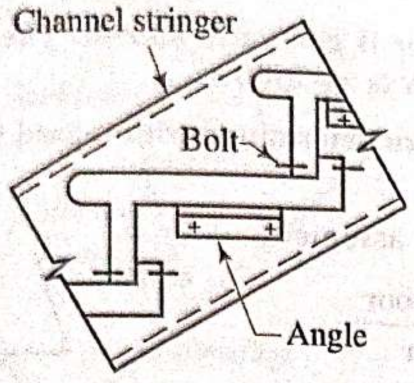
(iii) The tread and riser of a step may be of separate units as shown in fig. 19-23.

(iv) The treads and risers are supported on the angles which are connected to the stringers.

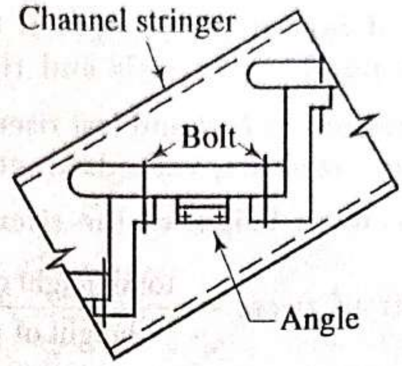
(v) The risers may be totally omitted in some cases.

(vi) The spiral stairs of cast-iron consist of a cast-iron newel fixed in the centre around which the cast-iron steps are fixed.

(vii) For metal stairs, the metal balusters with handrail of pipe are used.

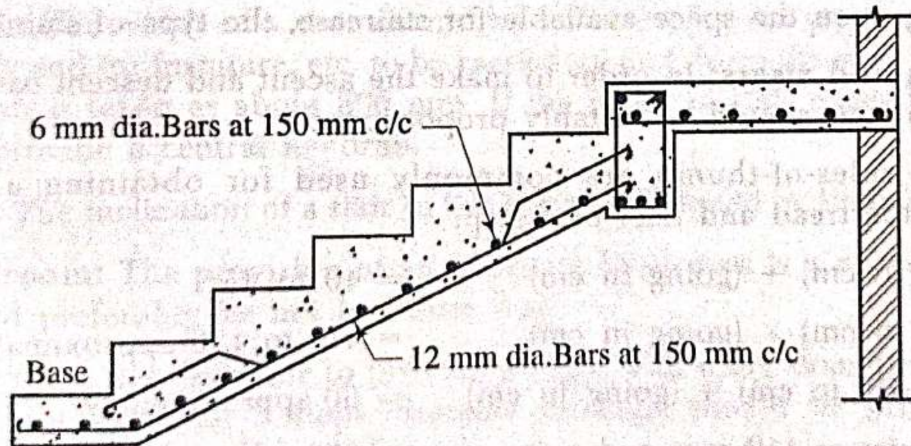


Metal stair
FIG. 19-22



Metal stair
FIG. 19-23

(5) **R.C.C. stairs:** These stairs are now commonly used in all types of construction and in case of a framed structure of reinforced concrete, the R.C.C. stair is perhaps the only choice. They are found to resist wear and fire better than any other material and can be moulded to the desired shape. The steps can be provided with suitable finishing material such as marble, terrazo, tile, etc. These stairs can be easily maintained clean and they are strong, durable and pleasing in appearance. They can also be easily rendered non-slippery and can be designed for greater widths and longer spans.



R.C.C. stair
FIG. 19-24

A typical R.C.C. stair is shown in fig. 19-24. The details and placing of reinforcement will naturally depend on the design of R.C.C. stair. The steps may be cast-in-situ or pre-cast. In the latter case, it is also possible to pre-cast a flight and then place it in position with the help of suitable equipment.

The above mentioned materials can be used in combination with each other so as to form what are known as the *composite stairs.* The various components of stairs are made of different materials and in addition, the lightweight materials such as aluminium, plastic, etc. may be employed to construct composite stairs.

The stairs of public entertainment places such as theatres require special treatment for finish. Usually the decorative carpets are spread over the steps to create the desired effects and the artistic balustrade is provided to give comfort to the users of stair.

19-7. REQUIREMENTS OF A GOOD STAIR

A well-designed stair should fulfil the following requirements for providing an easy, quick and safe mode of communication between the floors:

(1) **Design of layout:** The height of floor is generally known. The procedure for determining the number of treads and risers is as follows:

(i) The positions of first and last risers are determined with regard to the positions of doors, windows, verandahs, etc.

(ii) A convenient height of the riser is assumed.

(iii) Number of risers $= \dfrac{\text{total height of floor}}{\text{height of riser}}$.

(iv) Number of treads in a flight = number of risers – 1.

This is due to the fact that the surface of the upper floor forms the tread for the top step.

For instance, let us suppose that the height of floor is 3.50 m. Assume a riser of 140 mm.

Then, No. of risers $= \dfrac{3.50}{0.14} = 25.$

No. of treads for stair with single flight $= (25 - 1) = 24.$

No. of treads for stair with double flight $= (25 - 2) = 23.$

Depending upon the space available for staircase, the type of stair is selected.

(2) **Treads and risers:** In order to make the ascent and descent easy, the treads and risers of a stair should be suitably proportioned.

Following rules-of-thumb are commonly used for obtaining a satisfactory proportion of the tread and riser of a step:

(i) (Rise in cm) + (going in cm) = 40 to 45.

(ii) (Rise in cm) × (going in cm) = 410 to 450 approximately.

(iii) (2 × rise in cm) + (going in cm) = 60 approximately.

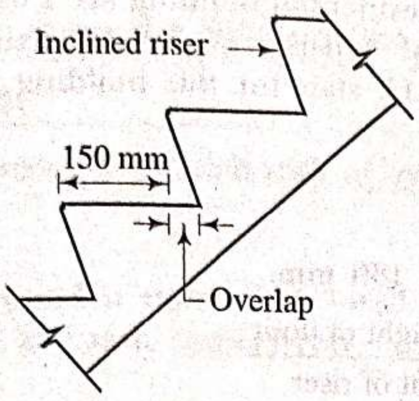
(iv) Take rise = 140 mm and going = 300 mm as standard.

Then, for each 20 mm subtracted from the going, add 10 mm to the rise. Thus other combinations of rise and going would be:

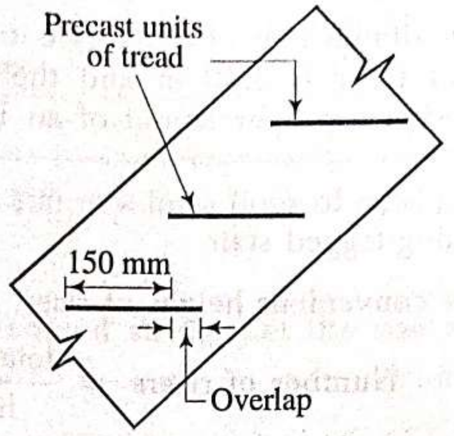
150 mm × 280 mm, 160 mm × 260 mm, 170 mm × 240 mm.

The staircase in a residential building should not have a rise of more than 230 mm and a going of less 230 mm. For public buildings, it is desirable to have a rise of not more than 180 mm and a going of not less than 270 mm. The wider the going, the less should be the riser and the greater the rise, the less should be the going. For a winder, the width of going is measured at a distance of 450 mm from the inside or the small end of the tread.

It should always be remembered that whatever may be the values of rise and going, they should be kept constant throughout the stair or at least throughout each flight. It may further be noted that when space available to accommodate treads is not adequate, the risers are kept in an inclined position or pre-cast units of treads are adopted. In such cases, the projections of subsequent treads in plan overlap each other and thus the total effective length of flight is reduced. Fig. 19-25 and fig. 19-26 show respectively the inclined risers and pre-cast units of tread.



Inclined risers
FIG. 19-25



Pre-cast units of treads
FIG. 19-26

(3) **Materials and workmanship:** The stair should be constructed of sound materials and good workmanship so as to impart durability and strength to the stair. The stairway provides a path by which fire can spread from one floor to another and hence the fire protection of the staircases is extremely important. The materials used for the linings of walls and ceiling of staircase should be non-combustible and of low flame spread.

(4) **Width:** The width of a stair should be sufficient for *two* persons to pass on it simultaneously and for furniture, etc. to be carried up and down the stair. The minimum width of a stair is taken as about 800 mm. If the width of stair exceeds 1.80 m, it is desirable to provide a central handrail.

(5) **Pitch:** The inclination of a stair to the horizontal should be limited to 30° to 45°.

(6) **Headroom:** The provision of an adequate headroom is a necessity in a good stair. It should preferably be not less than 2 m.

(7) **Flight:** It is not desirable to provide a flight with more than 12 or at the most 15 steps and not less than 3 steps. Suitable landings should be provided to give comfort and safety to the users of the stair.

(8) **Single step:** It is not at all desirable to introduce a flight of a single step at any place in a stair for any purpose.

(9) **Winders:** These are to be avoided as far as possible. However, if winders are unavoidable, they should be placed at the bottom rather than at the top of the flight.

(10) **Handrail:** When a flight consists of more than *three* steps, a handrail at least on one side is considered to be a necessity. The wide stairs should be provided with handrails on both the sides. Very wide stairs, as required for public buildings, should be provided with a central handrail. The height of handrail above the riser should be approximately 800 mm.

(11) Location: The stairs should be so located that they are well-lighted and well-ventilated and have convenient and spacious approaches. In case of public buildings, the stair should be located near the main entrance and in case of residential buildings, the stair should be centrally located so as to have easy access from all the rooms without disturbing the privacy of rooms. In case of big buildings, there may be more than one stair.

Chapter 21

DOORS, WINDOWS AND VENTILATORS

21-1. GENERAL

A *door* may be defined as an openable barrier secured in an opening left in a wall for the purpose of providing access to the users of the structure. It basically consists of *two* parts, namely, frame and shutter. The door shutter is held in position by the door frame which in turn is fixed in the opening of the wall by some suitable means.

A *window* may be defined as an opening made in a wall for the purpose of providing day light, vision and ventilation. It also like door consists of *two* parts i.e. frame and shutter. The window frame is suitably fixed in the opening of the wall and the window shutter is held in position by the window frame.

In this chapter, the salient features of various types of doors and windows will be discussed.

21-2. IMPORTANT CONSIDERATIONS FOR DOORS AND WINDOWS

The important considerations to be observed in case of doors and windows are as follows:

(1) **Purpose:** The main function of doors in a building is to serve as a connecting link between the various internal parts. The number of doors in a room should be kept minimum due to the fact that more number of doors will cause obstruction and reduce the effective usable carpet area of the room. The windows are generally provided to give light and ventilation both to the interior parts of a building. When windows are provided for the purpose of light only, as in case of storage rooms, show rooms, etc., they may be fixed so that they cannot be opened. But when the windows are provided for light and ventilation, some or all the portion of windows must open. This can be achieved by providing suitable hinges at top, bottom or sides.

(2) **Size:** In general, a door should have such dimensions as will allow the movement of the largest object likely to use the door. The minimum widths for interior doors, external doors and doors in public buildings such as hospitals, library, etc., are 800 mm, 1 m and 1.20 m respectively. Regarding height and width of a door, the general rule followed in India, is as follows:

Height = width + 1 m to 1.20 m approximately.

Width = 0.4 to 0.6 of height.

The size of window depends on the dimensions of the room, use of the room, location of the room, direction and speed of the wind, obstruction to light by neighbouring buildings and trees, dry bulb temperature, relative humidity, climatic conditions of the region, etc. Following general rules may be observed while deciding the size of window:

(i) Breadth of window = $\frac{1}{8}$ (width of room + height of room)

(ii) For 30 m^3 inside contents of the room, there should be at least one m^2 of window opening.

(iii) The total area of the window openings should be at least 15 per cent of the floor area of the room.

(iv) The total area of glass panels in the window openings should be at least 10 per cent of the floor area of the room.

(v) For public buildings, the provision of window openings should be more than above requirements.

The BIS recommends that the size of door frame and window frame should be derived after allowing a margin of 5 mm alround an opening for convenience of fixing. The width and height of an opening is indicated by number of modules where each module is of 100 mm. Table 21-1 and table 21-2 show respectively the recommended dimensions by BIS for doors and windows:

TABLE 21-1
RECOMMENDED DIMENSIONS FOR DOORS

No.	Designation	Size of opening (mm)	Size of door frame (mm)
1.	8 DS 20	800 × 2000	790 × 1990
2.	8 DS 21	800 × 2100	790 × 2090
3.	9 DS 20	900 × 2000	890 × 1990
4.	9 DS 21	900 × 2100	890 × 2090
5.	10 DS 20	1000 × 2000	990 × 1990
6.	10 DT 21	1000 × 2100	990 × 2090
7.	12 DT 20	1200 × 2000	1190 × 1990
8.	12 DT 21	1200 × 2100	1190 × 2090

TABLE 21-2
RECOMMENDED DIMENSIONS FOR WINDOWS

No.	Designation	Size of opening (mm)	Size of window frame (mm)
1.	6 WS 12	600 × 1200	590 × 1190
2.	10 WT 12	1000 × 1200	990 × 1190
3.	12 WT 12	1200 × 1200	1190 × 1190
4.	6 WS 13	600 × 1300	590 × 1290
5.	10 WT 13	1000 × 1300	990 × 1290
6	12 WT 13	1200 × 1300	1190 × 1290

The height of opening for door is considered from below the floor finish to the bottom of lintel. In the designation for door, the letters D, S and T represent respectively door, single shutter and double shutters. For instance, the designation 9 DS 20 denotes a door opening having width equal to 9 modules i.e. 900 mm and height equal to 20 modules i.e. 2000 mm. The door is with single shutter. In a similar way, the designation 12 DT 20 denotes a door opening having width equal to 12 modules i.e. 1200 mm and height equal to 20 modules i.e. 2000 mm. The door is of *two* shutters.

For the designation of windows, the letters W, S and T represent respectively window, single shutter and double shutters. For instance, the designation 6 WS 13 denotes a window opening with single shutter having width equal to 6 modules i.e. 600 mm and height equal to 13 modules i.e. 1300 mm. In a similar way, the designation 12 WT 12 denotes a window opening with *two* shutters having width and height each equal to 12 modules i.e. 1200 mm.

(3) **Location:** The doors and windows are generally located by the architect of the building. Following general rules may be observed while deciding the location of doors and windows:

(i) The doors should preferably be located near the corner of a room, at a distance of about 200 mm from the corner.

(ii) The sill of a window opening should preferably be located at a height of 700 mm to 800 mm from inside of the floor level.

(iii) The factors such as distribution of light, control of ventilation, prevalent direction of wind, privacy, etc., should be considered in the location of widows.

(iv) The doors and windows should be located by keeping in view the interior decoration and the functional requirements of the room.

(4) **Material:** The usual materials for doors and windows are wood, glass, plywood and metals. The wood is the most common material for doors and windows as it can be moulded in a variety of shapes and can thus present a decent appearance. The glass is used for panels to admit more light. The plywood can be used as a covering material. The metals, such as aluminium and steel, are now commonly used, especially for the windows. At places where wood is likely to be attacked by vermins, the R.C.C. frames may be provided for doors and windows.

The traditional wooden door shutters have inevitable problems of warping, rotting, painting and maintenance. They cannot therefore be considered suitable for bath rooms, toilets and kitchens where the water contact is continuous. The polyvinyl chloride or PVC is the wonder material from the plastic family and its use as door shutter is becoming popular because it provides total protection against corrosion, moisture, termites and chemicals. The PVC door shutters are made from multi-cavity hollow chamber sections and they are manufactured on computer aided machines under stringent quality control.

The use of PVC for doors and windows is also going to be popular because of the following *advantages* offered by such doors and windows:

(i) They are totally rust-proof, rot-proof, termite-proof and water-proof.

(ii) They are unaffected by coastal saline air, dry heat, sub-zero temperatures or tropical rains.

(iii) They do not fade, corrode, flake or warp and consequently, require no maintenance. All that is needed is an occasional cleaning with ordinary soap and water.

(iv) They provide an alternative to the wood.

(v) They provide better thermal insulation and may be considered as ideal for air-conditioned and heated rooms.

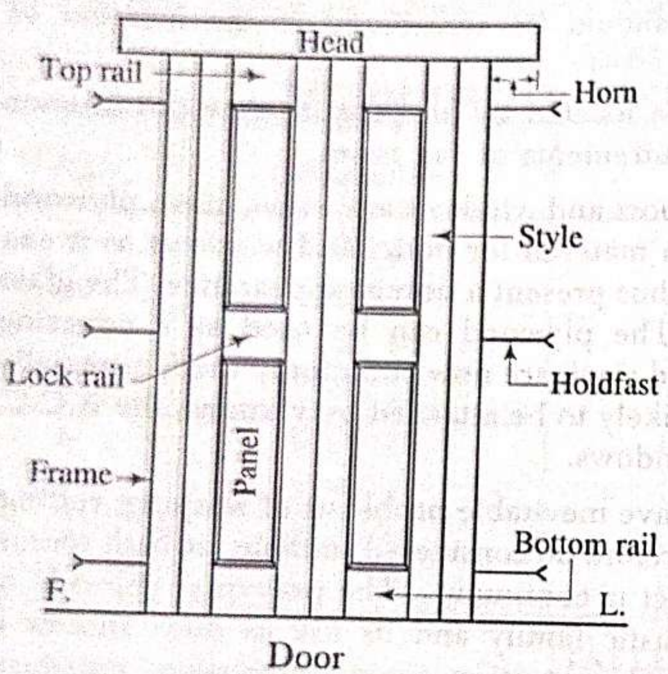
(vi) They restrict dust penetration through openings and hence prove ideal for operation theatres, computer rooms, food processing plants, electronics factories, pharmaceutical plants, etc.

(5) **Other requirements:** The provision of doors and windows should also be made from various other considerations such as safety, entry of moisture, etc. The glazed shutter of an external door should be provided with steel grill of suitable design.

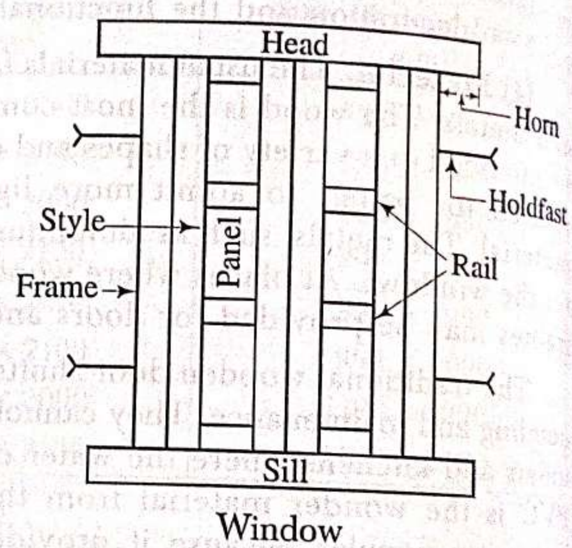
Similarly the openings of all external windows, especially those on ground floor, should be covered up by steel bars or grill of appropriate pattern. The shutters of external windows should open outside so as to check the entry of rain water inside the room. The weathersheds or projections of suitable material should be provided to all external doors and windows to prevent the entry of rain water inside the building. The windows must also provide insulation against heat loss and in some cases, against sound also. Some windows are also required to give facility for resisting a fire.

21-3. TECHNICAL TERMS

Fig. 21-1 and fig. 21-2 show respectively a door and a window. The definitions of technical terms used in connection with the doors and windows are as follows:



Door
FIG. 21-1



Window
FIG. 21-2

(1) **Frame:** This consists of a group of members which form a support for a door or a window.

(2) **Style:** This is the outside vertical member of the shutter of a door or a window.

(3) **Head:** The top or uppermost horizontal part of a frame is known as the *head*.

(4) **Sill:** The lowermost or bottom horizontal part of a window frame is known as the *sill*. The door frames are usually not provided with the sills.

(5) **Top rail:** This is the topmost horizontal member of the shutter.

(6) **Lock rail:** This is the middle horizontal member of the shutter where the locking arrangement is provided.

(7) **Bottom rail:** This is the lowermost horizontal member of the shutter.

(8) **Intermediate or cross-rails:** The additional horizontal rails fixed between the top and bottom rails of a shutter are known as the *intermediate or cross-rails*. A rail which is fixed between the top rail and lock rail is called the *frieze rail*.

(9) **Panel:** This is the area of shutter enclosed between the adjacent rails.

(10) **Holdfast:** This is generally in the form of a mild steel flat bar of section 30 mm × 6 mm and of length 200 mm. The *three* numbers of such holdfasts are provided on each side of the door frame and *two* numbers of such holdfasts are provided on each side of the window frame. They keep the frame in position.

(11) **Horn:** This is a horizontal projection of head or sill beyond the face of the frame. It facilitates the fixing of the frame on the wall opening and its length is about 100 mm to 150 mm.

(12) **Shutter:** The entire assembly of styles, panels and rails is known as the *shutter.*

(13) **Sash:** This is a special type of frame, made of light sections and designed to carry glass. A sash consists of *two* vertical styles, a top rail and a bottom rail. A sash can be divided vertically or horizontally by providing bars. These bars are known as the sash *bars* or *glazing bars.*

(14) **Mullion:** This is a vertical member which is employed to sub-divide a window or a door opening vertically.

(15) **Transom:** This is a horizontal member which is employed to sub-divide a window opening horizontally.

(16) **Louver:** This is a piece of timber which is fixed in an inclined position within a frame.

(17) **Jamb:** The vertical wall face of an opening which supports the frame of door and window is known as the *jamb.*

(18) **Reveal:** The external jamb of a door or a window opening at right angles to the wall face is known as the *reveal.*

(19) **Rebate:** The depression or recess made inside the door frame to receive the door shutter is known as the *rebate.*

(20) **Putty:** This is a mixture of linseed oil and whiting chalk. It is used for fixing glass panels.

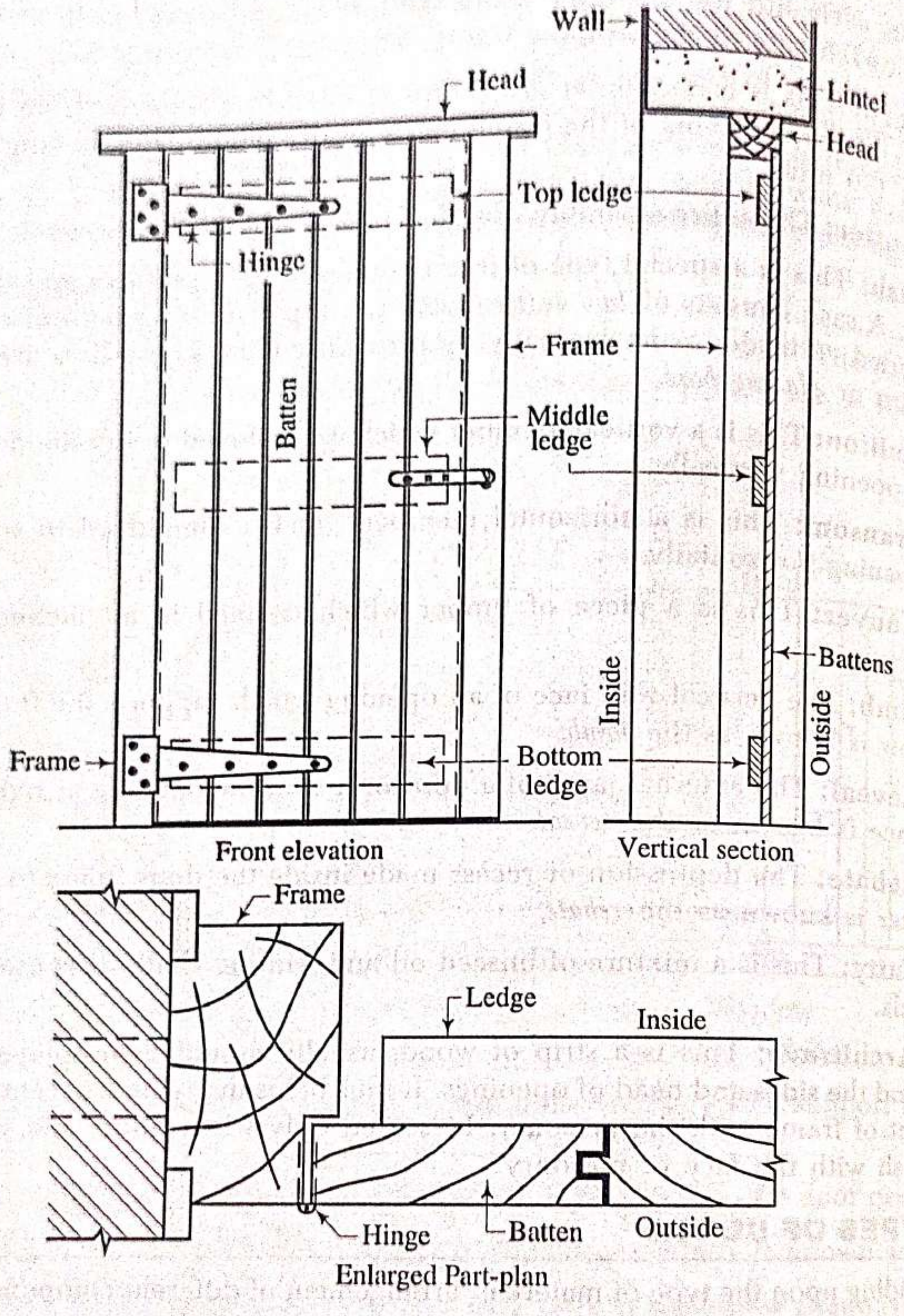
(21) **Architrave:** This is a strip of wood, usually moulded or splayed, which is fixed around the sides and head of openings. It thus helps in giving a decent appearance to the joint of frame with the masonry. It is used only when doors and windows are placed flush with the face of masonry.

21-4. TYPES OF DOORS

Depending upon the type of materials, arrangement of different components, method of construction, etc., the common types of doors used in the buildings can be grouped as follows:

(1) Ledged doors
(2) Ledged and braced doors
(3) Ledged and framed doors
(4) Ledged, framed and braced doors
(5) Framed and panelled doors
(6) Glazed or sash doors
(7) Flush doors
(8) Louvered doors
(9) Collapsible steel doors
(10) Revolving doors
(11) Rolling steel doors
(12) Sliding doors
(13) Swing doors.

(1) **Ledged doors** (fig. 21-3): A ledged door is formed of the vertical boards, known as the *battens*, which are secured by horizontal supports, known as the *ledges* as shown in fig. 21-3.

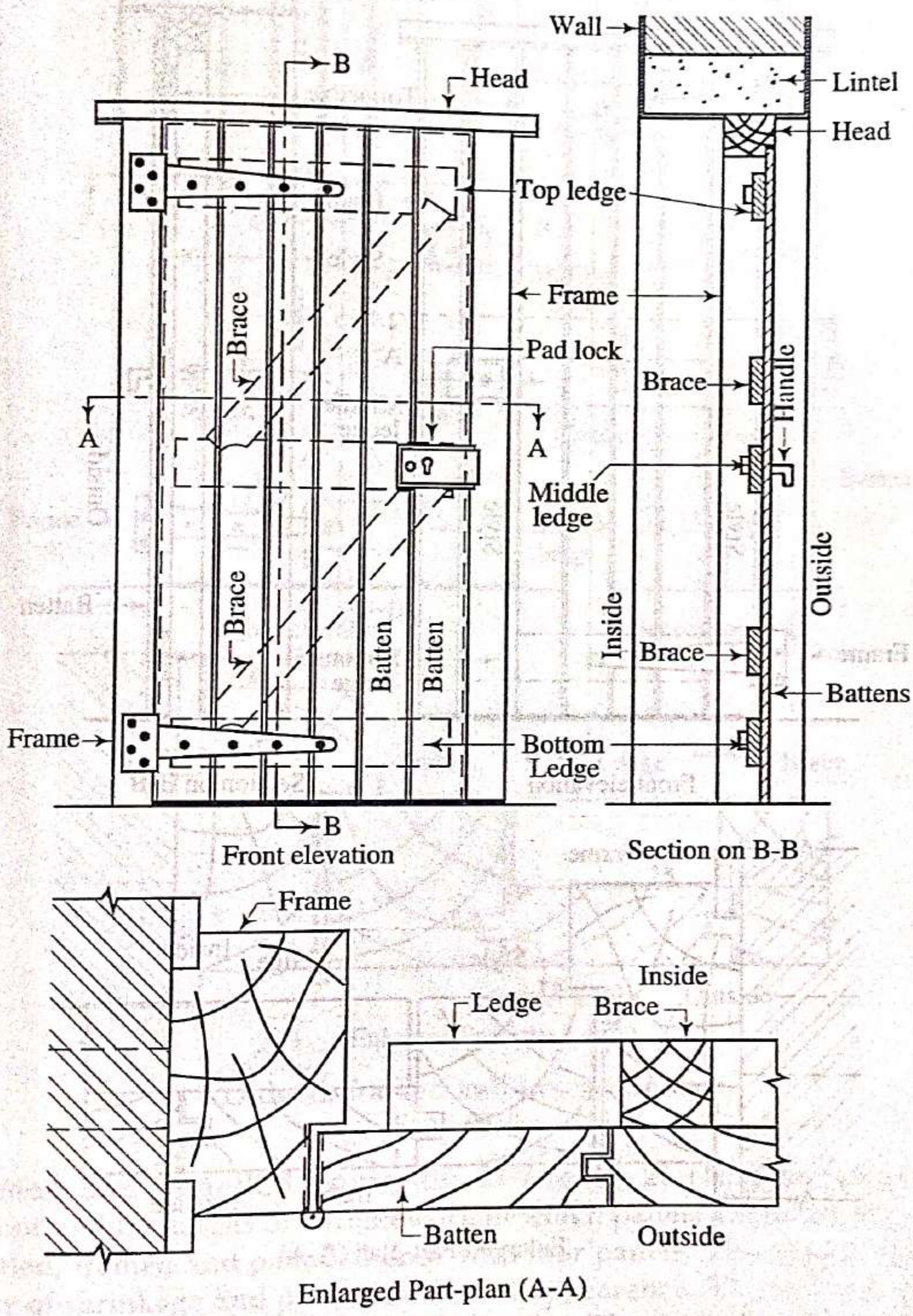


Ledged door
FIG. 21-3

The battens are 100 mm to 150 mm wide and 20 mm to 30 mm thick. The ledges are generally 100 mm to 200 mmwide and 30 mm thick. The *three* ledges are generally employed–top, middle and bottom. The battens are secured by means of suitable joints and the shutter is hung on T-hinges which are fixed on ledges. This is the simplest form of door and it is used where strength and appearance are not important.

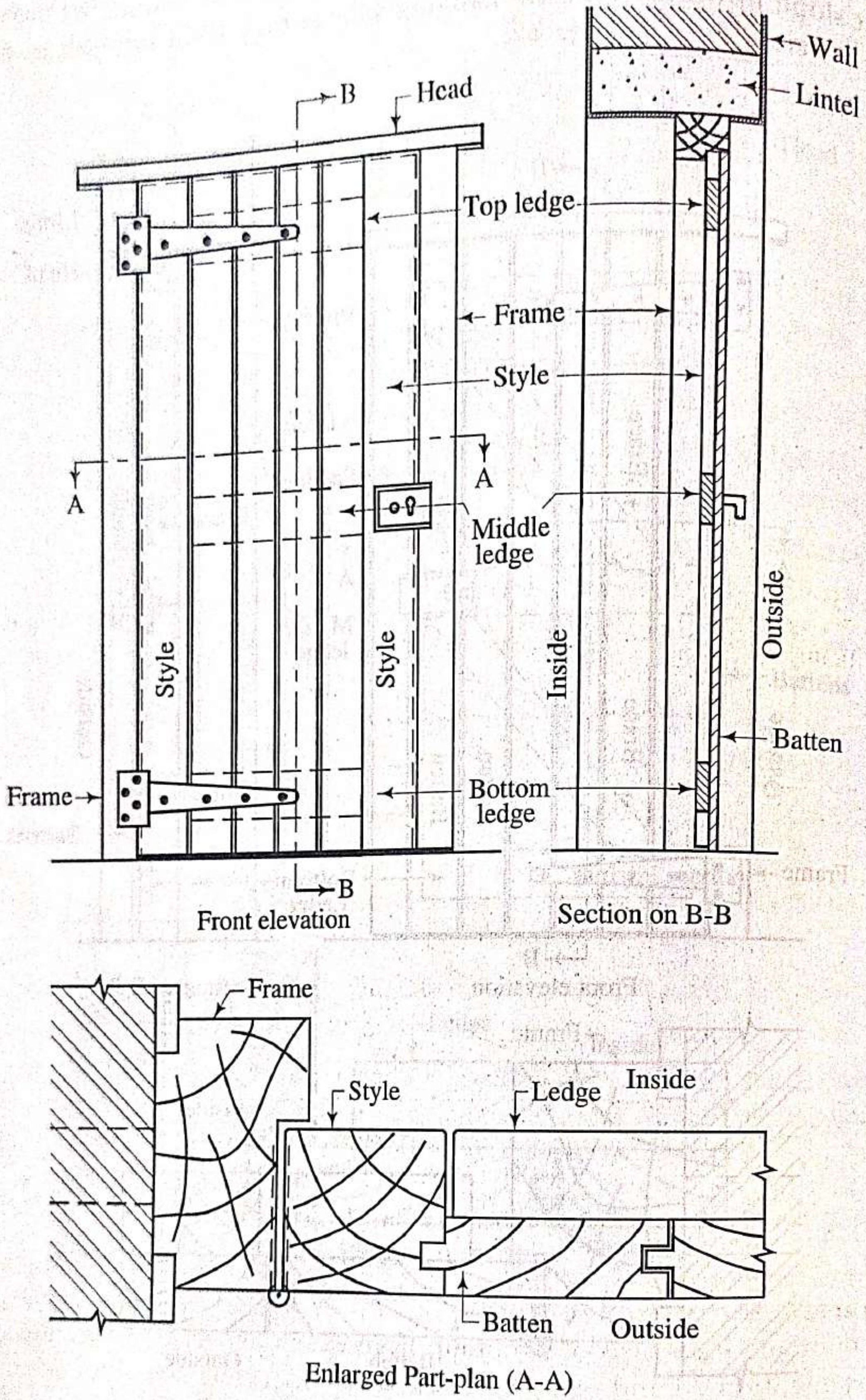
(2) **Ledged and braced doors** (fig. 21-4): These are similar to the ledged doors except that the diagonal members, known as the *braces,* are provided as shown in

fig. 21-4. The braces are generally 100 mm to 150 mm wide and 30 mm thick. The braces give rigidity to the door and hence the doors of this type are useful for wide openings. The braces are usually housed in the ledges. It should be noted that the braces must slope upwards from the hanging side as they have to work in compression and not in tension.



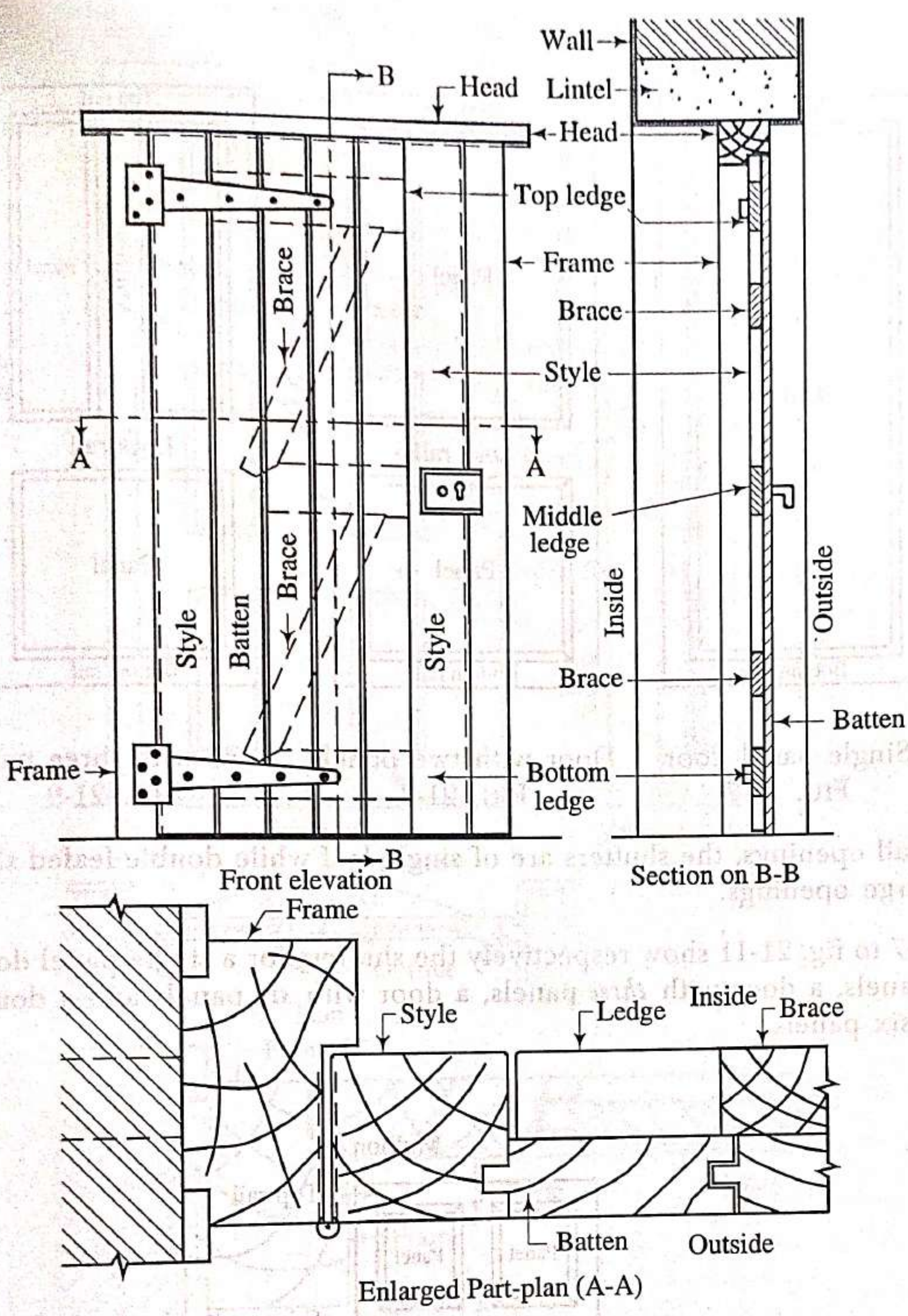
Ledged and braced door
FIG. 21-4

(3) **Ledged and framed doors** (fig. 21-5): In this type of doors, a framework for shutters is provided to make the doors stronger and better in appearance as shown in fig. 21-5. The styles are generally 100 mm wide and 40 mm thick. The battens and ledges are provided as usual.



Ledged and framed door
FIG. 21-5

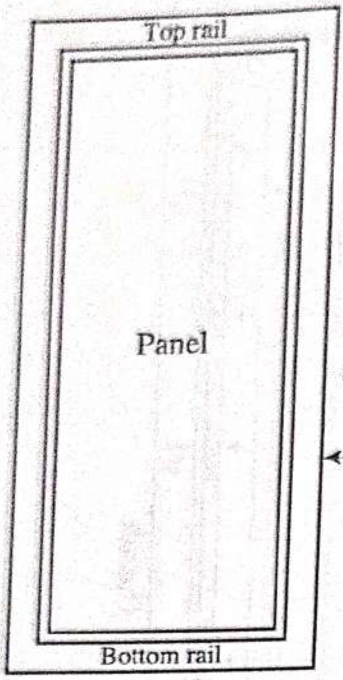
(4) Ledged, framed and braced doors (fig. 21-6): This is just similar to the above type except that the braces are introduced as shown in fig. 21-6. This type of door is more durable and stronger and hence it can be adopted for external use. The braces should incline upwards from the hanging side.



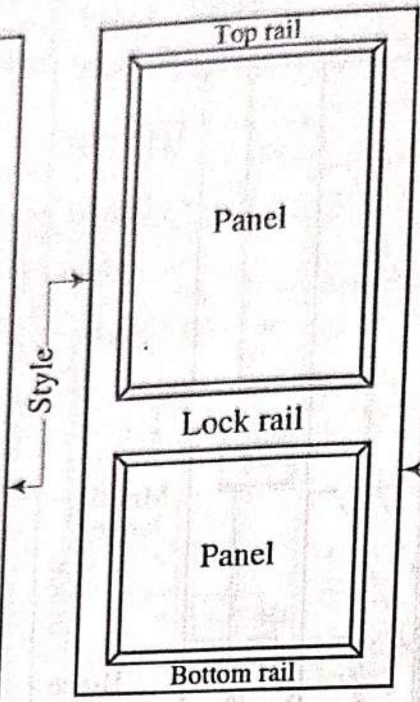
Ledged, framed and braced door
FIG. 21-6

(5) **Framed and panelled doors** (fig. 21-7 to fig. 21-11): This is the most usual variety of door and it consists of a framework in which panels are fitted. Fig. 21-1 shows a double-leafed, framed and panelled door with four panels. This type of door reduces the tendency of shrinkage and presents a decent appearance. The styles are continuous from top to bottom and rails are joined to the styles. The mullions, if any, are joined to rails. The thickness of shutter depends on various factors such as type of work, situation of door, number of panels, etc. But the thickness of shutter is about 30 mm to 40 mm.

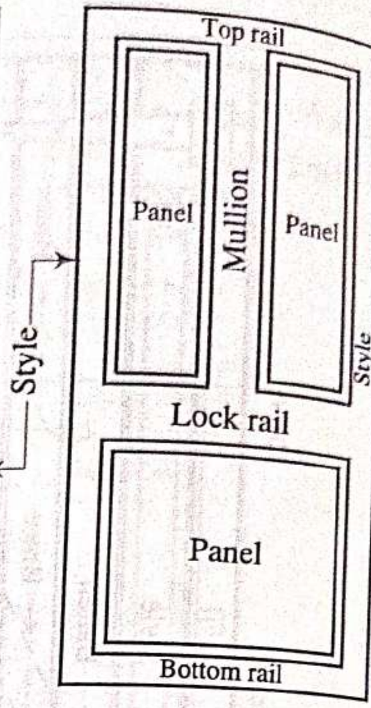
The thickness of panels is about 20 mm. The panels are secured in position by grooves made inside the edges of the framework. The number and size of panels depend upon the architect's design or owner's desire. But the number varies from one to *six* and panels are moulded to add to the beauty of the door.



Single panel door
FIG. 21-7



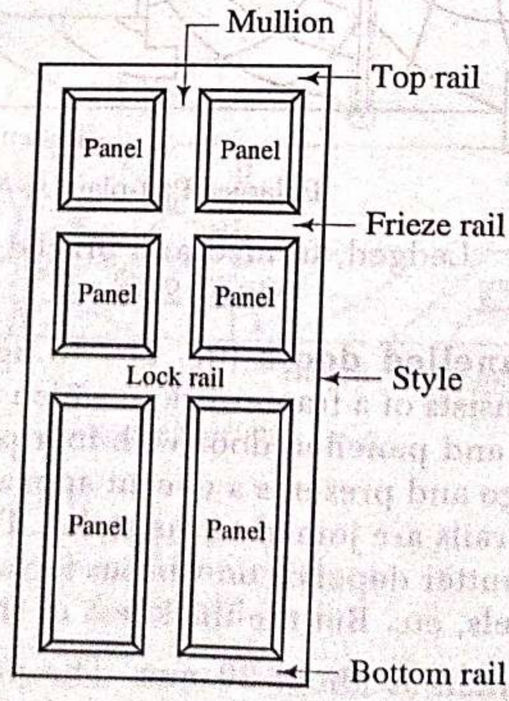
Door with two panels
FIG. 21-8



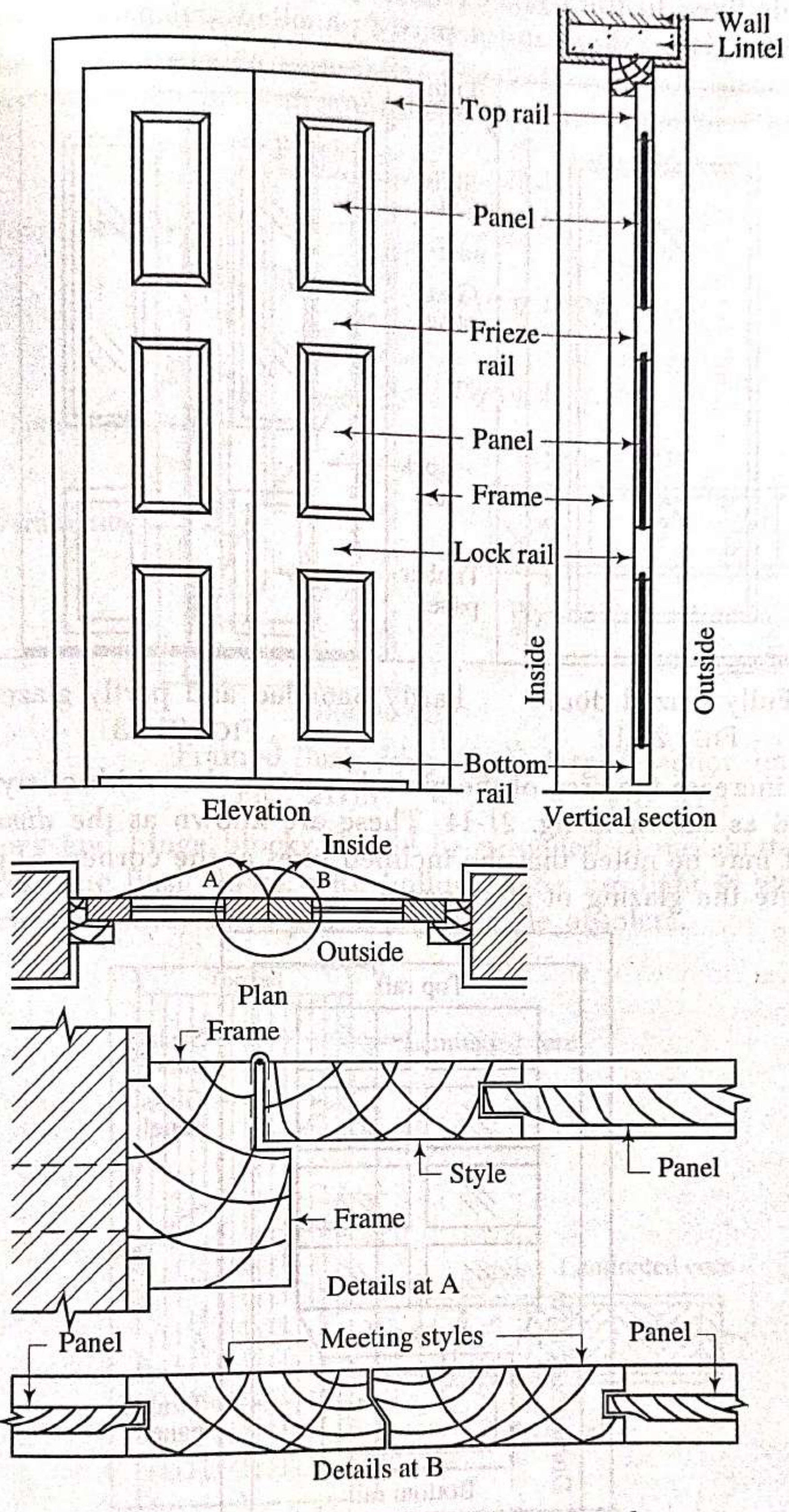
Door with three panels
FIG. 21-9

For small openings, the shutters are of single leaf while double-leafed shutters are used for large openings.

Fig. 21-7 to fig. 21-11 show respectively the shutters for a single panel door, a door with *two* panels, a door with *three* panels, a door with *six* panels and a double-leafed door with six panels.



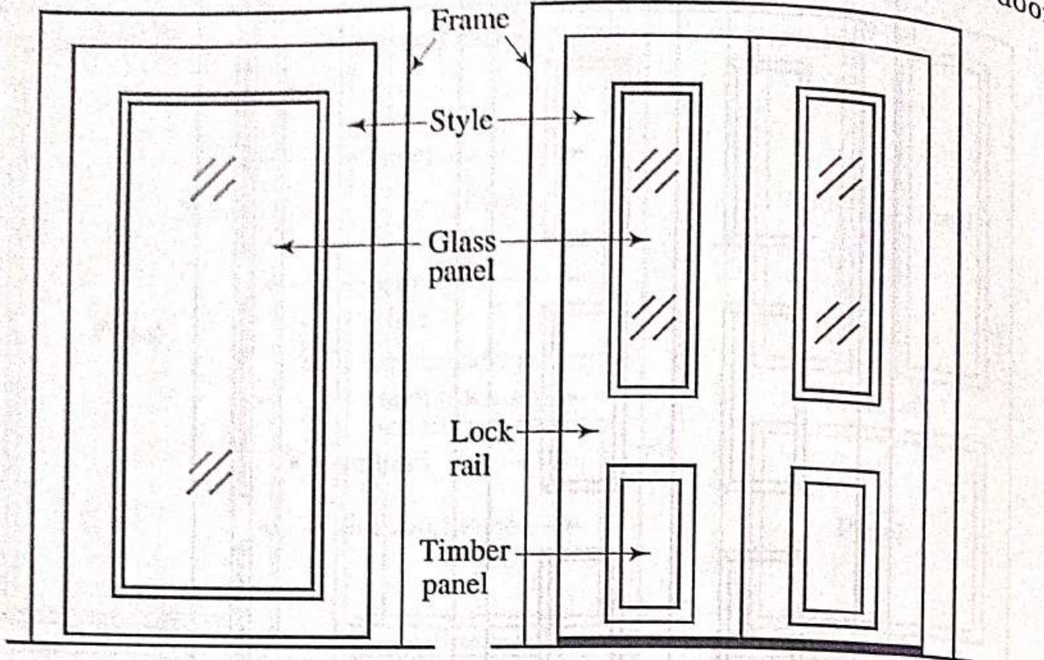
Door with six panels
FIG. 21-10



Double-leafed door with six panels
FIG. 21-11

(6) **Glazed or sash doors** (fig. 21-12 to fig. 21-14): In order to admit more light, in addition to that coming from the windows, the fully glazed or partly panelled and partly glazed doors areused.

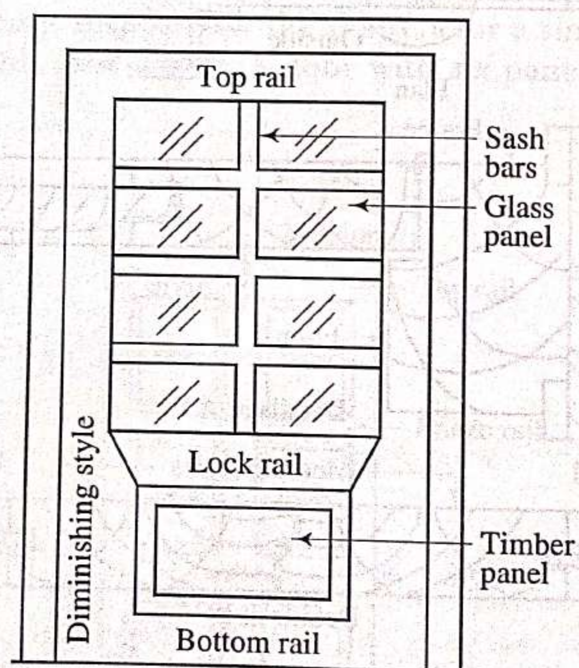
Usually the ratio of glazed portion to panelled portion is 2:1. The glass is received into the rebates provided in the wooden sash bars and secured by nails and putty or by wooden beads fixed to the frame. Fig. 21-12 and fig. 21-13 show respectively the shutters for a fully glazed door and a partly panelled and partly glazed door.



Fully glazed door
FIG. 21-12

Partly panelled and partly glazed door
FIG. 21-13

In order to increase the area of the glazed portion, the width of styles above lock rail is decreased as shown in fig. 21-14. These are known as the *diminished styles* or *gunstock styles*. It may be noted that the inclined lines at the corners of glass panel are drawn to indicate the glazing of glass panel.

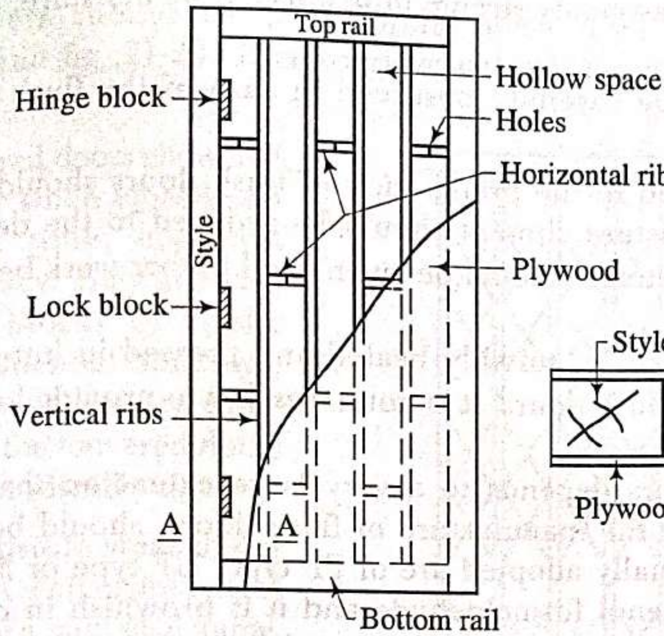


Door with diminishing styles
FIG. 21-14

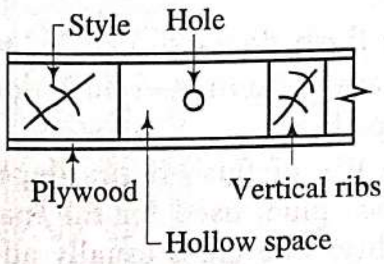
The glazed or sash doors are useful for hospitals, offices, libraries, show rooms, banks, shopping units, etc.

(7) **Flush doors** (fig. 21-15 to fig. 21-18): A flush door consists of a framework of rails and styles and it is covered with plywood or hard-board. There are *two* varieties of flush doors – a *framed flush door* and a *laminated flush door*.

A framed flush door consists of styles, rails, horizontal ribs, vertical ribs and plywood as shown in fig. 21-15 and fig. 21-16. The holes in horizontal ribs are provided for ventilation. The vertical ribs rest on rails. The hollow space, instead of being kept empty, is sometimes filled up with granulated cork or any other light material.

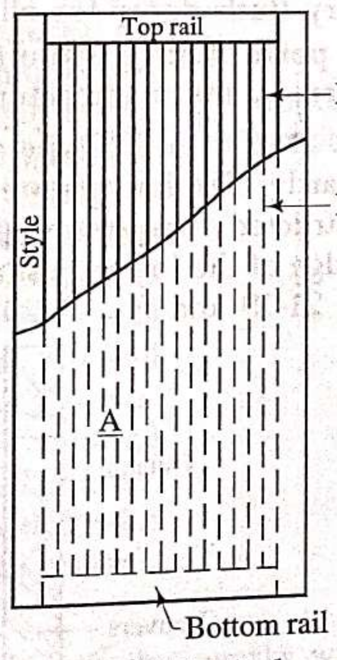


Framed flush door
FIG. 21-15

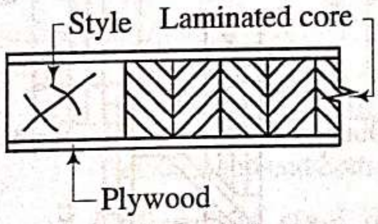


Enlarged section on AA
FIG. 21-16

A lock block and hinge blocks should be provided to the shutter to fix mortise lock and hinges. The flush doors, with hollow space, are light in weight and cheap. But as they are weak, they have practically become obsolete.



Laminated flush door
FIG. 21-17



Enlarged section on AA
FIG. 21-18

A laminated flush door consists of styles, rails, laminated core and plywood as shown in fig. 21-17 and fig. 21-18. The laminae of wood are glued together under great pressure. The plywood sheets on either side are also glued to the laminated core under great pressure. Thus a laminated flush door is heavy and requires more material for construction.

The flush doors are prepared by specialist firms and they are therefore available in standard sizes. The thickness of plywood facing is about 6 mm on either side and total thickness of a flush door varies from 25 mm to 40 mm. The flush doors are now commonly used, especially for interior work. The flush doors are economical, easy to clean, better in appearance, reasonably strong, little affected by moisture, termite-proof and crack-proof.

The important points to be carefully observed in case of the flush doors are as follows:

(i) The timber to be used in the preparation of flush doors should be properly seasoned and its moisture content should be reduced to the desired level.

(ii) The termite-proof treatment should be given to all timber work before applying glue.

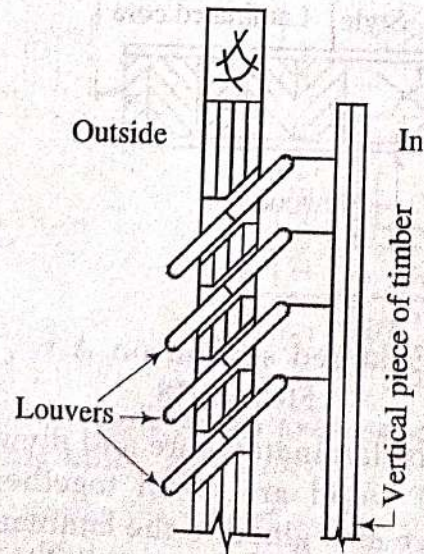
(iii) The flush doors should be suitably heated and pressed in hot-press.

(iv) In case of laminated flush doors, it is not necessary to provide lock block and hinge blocks.

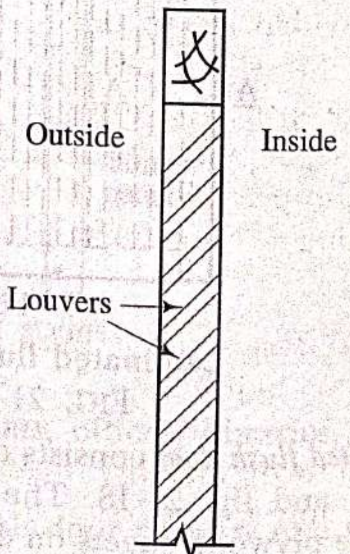
(v) The life of flush doors depends to a very large extent on the glue bonds. Hence glue, used for the manufacture of flush doors, should be of standard quality. The glues usually adopted are of PF type, UF type or MF type. The PF type indicates phenol formaldehyde and it is brownish in colour. It can join wooden pieces under high pressure and heat. It is the best for water-proofing qualities, but it is costly. The UF type indicates urea formaldehyde which is whitish in colour. It can join wooden pieces under pressure at room temperature. It cannot stand prolonged exposure to water. The MF type indicates melamine urea formaldehyde. It possesses intermediate qualities between PF and UF types. It may however be noted that only PF type resin would give durable and satisfactory flush doors for all situations.

(vi) The flush doors for optimum performance should be installed and maintained as per instructions given by the manufacturers.

(8) Louvered doors (fig. 21-19 and fig. 21-20): In this type of doors, the shutters are provided with louvers, either fully or partly. The louvers are arranged at such an inclination that the horizontal vision is obstructed. Thus the upper back edge of any louver will be higher than the lower front edge of the louver just above it. The louvers may be movable or fixed as shown in fig. 21-19 and fig. 21-20 respectively.



Movable louvers
FIG. 21-19



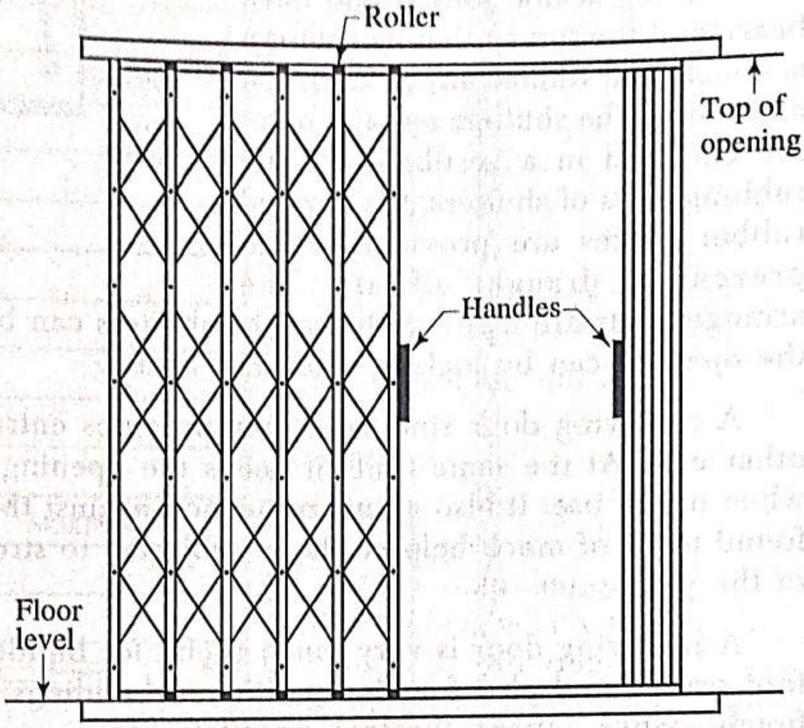
Fixed louvers
FIG. 21-20

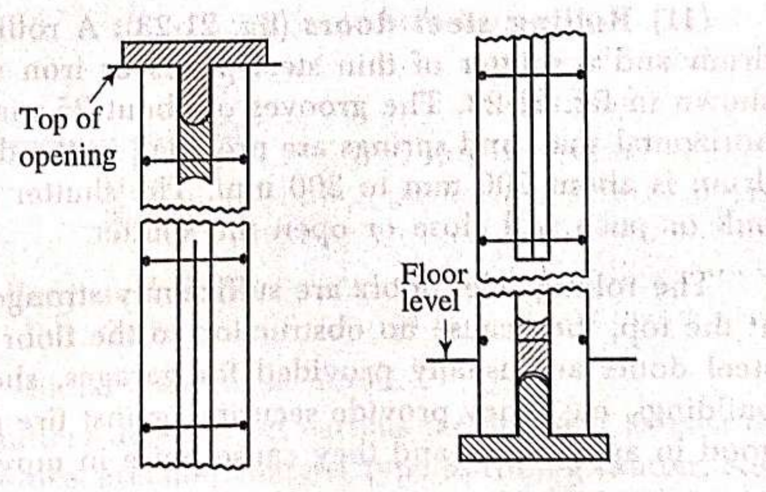
In case of movable louvers, a vertical piece of timber is provided to which the louvers are attached through hinges. The upward or downward movement of the louvers can be carried out with the help of vertical piece of timber. The louvers may be either of wood orglass.

The louvers should be kept sloping away from the inner portion as shown in fig. 21-19 and fig. 21-20. This arrangement will prevent the entry of moisture from outside.

The louvered doors allow free passage of air when closed and at the same time, maintain sufficient privacy. They are used for sanitary blocks of public buildings, residential buildings, etc. The louvers collect dust easily and therefore the louvered doors should be periodically cleaned.

(9) Collapsible steel doors (fig. 21-21): A collapsible steel door consists of a mild steel frame. The *two* vertical pieces of mild steel channels, about 15 mm to 20 mm wide, are joined together with the hollow portion of the channel inside. A vertical gap of about 12 mm to 15 mm is thus created. Such pieces are spaced at about 120 mm centre to centre and are joined to one another by cross iron pieces as shown in fig. 21-21. The cross iron pieces are usually 10 mm to 15 mm wide and 15 mm thick. The rollers, mounted on horizontal piece, are provided at top and bottom ends of the vertical pieces. The door can be opened or closed manually by a slight pull or push. The door is also provided with handles, locking arrangement, stoppers, etc.

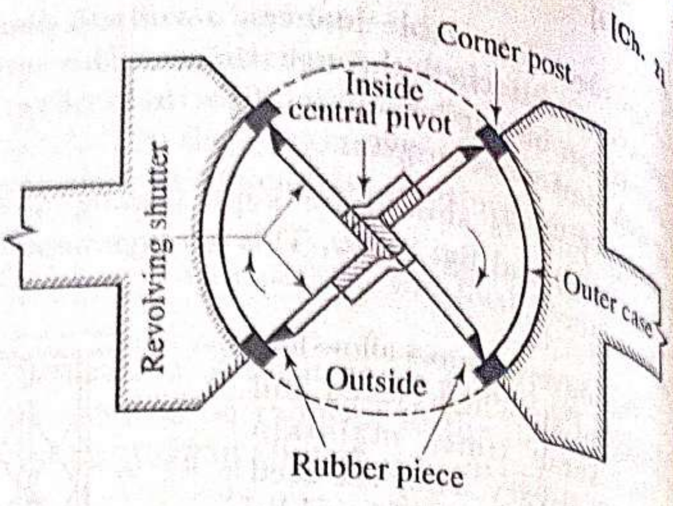




Collapsible steel door
FIG. 21-21

A collapsible steel door thus works without hinges and it is used for compound gates, residential buildings, schools, sheds, godowns, workshops, public buildings, etc. for providing increased safety and protection to the property. The collapsible steel doors are also recommended in situations where light and ventilation are desired even when the opening is closed.

(10) Revolving doors (fig. 21-22): A revolving door essentially consists of a centrally placed mullion or pivot in a circular opening. The revolving shutters or leaves which are *four* in number are radially attached to the pivot as shown in fig. 21-22. The shutters may be fully glazed, fully panelled or partly panelled and partly glazed.



Revolving door
FIG. 21-22

The central pivot is provided with ball bearing at the bottom and bush bearing at the top so that its rotation is smooth and without any jerk, friction and noise. The shutters and the pivot are enclosed in a vestibule. At the rubbing ends of shutters, the vertical rubber pieces are provided which prevent a draught of air. The arrangements are made such that the shutters can be folded when traffic is more and the opening can be locked, when not in use.

A revolving door simultaneously provides entrance on one side and exit on the other end. At the same time, it keeps the opening automatically in closed position, when not in use. It also grants protection against the wind draught and it is therefore found to be of much help at places subjected to strong winds during most of the part of the year.

A revolving door is very much useful for buildings, where there is heavy rush of foot traffic, and also for air-conditioned buildings. Hence they are provided in big hotels, banks, offices, theatres, hospitals, etc.

(11) Rolling steel doors (fig. 21-23): A rolling steel door consists of a frame, a drum and a shutter of thin steel plates or iron sheets of thickness about 1 mm, as shown in fig. 21-23. The grooves of about 25 mm thickness are left in the frame. A horizontal shaft and springs are provided in the drum at the top. The diameter of the drum is about 200 mm to 300 mm. The shutter usually rolls in turns. Thus a slight pull or push will close or open the shutter.

The rolling steel doors are sufficiently strong and as they can be easily rolled up at the top, they cause no obstruction to the floor as well as the opening. The rolling steel doors are usually provided for garages, show rooms, shops, godowns, factory buildings, etc. They provide security against fire and burglars. They are however not good in appearance and they cause noise in movements.

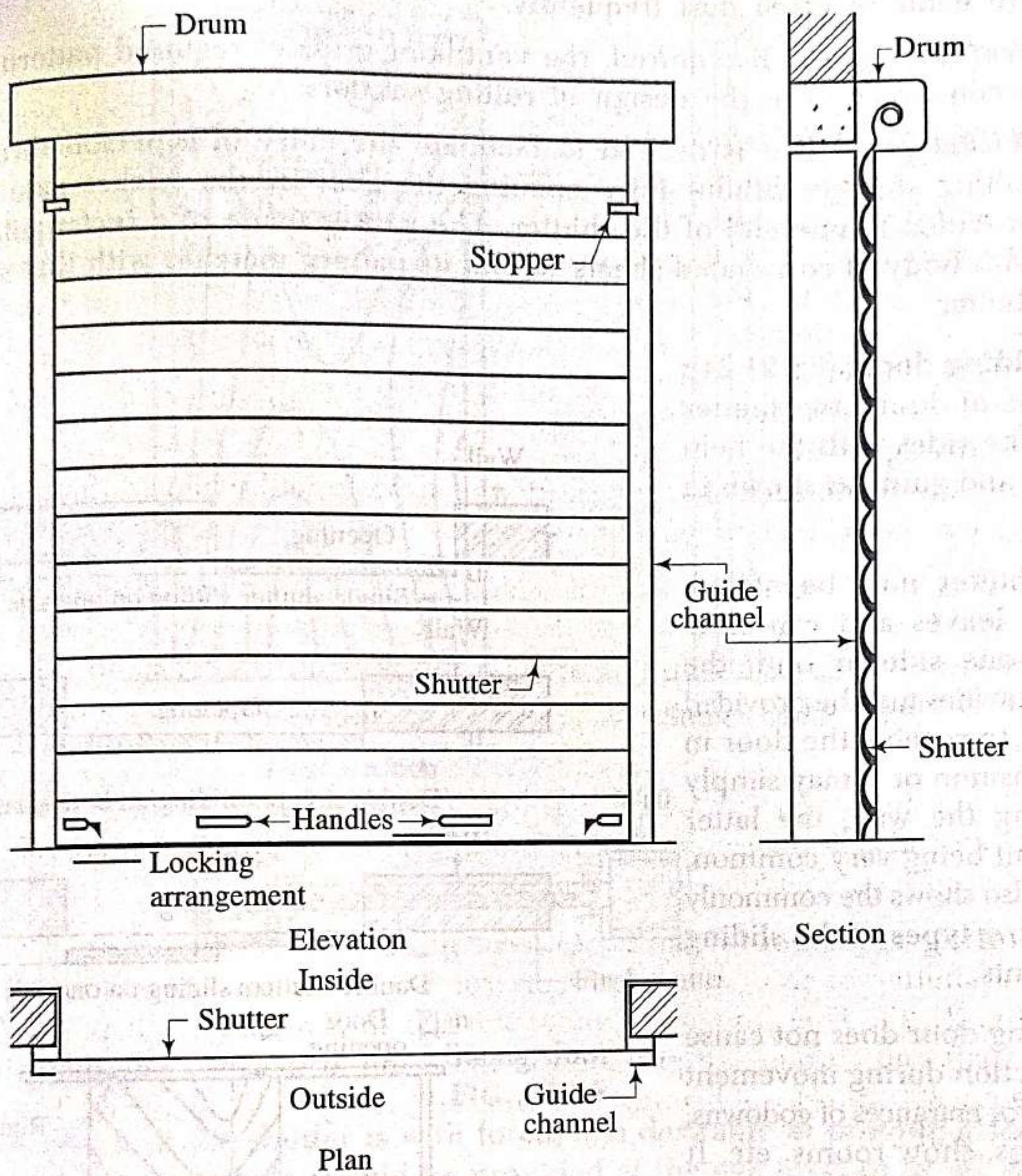
The rolling shutters are of the following *two* types:

(i) Pull-push type shutters

(ii) Mechanical gear type shutters.

(i) ***Pull-push type shutters:*** These shutters are suitable for areas less than 10 m^2 and they are operated by simply applying pull or push. The total weight of pull-push type rolling shutter is about 240 N per m^2.

(ii) ***Mechanical gear type shutters:*** These shutters are suitable for areas greater than 10 m^2 and they are operated by worm-gears, connecting rod and winding handle or by means of chain pulley blocks. The thickness of shutters is kept about 1.25 mm. The pulleys are interconnected with steel bars so that motion given by one pulley by the mechanical device is shared by all the pulleys. The total weight of mechanical gear type rolling shutter is about 280 N per m^2.



Rolling steel door
FIG. 21-23

Following aspects of the rolling shutters are to be noted:

(i) ***Cost:*** The cost of rolling shutters depends on various factors such as cost of raw materials, transport facilities, erection charges, type of rolling shutter, etc.

(ii) ***Erection:*** The erection of rolling shutters should be carried out carefully. The shaft and pulleys are first placed in position. The partition or shutter is then suspended. The frame is finally fixed to the masonry after checking for line and level.

(iii) ***Maintenance:*** To increase the life of rolling shutters, they should be painted every *two* years and the various components should be oiled or greased at regular intervals of *three* to *six* months. The tension of springs should also be checked once in a year. If properly maintained, the rolling shutter can easily last for 15 years or so.

(iv) ***Orientation:*** The rolling shutters are usually of horizontal type i.e. they roll around horizontal axis. They can also be made to roll around vertical axis, if the height does not exceed 3 m. The vertical type rolling shutters are not desirable because they cause difficulty in movements and the bottom guides are liable to catch dust frequently.

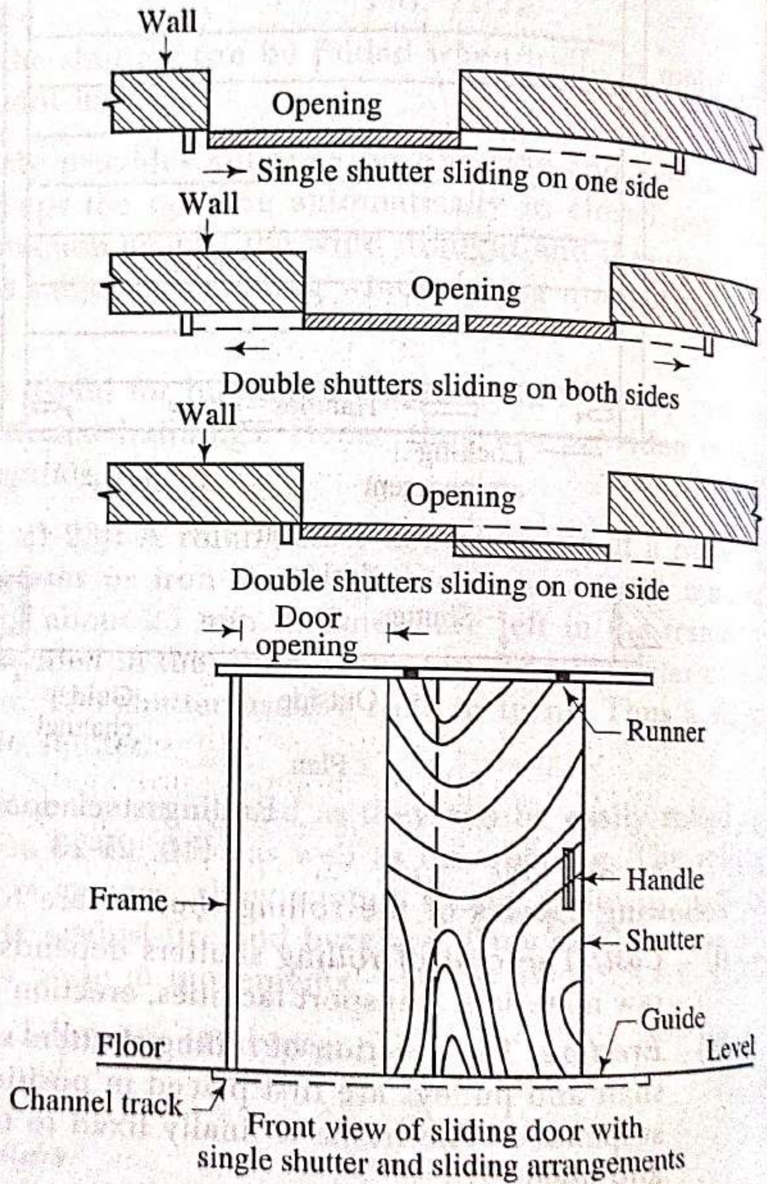
(v) *Ventilator grills:* If required, the ventilator grills of required pattern may be accommodated in the design of rolling shutters.

(vi) *Wicket gates:* If it is desired to facilitate the entry of a person through the rolling shutter without fully opening the shutter, the wicket gate may be provided at one end of the shutter. The gate is made of a rectangular frame with body of corrugated sheets so that its pattern matches with that of rolling shutter.

(12) Sliding doors (fig. 21-24): In this type of doors, the shutter slides on the sides with the help of runners and guide as shown in fig. 21-24.

The shutter may be of one or several leaves and can slide either on one side or both the sides. The cavities may be provided in the wall to receive the door in an open position or it may simply lie touching the wall, the latter arrangement being very common. Fig. 21-24 also shows the commonly adopted *three* types of the sliding arrangements.

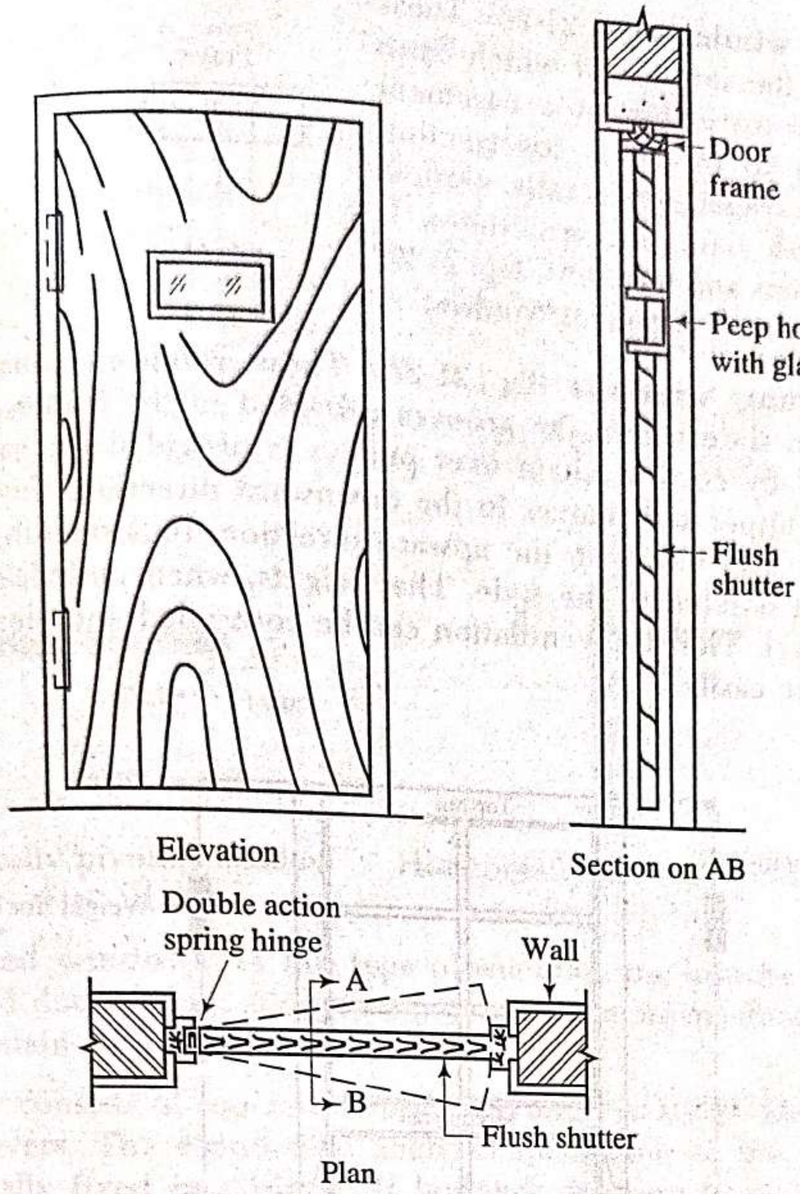
A sliding door does not cause any obstruction during movement and is used for entrances of godowns, sheds, shops, show rooms, etc. It is provided with handles, locking arrangement, stopper, etc.



Sliding door
FIG. 21-24

(13) Swing doors: A *swing door* is provided with special hinges known as the *double action spring hinges* and thus the shutters of the door are held in closed position, when the door is not in use. The shutter may be of one or several leaves. When the door is to be used, a slight push is made and then the action of spring brings the shutter in closed position.

Fig. 21-25 shows the details of a swing door of size 0.90 m × 2.10 m with 35 mm thick flush shutter. The dimensions of peep hole are 150 mm × 300 mm and it is placed at a distance of about 450 mm from the top.



Swing door

FIG. 21-25

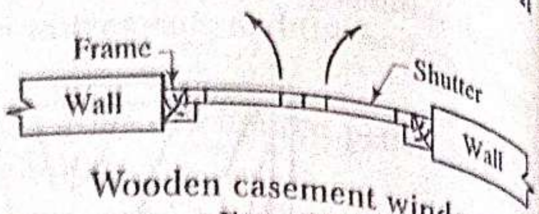
As the return of the shutter is with force, it is desirable to provide glazed shutters or alternatively a peep hole should be provided at the eye level to avoid the accident to the door users. The closing edges of the meeting styles should not be rebated and they should be made segmental. This type of door is widely used in passages of public buildings such as govt. offices, banks,etc.

21-5. TYPES OF WINDOWS

Depending upon the manner of fixing, materials used for construction, nature of operational movements of shutters, etc., the common varieties of windows used in the buildings can be grouped as follows:

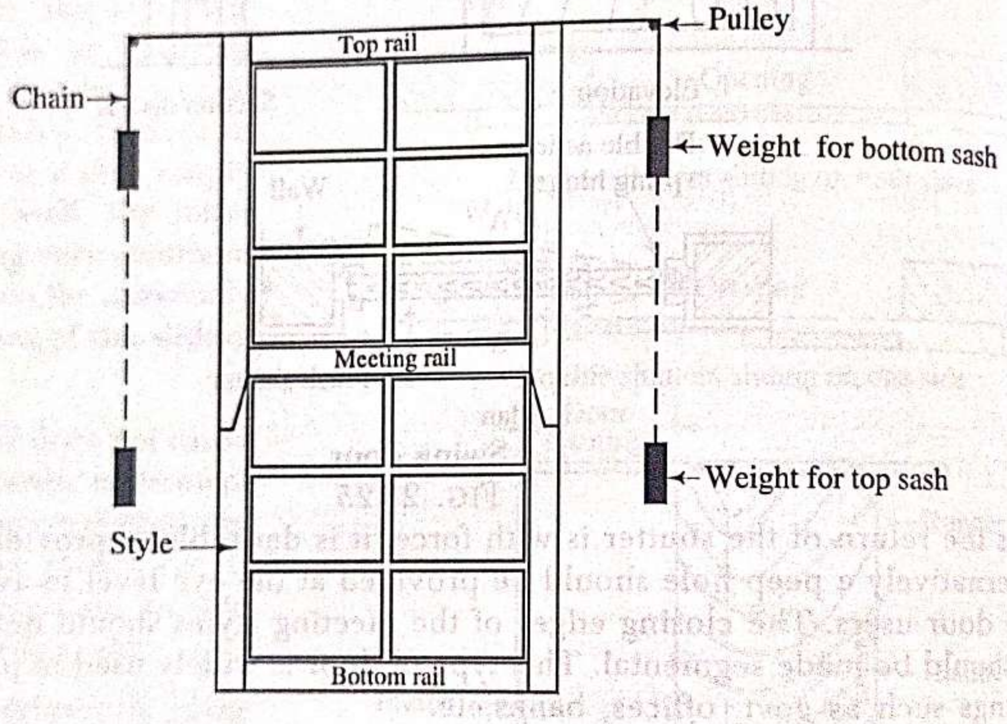
(1) Casement windows
(2) Double-hung windows
(3) Pivoted windows
(4) Sliding windows
(5) Louvered windows
(6) Sash or glazed windows
(7) Metal windows
(8) Circular windows
(9) Corner windows
(10) Gable windows
(11) Dormer windows
(12) Bay windows
(13) Clerestorey windows
(14) Lanterns or lantern lights
(15) Skylights.

(1) **Casement windows** (fig. 21-26): These are the windows, the shutters of which open like doors. The construction of a casement window is similar to the door construction and it consists of a frame, styles, rails, vertical and horizontal sash bars and sometimes, it also includes mullions and transoms. Fig. 21-26 shows a typical wooden casement window.



Wooden casement window
FIG. 21-26

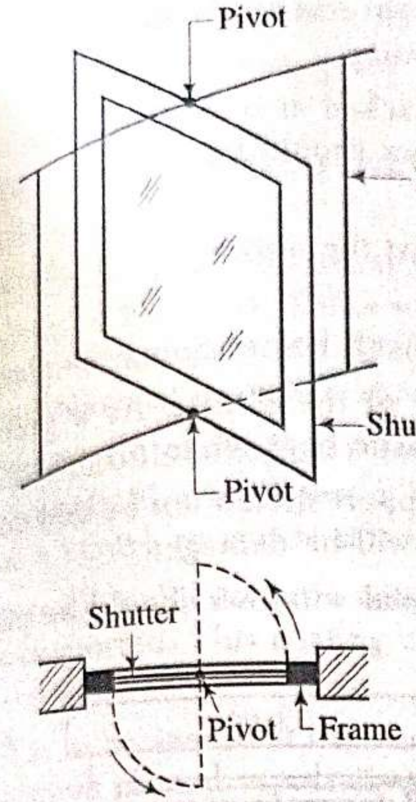
(2) **Double-hung windows** (fig. 21-27): These windows consist of a pair of shutters which can slide within the grooves provided in the frame. A pair of metal weights connected by cord or chain over pulleys is provided for each sash. It is so arranged that the upper sash moves in the downward direction, thus opening at the top and the lower sash moves in the upward direction, thus opening at the bottom. The cord or chain is fixed to the style. The weights, when pulled, open the shutter to the required level. Thus the ventilation can be controlled and cleaning of shutters can be carried out easily.

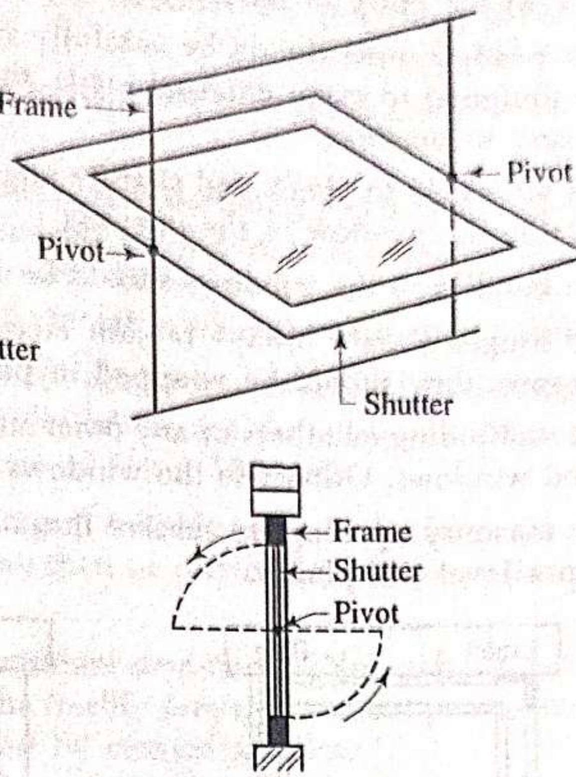


Double-hung window
FIG. 21-27

(3) **Pivoted windows** (fig. 21-28 and fig. 21-29): In this type of windows, the shutters are allowed to swing round the pivots. The frame of a pivoted window is just similar to casement window except that no rebates are provided. The windows may be vertically pivoted or horizontally pivoted as shown in fig. 21-28 and fig. 21-29 respectively. The pivoted windows are easy to clean and they admit more light than the side-hung windows.

(4) **Sliding windows:** These windows are similar to the sliding doors and the shutters move on the roller bearings, either horizontally or vertically. Suitable openings are provided in the walls to receive the shutters when windows are opened out. Such windows are provided in trains, buses, bank counters, shops, etc.





Vertically pivoted window
FIG. 21-28

Horizontally pivoted window
FIG. 21-29

(5) **Louvered windows:** In this type of windows, the louvers are provided as in case of louvered doors. They allow free passage of air when closed and at the same time, they maintain sufficient privacy.

The shutter consists of top rail, bottom rail and *two* styles which are grooved to receive the louvers. The economical angle of inclination of the louvers is 45° and they are generally fixed in position. If however they are to be raised or lowered, some mechanical operating device will have to be provided. The louvers should slope downward to the outside so that the rain water does not get entry to the inside of building.

(6) **Sash or glazed windows:** These are fully glazed casement windows. The sashes are rebated to receive glass panels. The width and depth of rebates are about 15 mm and 5 mm respectively. The glass is secured in position either by putty or by small fillets, known as the *glazing beads*.

(7) **Metal windows** (fig. 21-30 and fig. 21-31): These are now-a-days widely used, especially for public buildings. The metal used in the construction may be mild steel, bronze or other alloys. The steel windows are manufactured in standard sizes and are widely used metal windows. The metal frame may be fixed direct to the wall as shown in fig. 21-30 or it may be fixed on a wooden frame as shown in fig. 21-31. In the former case, the lugs and plugs are provided to keep the frame in position. In the latter case, the screws are used to fix the metal frame with the wooden frame.

The *precautions* to be taken in case of the *metal windows* are as follows:

(i) The members of the frame and sash should be properly welded at the corners.

(ii) The precautions should be taken to prevent corrosion of the metal windows.

(iii) The glass panels should be properly fixed.

(iv) The metal frame should be embedded in cement or bituminous mastic to prevent the entry of moisture or rain water.

(v) The window units should be carefully stacked at site. As window frames are not designed to carry external loads, they should be carefully carried while placing in position.

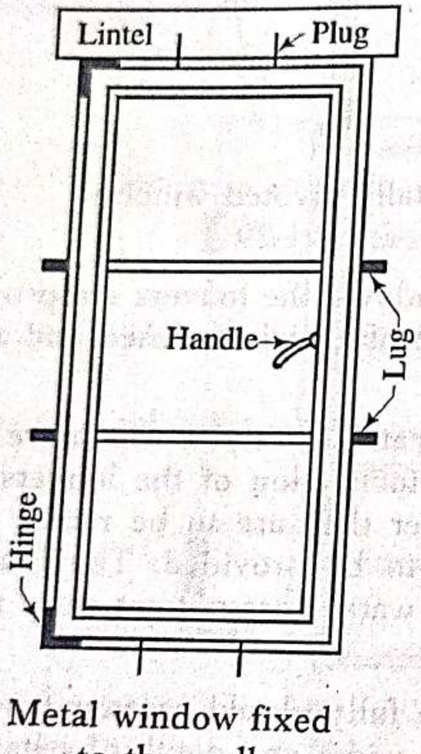
(vi) It is advisable to check and slightly adjust the movements of shutters before erecting the window in the opening.

(vii) The handles to the windows should be fixed before doing the glazing work.

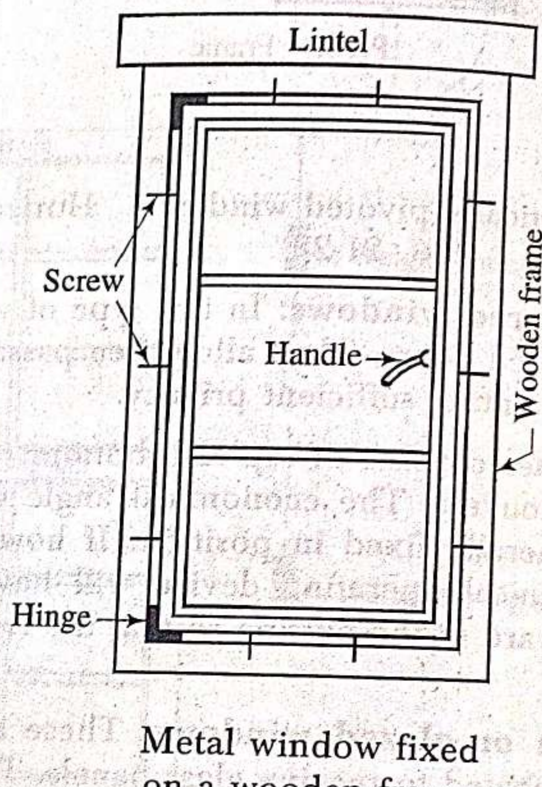
(viii) The hinges should always remain clear of the plaster. As a precautionary measure, they should be wrapped in plastic bags while plastering.

(ix) The scaffolding members or any other support should not be tied down to the metal windows. Otherwise the windows will be damaged.

(x) The masonry openings to receive the metal windows should be prepared in proper level and plumb.



Metal window fixed to the wall
FIG. 21-30



Metal window fixed on a wooden frame
FIG. 21-31

Following are the *advantages* of the *steel windows* over the *wooden windows*:

(i) The steel windows are factory made products and hence they possess greater precision as compared to the wooden windows.

(ii) The steel windows are not subject to contraction or expansion due to weather effects as in the case of wooden windows.

(iii) The steel windows exhibit elegant appearance.

(iv) The members of steel windows are narrow and hence the steel windows admit more light and ventilation for the same area, as compared to the wooden windows.

(v) The steel windows are easy to maintain and their cost of maintenance is almost negligible as compared to that of the wooden windows.

(vi) The steel windows are highly fire-proof and termite-proof.

(vii) The steel windows grant better facilities for providing different types of openable parts.

(viii) The steel windows are more durable and stronger as compared to the wooden windows.

The aluminium is a non-ferrous metal and *aluminium windows* are used in relatively posh buildings in big cities. These windows are decent in appearance and they require no maintenance and painting. They may be either of casement type or horizontal sliding type. Following *precautions* should be taken when the aluminium windows are used:

(i) Instead of holdfasts, the cadium plated screws about 50 mm long are inserted through 10 mm diameter holes which are drilled on all sides of the frames at a centre to centre distance of about 500 mm.

(ii) It is advisable to get a coating of suitable paint to the frames before they are transported. This coating can then be removed from the visible surfaces after erection.

(iii) It is to be seen that the aluminium members do not come in contact with the cement plaster, especially the freshly prepared cement plaster surface because aluminium is easily attacked by cement alkalies.

(iv) The frames for aluminium windows are truly rectangular with tolerance of about 3 mm. Hence the masonry openings to receive these frames should be made true to levels.

(v) The frames should be given a coat of mastic on the outside before they are fixed in the masonry openings.

(vi) These windows are delicate items and hence they should be fixed in the last stage of completion of the job.

The *disadvantages* of the aluminium windows are as follows:

(i) They are costly.

(ii) They are not very strong.

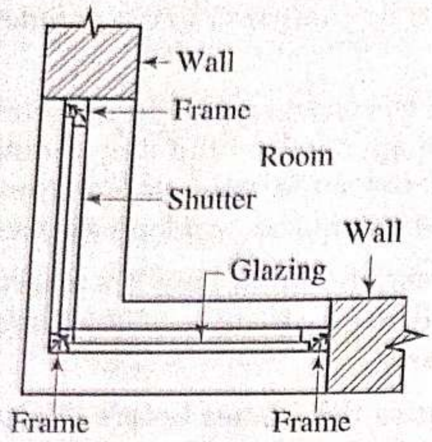
(iii) They cannot be used for industrial buildings which require windows with safety bars.

(8) **Circular windows:** These are pivoted windows of circular shape. They are useful for factories, workshops, etc.

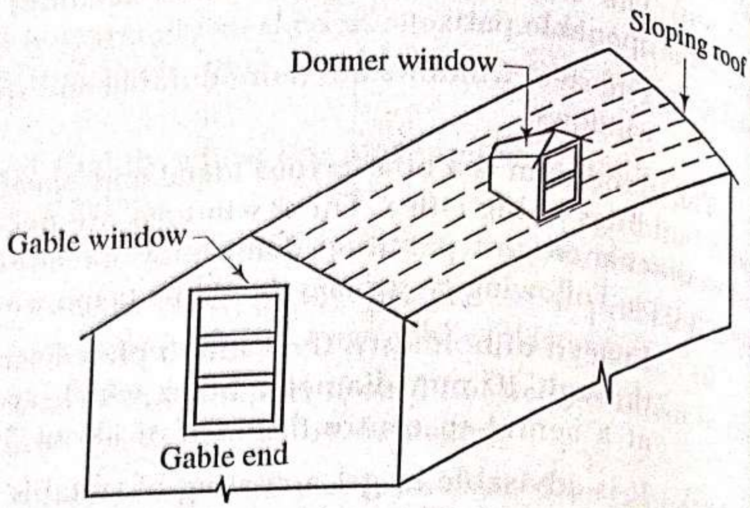
(9) **Corner windows** (fig. 21-32): These windows are provided at the corner of a room as shown in fig. 21-32. They are placed at the corner of a room and thus they have *two* faces in *two* perpendicular directions. Due to such situation, there is entry of light and air from *two* directions and in many cases, the elevation of the building is also improved. However special lintel will have to be cast at the corner and the jamb post of the window at the corner will have to be made of heavy section.

(10) **Gable windows** (fig. 21-33): These are the windows which are provided in the gable ends of a roof as shown in fig. 21-33.

(11) **Dormer windows** (fig. 21-33): These are the windows provided on the sloping roofs as shown in fig. 21-33. The main purpose of providing dormer windows is to admit light and air to rooms which are constructed within or below the roof slopes.

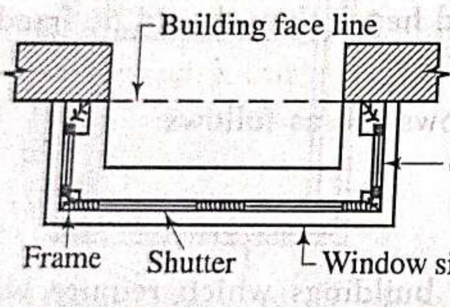


Corner window
FIG. 21-32

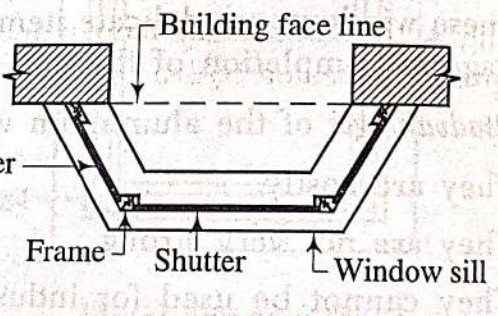


Gable window and dormer window
FIG. 21-33

(12) **Bay windows** (fig. 21-34 and fig. 21-35): These windows project outside the external walls of a room. They may be square, splayed, circular, polygonal or of any shape. Fig. 21-34 and fig. 21-35 show respectively a square bay window and a splayed bay window. The projection of bay windows may start from floor level or sill level. These windows admit more light, increase opening area, provide ventilation and improve the appearance of the building.



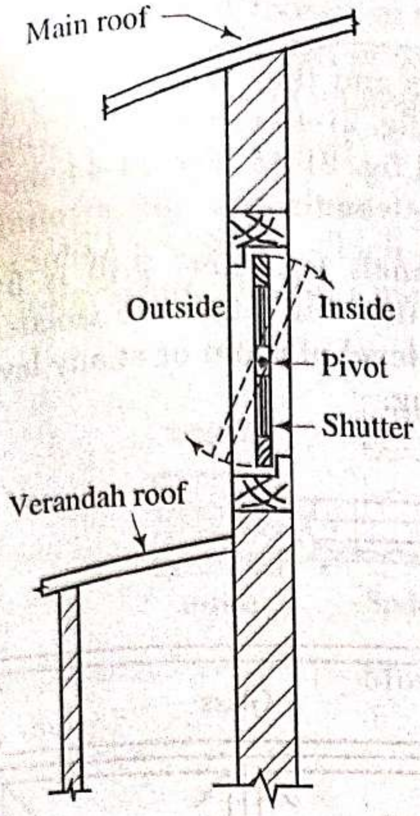
Square bay window
FIG. 21-34



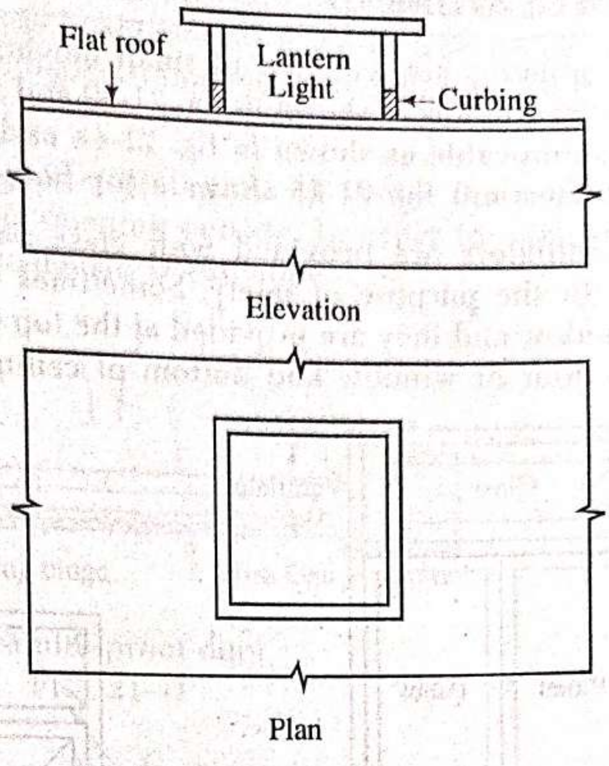
Splayed bay window
FIG. 21-35

(13) **Clerestorey windows** (fig. 21-36): These windows are provided near the top of main roof as shown in fig. 21-36. The pivoted windows are used for this purpose. The clerestorey windows provide ventilation to the inside of the room as the front is blocked by the verandah. They also improve the appearance of building. The care should be taken to see that the upper part opens inside and the lower part opens outside. Otherwise the rain water will accumulate in the room.

(14) **Lanterns or lantern lights** (fig. 21-37): These are the windows which are fixed on flat roofs to provide light to the inner portion of the building where light coming from the windows in the external walls is insufficient. They may be square or rectangular or curved. Fig. 21-37 shows a square lantern light. The glass panels are generally fixed. But if ventilation is also required in addition to light, the pivoted windows may be provided.

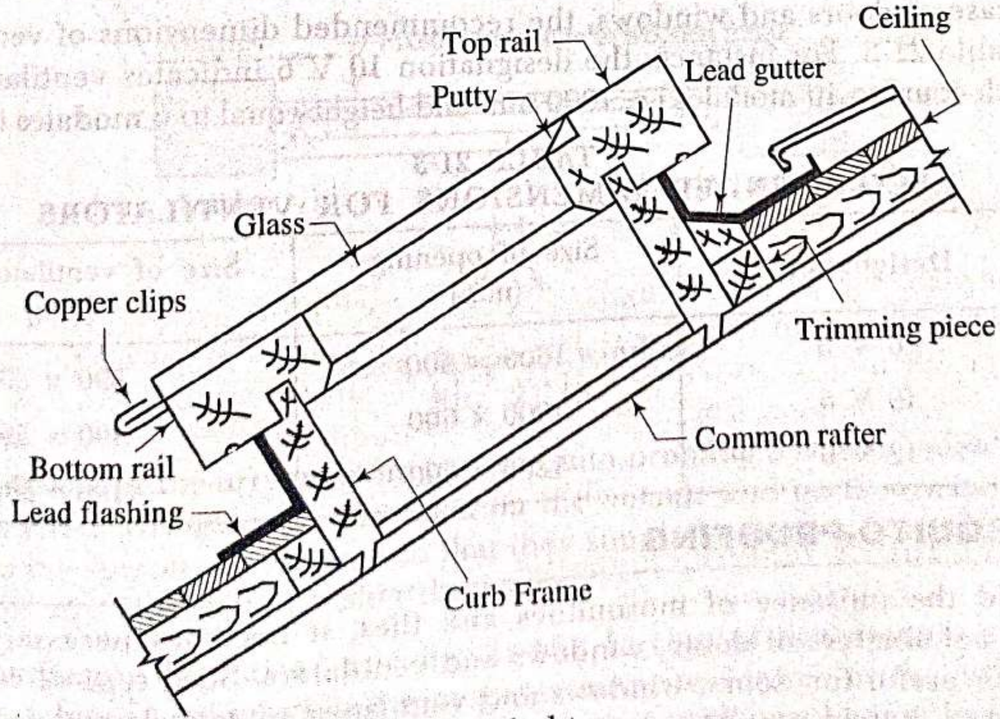


Clerestorey window
FIG. 21-36



Lantern light
FIG. 21-37

(15) **Skylights** (fig. 21-38): These are the windows which are provided on the sloping surface of a pitched roof. The common rafters are suitably trimmed and the skylight is erected on a curb frame as shown in fig. 21-38. As skylights are mainly meant for light, they are usually provided with the fixed glass panels. The opening of skylight is properly treated by lead flashing to make water-proof the roof area surrounding the opening.



Skylight
FIG. 21-38