Rashtreeya Sikshana Samithi Trust

RV Institute of Technology and Management®

(Affiliated to VTU, Belagavi)

JP Nagar, Bengaluru – 560076

Department of Department Engineering

Course Name: ELEMENTS OF CIVIL ENGINEERING AND MECHANICS

Course Code: 21CIV14/24

I/II Semester 2021 Scheme

Prepared By:
Thejas C M
Assistant Professor
Department of Mechanical Engineering
RVITM, Bengaluru – 560076
E-mail: thejascm.rvitm@rvei.edu.in

Module 1

Overview of Civil Engineering Systems: Introduction to structural engineering, geotechnical engineering, Construction technology, hydraulics, water resources and irrigation engineering transportation engineering, environmental and sanitary engineering, GIS, earthquake engineering. Role of civil engineers in the development of the nation.

Building materials: Stone, brick, wood, glass, aluminum, cement, aggregates, concrete, steel, RCC, PSC, smart materials.

1.1 Introduction to Civil Engineering

Civil engineering is the oldest branch of engineering which is growing right from the stone age of civilization. American society of civil engineering defines civil engineering as the profession in which a knowledge of the mathematical and physical sciences gained by study, experience and practice is applied with judgment to develop ways to utilize economically the materials and forces of the nature for the progressive wellbeing of man.

1.2 Roles of Civil Engineering

- Plan new townships and extension of existing towns.
- Providing shelter to people in the form of low cost houses to high rise apartments.
- Laying ordinary village roads to express highways.
- Constructing irrigation tanks, multipurpose dams & canals for supplying water to agricultural fields.
- Supplying safe and potable water for public & industrial uses.
- Protecting our environment by adopting sewage treatment & solid waste disposal techniques.
- Constructing hydro-electric & thermal-power plants for generating electricity.
- Providing other means of transportation such as railways, harbor& airports.
- Constructing bridges across streams, rivers and also across seas.
- Tunneling across mountains & also under water to connect places easily & reduce distance.

Management Techniques: Civil engineers must manage men, materials and equipment sufficiently. Since huge funds are to be handled in civil engineering projects, a civil engineer must know the basics in financial management and legal obligations. Knowledge of management techniques is an asset to practicing civil engineer.

Computer Applications: Since the magnitude of designing the structures and storing information is increasing very fast nowadays civil engineers go for computer applications in planning and designing of structures. There is good number of civil engineering software commercially available.

1.3 Fields of Civil Engineering and their scope

The different fields of civil engineering and the scope of each can be briefly discussed as follows.

Surveying: It is a science and art of determining the relative position of points on the earth's surface by measuring distances, directions and vertical heights directly or indirectly. Surveying helps in preparing maps and plans, which help in project implementation. (Setting out the alignment for a road or railway track or canal, deciding the location for a dam or airport or harbor) The cost of the project can also be estimated before implementing the project. Now-a-days, using data from remote sensing satellites is helping to prepare maps & plans & thus cut down the cost of surveying. Elements of Civil

Types of Surveying

(i) Plane surveying: The survey in which the shape or curvature of earth is not considered is called plane surveying

(ii) Geodetic surveying: The survey in which the shape or curvature of earth is considered is called Geodetic surveying

SCOPE OF SUREYING

- To prepare the plan or map
- To determine the dimension and contour of any part of the earth's surface
- To establish boundaries of land
- To measure the area and volume of land
- To select suitable site for an engineering project

Geo-Technical Engineering (Soil Mechanics): Any building, bridge, dam, retaining wall etc. consist of components like foundations. Foundation is laid from a certain depth below the ground surface till hard layer is reached. The soil should be thoroughly checked for its suitability for construction purposes. The study dealing with the properties &behavior of soil under loads & changes in environmental conditions is called geo-technical engineering. The knowledge of the geology of an area is also very much necessary.

SCOPE OF GEOTECHNICAL ENGINEERING

- Foundation design and construction
- Highway pavement design
- Design and construction of tunnels underground structure and drainages structures
- Design of retaining structures
- Design of earthen dams and embankment

Structural Engineering: A building or a bridge or a dam consists of various elements like foundations, columns, beams, slabs etc. These components are always subjected to forces. It becomes important to determine the magnitude & direction the nature of the forces and acting all the time. Depending upon the materials available or that can be used for construction, the components or the parts of the building should be safely & economically designed.

A structured engineer is involved in such designing activity. The use of computers in designing the members, is reducing the time and also to maintain accuracy.

SCOPE OF STRUCTURAL ENGINEERING

- Responsible for creation of structural system in accordance with the needs of the client and architect
- Plays an important role to build industrial production and manufacturing unit
- Keys main for total planning and designing of nuclear power plants.
- Take the responsibility about the safety and serviceability of the structure for its lifetime

Transportation Engineering: The transport system includes roadways, railways, air & waterways. Here the role of civil engineers is to construct facilities related to each one. Sometimes crucial sections of railways & roads should be improved. Roads to remote places should be developed. Ports &harbors should be designed to accommodate, all sizes of vehicles. For an airport, the runway & other facilities such as taxiways, terminal buildings, control towers etc. should be properly designed.

SCOPE OF TRANSPORTATION ENGINEERING

- Traffic management
- Parking facilities
- Rapid transportation
- Urbanization and industrialization
- Accident study for safe and comfort transport system

Irrigation& Water resources engineering (Hydraulics Engineering): Irrigation is the process of supplying water by artificial means to agricultural fields for raising crops. Since rainfall in an area is insufficient or unpredictable in an area, water flowing in a river can be stored by constructing dams and diverting the water into the canals & conveyed to the agricultural fields. Apart from dams & canals other associated structures like canals regulators, aqua ducts, weirs, barrages etc. are also necessary. Hydroelectric power generation facilities are also included under this aspect.

SCOPE OF WATER RESOURCE ENGINEERING

- Flood mitigation
- Irrigation
- Hydroelectric power

- Domestic and industrial water supply
- Aquatic animal management

SCOPE OF IRRIGATION ENGINEERING

- Diversion of stored water to canal for distribution
- Lifting of water by digging wells and fed to small channels
- Development of hydro electric power
- Increase in flood production
- Protection from famine
- Ground water storage improvement

Water Supply and Sanitary Engineering (Environmental Engineering):

People in every village, town & city need potable water. The water available (surface water

& ground water) may not be fit for direct consumption. In such cases, the water should be purified and then supplied to the public. For water purification, sedimentation tanks, filter beds, etc. should be designed. If the treatment plants are for away from the town or city, suitable pipelines for conveying water & distributing it should also be designed. In a town or city, a part of the water supplied returns as sewage. This sewage should be systematically collected and then disposed into the natural environment after providing suitable treatment.

The solid waste that is generated in a town or locality should be systematically collected and disposed of suitably. Before disposal, segregation of materials should be done so that any material can be recycled & we can conserve our natural resources.

Scope of Environmental Engineering

- Protection and conservation of environment
- Good water supply
- Waste water treatment
- Pollution treatment
- Solid waste management

Building Materials & Construction Technology: Any engineering structure requires a wide range of materials known as building materials. The choice of the materials is wide & open. It becomes important for any construction engineer to be well versed with the properties & applications of the different materials. Any construction project involves many activities and also required many materials, manpower, machinery & money. The different activities should be planned properly; the manpower, materials & machinery should be optimally utilized, so that the construction is completed in time and in an economical manner. In case of large construction projects management techniques of preparing bar charts & network diagrams, help in completing the project orderly in time.

Classification of Building Materials:

(i) Traditional materials - Stones, timber, bricks, lime, cement, tar, bitumen, mortar, ferrous and nonferrous metals, ceramic materials ,etc.
(ii) Alternative Building Materials - Mud –blocks, concrete-blocks, plastics, glass, aluminum, paints, fly ash, etc.
(iii) Composite Materials - RCC, fiber reinforcement concrete, ferro-cement, composite laminate doors, plastic laminates, asbestos sheets, fiber reinforced glass, etc.
(iv) Smart Materials or Intelligent Materials - Optic fiber, piezoelectric material, electro-strictive and magneto-strictive materials, etc.

Town Planning and Architecture: with the growth of population and industries new towns are coming up and existing ones are growing. Proper town planning is to be made by civil engineers. Structures should be aesthetically good also. Architecture covers this area. This field of civil engineering has grown up so much that it has become a separate branch of engineering.

1.4 Building materials

STONES:

In most areas of civilization where stone is available, it has been a favoured material for buildings of importance and permanence for up to 5000 years. The qualities of stones vary, depending on their geological origins, but most used for building purposes are basically fire and weather resistant and not affected by insect or organic attack; consequently many of the great historic monuments of the past are constructed largely of stone. Stone's good compressive strength allows it to be used for walls and arches, but most stones lack sufficient tensile strength to be used for long span beams. Being naturally produced materials, stones cannot be guaranteed to meet the same established performance standards as factory-made products, so sampling, testing, observations and traditions have to be taken into account to select and use stone wisely. This fact is becoming increasingly important now these materials are used as veneers to achieve decorative finishes rather than as solid structural members. In these thin-member situations differential movements, thermal effects, weathering, etc. become much more critical than in solid masonry construction.


Fig 1.1 – Stone used as a building material

Stones can provide beautiful colours, textures and effects in buildings, and weathering qualities are far better for many stones than for modern precast materials. Fig 1.1 shows used of stone as building material as a material that can be used as both structural as well as for non structural purpose. It is unlikely therefore that natural stones will be superseded completely as surface finishes. The crushing strength of a stone is not a criterion of its quality or durability. Crushing strength is affected largely by moisture content and whether pressure is applied parallel or perpendicular to the bedding planes.

All stone is initially won from the earth's crust by some form of quarrying. Methods of quarrying vary accordingly to the type and hardness of the stone, its natural bedding and planes of weakness. Most rocks are compressed, shrunk and stretched in their geological formation, causing real or incipient parting planes. To remove the stone for building blocks requires slow and careful drilling of holes and insertion of wedges to split the rock into large blocks in the required places. Some modern developments include use of gas and water under pressure, to orce the rocks apart. Previously hand hammered metal wedges or timber wedges, swollen by watering, often provided the pressures needed. The initial large blocks are moved to cutting sheds where mechanical saws are employed to break the stone down to usable sizes. Sand and water, carborundum grit or wheels of hard alloys and industrial diamond saws are all used in the shaping processes, dependent on the type of stone and equipment preferred or available. Finishing and polishing require another set of machines and abrasives to produce the surfaces specified. Hand chiselling is still used for some fine detail work, especially where restoration or renovations are involved. These hand methods have changed very little over centuries of use. With them a great variety of surface textures, patterns and ornament are possible.

Qualities of a good building stone:

The following are the qualities or requirements of a good building stone.

1. Crushing strength: For a good building stone, the crushing strength should be greater than l000 kg/cm^2.
2. Appearance: Good building stone should be a uniform colour, and free from clay holes, spots of other colour bands etc capable of preserving the colour for longtime.
3. Durability: A good building stone should be durable. The factors like heat and cold alternative wet and dry, dissolved gases in rain, high wind velocity etc affect the durability.
4. Fracture: For good building stone its fracture should be sharp, even and clear.
5. Hardness: The hardness greater than 17, treated as hard used 14 said be poor hardness.
6. Percentage wear: For a good building stone, the percentage wear should be equal to or less then 3 percent.
7. Resistance to fire: A good building stone be fire proof. Sandstone, Argillaceous stone resists fire quite well
8. Specific gravity: For a good building stone the specific gravity should be greater than 8.7 or so.
9. Texture: A good building stone should have compact fine crystalline structure should be free from cavities, cracks or patches of stuff or loose material. Stones

10. Water absorption: For a good building stone, the percentage absorption by weight after 24 hours should not exceed 1 - 2. %
11. Seasoning: Stones should be well seasoned before putting into use. A period of about 6 to 12 months is considered to be sufficient for proper seasoning.
12. Toughness Index: Impact test, the value of toughness less than 13 – Not tough, between 13 and 19 – Moderate, greater than 19- high

Classification of Rocks: Building stones are obtained from rocks occurring in nature and classified in three ways.

1. Geological Classification: According to this classification, the rocks are of the following types.

   a. Igneous rocks: Rocks that are formed by cooling of Magana (molten or pasty rocky material) are known as igneous rocks. Eg: Granite, Basalt and Dolerite etc.

   b. Sedimentary rocks: these rocks are formed by the deposition of production of weathering on the pre-existing rocks. Examples: gravel, sandstone, limestone, gypsum, lignite etc.

   c. Metamorphic rocks. These rocks are formed by the change in character of the pre-existing rocks. Igneous as well as sedimentary rocks are changed in character when they are subject to great heat and pressure. Known as metamorphism. Examples: Quartzite, Schist, Slate, Marble and Gneisses.

2. Physical Classification: This classification based on general structure of rocks. According to this, the rocks are classified into three types

   a. Stratified Rocks: These rocks posses planes of stratification
   or cleavage and such rocks can be easily split along these planes Ex: sedimentary rocks

   b. Unstratified rocks: The structure may be crystalline granular or compact granular. Examples: Igneous rocks and Sedimentary rocks affected by movements of the earth.

   c. Foliated Rocks: These rocks have a tendency to split up in a definite direction only. Ex: Metamorphic rocks.

3. Chemical Classification: According to this classification rocks are classified into three types.

   a. Siliceous rocks: In these rocks, silica is predominates. The rocks are hard; durable and not easily effected by weathering agencies. Ex: Granite, Quartzite, etc.

   b. Argillaceous Rocks: In these rocks, clay predominates. The rocks may be dense and compact or may be soft. Ex: slates, Laterites etc.

   c. Calcareous rocks: In these rocks, calcium carbonate predominates. The durability to these rocks will depend upon the constituents present in surrounding atmosphere. Ex: Lime Stone, marble etc.

Uses of stones:

1. Structure: Stones are used for foundations, walls, columns, lintels, arches, roofs, floors, damp proof course etc.
2. Face works. Stones are adopted to give massive appearance to the structure. Walls are of bricks and facing (front elevation) is done in stones of desired shades. This is known as composite masonry.
3. Paving stones: These are used to cover floor of building of various types such as residential, commercial, industrial etc. They are also adopted to form paving of roads, foot paths etc.

4. Basic material: Stones are disintegrated and converted to form a basic material for cement concrete, morum of roads, calcareous cements, artificial stones, hallow blocks etc.

5.Misalliances: Stones are also used for

(i) ballast for railways

(ii) flux in blast furnace

(iii) Blocks in the construction of bridges, piers, abutments, retaining walls, light houses, dams etc.

Commonly used building stones

Granites are coarsely crystalline stones which range in colour from almost black through greys, browns, reds to pinks and yellows. The reddish-brown colours are usually due to iron stainers or feldspars. There are often two distinct coloured crystals in granite specimens, one being white quartz. The proportion of white to coloured determines the apparent colour of the specimen. Granites are hard wearing and can be polished to reveal the full colour and texture of the stone. They have a relatively high tensile strength for stones and are among the heaviest of these natural materials, with high compressive strength; and they are non- porous. Granite is mostly used as decorative material for flooring and wall cladding in many shades and colours as shown in Fig 1.2. and also one more common use of granite is as aggregates in concrete as shown in Fig 1.3

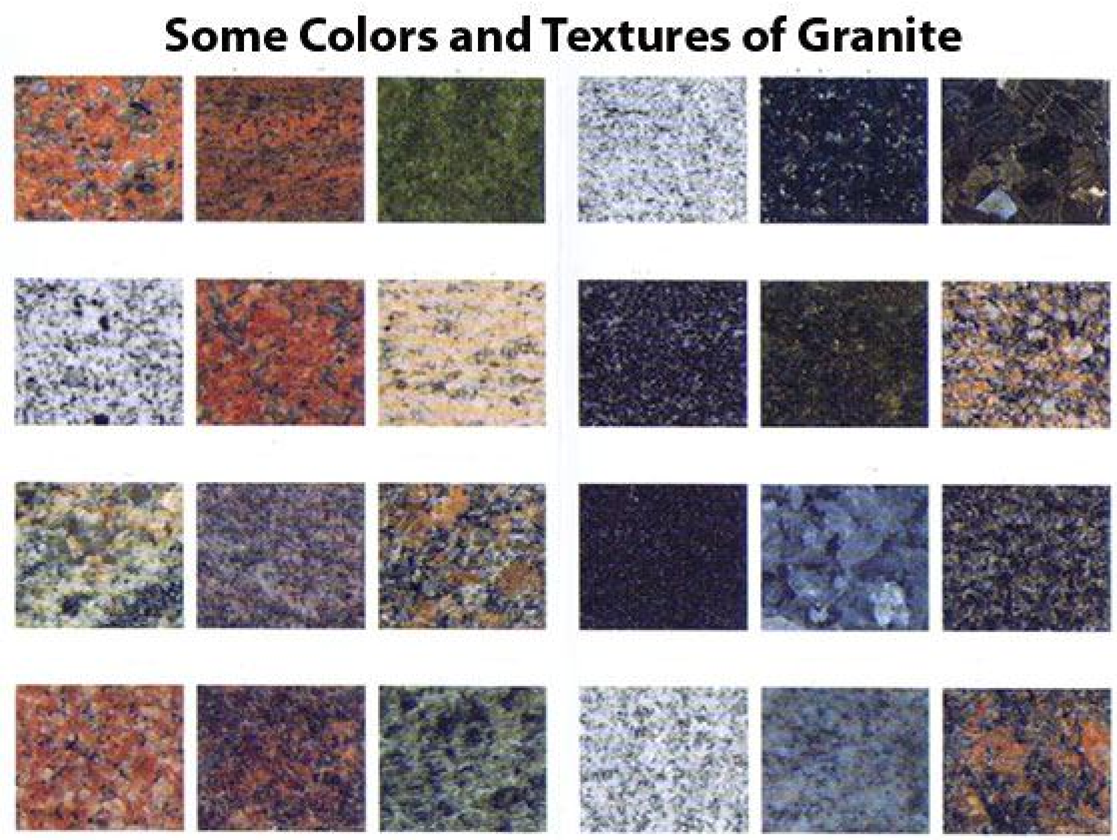


Fig 1.2 – Different types of granite.

Fig 1.2 – Granite as aggregate used in concrete

Basalt, often called bluestone, is generally a finely grained crystalline stone of dark grey to blue-grey, sometimes with white quartz seams in it. It is the stone generally preferred for crushed aggregate for concrete when available. It comes from volcanic origins and is closely related to other volcanic rocks called diorite, gabbro, lavas and volcanic tuffs, which, however, may be comparatively less dense. Basalt is not usually polished, but it can be. It is very hard wearing and for construction is similar to granite in most of its qualities. Fig 1.4 shows use of basalt in buildings.

Fig 1.4 – Basalt stone used for construction

Sandstones consist of sand grains cemented with silica, calcium carbonate or clay. The cementing material greatly affects the stones' durability when exposed to weathering. Colours range from white through creams and pale browns to purples and orange. Sometimes strong bands of colour occur within lighter stones due to the presence of iron solutions. Hardness and granule size can vary greatly. Most sandstones are porous and therefore are affected by moisture, pollution or foundation dampness. Many sandstones show clear bedding planes in the quarry. These stones can often be split easily for use as paving stones or coursed rubble walls. Sandstone is extensively used for many of the buildings in the Mughal era and the years following till the present day. Sandstone structures are common site in Northern part of India. One of the famous buildings built using sandstone is shown in Fig 1.5.

Fig 1.5 – Fatehpur Sikri, Red stand stone Structure

Limestone is the most widely used of all the building stones throughout the world. They can vary greatly in hardness, quality and durability but are usually of a white-cream or grey colour. They are slowly soluble in water and very reactive to most acids because a major component is calcium carbonate. Limestone can readily be finished to a soft, lustrous and smooth surface, but it will not take a high polish. Limestone frequently has local names such as alabaster, etc. which should be used to distinguish a particular choice if needed. Compressive strength is usually adequate for building stresses in masonry walls where stones of 200 mm plus thicknesses are used. Some limestone can be very easily worked and carved so that highly decorated details are possible. Some very soft and easily worked forms of limestone harden on exposure.

Brick

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, light in weight and hence bricks replace stones.
Composition - Manufacture Process.
Composition – Following are the constituents of good brick earth.
Alumina: - It is the chief constituent of every kind of clay. A good brick earth should contain 20 to 30 percent of alumina. This constituent imparts plasticity to earth so that it can be moulded. If alumina is present in excess, raw bricks shrink and warp during drying and burning.
Silica-A good brick earth should contain about 50 to 60 percent of silica. Silica exists in clay either as free or combined form. As free sand, it is mechanically mixed with clay and in combined form; it exists in chemical composition with alumina. Presence of silica prevents crackers shrinking and warping of raw bricks. It thus imparts uniform shape to the bricks.

Durability of bricks depends on the proper proportion of silica in brick earth. Excess of silica destroys the cohesion between particles and bricks become brittle.

Lime – A small quantity of lime is desirable in finely powdered state to prevents shrinkage of raw bricks. Excess of lime causes the brick to melt and hence, its shape is last due to the splitting of bricks.

Oxide of iron- A small quantity of oxide of Iron to the extent of 5 to 6 percent is desirable in good brick to imparts red colour to bricks. Excess of oxide of iron makes the bricks dark blue or blackish.

Magnesia- A small quantity of magnesia in brick earth imparts yellow tint to bricks, and decreases shrinkage. But excess of magnesia decreases shrink leads to the decay of bricks. The ingredients like, lime, iron pyrites, alkalies, pebbles, organic matter should not present in good brick earth

Manufacture of bricks:

The manufacturing of brick, the following operations are involved

(1) Preparation of clay: - The preparation of clay involves following operations

a) Unsoiling :- Top layer of 20cm depth is removed as it contain impurities.

b) Digging: - Clay dug out from ground is spread on level ground about 60cm to 120cm heaps.

c) Cleaning:-Stones, pebbles, vegetable matter etc removed and converted into powder form.

d) Weathering:- Clay is exposed to atmosphere from few weeks to full season.

e) Blending:- Clay is made loose and any ingredient to be added to it is spread out at top and turning it up and down in vertical direction.

f) Tempering:- Clay is brought to a proper degree of hardness, then water is added to clay and whole mass is kneaded or pressed under the feet of men or cattle for large scale, tempering is usually done in pug mill as shown in the Fig 1.6

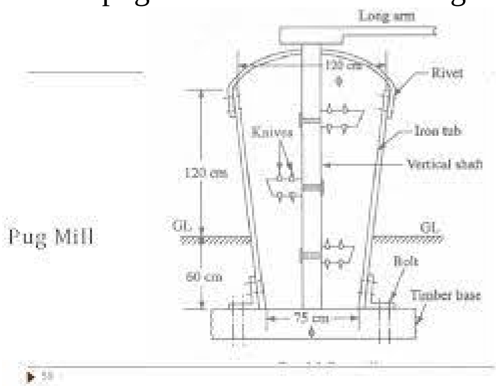
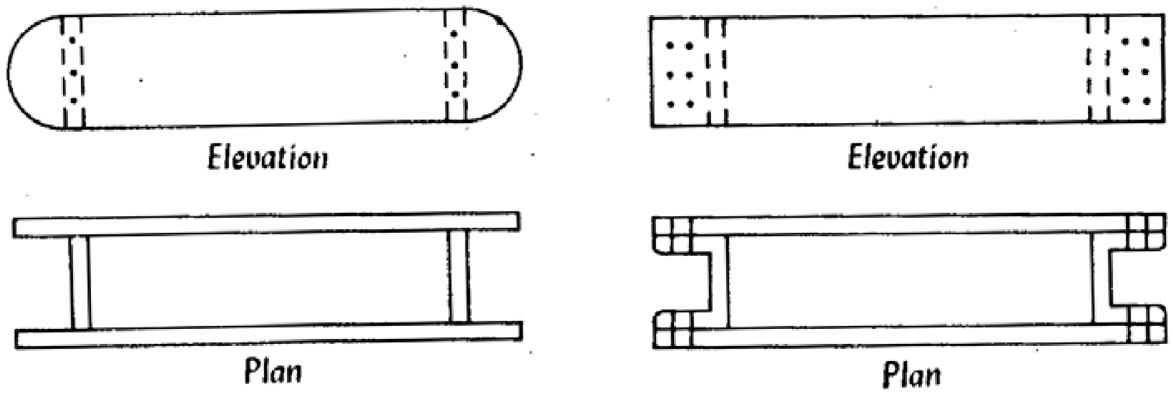


Fig 1.6 Pug Mill

Process:- Clay with water is placed in pug mill from the top. When the vertical staff is rotated by using electric pair, steam or diesel or turned by pair of bullocks. Clay is thoroughly mixed up by the actions of horizontal arms and knives when clay has been sufficiently pugged, hole at the bottom of tub, is opened cut and the pugged earth is taken out from
ramp for the next operation of moulding.

Moulding: Clay, which is prepared form pug mill, is sent for the next operation of moulding. Following are the two ways of moulding.

Hand Moulding: Moulds are rectangular boxes of wood or steel, which are open at top and bottom. Steel moulds are more durable and used for manufacturing bricks on large scale as shown in fig 1.7.



.Fig 1.7 - Wooden mould & Steel mould

Bricks prepared by hand moulding are of two types
(a) Ground moulded bricks: ground is first made level and fine sand is sprinkled over it. Mould is dipped in water and placed over the ground to fill the clay. Extra clay is removed by wooden or metal strike after the mould is filled forced mould is then lifted up and raw brick is left on the ground. Mould is then dipped in water every time lower faces of ground moulded bricks are rough and it is not possible to place frog on such bricks. Ground moulded bricks of better quality and with frogs on their surface are made by using a pair of pallet boards and a wooden block
(b) Table-moulded bricks: Process of moulding these bricks is just similar to ground bricks on a table of size about 2m x 1m.

(1) Machine moulding: This method proves to be economical when bricks in huge quantity are to be manufactured at the same spot. It is also helpful for moulding hard and string clay. These machines are broadly classified in two categories

a) Plastic clay machines: This machine containing rectangular opening of size equal to length and width of a brick. Pugged clay is placed in the machine and as it comes out through the opening, it is cut into strips by wires fixed in frames, so there bricks are called wire cut bricks.

b) Dry clay machines: In these machines, strong clay is first converted into powder form and then water is added to form a stiff plastic paste. Such paste is placed in mould and pressed by machine to form hard and well shaped bricks. These bricks are behavior than ordinary hand moulded bricks. They carry distinct frogs and exhibit uniform texture.

(2) Drying: The damp bricks, if burnt, are likely to be cracked and distorted. Hence moulded bricks are dried before they are taken for the next operation of burning. Bricks are laid along and across the stock in alternate layers. The drying of brick is by the following means

(i) Artificial drying – drying by tunnels at temperatures usually 120 ^{o}C about 1 to 3 days

(ii) Circulation of air- Stacks are arranged in such a way that sufficient air space is left between them free circulation of air.
(iii)Drying yard- special yards should be prepared slightly higher level prevent the accumulation of rain water
(iv) Period for frying – usually about 3 to 10 days to bricks to become dry
(v) Screens – screens are necessary, may be provided to avoid direct exposure to wind or sun.

(3) Burning: This is very important operation in the manufacturing of bricks to impart hardness, strength and makes them dense and durable. Burning of bricks is done either in clamps or in kilns. Clamps are temporary structures and they are adopted to manufacture bricks on small scale. Kilns are permanent structures and they are adopted to manufacture bricks on a large scale. A typical clamp is as shown in Fig 1.8

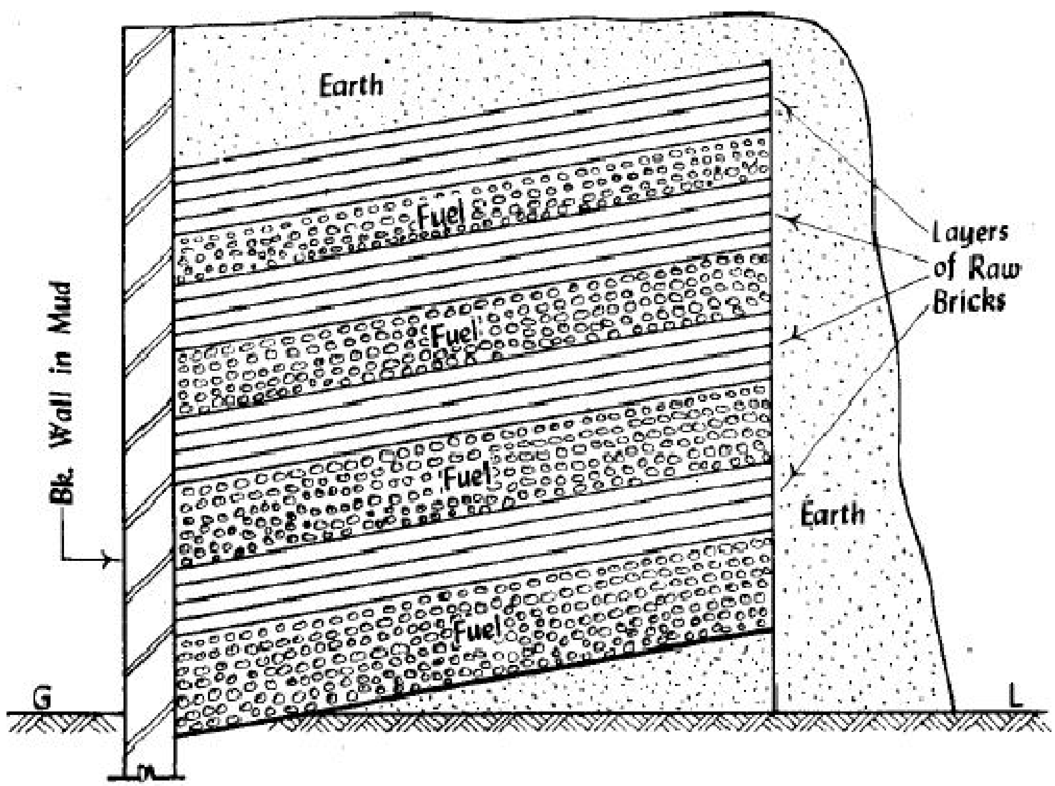


Fig 1.8 - Clamp

A trapezoidal shape in plan with shorter is slightly in excavation and wider end raised at an angle of 150 from ground level A brick wall with mud is constructed on the short end and a layer of 70 cm to 80cm thick fuel (grass, cow dung, ground nuts, wood or coal) laid on the floor. A layer consists of 4 or 5 courses of raw bricks laid on edges with small spaces between them for circulation of air. A second layer of fuel is then placed, and over it another layer of raw bricks is placed. The total height of clamp in alternate layers of brick and fuel is about 3 to 4 m. When clamp is completely constructed, it is plastered with mud on sides and top and filled with earth to prevent the escape of heat. The period of burning is about one to two months and allow the same time for coding. Burnt bricks are taken out from the clamp

Advantages:

(i) The bricks produced are tough and strong because burning and cooling are gradual
(ii) Burning in clamps proves to be cheap and economical
(iii) No skilled labour and supervision are required for the construction of clamps
(iv) There is considerable saving of clamps fuel

Disadvantages:

(i) Bricks are not of required shape
(ii) It is very slow process
(iii) It is not possible to regulate fire in a clamp
(iv) Quality of brick is not uniform

Kilns: A kiln is a large oven, which is used to burnt bricks by

1) Intermittent kilns: These intermittent in operation, which means that they are loaded, fired, cooled and unloaded.

a) Intermittent up-draught kiln: This is in the form of rectangular with thick outside walls as shown in the Fig 1.9 Wide doors are provided at each end for loading and unloading of kilns. A temporary roof may be installed to protect from rain and it is removed after kiln is fired. Flues are provided to carry flames or hot gases through the body of kiln.

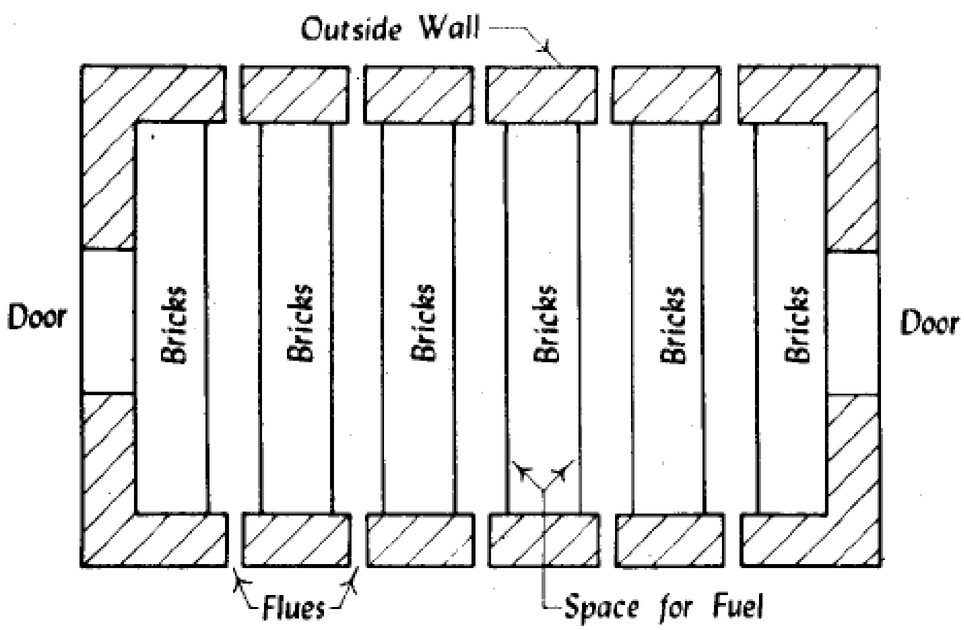


Fig 1.9 Intermittent kiln

(i) Raw bricks are laid in row of thickness equal to 2 to 3 bricks and height 6 to 8 bricks with 2 bricks spacing between rows
(ii) Fuels are filled with brush wood which takes up a free easily

(iii) Loading of kiln with raw bricks with top course is finished with flat bricks and other courses are formed by placing bricks on edges
(iv) Each door is built up with dry bricks and are covered with mud or clay
(v) The kiln is then fired for a period of 48 to 60 hours draught rises in the upward direction from bottom of kiln and brings about the burning of bricks.
(vi) Kiln is allowed to cool down and bricks are then token out
(vii) Same procedure is repeated for the next burning

Bricks manufactured by intermittent up drought kilns are better than those prepared by clamps but bricks burnt by this process is not uniform, supply of bricks is not continuous and wastage of fuel heat.

(b) Intermittent down-draught kilns:
These kilns are rectangular or circular in shape. They are provided with permanent walls and closed tight roof. Floor of the kiln has opening which are connected to a common chimney stack through flues. Working is same as up-draught kiln. But it is so arranged in this kiln that hot gases are carried through vertical flues up to the level of roof and they are then released. These hot gases move down ward by the chimney draught and in doing so, they burn the bricks.

Advantages:
(i) Bricks are evenly burnt
(ii) Performance of this kiln is better than that of up-draught kiln
(iii) This kiln is suitable for burning of structural clay tiles, terra cota because of close control of heat.

2. Continuous kilns: These kilns are continuous in operations. This means that loading, firing, cooling and unloading are carried out simultaneously in these kilns. There are three types of continuous kilns.
a) Bull's trench kiln: This kiln may be of rectangular, circular or oval shape in the plan as shown in Fig 1.10. It is constructed in a trench excavated in ground either fully underground partially projecting above ground openings is provided in the outer walls to act as flue holes. Dampers are in the form of iron plates and they are used to divide the kilns in suitable sections and most widely used kiln in India.

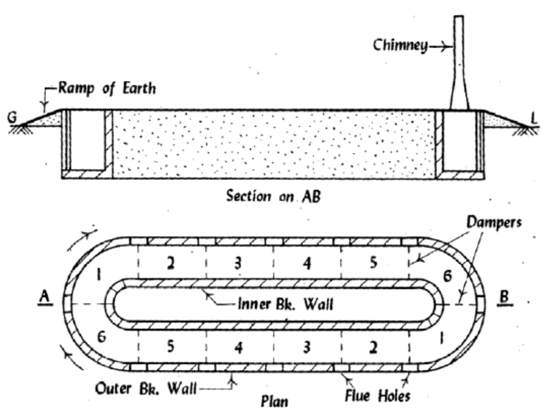


Fig 1.10 Bull's trench kiln

The bricks are arranged in such a way that flues are formed. Fuel is placed in flues and it is ignited through flue holes after covering top surface with earth and ashes to prevent the escape of heat usually two movable iron chimneys are employed to form draught. These chimneys are placed in advance of section being fired. Hence, hot gases leaving the chimney warm up the bricks in next section. Each section requires about one day to burn. The tentative arrangement for different sections may be as follows

Section 1 – loading
Section 2 – empty
Section 3 – unloading
Section 4 – cooling
Section 5 – Burning
Section 6 – Heating

b) Haffman's kiln: this kiln is constructed over ground and hence, it is sometimes known as flame kiln. Its shape is circular to plan and it is divided into a number of compartments or chambers. A permanent roof is provided; the kiln can even function during rainy season. Fig 1.11 shows plan and section of Hoffman's kiln with 12 chambers

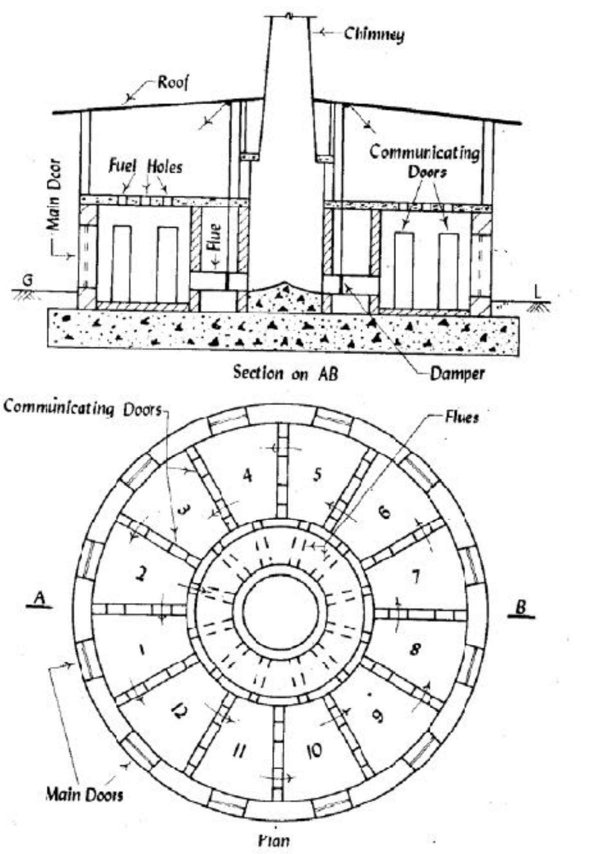


Fig 1.11 Hoffman's kiln

Chamber 1 - loading
Chamber 2 to 5 – drying and pre-heating
Chambers 6 and 7 - burning
Chambers 8 to 11 - cooling
Chamber 12 – unloading
The initial cost in stalling this kiln is high, the following advantages
(i) Good quality of bricks are produced
(ii) It is possible to regulate heat inside the chambers through fuel holes
(iii) Supply of bricks is continuous and regular
(iv) There is considerable saving in fuel due to pre heating of raw bricks by flue gases

c) Tunnel kiln: This type of kiln is in the form of tunnel, which may be straight, circular or oval in the plan. Raw bricks are placed in trolleys which are then moved from one end to the other end of tunnel. Raw bricks get dried and pre-heated as they approach zone of fire. In zone of fire, bricks are burnt to the required degree and they are then pushed forward for cooling. When bricks are sufficiently cooled, they are unloaded. The kiln proves to be economical when the bricks are manufactures on a large scale. As temperature is under control, uniform bricks of better quality are produced.

Qualities of Good Brick:
(i) Bricks should be table moulded, well burnt in kilns, copper coloured, free from cracks and with sharp and square edges.
(ii) Bricks should be uniform shape and should be of standard size.
(iii) Bricks should give clear ringing sound when struck each other.
(iv) Bricks when broken should show a bright homogeneous and compact structure free from voids.
(v) Bricks should not absorb water more than 20 percent by weight for first class bricks and 22 percent by weight for second class bricks, when soaked in coldwater for a period of 24 hours.
(vi) Bricks should be sufficiently hard no impression, should be left on brick surface, when it is scratched with finger nail.
(vii) Bricks should be low thermal conductivity and they should be sound proof.
(viii) Bricks should not break when dropped flat on hard ground from a height of about one meter.
(ix) Bricks, when soaked in water for 24hours, should not show deposits of white salts when allowed to dry in shade.
(x) No brick should have crushing strength below 55 kg/cm^2

Construction of brick units bonded together with mortar is termed as brick masonry.
Two essential components of brick masonry are
1. Bricks
2. Mortar

Definition of terms used in Masonry
Following are some of the technical terms used in masonry work. A typical brick wall is depicted in Fig 1.12
1. Arrises: The edge formed by the intersection of plane surfaces of brick are called the arrises.

2. Bed: The lower surface of a brick or stone in each course.
3. Course: a Course is a horizontal layer of masonry
4. Bed joint: the horizontal layer of mortar upon which the bricks or stones are laid is known as a bed joint.
5. Stretcher: a stretcher is the longer face of the brick (23cmX11.4cm) as seen in the elevation of the wall. A course of bricks in which all the bricks are laid as stretcher on facing is known as a stretcher course.
6. Header: it is the shorter face of the brick (11.4cm X 7.6cm) as seen in the elevation of the wall. A course of bricks in which all the bricks are laid as headers on facing is known as header course.
7. Quions: the exterior angle or corner of a wall is known as quoin. The stones or bricks forming the quoins are known as stone quoins or quoin bricks.
8. Lap: the horizontal distance between the vertical joints in successive courses is termed lap.
9. Perpend: It is a imaginary vertical line which includes the vertical joint separating two adjoining bricks.
10. Racking back: it is a termination of a wall in a stepped fashion.
11. Toothing: it is the termination of the wall in such a fashion that each alternate course at the end projects in order to provide adequate bond if the wall is continued horizontally at a later stage.

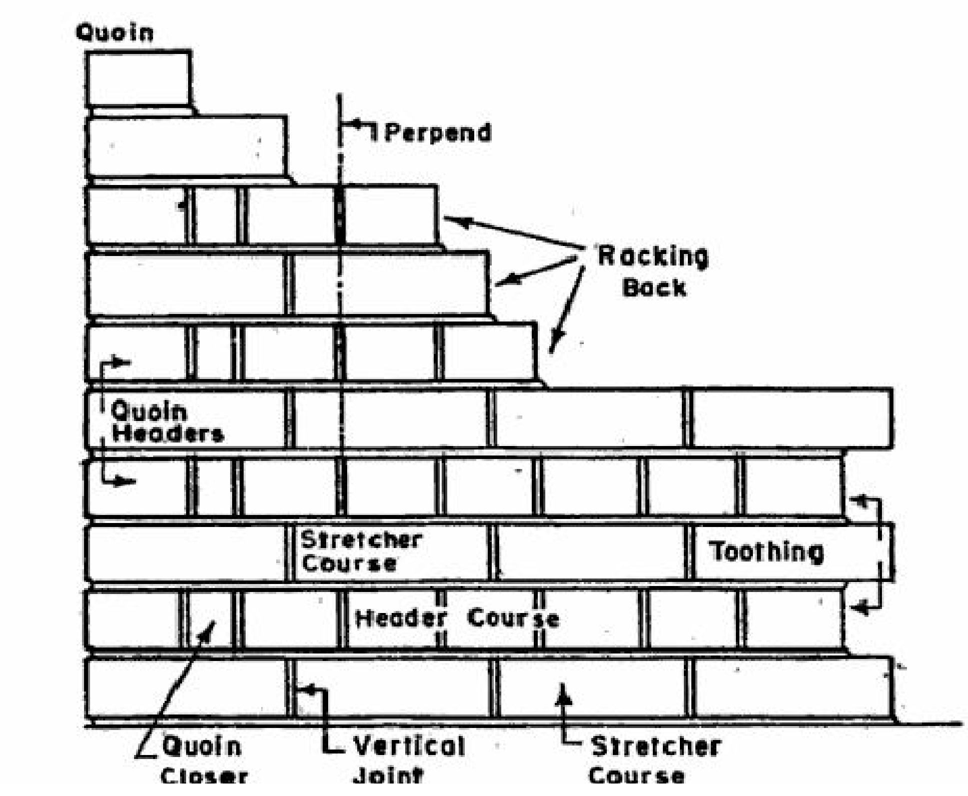


Fig 1.12 – Brick wall

12. Closer: A piece of brick which is used to close up the bond at the end of brick courses is known as a closer. Following are the types of closers:

i. Queen closer ii. King closer

iii. Beveled closer iv. Mitred closer

13. Bat: is the portion of the brick cut across the width. Thus, a bat is smaller in length than the full brick.

14. Face: The surface of wall exposed to the weather is known as the facing.

15. Back: The inner surface of wall which is not exposed to the weather

16. Backing: The material used in the formation of the back of the wall.

17. Facing: The material used in the face of the wall.

18. Hearting: The inner portion of the wall between the facing and backing.

Bonds in Brick work

- A bond is an arrangement of layers of stones or bricks by which no continuous vertical joints are formed.
- Bond is the interlacement of bricks, formed when they lay those immediately below or above them.
- Bonds of various types are distinguished by their elevation or face appearance
- It is essential to eliminate continuous vertical joints in the face of the wall.
- The bond distribute the load coming on the structure evenly and prevents the formation of a vertical crack
- A wall having continuous vertical joint does not act as a homogeneous mass to distribute the super imposed loads.

Types of Bonds

Following are the types of bonds provided in brick work.

- Stretcher bond
- Header bond
- English bond
- Flemish bond
- Facing bond
- Dutch bond

English bond

This is the most commonly used bond and is shown in Fig1.13. It is considered to be the strongest bond.

Following are the features of English bond

1. It consists of alternate courses of headers and stretchers

2. In this bond, vertical joints of the header courses come over each other, similarly the vertical joints of the stretcher courses also come over each other.

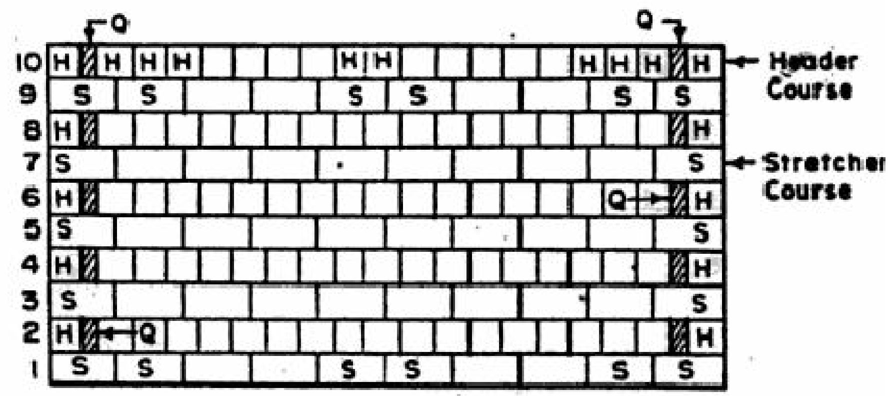
3. There is no continuous vertical joint

4. Every alternate header comes centrally over the joint between two stretchers in course below.

5. Queen closer is put next to the quoin header to develop the face lap.

6. In the stretcher course, the stretchers have a minimum lap of 1/4th their length over headers.

7. Walls of even multiple of half bricks represent the same appearance on both faces.
Thus a course showing stretchers on the front face will also show stretchers on the back face.
8. Wall of odd multiple of half bricks will show stretchers on one face and headers on the other face.
9. The hearting (middle portion) of each of the thicker walls consists entirely of headers
10. The queen closers are not required in stretcher courses.



S = STRETCHER ; H = HEADER ; Q = QUEEN CLOSER
FIG. 6.6. ENGLISH BOND.

Fig 1.13 – English Bond masonry

Flemish bond
In this type of bond, each course is comprised of alternate headers and stretchers. Fig 1.14 shows Flemish Bond. Every alternate course starts with a header at the corner (quoin header). Quoin closers are placed next to the quoin header in alternate courses to develop the face lap. Every header is centrally supported over the stretcher below it. Flemish bonds are two types:
1. Single Flemish bond
2. Double Flemish bond

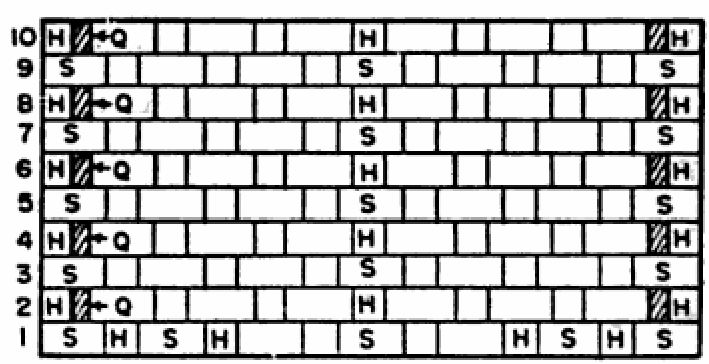


FIG. 6.9. FLEMISH BOND (ELEVATION).

Fig 1.14 – Flemish Bond Masonry

Single Flemish bond

Special features of single Flemish bond are

1. This bond is a combination of English and Flemish bond.
2. This bond uses the strength of the English bond and appearance of Flemish bond
3. In this work the facing of the wall consists of Flemish bond and the backing consists of English bond in each course.
4. It is used for those walls having thickness at least equal to 1½ brick.

Double Flemish bond

Special features of double Flemish bond are

1. Alternate headers and stretcher are laid in each course.
2. The facing and backing of the wall, in each course have the same appearance.
3. In walls having thickness equal to odd multiple of half bricks, half bats and 31/4 bats are amply used
4. For walls having thickness equal to even multiple of half bricks, no bats are required.
5 A header or stretcher will come out as header or stretcher on the same course in front as well as back faces.

Comparison of English bond and Flemish bond

1. English bond is stronger than Flemish bond for walls thicker than 1½ brick
2. Flemish bond gives more pleasing appearance than the English bond.
3. Broken bricks can be used in the form of bats in Flemish bond. However more mortar is required.
4. Construction with Flemish bond requires greater skill in comparison to English bond.

Cement

Definition: Cement is defined in many ways as follows,

- Cement, any material that hardens and becomes strongly adhesive after application.
- Manufactured substance consisting of gypsum plaster, or Portland cement.
- Portland cement hardens and adheres after being mixed with water.

History of Cement:

The term “Portland cement” was first used in 1824 by Joseph Aspdin, a British cement-maker, because of the resemblance between concrete made from his cement and Portland stone, which was commonly used in buildings in Britain. At that time cements were usually made in upright kilns where the raw materials were spread between layers of coke, which was then burnt.
The first rotary kilns were introduced about 1880. Portland cement is now almost universally used for structural concrete.

Manufacturing Process:
Main ingredients used in the manufacture of cement are:

- Limestone -Calcium
- Clay, shale
- Silica/Alumina

Limestone ($CaCO_3$) and Clay are two main raw materials used for manufacturing Portland cement clinker. Clays have various amount of SiO_2 and Al_2O_3. In the manufacturing process of Portland cement, clinker consist essentially of grinding the raw materials, mixing them in appropriate proportion, burning the raw material in a kiln at a temperature of 1400-1500^oC until material partially fuses into balls known as Clinker and grinding cooled clinker together with a small amount of gypsum rock.

Physical Properties and Types of Cement

Physical Properties
Portland cements are commonly characterized by their physical properties for quality control purposes. Their physical properties can be used to classify and compare Portland cements. The challenge in physical property characterization is to develop physical tests that can satisfactorily characterize key parameters.

The physical properties of cement
• Setting Time
• Soundness
• Fineness
• Strength

Setting Time
• Cement paste setting time is affected by a number of items including: cement fineness, water-cement ratio, chemical content (especially gypsum content) and admixtures. Setting tests are used to characterize how a particular cement paste sets.
• For construction purposes, the initial set must not be too soon and the final set must not be too late. Normally, two setting times are defined:
• Initial set. Occurs when the paste begins to stiffen considerably.
• Final set. Occurs when the cement has hardened to the point at which it can sustain some load.
• Setting is mainly caused by C_3A and C_3S and results in temperature rise in the cement paste.
• False set : No heat is evolved in a false set and the concrete can be re-mixed without adding water
• Occurs due to the conversion of un hydrous/semi-hydrous gypsum to hydrous gypsum($CaSO_4.2H_2O$)
• Flash Set: is due to absence of Gypsum. Specifically used for under water repair.

Tests:
Consistency

- The consistency is measured by the Vicat apparatus using a 10mm diameter plunger.

- A trial paste of cement and water is mixed and placed in the mold having an inside diameter of 70mm at the base and 60mm at the top, and a height of 40mm.
- The plunger is then brought into contact with the top surface of the paste and released. Under the action of its weight the plunger will penetrate the paste. The depth depending on the consistency.
- When the plunger penetrates the paste to a point 5 to 7mm from the bottom of the mold. The paste is considered to be at “normal consistency”.
- The water content of the paste is expressed as a percentage by weight of dry cement. The usual range of values being between 26% and 33%.

Setting time

- The setting time test is conducted by using the same Vicat apparatus, except that a 1mm diameter needle is used for penetration.
- The test is started about 15 minutes after placing the cement paste (which has normal consistency) into the mold. Trials for penetration of the needle are made.
- The final setting time is defined as the length of time between the penetration of the paste and the time when the needle(with annular ring) no longer sinks visibly into the paste.
- The initial setting time is defined as the length of time between the penetration of the paste and the time when the needle penetrates 25mm into the cement paste.

Soundness

- When referring to Portland cement, "soundness" refers to the ability of a hardened cement paste to retain its volume after setting without delayed expansion. This expansion is caused by excessive amounts of free lime (CaO) or magnesia (MgO). Most Portland cement specifications limit magnesia content and expansion.
- The cement paste should not undergo large changes in volume after it has set. However, when excessive amounts of free CaO or MgO are present in the cement, these oxides can slowly hydrate and cause expansion of the hardened cement paste.
- Soundness is defined as the volume stability of the cement paste.

Test For Soundness

- IS prescribe a Soundness Test conducted by using the Le Chatelier apparatus. The apparatus consists of a small brass cylinder split along its generatrix. Two indicators with pointed ends are attached to the cylinder on either side of the split.
- The cylinder (which is open on both ends) is placed on a glass plate filled with cement paste of normal consistency, and covered with another glass plate.
- The whole assembly is then immersed in water at 20 ± 1oC for 24 hours. At the end of that period the distance between the indicator points is measured. The mold is then immersed in water again and brought to a boil. After boiling for one hour the mold is removed from the water, after cooling, the distance between the indicator points is measured again. This increase represents the expansion of the cement paste for Portland cements, expansion is limited to 10mm.

Fineness

Fineness, or particle size of Portland cement affects Hydration rate and thus the rate of strength gain. The smaller the particle size, the greater the surface area-to-volume ratio, and thus, the more area available for water-cement interaction per unit volume. The effects of greater fineness on strength are generally seen during the first seven days.

When the cement particles are coarser, hydration starts on the surface of the particles. So the coarser particles may not be completely hydrated. This causes low strength and low durability. For a rapid development of strength a high fineness is necessary.

Test for Fineness

There are various methods for determining the fineness of cement particles. The Blaine air-permeability method is the most commonly used method. In the Blaine air-permeability method, given volume of air is passed through a prepared sample of definite density. The number and size of the pores in a sample of given density is a function of the particles and their size distribution and determines the rate of air flow through the sample. Calculations are made and the fineness is expressed in terms of cm^2/g or m^2/kg.

Strength

Cement paste strength is typically defined in three ways: compressive, tensile and flexural. These strengths can be affected by a number of items including: water cement ratio, cement-fine aggregate ratio, type and grading of fine aggregate, curing conditions, size and shape of specimen, loading conditions and age.

Duration of Testing

Typically, Durations of testing are:

• 1 day (for high early strength cement)
• 3 days, 7 days, 28 days and 90 days (for monitoring strength progress)
• 28 days strength is recognized as a basis for control in most codes.
• When considering cement paste strength tests, there are two items to consider:
• Cement mortar strength is not directly related to concrete strength. Strength tests are done on cement mortars (cement + water + sand) and not on cement pastes.

Compressive Strength

- Compressive strength of Portland cement is determined by the BIS method.
- The cement paste (consisting of 1 part cement+3 parts standard sand+ water, by weight) is placed in 7cm molds. And the specimens are water cured for various ages for testing.
- The mortar specimens taken out of the molds are subjected to compression to determine the strength.
- The compressive strength test is conducted on mortar cubes.. After finding the breaking load in compression, Pmax , Compressive Strength is calculated by the relation $c = P_{max} / A$, where $A=50cm^2$.

- The average of the results found by testing six specimen is the compressive strength of the mortar cubes

Types of Cement
Types of Portland Cement

The rapid increase in sophistication of design and construction techniques and the greater attention to variations in regional and job conditions have created demand for modifications of certain properties of concrete. This has resulted in the development of several "types" of Portland cement and a greater use of concrete admixtures.

The production of a different type of Portland cement involves certain adjustments in the manufacturing process; mainly the selection of raw materials, chemical proportions, special additives, and degree of grinding.

Chemical Composition and Hydration
Oxide Composition of Portlant Cement

- Portland cement is composed of four major oxides: lime (CaO), silica (SiO_2),alumina (Al_2O_3), and iron (Fe_2O_3).
- Also Portland cement contains small amount of magnesia (MgO), alkalies (Na_2O and K_2O), and sulfuric anhydrite (SO_3).

Approximate Composition Limits of Oxides in Portland Cement

Oxide	Common Name	Content, %
CaO	Lime	60-67
SiO_2	Silica	17-25
$Al2O_3$	Alumina	3-8
Fe_2O_3	Iron	0,5-6
MgO	Magnesia	0,1-4
Na_2O and K_2O	Alkalies	0,2-1,3
SO_3	Sulfuric anhydride	1-3

Major Compounds of Portland Cement (Bogue's Compound Composition)

Name	Chemical formula	Abbreviation
Tri calcium Silicate	$3CaO.SiO_2$	C_3S
Di calcium Silicate	$2CaO.SiO_2$	C_2S
Tri calcium Aluminate	$3CaO.Al2O_3$	C_3A
Tetra calcium Alumino Ferrite	$4CaO.Al_2O_3.Fe_2O_3$	C_4AF

Bogue's Compound Composition

- C_3S=4.07(CaO)-7.6(SiO2)- 6.72(Al2O3)-1.43(Fe2O3) – 2.85(SO3)
- C_2S= 2.87 (SiO2) - 0.75(3Cao. SiO2)
- C_3A= 2.65(Al2O3) – 1.69 (Fe2O3)
- C_4AF = 3.04 (Fe2O3)

Hydration of cement

When Portland cement is mixed with water its chemical compound constituents undergo a series of chemical reactions that cause it to harden. This chemical reaction with water is called "hydration". Each one of these reactions occurs at a different time and rate. Together, the results of these reactions determine how Portland cement hardens and gains strength. Hydration starts as soon as the cement and water are mixed. The rate of hydration and the heat liberated by the reaction of each compound is different.

Each compound produces different products when it hydrates. Tricalcium silicate (C_3S). Hydrates and hardens rapidly and is largely responsible for initial set and early strength. Portland cements with higher percentages of C_3S will exhibit higher early strength. Tricalcium aluminate (C_3A). Hydrates and hardens the quickest. Liberates a large amount of heat almost immediately and contributes somewhat to early strength. Gypsum is added to Portland cement to retard C3A hydration. Without gypsum, C_3A hydration would cause Portland cement to set almost immediately after adding water. Dicalcium silicate (C_2S). Hydrates and hardens slowly and is largely responsible for strength increases beyond one week. Tetracalcium alumino ferrite (C_4AF). Hydrates rapidly but contributes very little to strength. Its use allows lower kiln temperatures in Portland cement manufacturing. Most Portland cement color effects are due to C_4AF.

Aggregates

Classification

Aggregates are classified as below: Based on

- Size:- Fine aggregates and Coarse Aggregates
- Specific Gravity: - Light Weight, Normal Weight and Heavy Weight Aggregates.
- Availability: - Natural Gravel and Crushed Aggregates.
- Shape: - Round, Cubical, Angular, Elongated and Flaky Aggregates.
- Texture: - Smooth, Granular, Crystalline, honeycombed and Porous.

There are two types of Aggregates used in concrete making based on their size: Fig 1.15 shows commonly used Coarse and Fine aggregates

Fine Aggregate (FA) – its either sand or crushed stone of size below 4.75 mm. FA content usually 35% to 45% by mass or volume of total aggregate.

Coarse Aggregate (CA) – mainly Gravel and crushed stone above the size of 4.75 mm sometimes up to 80 mm (maximum used in mass concrete is about 300 mm) but typically between 6 and 40 mm in size. The aggregates form about 50 – 70 % of concrete mass. Aggregates are mostly to fill the space (as expressed in simple terms), they don't usually participate in strength characteristics of concrete directly.

Fig 1.15 – Coarse and Fine aggregates

Rock and Mineral Constituents in Aggregates

1.Minerals

- Silica
- Quartz, Opal
- Silicates
- Feldspar, Clay
- Carbonate
- Calcite, DolomiteSulfate
- Sulfate
- Gypsum, Anhydrite

- Iron sulfide
- Pyrite, Marcasite
- Iron oxide
- Magnetite, Hematite

2.Igneous rocks

- Granite
- Syenite
- Diorite
- Gabbro
- Peridotite
- Pegmatite
- Volcanic glass
- Felsite
- Basalt

3. Sedimentary rocks

- Conglomerate
- Sandstone
- Claystone, siltstone, argillite, and shale
- Carbonates
- Chert

4. Metamorphic rocks

- Marble
- Metaquartzite
- Slate
- Phyllite
- Schist
-

Normal-Weight Aggregate
Most common aggregates
• Sand
• Gravel
• Crushed stone

Produce normal-weight concrete 2200 to 2400 kg/m3

Lightweight Aggregate

Expanded

• Shale
• Clay
• Slate
• Slag

Produce structural lightweight concrete 1350 to 1850 kg/m3

Pumice

_ Scoria
_ Perlite
_ Vermiculite
_ Diatomite

Produce lightweight insulating concrete— 250 to 1450 kg/m3

Heavyweight Aggregate

• Barite
• Limonite
• Magnetite
• Hematite
• Iron
• Steel punching or shot

Produce high-density concrete up to 6400 kg/m3 Used for Radiation Shielding

Aggregate Characteristics

Grading of Aggregates - Grading is the particle-size distribution of an aggregate as determined by a sieve analysis using wire mesh sieves with square openings.

As per IS:2386(Part-1)

Fine aggregate standard sieves with openings from 150 µm to 4.75 mm.

Coarse aggregate sieves with openings from 4.75mm to 80 mm.

Gradation (grain size analysis) Grain size distribution for concrete mixes that will provide a dense strong mixture. Ensure that the voids between the larger particles are filled with medium particles. The remaining voids are filled with still smaller particles until the smallest voids are filled with a small amount of fines. Ensure maximum density and strength using a maximum density curve. Concrete with good gradation will have fewer voids to be filled with cement paste (economical mix) Concrete with good gradation will have fewer voids for water to permeate (durability) Particle size distribution affects Workability, Mix proportioning, Freeze-thaw resistance (durability)

Fine Aggregate effect on concrete

- Over sanded (More than required sand)
  - Over cohesive mix.
  - Water reducers may be less effective.
  - Air entrainment may be more effective.
- Under sanded (deficit of sand)
  - Prone to bleed and segregation.
  - May get high levels of water reduction.
  - Air entertainers may be less effective.
- Sand grading
  - gap graded or single sized may enhance bleed and segregation. Air entrainment may help fill the gaps.

- Coarse aggregate
  - Poor grading may give a harsh mix at low work abilities and segregation at high work abilities.
  - Effect on admixtures is small.
  - Elongated or flaky aggregates may cause workability difficulties .

Maximum Size vs. Nominal Maximum Size of Aggregate

Maximum size is the smallest sieve that all of a particular aggregate must pass through. Nominal maximum size _ is the standard sieve opening immediately smaller than the smallest through which all of the aggregate must pass. The nominal maximum-size sieve may retain 5% to 15%

Moisture In Aggregates

Aggregates have two types of moisture:

1. Absorbed moisture – retained in pores
2. Surface moisture – water attached to surface

Aggregates have four moisture states:

Oven dry: all moisture removed

Air dry: internal pores partially full & surface dry

Saturated-surface dry: pores full & surface moisture removed

Wet: pores full and surface film

Moisture Absorption

We must determine how much water dry aggregate will consume into its voids This takes water away from the mix and reduces workability & W/C ratio

Shape and surface texture of aggregates

The shape of aggregate is an important characteristic since it affects the workability of concrete. It is difficult to measure the shape of irregular shaped aggregates. Not only the type of parent rock but also the type of crusher used also affects the shape of the aggregate produced.

Surface texture is the property, the measure of which depends upon the relative degree to which particle surface are polished or dull, smooth or rough. Surface texture depends upon hardness, grain size, pore structure, structure of the rock and the degree to which the forces acting on it have smoothened the surface or roughened. Experience and laboratory experiments have shown that the adhesion between cement paste and the aggregate is influenced by several complex factors in addition to the physical and mechanical properties.

Aggregate shape and texture affect the workability of fresh concrete through their influence on cement paste requirements. Sufficient paste is required to coat the aggregates and to provide lubrication to decrease interactions between aggregate particles during mixing. Ideal particle is one close to spherical in shape (well rounded and compact) with a relatively smooth surfaces (natural sands and gravels come close to this ideal). More angular shapes - rough surfaces – interfere with the movement of adjacent particles (less workable) –They also have a higher surface –to –volume ratio – more paste. Flat or elongated aggregates should be avoided.

Rough surface requires more lubrication for movement (crushed stone).