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UNIT 1

FUNDAMENTALS OF BUILDING MATERIALS

Stones, bricks, cement, lime and timber are the traditional materials used for civil engineering constructions for several centuries.

I. Stones

Stone is a 'naturally available building material' which has been used from the early age of civilization. It is available in the form of rocks, which is cut to required size and shape and used as building block. It has been used to construct small residential buildings to large palaces and temples all over the world. Red Fort, Taj Mahal, Vidhan Sabha at Bangalore and several palaces of medieval age all over India are the famous stone buildings.

1.1 Classification of stones

Stones used for civil engineering works may be classified in the following three ways:

- Geological
- Physical
- Chemical

1. Geological Classification

Based on their origin of formation stones are classified into three main groups—Igneous, sedimentary and metamorphic rocks.

1. Igneous Rocks: These rocks are formed by cooling and solidifying of the rock masses from their molten magmatic condition of the material of the earth. Generally igneous rocks are strong and durable. Granite, trap and basalt are the rocks belonging to this category.

2. Sedimentary Rocks: Due to weathering action of water, wind and frost existing rocks disintegrates. The disintegrated material is carried by wind and water; the water being most powerful medium. Flowing water deposits its suspended materials at some points of obstacles to its flow. These deposited layers of materials get consolidated under pressure and by heat. Chemical agents also contribute to the cementing of the deposits. The rocks thus formed are more uniform, fine grained and compact in their nature. They represent a bedded or stratified structure in general. Sand stones, lime stones, mud stones etc. belong to this class of rock.

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3. Metamorphic Rocks: Previously formed igneous and sedimentary rocks under go changes due to metamorphic action of pressure and internal heat. For example due to metamorphic action granite becomes gneiss, trap and basalt change to schist and laterite, lime stone changes to marble, sand stone becomes quartzite and mud stone becomes slate.

2. Physical Classification

Based on the structure, the rocks may be classified as:

1. Stratified rocks
2. Unstratified rocks
3. Foliated rocks

(*i*) **Stratified Rocks:** These rocks are having layered structure. They possess planes of stratification. They can be easily split along these planes. Sand stones, lime stones, slate etc. are the examples of this class of stones.

(*ii*) **Unstratified Rocks:** These rocks are not stratified. They possess crystalline and compact grains. They cannot be split in to thin slab. Granite, trap, marble etc. are the examples of this type of rocks.

(*iii*) **Foliated Rocks:** These rocks have a tendency to split along a definite direction only. The direction need not be parallel to each other as in case of stratified rocks. This type of structure is very common in case of metamorphic rocks.

3.Chemical Classification

On the basis of their chemical composition engineers prefer to classify rocks as:

1. Siliceous rocks
2. Argillaceous rocks and
3. Calcareous rocks

i) **Siliceous rocks:** The main content of these rocks is silica. They are hard and durable. Examples of such rocks are granite, trap, sand stones etc

(*ii*) **Argillaceous rocks:** The main constituent of these rocks is argil *i.e.*, clay. These stones are hard and durable but they are brittle. They cannot withstand shock. Slates and laterite are examples of this type of rocks

(*iii*) **Calcareous rocks:** The main constituent of these rocks is calcium carbonate. Limestone is a calcareous rock of sedimentary origin while marble is a calcareous rock of metamorphic origin.

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1.2 Properties of stones: The following properties of the stones should be looked into before selecting them for engineering works:

1. **Structure:** The structure of the stone may be stratified (layered) or unstratified. Structured stones should be easily dressed and suitable for super structure. Unstratified stones are hard and difficult to dress. They are preferred for the foundation works.

2. **Texture:** Fine grained stones with homogeneous distribution look attractive and hence they are used for carving. Such stones are usually strong and durable.

3. **Density:** Denser stones are stronger. Light weight stones are weak. Hence stones with specific gravity less than 2.4 are considered unsuitable for buildings.

4. **Appearance:** A stone with uniform and attractive colour is durable, if grains are compact. Marble and granite get very good appearance, when polished. Hence they are used for face works in buildings.

5. **Strength:** Strength is an important property to be looked into before selecting stone as building block. Indian standard code recommends, a minimum crushing strength of 3.5 N/mm^2 for any building block. Due to non-uniformity of the material, usually a factor of safety of 10 is used to find the permissible stress in a stone. Hence even laterite can be used safely for a single storey building, because in such structures expected load can hardly give a stress of 0.15 N/mm^2. However in stone masonry buildings care should be taken to check the stresses when the beams (Concentrated Loads) are placed on laterite wall.

6. **Hardness:** It is an important property to be considered when stone is used for flooring and pavement. Coefficient of hardness is to be found by conducting test on standard specimen in Dory's testing machine. For road works coefficient of hardness should be at least 17. For building works stones with coefficient of hardness less than 14 should not be used.

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7. Percentage wear: It is measured by attrition test. It is an important property to be considered in selecting aggregates for road works and railway ballast. A good stone should not show wear of more than 2%.

8. Porosity and Absorption: All stones have pores and hence absorb water. The reaction of water with material of stone cause disintegration. Absorption test is specified as percentage of water absorbed by the stone when it is immersed under water for 24 hours. For a good stone it should be as small as possible and in no case more than 5.

9. Weathering: Rain and wind cause loss of good appearance of stones. Hence stones with good weather resistance should be used for face works.

10. Toughness: The resistance to impact is called toughness. It is determined by impact test. Stones with toughness index more than 19 are preferred for road works. Toughness index 13 to 19 are considered as medium tough and stones with toughness index less than 13 are poor stones.

11. Resistance to Fire: Sand stones resist fire better. Argillaceous materials, though poor in strength, are good in resisting fire.

12. Ease in Dressing: Cost of dressing contributes to cost of stone masonry to a great extent. Dressing is easy in stones with lesser strength. Hence an engineer should look into sufficient strength rather than high strength while selecting stones for building works.

13. Seasoning: The stones obtained from quarry contain moisture in the pores. The strength of the stone improves if this moisture is removed before using the stone. The process of removing moisture from pores is called seasoning. The best way of seasoning is to allow it to the action of nature for 6 to 12 months. This is very much required in the case of laterite stones.

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Uses of Stones

Stones are used in the following civil engineering constructions:

(*i*) Stone masonry is used for the construction of foundations, walls, columns and arches.
(*ii*) Stones are used for flooring.
(*iii*) Stone slabs are used as damp proof courses, lintels and even as roofing materials.
(*iv*) Stones with good appearance are used for the face works of buildings. Polished marbles and granite are commonly used for face works.
(*v*) Stones are used for paving of roads, footpaths and open spaces round the buildings.
(*vi*) Stones are also used in the constructions of piers and abutments of bridges, dams and retaining walls.
(*vii*) Crushed stones with gravel are used to provide base course for roads. When mixed with tar they form finishing coat.
(*viii*) Crushed stones are used in the following works also:
(*a*) As a basic inert material in concrete
(*b*) For making artificial stones and building blocks
(*c*) As railway ballast.

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Tests on Stones To a certain the required properties of stones, the following tests can be conducted:

(*i*) crushing strength test

(*ii*) water absorption test

(*iii*) abrasion test

(*iv*) impact test

(*v*) acid test.

(1) Crushing Strength Test: For conducting this test, specimen of size 40 × 40 × 40 mm are prepared from parent stone. Then the sides are finely dressed and placed in water for 3 days. The saturated specimen is provided with a layer of plaster of paris on its top and bottom surfaces to get even surface so that load applied is distributed uniformly. Uniform load distribution can be obtained satisfactorily by providing a pair of 5 mm thick plywood instead of using plaster of paris layer also. The specimen so placed in the compression testing machine is loaded at the rate of 14 N/mm^2 per minute. The crushing load is noted. Then crushing strength is equal to the crushing load divided by the area over which the load is applied. At least three specimen should be tested and the average should be taken as crushing strength.

(2) Water Absorption Test: For this test cube specimen weighing about 50 grams are prepared and the test is carried out in the steps given below:

(*a*) Note the weight of dry specimen as W_1.

(*b*) Place the specimen in water for 24 hours.

(*c*) Take out the specimen, wipe out the surface with a piece of cloth and weigh the specimen. Let its weight be W_2.

(*d*) Suspend the specimen freely in water and weight it. Let its weight be W_3.

(*e*) Place the specimen in boiling water for 5 hours. Then take it out, wipe the surface with cloth and weigh it. Let this weight be W_4. Then, Percentage absorption by weight = $\frac{W2-W1}{W1} \times 100$

Percentage absorption by volume= $\frac{W2-W1}{W2-W3} \times 100$

Percentage porosity by volume= $\frac{W4-W1}{W2-W3} \times 100$

Density= $\frac{W1}{W2-W1}$

Specific gravity= $\frac{W1}{W2-W3}$

Saturation coefficient $= \frac{\text{water absorption}}{\text{total porosity}}$

Saturation coefficient= $\frac{W2-W1}{W4-W1}$

<u>(3) Abrasion Test</u>: This test is carried out on stones which are used as aggregates for road construction. The test result indicate the suitability of stones against the grinding action under traffic. Any one of the following test may be conducted to find out the suitability of aggregates:
(*i*) Los Angeles abrasion test
(*ii*) Deval abrasion test
(*iii*) Dorry's abrasion test.
However Los Angeles abrasion test is preferred since these test results are having good correlation with the performance of the pavements. The Los Angeles apparatus as shown in the figure below consists of a hollow cylinder 0.7 m inside diameter and 0.5 m long with both ends closed. It is mounted on a frame so that it can be rotated about horizontal axis. IS code has standardised the test procedure for different gradation of specimen. Along with specified weight of specimen a specified number of cast iron balls of 48 mm diameter are placed in the cylinder. Then the cylinder is rotated at a speed of 30 to 33 rpm for specified number of times (500 to 1000). Then the aggregate is removed and sieved on 1.7 mm. IS sieve. The weight of aggregates passing is found.

Then Los Angeles value is found as= $\frac{\textbf{Weight of aggregates passing through the sieve}}{\textbf{Original weight}} \times \mathbf{100}$

The following values are recommended for road works:
For bituminous mixes – 30%
For base course – 50%

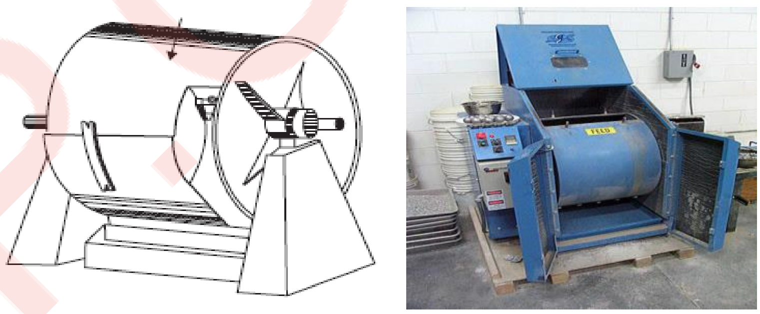

Fig: Los Angeles apparatus

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(4) **Impact Test:** The resistance of stones to impact is found by conducting tests in impacting testing machine (shown in figure). It consists of a frame with guides in which a metal hammer weighing 13.5 to 15 kg can freely fall from a height of 380 mm. Aggregates of size 10 mm to 12.5 mm are filled in cylinder in 3 equal layers; each layer being tamped 25 times. The same is then transferred to the cup and again tamped 25 times. The hammer is then allowed to fall freely on the specimen 15 times. The specimen is then sieved through 2.36 mm sieve. Then,

$$\textbf{Impact value} = \frac{W2}{W1}$$

W2 = weight of fines
W1 = original weight.
The recommended impact values for various works are:
(*i*) for wearing course >/ 30%
(*ii*) for bituminous mechadam >/ 35%
(*iii*) for water bound mechadam >/ 40%

(5) **Acid Test:** This test is normally carried out on sand stones to check the presence of calcium carbonate, which weakens the weather resisting quality. In this test, a sample of stone weighing about 50 to 100 gm is taken and kept in a solution of one per cent hydrochloric acid for seven days. The solution is agitated at intervals. A good building stone maintains its sharp edges and keeps its surface intact. If edges are broken and powder is formed on the surface, it indicates the presence of calcium carbonate. Such stones will have poor weather resistance.

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Common building stones:

The following are the some of commonly used stones:

(*i*) Basalt and trap (*ii*) Granite
(*iii*) Sand stone (*iv*) Slate
(*v*) Laterite (*vi*) Marble
(*vii*) Gneiss (*viii*) Quartzite

Their qualities and uses are explained below:

(*i*) Basalt and Trap: The structure is medium to fine grained and compact. Their colour varies from dark gray to black. Fractures and joints are common. Their weight varies from 18 kN/m^3 to 29 kN/m^3.The compressive strength varies from 200 to 350 N/mm^2. These are igneous rocks. They are used as road metals, aggregates for concrete. They are also used for rubble masonry works for bridge piers, river walls and dams. They are used as pavement.

Fig: Basalt and trap

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(*ii*) **Granite:** Granites are also igneous rocks. The colour varies from light gray to pink. The structure is crystalline, fine to coarse grained. They take polish well. They are hard durable. Specific gravity is from 2.6 to 2.7 and compressive strength is 100 to 250 N/mm2. They are used primarily for bridge piers, river walls, and for dams. They are used as kerbs and pedestals. The use of granite for monumental and institutional buildings is common. Polished granites are used as table tops, cladding for columns and wall. They are used as coarse aggregates in concrete.

Fig: Granite

(*iii*) Sand stone: These are sedimentary rocks, and hence stratified. They consist of quartz and feldspar. They are found in various colours like white, grey, red, buff, brown, yellow and even dark grey. The specific gravity varies from 1.85 to 2.7 and compressive strength varies from 20 to 170 N/mm2. Its porosity varies from 5 to 25 per cent. Weathering of rocks renders it unsuitable as building stone. It is desirable to use sand stones with silica cement for heavy structures, if necessary. They are used for masonry work, for dams, bridge piers and river walls.

Fig: Sandstone

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(*iv*)**Slate:** These are metamorphic rocks. They are composed of quartz, mica and clay minerals. The structure is fine grained. They split along the planes of original bedding easily. The colour varies from dark gray, greenish gray, purple gray to black. The specific gravity is 2.6 to 2.7. Compressive strength varies from 100 to 200 N/mm^2. They are used as roofing tiles, slabs, pavements etc.

Fig: Slate

(*v*) **Laterite:** It is a metamorphic rock. It is having porous and sponges structure. It contains high percentage of iron oxide. Its colour may be brownish, red, yellow, brown and grey. Its specific gravity is 1.85 and compressive strength varies from 1.9 to 2.3 N/mm^2. It can be easily quarried in blocks. With seasoning it gains strength. When used as building stone, its outer surface should be plastered.

Fig: Laterite

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(*vi*) **Marble:** This is a metamorphic rock. It can take good polish. It is available in different pleasing colours like white and pink. Its specific gravity is 2.65 and compressive strength is 70–75 N/ mm^2. It is used for facing and ornamental works. It is used for columns, flooring, steps etc.

Fig :Marble

(*vii*) **Gneiss:** It is a metamorphic rock. It is having fine to coarse grains. Alternative dark and white bands are common. Light grey, pink, purple, greenish gray and dark grey coloured varieties are available. These stones are not preferred because of deleterious constituents present in it. They may be used in minor constructions. However hard varieties may be used for buildings. The specific gravity varies from 2.5 to 3.0 and crushing strength varies from 50 to 200 N/mm^2.

Fig: Gneiss

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(*viii*) **Quartzite:** Quartzites are metamorphic rocks. The structure is fine to coarse grained and often granular and branded. They are available in different colours like white, gray, yellowish. Quartz is the chief constituent with feldspar and mica in small quantities. The specific gravity varies from 2.55 to 2.65. Crushing strength varies from 50 to 300 N/mm^{2}. They are used as building blocks and slabs. They are also used as aggregates for concrete.

Fig: Quartzite

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II-BRICKS

- Brick is obtained by moulding good clay into a block, which is dried and then burnt. This is the oldest building block to replace stone.
- Manufacture of bricks started with hand moulding, sun drying and burning in clamps. A considerable amount of technological development has taken place with better knowledge about to properties of raw materials, better machineries and improved techniques of moulding drying and burning.
- The size of the bricks are of **190 mm × 90 mm × 90 mm** and **190 mm × 90 mm × 40 mm**.
- With mortar joints, the size of these bricks are taken as **200 mm × 100 mm × 100 mm** and **200 mm × 100 mm × 50 mm.**
- However the old size of measured in inches in still being used in some parts of India.

Fig: Brick

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2.2 Properties of bricks

1. **Colour:** Colour should be uniform and bright.
2. **Shape:** Bricks should have plane faces. They should have sharp and true right angled corners.
3. **Size:** Bricks should be of standard sizes as prescribed by codes.
4. **Texture:** They should possess fine, dense and uniform texture. They should not possess fissures, cavities, loose grit and unburnt lime.
5. **Soundness:** When struck with hammer or with another brick, it should produce metallic sound.
6. **Hardness:** Finger scratching should not produce any impression on the brick.
7. **Strength:** Crushing strength of brick should not be less than 3.5 N/mm^2. A field test for strength is that when dropped from a height of 0.9 m to 1.0 m on a hard ground, the brick should not break into pieces.
8. **Water Absorption:** After immersing the brick in water for 24 hours, water absorption should not be more than 20 per cent by weight. For class-I works this limit is 15 per cent.
9. **Efflorescence:** Bricks should not show white patches when soaked in water for 24 hours and then allowed to dry in shade. White patches are due to the presence of sulphate of calcium, magnesium and potassium. They keep the masonry permanently in damp and wet conditions.
10. **Thermal Conductivity:** Bricks should have low thermal conductivity, so that buildings built with them are cool in summer and warm in winter.
11. **Sound Insulation:** Heavier bricks are poor insulators of sound while light weight and hollow bricks provide good sound insulation.
12. **Fire Resistance:** Fire resistance of bricks is usually good. In fact bricks are used to encase steel columns to protect them from fire.

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2.3 Uses of bricks

Bricks are used in the following civil works:

1. As building blocks.
2. For lining of ovens, furnaces and chimneys
3. For protecting steel columns from fire
4. As aggregates in providing water proofing to R.C.C. roofs
5. For pavers for footpaths and cycle tracks
6. For lining sewer lines.

2.4Classification of Bricks Based on their Quality

The bricks used in construction are classified as:
(*i*) First class bricks
(*ii*) Second class bricks
(*iii*) Third class bricks and
(*iv*) Fourth class bricks

(*i*) First Class Bricks: These bricks are of standard shape and size. They are burnt in kilns. They fulfill all desirable properties of bricks.

(*ii*)Second Class Bricks: These bricks are ground moulded and burnt in kilns. The edges may not be sharp and uniform. The surface may be some what rough. Such bricks are commonly used for the construction of walls which are going to be plastered.

(*iii*) Third Class Bricks: These bricks are ground moulded and burnt in clamps. Their edges are somewhat distorted. They produce dull sound when struck together. They are used for temporary and unimportant structures.

(*iv*) Fourth Class Bricks: These are the over burnt bricks. They are dark in colour. The shape is irregular. They are used as aggregates for concrete in foundations, floors and roads.

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2.5 Tests on bricks

The following *laboratory tests* may be conducted on the bricks to find their suitability:

(*i*) Crushing strength
(*ii*) Absorption
(*iii*) Shape and size and
(*iv*) Efflorescence.

(*i*) **Crushing Strength:** The brick specimen are immersed in water for 24 hours. The frog of the brick is filled flush with 1:3 cement mortar and the specimen is stored in damp jute bag for 24 hours and then immersed in clean water for 24 hours. The specimen is placed in compression testing machine with 6 mm plywood on top and bottom of it to get uniform load on the specimen. Then load is applied axially at a uniform rate of 14 N/mm^2 . The crushing load is noted. Then the crushing strength is the ratio of crushing load to the area of brick loaded. Average of five specimen is taken as the crushing strength.

(*ii*) **Absorption Test:** Brick specimen are weighed dry. Then they are immersed in water for a period of 24 hours. The specimen are taken out and wiped with cloth. The weight of each specimen in wet condition is determined. The difference in weight indicate the water absorbed. Then the percentage absorption is the ratio of water absorbed to dry weight multiplied by 100. The average of five specimen is taken. This value should not exceed 20 per cent.

(*iii*) **Shape and Size:** Bricks should be of standard size and edges should be truly rectangular with sharp edges. To check it, 20 bricks are selected at random and they are stacked along the length, along the width and then along the height. For the standard bricks of size 190 mm × 90 mm × 90 mm. IS code permits the following limits:

Lengthwise: 3680 to 3920 mm
Widthwise: 1740 to 1860 mm
Heightwise: 1740 to 1860 mm

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The following *field tests* help in ascertaining the good quality bricks:

(*i*) uniformity in size

(*ii*) uniformity in colour

(*iii*) structure
(*iv*) hardness test
(*v*) sound test
(*vi*) strength test.
(*i*) ***Uniformity in Size:*** A good brick should have rectangular plane surface and uniform in size. This check is made in the field by observation.
(*ii*) ***Uniformity in Colour:*** A good brick will be having uniform colour throughout. This observation may be made before purchasing the brick.
(*iii*) ***Structure:*** A few bricks may be broken in the field and their cross-section observed. The section should be homogeneous, compact and free from defects such as holes and lumps.
(*iv*) ***Sound Test:*** If two bricks are struck with each other they should produce clear ringing sound. The sound should not be dull.
(*v*) ***Hardness Test:*** For this a simple field test is scratch the brick with nail. If no impression is marked on the surface, the brick is sufficiently hard.

(*vi*) ***Efflorescense:*** The presence of alkalis in brick is not desirable because they form patches of grey powder by absorbing moisture. Hence to determine the presence of alkalis this test is performed as explained below. Place the brick specimen in a glass dish containing water to a depth of 25 mm in a well ventilated room. After all the water is absorbed or evaporated again add water for a depth of 25 mm. After second evaporation observe the bricks for white/grey patches. The observation is reported as 'nil', 'slight', 'moderate', 'heavy' or serious to mean
(*a*) Nil: No patches

(*b*) Slight: 10% of area covered with deposits

(*c*) Moderate: 10 to 50% area covered with deposit but unaccompanied by flaking of the surface.

(*d*) Heavy: More than 50 per cent area covered with deposits but unaccompanied by flaking of the surface.
(*e*) Serious: Heavy deposits of salt accompanied by flaking of the surface.

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2.6 Types of bricks

Bricks may be broadly classified as:

(*i*) Building bricks
(*ii*) Paving bricks
(*iii*) Fire bricks
(*iv*) Special bricks.

(*i*) **Building Bricks:** These bricks are used for the construction of walls.

(*ii*) **Paving Bricks:** These are vitrified bricks and are used as pavers.

(*iii*) **Fire Bricks:** These bricks are specially made to withstand furnace temperature. Silica bricks belong to this category.

(*iv*) **Special Bricks:** These bricks are different from the commonly used building bricks with respect to their shape and the purpose for which they are made. Some of such bricks are listed below:

(*a*) Specially shaped bricks

(*b*) Facing bricks
(*c*) Perforated building bricks
(*d*) Burnt clay hollow bricks
(*e*) Sewer bricks
(*f*) Acid resistant bricks.
(*a*) ***Specially Shaped Bricks:*** Bricks of special shapes are manufactured to meet the requirements of different situations. Some of them are shown in the figure below.

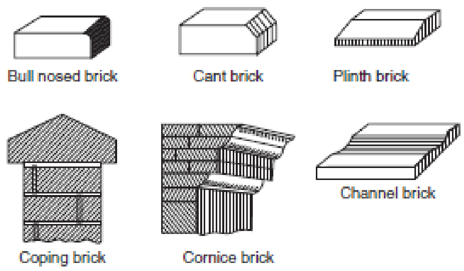

Figure 4: Special shaped bricks

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(*b*) ***Facing Bricks:*** These bricks are used in the outer face of masonry. Once these bricks are provided, plastering is not required. The standard size of these bricks are 190 × 90 ×90 mm or 190 × 90 × 40 mm

(*c*) ***Perforated Building Bricks:*** These bricks are manufactured with area of perforation of 30 to 45 per cent. The area of each perforation should not exceed 500 mm2. The perforation should be uniformly distributed over the surface. They are manufactured in the size 190 × 190 × 90 mm and 290 × 90 × 90 mm.

(*d*) ***Burnt Clay Hollow Bricks:*** They are light in weight. They are used for the construction of partition walls. They provide good thermal insulation to buildings. They are manufactured in the sizes 190 × 190 × 90 mm, 290 × 90 × 90 mm and 290 × 140 × 90 mm. The thickness of any shell should not be less than 11 mm and that of any web not less than 8 mm.

(*e*) ***Sewer Bricks:*** These bricks are used for the construction of sewage lines. They are manufactured from surface clay, fire clay shale or with the combination of these. They are manufactured in the sizes 190 × 90 × 90 mm and 190 × 90 × 40 mm. The average strength of these bricks should be a minimum of 17.5 N/mm^2 . The water absorption should not be more than 10 per cent.

(*f*) ***Acid Resistant Bricks:*** These bricks are used for floorings likely to be subjected to acid attacks, lining of chambers in chemical plants, lining of sewers carrying industrial wastes etc. These bricks are made of clay or shale of suitable composition with low lime and iron content, flint or sand and vitrified at high temperature in a ceramic kiln.

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III. CEMENT

Cement is a commonly used binding material in the construction. The cement is obtained by burning a mixture of calcarious (calcium) and argillaceous (clay) material at a very high temperature and then grinding the clinker so produced to a fine powder. It was first produced by a mason Joseph Aspdin in England in 1924. He patented it as portland cement.

3.1 Types of cement

In addition to ordinary portland cement there are many varieties of cement. Important varieties are briefly explained below:

(*i*) **White Cement:** The cement when made free from colouring oxides of iron, manganese and chlorium results into white cement. In the manufacture of this cement, the oil fuel is used instead of coal for burning. White cement is used for the floor finishes, plastering, ornamental works etc. In swimming pools white cement is used to replace glazed tiles. It is used for fixing marbles and glazed tiles.

(*ii*) **Coloured Cement:** The cements of desired colours are produced by intimately mixing pigments with ordinary cement. The chlorium oxide gives green colour. Cobalt produce blue colour. Iron oxide with different proportion produce brown, red or yellow colour. Addition of manganese dioxide gives black or brown coloured cement. These cements are used for giving finishing touches to floors, walls, window sills, roofs etc

(*iii*) **Quick Setting Cement:** Quick setting cement is produced by reducing the percentage of gypsum and adding a small amount of aluminium sulphate during the manufacture of cement. Finer grinding also adds to quick setting property. This cement starts setting within 5 minutes after adding water and becomes hard mass within 30 minutes. This cement is used to lay concrete under static or slowly running water.

(*iv*) **Rapid Hardening Cement:** This cement can be produced by increasing lime content and burning at high temperature while manufacturing cement. Grinding to very fine is also necessary. Though the initial and final setting time of this cement is the same as that of portland cement, it gains strength in early days. This property helps in earlier removal of form works and speed in construction activity.

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(*v*) **Low Heat Cement:** In mass concrete works like construction of dams, heat produced due to hydration of cement will not get dispersed easily. This may give rise to cracks. Hence in such constructions it is preferable to use low heat cement. This cement contains low percentage (5%) of tricalcium aluminate (C3A) and higher percentage (46%) of dicalcium silicate (C2S).

(*vi*) **Pozzulana Cement:** Pozzulana is a volcanic power found in Italy. It can be processed from shales and certain types of clay also. In this cement pozzulana material is 10 to 30 per cent. It can resist action of sulphate. It releases less heat during setting. It imparts higher degree of water tightness. Its tensile strength is high but compressive strength is low. It is used for mass concrete works. It is also used in sewage line works.

(*vii*) **Expanding Cement:** This cement expands as it sets. This property is achieved by adding expanding medium like sulpho aluminate and a stabilizing agent to ordinary cement. This is used for filling the cracks in concrete structures.

(*viii*) **High Alumina Cement:** It is manufactured by calcining a mixture of lime and bauxite. It is more resistant to sulphate and acid attack. It develops almost full strength within 24 hours of adding water. It is used for under water works.

(*ix*) **Blast Furnace Cement:** In the manufacture of pig iron, slag comes out as a waste product. By grinding clinkers of cement with about 60 to 65 per cent of slag, this cement is produced. The properties of this cement are more or less same as ordinary cement, but it is cheap, since it utilise waste product. This cement is durable but it gains the strength slowly and hence needs longer period of curing.

(*x*) **Acid Resistant Cement:** This cement is produced by adding acid resistant aggregated such as quartz, quartzite, sodium silicate or soluble glass. This cement has good resistance to action of acid and water. It is commonly used in the construction of chemical factories.

(*xi*) **Sulphate Resistant Cement:** By keeping the percentage of tricalcium aluminate C_3A below five per cent in ordinary cement this cement is produced. It is used in the construction of structures which are likely to be damaged by alkaline conditions. Examples of such structures are canals, culverts etc

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(*xii*) **Fly Ash Blended Cement:** Fly ash is a by product in thermal stations. The particles of fly ash are very minute and they fly in the air, creating air pollution problems. Thermal power stations have to spend lot of money to arrest fly ash and dispose safely. It is found that one of the best way to dispose fly ash is to mix it with cement in controlled condition and derive some of the beneficiary effects on cement. Now-a-days cement factories produce the fly ash in their own thermal stations or borrow it from other thermal stations and further process it to make it suitable to blend with cement. 20 to 30% fly ash is used for blending. Fly ash blended cements have superior quality of resistance to weathering action. The ultimate strength gained is the same as that with ordinary portland cement. However strength gained in the initial stage is slow. Birla plus, Birla star, A.C.C. Suraksha are some of the brand mame of blended cement.

3.2 Properties of Ordinary Portland Cement

(*i*) **Chemical properties:** Portland cement consists of the following chemical compounds:

(*a*) Tricalcium silicate 3 CaO.SiO2 (C_3S) 40%

(*b*) Dicalcium silicate 2CaO.SiO2 (C_2S) 30%

(*c*) Tricalcium aluminate 3CaO.Al2O3 (C_3A) 11%

(*d*) Tetracalcium aluminate 4CaO.Al2O3.Fe2O3 (C_3AF) 11%

There may be small quantities of impurities present such as calcium oxide (CaO) and magnesium oxide (MgO). When water is added to cement, C_3A is the first to react and cause initial set. It generates great amount of heat. C_3S hydrates early and develops strength in the first 28 days. It also generates heat. C_2S is the next to hydrate. It hydrates slowly and is responsible for increase in ultimate strength. C_4AF is comparatively inactive compound.

(*ii*) Physical properties: The following physical properties should be checked before selecting a portland cement for the civil engineering works. IS 269–1967 specifies the method of testing and prescribes the limits:

(*a*) Fineness (*b*) Setting time

(*c*) Soundness (*d*) Crushing strength

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(*a*) ***Fineness:*** It is measured in terms of percentage of weight retained after sieving the cement through 90 micron sieve or by surface area of cement in square centimetres per gram of cement. According to IS code specification weight retained on the sieve should not be more than 10 per cent. In terms of specific surface should not be less than 2250 cm^2/gm.

(*b*) ***Setting time:*** A period of 30 minutes as minimum setting time for initial setting and a maximum period of 600 minutes as maximum setting time is specified by IS code, provided the tests are conducted as per the procedure prescribed by IS 269-1967.

(*c*) ***Soundness:*** Once the concrete has hardened it is necessary to ensure that no volumetric changes takes place. The cement is said to be unsound, if it exhibits volumetric instability after hardening. IS code recommends test with Le Chatelier mould for testing this property. At the end of the test, the indicator of Le Chatelier mould should not expand by more than 10 mm.

(*d*) ***Crushing strength:*** For this mortar cubes are made with standard sand and tested in compression testing machine as per the specification of IS code. The minimum strength specified is 16 N/mm^2 after 3 days and 22 N/mm^2 after 7 days of curing.

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3.3 Physical Tests on Cement

(*a*) **Soundness Test:** It is conducted by sieve analysis. 100 grams of cement is taken and sieved through IS sieve No. 9 for fifteen minutes. Residue on the sieve is weighed. This should not exceed 10 per cent by weight of sample taken.

(*b*) **Setting Time:** Initial setting time and final setting time are the two important physical properties of cement. Initial setting time is the time taken by the cement from adding of water to the starting of losing its plasticity. Final setting time is the time lapsed from adding of the water to complete loss of plasticity. **Vicat apparatus is used for finding the setting times.** Vicat apparatus consists of a movable rod to which any one of the three needles shown in figure can be attached. An indicator is attached to the movable rod. A Vicat mould is associated with this apparatus which is in the form of split cylinder. Cement paste of standard consistency is used in this test. Then the tests for initial and final setting times can be carried out as explained below:

Initial Setting Time: 300 grams of cement is thoroughly mixed with 0.85 times the water for standard consistency and Vicat mould is completely filled and top surface is levelled. 1 mm square needle is fixed to the rod and gently placed over the paste. Then it is freely allowed to penetrate. In the beginning the needle penetrates the paste completely. As time lapses the paste start losing its plasticity and offers resistance to penetration. When needle can penetrate up to 5 to 7 mm above bottom of the paste experiment is stopped and time lapsed between the addition of water and end if the experiment is noted as initial setting time.

Final Setting Time: The square needle is replaced with annular collar. Experiment is continued by allowing this needle to freely move after gently touching the surface of the paste. Time lapsed between the addition of water and the mark of needle but not of annular ring is found on the paste. This time is noted as final setting time.

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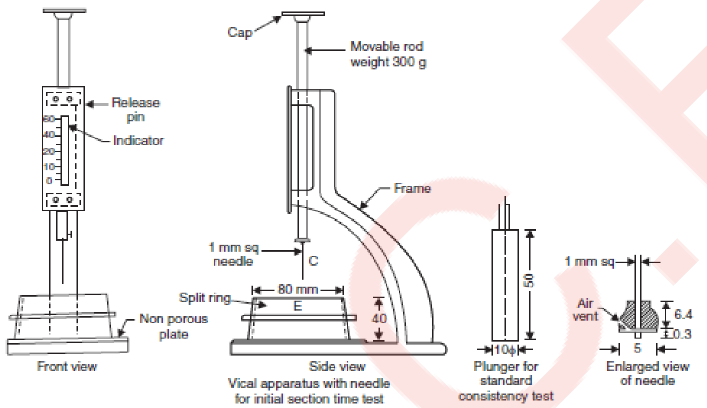

Fig: Vicat Apparatus

(*c*) **Soundness Test:** This test is conducted to find free lime in cement, which is not desirable. **Le Chatelier apparatus is used for conducting this test.** It consists of a split brass mould of diameter 30 mm and height 30 mm. On either side of the split, there are two indicators, with pointed ends. The ends of indicators are 165 mm from the centre of the mould. Properly oiled Le Chatelier mould is placed on a glass plate and is filled completely with a cement paste having 0.78 times the water required for standard consistency. It is then covered with another glass plate and a small weight is placed over it. Then the whole assembly is kept under water for 24 hours. The temperature of water should be between 24°C and 50°C. Note the distance between the indicator. Then place the mould again in the water and heat the assembly such that water reaches the boiling point in 30 minutes. Boil the water for one hour. The mould is removed from water and allowed to cool. The distance between the two pointers is measured. The difference between the two readings indicate the expansion of the cement due to the presence of un burnt lime. This value should not exceed 10 mm.

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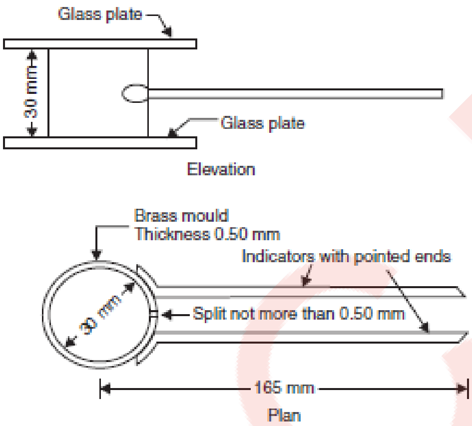

Figure : Le Chatelier apparatus

(*d*) **Crushing Strength Test:** For this 200 gm of cement is mixed with 600 gm of standard sand confirming to IS 650–1966. After mixing thoroughly in dry condition for a minute, distilled potable water is added to get a cement paste of standard consistency. They are mixed with trowel for 3 to 4 minutes to get uniform mixture. The mix is placed in a cube mould of 70.6 mm size (Area 5000 mm2) kept on a steel plate and prodded with 25 mm standard steel rod 20 times within 8 seconds. Then the mould is placed on a standard vibrating table that vibrates at a speed of 12000 ± 400 vibration per minute. A hopper is secured at the top and the remaining mortar is filled. The mould is vibrated for two minutes and hopper removed. The top is finished with a knife or with a trowel and levelled. After 24 ± 1 hour mould is removed and cube is placed under clean water for curing. After specified period cubes are tested in compression testing machine, keeping the specimen on its level edges. Average of three cubes is reported as crushing strength.

Uses of Cement

Cement is used widely for the construction of various structures. Some of them are listed below: (*i*) Cement slurry is used for filling cracks in concrete structures.

(*ii*) Cement mortar is used for masonry work, plastering and pointing.

(*iii*) Cement concrete is used for the construction of various structures like buildings, bridges. water tanks, tunnels, docks, harbours etc.
(*iv*) Cement is used to manufacture lamp posts, telephone posts, railway sleepers, piles etc.
(*v*) For manufacturing cement pipes, garden seats, dust bins, flower pots etc. cement is commonly used.
(*vi*) It is useful for the construction of roads, footpaths, courts for various sports etc.

Effect of cement industry on the environment

Cement is an extremely important construction material used for housing and infrastructure development and a key to economic growth. Cement demand is directly associated to economic growth and many growing economies are striving for rapid infrastructure development which underlines the tremendous growth in cement production .
India is the second-largest cement producer in the world. The industry continues to enjoy robust market demand and India continues to be the second-largest global consumer of cement. The cement industry is the one of the biggest contributors to air pollution. This rising demand for cement also associated with it the environment damaging greenhouse gas (GHG) emissions. Cement manufacture contributes to greenhouse gases directly through the production of carbon dioxide during cement manufacturing and indirectly through the use of energy, particularly if the energy is sourced from fossil fuels like coal etc. Greenhouse gases are responsible for climate change. Cement manufacture causes environmental impacts at all stages of the process. These include emissions of airborne pollution in the form of dust and gases; noise and vibration when operating machinery and during quarrying operations for obtaining raw materials. Measures should be taken to reduce the carbon footprint of cement industry. Renewable sources of energy can be used for cement production. Low carbon alternatives to cement should be increasingly used in construction. We have to replace cement with other materials with a lighter carbon footprint. Technology for carbon capture and storage should be developed so that carbon dioxide emissions in the atmosphere are reduced. Other changes such as increased use of building-information modelling (BIM) and modular construction to further reduce cement consumption.