UNIT I - STONES

Course Content: *Classification - Selection – Use of stones in buildings - Requirement and testing of stones– Deterioration and preservation of stone work - Artificial stones.*

Introduction: 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.

Type of Stones

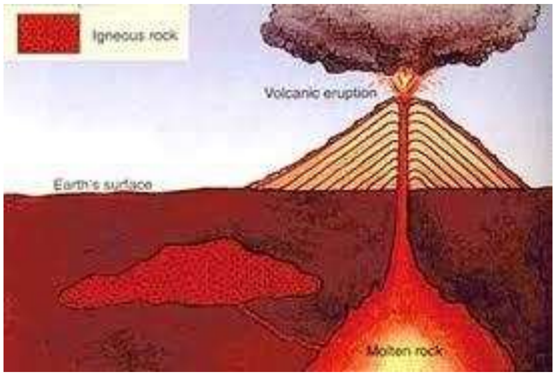
Stones used for civil engineering works may be classified in the following three ways:

- Geological
- Physical
- Chemical

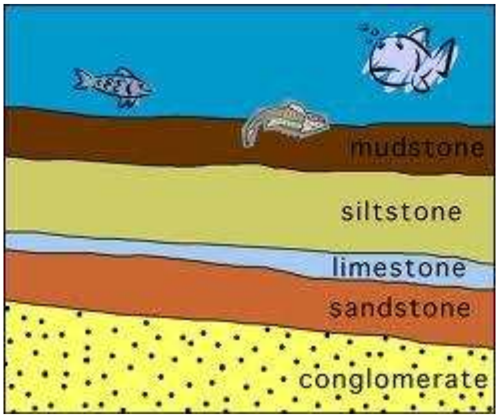
Geological Classification

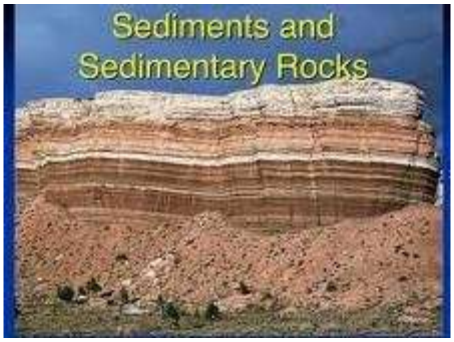
Based on their origin of formation stones are classified into three main groups—Igneous, sedimentary and metamorphic rocks.

(*i*) **Igneous Rocks:** Igneous Rock, rock formed when molten or partially molten material, called magma, cools and solidifies. The inner layers of the earth are at a very high temperature causing the masses of silicates to melt. The melted masses of silicates is called magma, which forced up and released on the surface of the earth. This release is called volcanic eruption. The magma that is released cools and solidify into a crystalline rock. 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, Granites are formed by slow cooling of the lava under thick cover on the top. Hence they have crystalline surface. The cooling of lava at the top surface of earth results into non-crystalline and glassy texture. Trap and basalt belong to this category.

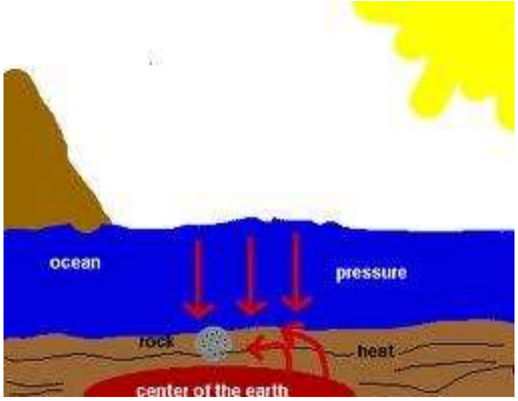


(*ii*) **Sedimentary Rocks:** Due to weathering action of water, wind and frost existing rocks disintegrates. The disintegrated material is carried by wind and water; the water being most powerful medium. Flowing water deposits its suspended materials at some points of obstacles to its flow. These deposited 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.





(*iii*) **Metamorphic Rocks:** Previously formed igneous and sedimentary rocks undergo changes due to metamorphic action of pressure and internal heat. For example due to metamorphic action granite becomes greisses, trap and basalt change to schist and laterite, lime stone changes to marble, sand stone becomes quartzite and mud stone becomes slate.



Physical Classification

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

- Stratified rocks
- Unstratified rocks

(*i*) **Stratified Rocks:** These rocks are having layered structure. They possess planes of Stratification or cleavage. 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.

Chemical Classification

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

- Silicious rocks
- Argillaceous rocks and
- Calcareous rocks

(*i*) ***Silicious 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 laterites 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.

Properties of Stones

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

(*i*) **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.

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

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

(*iv*) **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

(*v*) **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/mm2 for any building block. Table 1.1 shows the crushing strength of various stones. 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/mm2. However in stone masonry buildings care should be taken to check the stresses when the beams (Concentrated Loads) are placed on laterite wall.

Table 1.1. Crushing strength of common building stones

Name of Stone	*Crushing Strength in N/mm²*
Trap	300 to 350
Basalt	153 to 189
Granite	104 to 140
Slate	70 to 210
Marble	72
Sand stone	65
Lime stone	55
Laterite	1.8 to 3.2

(*vi*) **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.

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

(*viii*) **Porosity and Absorption:** All stones have pores and hence absorb water. The reaction of water with material of stone causes 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.

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

(*x*) **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 indexes 13 to 19 are considered as medium tough and stones with toughness index less than 13 are poor stones.

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

(*xii*) **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.

(*xiii*) **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.

Requirements of Good Building Stones

The following are the requirements of good building stones:

(*i*) **Strength:** The stone should be able to resist the load coming on it. Ordinarilly this is not of primary concern since all stones are having good strength. However in case of large structure, it may be necessary to check the strength.

(*ii*) **Durability:** Stones selected should be capable of resisting adverse effects of natural forces like wind, rain and heat.

(*iii*) **Hardness:** The stone used in floors and pavements should be able to resist abrasive forces caused by movement of men and materials over them.

(*iv*) **Toughness:** Building stones should be tough enough to sustain stresses developed due to vibrations. The vibrations may be due to the machinery mounted over them or due to the loads moving over them. The stone aggregates used in the road constructions should be tough.

(*v*) **Specific Gravity:** Heavier variety of stones should be used for the construction of dams ,retaining walls, docks and harbours. The specific gravity of good building stone is between 2.4 and 2.8.

(*vi*) **Porosity and Absorption:** Building stone should not be porous. If it is porous rain water enters into the pour and reacts with stone and crumbles it. In higher altitudes, the freezing of water in pores takes place and it results into the disintegration of the stone.

(*vii*) **Dressing:** Giving required shape to the stone is called dressing. It should be easy to dress so that the cost of dressing is reduced. However the care should be taken so that, this is not be at the cost of the required strength and the durability.

(*viii*) **Appearance:** In case of the stones to be used for face works, where appearance is a primary requirement, its colour and ability to receive polish is an important factor.

(*ix*) **Seasoning:** Good stones should be free from the quarry sap. Laterite stones should not be used for 6 to 12 months after quarrying. They are allowed to get rid of quarry sap by the action of nature. This process of removing quarry sap is called seasoning.

(*x*) **Cost:** Cost is an important consideration in selecting a building material. Proximity of the quarry to building site brings down the cost of transportation and hence the cost of stones comes down. However it may be noted that not a single stone can satisfy all the requirements of a good building stones, since one requirement may contradict another. For example, strength and durability requirement contradicts ease of dressing requirement. Hence it is necessary that site engineer looks into the properties required for the inteded work and selects the stone.

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.

(*i*) **Crushing Strength Test:** For conducting this test, specimens 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 playwood 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/mm2 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.

(*ii*) **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 W1.

(*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 W2.

(*d*) Suspend the specimen freely in water and weight it. Let its weight be W3.

(*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 W4. Then,

$$\text{Percentage absorption by weight} = \frac{W_2 - W_1}{W_1} \times 100 \qquad \ldots(1)$$

$$\text{Percentage absorption by volume} = \frac{W_2 - W_1}{W_2 - W_3} \times 100 \qquad \ldots(2)$$

$$\text{Percentage porosity by volume} = \frac{W_4 - W_1}{W_2 - W_3} \times 100 \qquad \ldots(3)$$

$$\text{Density} = \frac{W_1}{W_2 - W_1} \qquad \ldots(4)$$

$$\text{Specific gravity} = \frac{W_1}{W_2 - W_3} \qquad \ldots(5)$$

$$\therefore \quad \text{Saturation coefficient} = \frac{\text{Water absorption}}{\text{Total porosity}}$$

$$= \frac{W_2 - W_1}{W - W}$$

(*iii*) **Abrasion Test:** 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

Prepared By: **Ms. G. Divya M.E**
Dept of Civil Engg

(*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 [Fig. 1.1] 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.

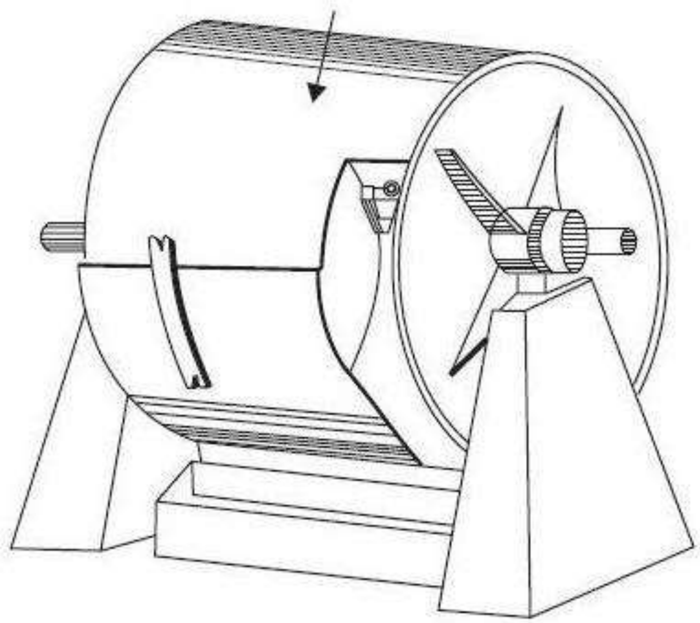


Fig. 1.1. Los Angeles testing machine

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 aggregate passing is found.

Then Los Angeles value is found as

$$= \frac{\text{Weight of aggregate passing through sieve}}{\text{Original weight}} \times 100.$$

The following values are recommended for road works:

For bituminous mixes – 30%

For base course – 50%

(*iv*) **Impact Test:** The resistance of stones to impact is found by conducting tests in impacting testing machine (Fig. 1.2). 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.

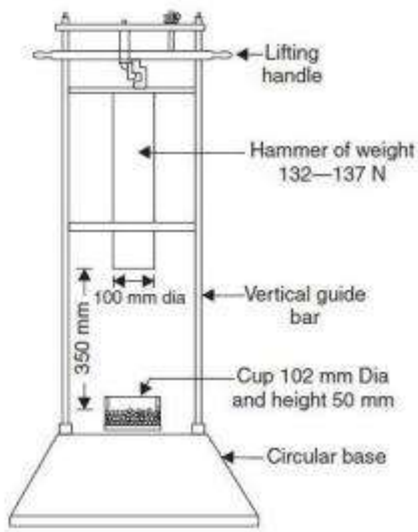


Fig. 1.2. Aggregate impact testing machine

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,

$$\text{Impact value} = \frac{W_2}{W_1}$$

Where

W2 = weight of fines

W1 = original weight.

(*v*) **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.

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
(*vii*) Crushed stones with graved 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.

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/m3 to 29 kN/m3. The compressive strength varies from 200 to 350 N/mm2. 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.

(*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.

(*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 gray. 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.

(*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/mm2. They are used as roofing tiles, slabs, pavements etc.

(*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/mm2. It can be easily quarried in blocks. With seasoning it gains strength. When used as building stone, its outer surface should be plastered.

(*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/ mm2. It is used for facing and ornamental works. It is used for columns, flooring, steps etc.

(*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/mm2.

(*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/mm2. They are used as building blocks and slabs. They are also used as aggregates for concrete.

Deterioration of Stones

The factors considered to be among the leading causes of building stone deterioration include salt crystallization, aqueous dissolution, frost damage, microbiological growth, human contact, and original construction.

Causes of stone deterioration

The various natural agents such as rain, heat, etc. and chemicals deteriorate the stones with time.

1. RAIN

Rain water acts both physically and chemically on stones. The physical action is due to the erosive and transportation powers and the latter due to the decomposition, oxidation and hydration of the minerals present in the stones.

2. PHYSICAL ACTION

Alternate wetting by rain and drying by sun causes internal stresses in the stones and consequent disintegration.

3. CHEMICAL ACTION

In industrial areas the acidic rain water reacts with the constituents of stones leading to its deterioration.

DECOMPOSITION

The disintegration of alkaline silicate of alumina in stones is mainly because of the action of chemically active water. The hydrated silicate and the carbonate forms of the alkaline materials are very soluble in water and are removed in solution leaving behind a hydrated silicate of alumina (Kaolinite). The decomposition of felspar is represented as

$K_2Al_2O_3.6H_2O + CO_2 + nH_2O = K_2CO_3 + Al_2O_3.2SiO_2.2H_2O + 4SiO_2.nH_2O$

OXIDATION AND HYDRATION

Rock containing iron compounds in the forms of peroxide, sulphide and carbonate are oxidised and hydrated when acted upon by aciduated rain water. As an example the peroxide—FeO is converted into ferric oxide—Fe2O3 which combines with water to form FeO.nH2O. This chemical change is accompanied by an increase in volume and results in a physical change manifested by the liberation of the neighbouring minerals composing the rocks. As another example iron sulphide and siderite readily oxidize to limonite and liberates sulphur, which combines with water and oxygen to form sulphuric acid and finally to sulphates.

4. FROST

In cold places frost pierces the pores of the stones where it freezes, expands and creates cracks.

5. WIND

Since wind carries dust particles, the abrasion caused by these deteriorates the stones.

6. TEMPERATURE CHANGES

Expansion and contraction due to frequent temperature changes cause stone to deteriorate especially if a rock is composed of several minerals with different coefficients of linear expansion.

7. VEGETABLE GROWTH

Roots of trees and weeds that grow in the masonry joints keep the stones damp and also secrete organic and acidic matters which cause the stones to deteriorate. Dust particles of organic or nonorganic origin may also settle on the surface and penetrate into the pores of stones. When these come in contact with moisture or rain water, bacteriological process starts and the resultant micro-organism producing acids attack stones which cause decay.

8. MUTUAL DECAY

When different types of stones are used together mutual decay takes place. For example when sandstone is used under limestone, the chemicals brought down from limestone by rain water to the sandstone will deteriorate it.

9. CHEMICAL AGENTS

Smokes, fumes, acids and acid fumes present in the atmosphere deteriorate the stones. Stones containing $CaCO_3$, $MgCO_3$ are affected badly.

10. LICHENS

These destroy limestone but act as protective coats for other stones. Molluses gradually weaken and ultimately destroy the stone by making a series of parallel vertical holes in limestones and sandstones.

PRESERVATION OF STONE WORK

To increase the life of a stone structure it should be cleaned with water or with steam so that dirt and soluble salts are removed and threat of decay is reduced. Following few points, if kept in view, will help increase the life of a stone structure particularly in the polluted atmosphere of big industrial towns.

1. *Selection.* It is much better to initially use a durable compact and crystalline stone rather than to depend upon preservatives later. Instead of lime stones or calcareous sand stones use of compact crystalline sand stone with its grains cemented with siliceous matter would be the right choice for industrial areas. Use of less porous stones on exposed faces of buildings is to be preferred even in non-industrial areas.
2. *Seasoning.* Use of stones seasoned after they had been cut and dressed immediately after quarrying will increase the life of structure. Quarry sap on evaporation leaves behind a thin hard skin which increases weathering property of the stone. This skin should not be disturbed. Also seasoned stones are less liable to deterioration because of frost and acids.
3. *Size.* Bigger sized stones are more durable than the smaller ones.
4. *Natural bed.* Care should be taken to so place the stones that loads act at right angles to the natural bed of stones used as otherwise the stone will flake off. Also with the natural bed vertical effect of rain and frost shall be more detrimental.
5. *Surface finish.* Well dressed, smoothly finished and polished surfaces are more durable than the rough and rugged ones.
6. *Workmanship.* Good workmanship helps in the preservation of stone work. All joints should be properly filled in leaving no hollows or cavities inside the masonry.
7. *External rendering.* Either the entire external surface should be plastered over with cement sand plaster or at least it should be properly pointed so as to stop rain water from entering the joints.
8. *Proper maintenance.* Maintenance of structure in neat condition is quite effective in preserving it. To do so, it should be washed with water or with steam so that the dirt and soluble salts are removed and the rate of decay is reduced.
9. *Application of preservatives.* The best way of preserving a stone is to eliminate as far as possible the causes of its deterioration e.g., not to use lime stone and sand stone together, not to let vegetable growth take place in joints of masonry, not to use lime stone in industrial areas etc.

Several proprietary makes of preservatives have been put on the market from time to time but no satisfactory preservative for stones has yet been evolved. *Szerelmy's liquid*, has been very commonly used but rather than preserving the treated stone it renders a porous stone somewhat water proof. The most common method used is painting the exposed face of stones with lead paint or with some other oil paint. But for the apparent defect that this treatment would change the colour and appearance of stone it remains still the best preservative for surface application if the paint be renewed from time to time.