

# Engineering Properties of Rocks

## Objectives :

The aim of this lesson is to understand the important physical properties of rocks and their determination, geological characteristics, general characteristics, modulus properties of rocks, building stones and their occurrences. The role of a geotechnical engineer is also highlighted.

## 1.0 Introduction :

Engineering properties of rocks is a collective nomenclature which includes all such properties of rocks that are relevant to engineering application after their extraction from natural beds or without extraction i.e. *insitu* conditions. The first set include all those properties for which a rock must be tested for selection as a material for construction such as a building stone, road stone or aggregate for concrete making. The second set of the properties include the qualities of a natural bed rock as and where it exists. That would determine its suitability or otherwise as a construction site for a proposed engineering project.

Obviously, in both cases, the economy and safety of an engineering project are greatly dependent upon the proper understanding and determination of the engineering properties of rocks. Engineering properties of rock are controlled by the discontinuities within the rock mass and the inherent properties of the intact rock. Therefore, engineering properties must account for the properties of the intact rock and for the properties of the rock mass as a whole. A combination of laboratory testing of small samples, empirical analysis, and field observations should be employed to determine the requisite engineering properties. Rock properties can be divided into two categories: intact rock properties and rock mass properties. Intact rock properties are determined from laboratory tests on small samples typically obtained from coring, outcrops or exposures along existing cuts. Common engineering properties typically obtained from laboratory tests include specific gravity, point load strength, compressive strength, tensile strength, shear strength, modulus, and durability.

Rock mass properties are determined by visual examination and description of discontinuities within the rock mass. It should follow the suggested methodology of the International Society of Rock Mechanics (ISRM 1978), and how these discontinuities will affect the behavior of the rock mass when subjected to the proposed construction.

## 2.0 Physical properties of rocks:

In most of the engineering applications, rocks are used as building stones. A building stone may be defined as a rock that can be safely used as a rough unit or as a properly cut and shaped (dressed) block or slab or column or sheet in different situation in an engineering construction. The following physical properties are considered to be important for a rock to be used as a building material.

### 2.1 Crushing Strength

It is also termed as compressive strength of a stone. It may be defined as maximum force expressed per unit area which a stone can withstand. Any force beyond the compression strength will cause a failure of the stone.

Mathematically, compressive strength is expressed by simpler method as follows

Where Compressive strength,  $P = \text{Load at failure}$ ,  $A = \text{Area of cross section of stone under } P$

The determination of compressive strength of a building stone involves making standard test specimens (which are either cubes of 5cm side or cylinders of length: diameter ratio of 2 or 2.5). These specimens are then loaded gradually one at a time after placing on the base plate of a universal testing machine, till the first crack appears in the specimen. Any further loading will crush the specimen. The compressive strength determined in this way using the above relationship is called “unconfined or universal compressive strength”. Because the test specimen has no lateral support or restraint.

When the compressive strength is tested by a method providing a lateral support, as by keeping the specimen in a special cell filled with a liquid under pressure. The value obtained, then it is called as confined or triaxial compressive strength.

The crushing strength of a rock depends on a number of factors, such as its

i. Mode of formation

ii. Composition

iii. Texture and structure

iv. Moisture content and

v. extent of weathering it has already suffered

Igneous rocks are crystalline rocks. They are compact and characterized by interlocking in texture and uniform in structure. These rocks possess very high crushing strengths compared to sedimentary and metamorphic rocks. In the sedimentary and metamorphic rocks, the presence of planes of weakness along bedding planes, foliation and schistosity and cleavage, greatly affects the compressive strength, both in direction and magnitude.

The sand stone may show a very low crushing strength when loaded parallel to bedding planes than when loaded perpendicular to the same structure. Except for sandstone, quartzite and most other sedimentary and metamorphic rocks are composed of clays, calcareous and hydrated silicate minerals which are inherently weak in strength.

Crushing strengths of common types of building stones are generally higher than the loads that they are supposed to withstand, in ordinary type of building constructions. The compressive strengths of some rocks and their range are as follows. They are expressed in Kg/cm<sup>2</sup>. Dolerite=1500-3500, Basalt= 1500-3500, Quartzite=1500-300, Granite= 1000-2500, Marbles=700-2000, Gneisses=500-2500, Sand Stone= 200-2500, Limestone= 200-2000.

During the last few years thousands of tests have been made to classify the rocks on the basis of uniaxial compressive strength in to grades. The following classification proposed by Deere and Miller has been found useful.

Class Description Uniaxial compressive strength(Kg/cm<sup>2</sup>)

A Very high strength More than 2240

B High strength 1120—2240

C Medium strength 500—1120

D Low strength 200—500

E Very low strength less than 200

### 2.2 Transverse strength:

It is defined as the capacity of the stones to withstand bending loads. Such loads are only rarely involved in situations where stones are commonly used. But when a stone is intended for use as a beam or a lintel, its transverse strength is determined as modulus of rupture using the following relationship.

$R = \text{Modulus of rupture}$ ;  $W = \text{weight at which sample breaks}$ ;  $l = \text{length of the specimen}$ ;  $b = \text{width of specimen}$ ;  $d = \text{thickness of the specimen}$ .

This property is determined practically by loading transversely a bar shaped test specimen generally of 20cmx8cmx8cm dimension and is supported at ends from below.

It has been found that in stone, the transverse strength is generally  $1/20^{\text{th}}$  to  $1/10^{\text{th}}$  of their compressive strengths.

### **2.3 Shear Strength :**

Shear strength is the resistance offered by a stone to shear stresses, which tends to move one part of a specimen with respect to the other. It is obtained by using the relationship. Shear strength of a stone is also not commonly determined except when the stone is to be used as a column

Where  $P$  = load at failure;  $A$  = area of cross section of the specimen.

It has been observed that shear strength of most common building stones ranges from 70 to 140 kg/cm<sup>2</sup>.

In laboratory testing, a bar shaped specimen is held with grip and is supported at ends below, is loaded from above.

Rupture occurs when the shear strength is exceeded.

### **2.4 Tensile Strength:**

Tensile strength of a rock is related to its ability to withstand breakage. It happens after some level. That level is its strength. It may be determined directly or indirectly. The tensile (pulling) strength that has to be applied to a material to break it. It is measured as a force per unit area. The direct method would require elaborate means to avoid bending while applying tensile forces by gripping the specimens at the ends. Since tensile stresses are seldom required accurately, an indirect method is commonly applied.

The indirect method is called the Brazilian test. It consists of loading a test cylinder diametrically in such a way that the applied loads would develop tensile rupturing along the diametrical plane of the specimen.

Loads are gradually increased till the cylinder fractures. The load  $P$ , at rupture being thus known. Transverse strength  $T_s$  is calculated by using the formula

$D$  = diameter of the specimen;  $L$  = length of the specimen

### **2.5 Porosity :**

The shape, size and nature of packing of the grains of a rock give rise to the property of porosity or development of pore spaces within a rock. Numerically it is expressed as the ratio between the total volume of pore spaces and the total volume of the rock sample. Porosity is commonly given in percentage terms. Presence of interlocking crystals, angular grains of various sizes and abundant cementing materials are responsible for low porosity of stones. Conversely the rock will be highly porous if composed of spherical or rounded grains, (sandstone) or if the cementing material is distributed unevenly or is of poor character.

Porosity is an important engineering property of rocks. It accounts for the fluid absorption value of the stones in most cases and also that a higher porosity signifies a lesser density which generally means a lesser compressive strength.

Porosity values for a few common building stones. Granite-0.1 to 0.5%, Basalt- 0.1 to 1%, Sandstone- 5 to 25%, Limestone- 5 to 20%, Marble- 0.5 to 2%, Quartzite- 0.1 to 0.5%,

### **2.6 Absorption Value:**

It defines the capacity of a stone to absorb moisture when immersed in water for 72 hours or till it gets full saturation. It is generally expressed in percentage terms of original dry weight of the mass. It may be obtained from the relationship

Where  $W_s$  = weight at saturation;  $W_0$  = dry weight of the sample used.

### **2.7 Permeability:**

It is the capacity of a rock to transmit water. Sand stones and limestones may show high values for absorption or 10% or even more. Selection of such highly porous varieties of these stones for use in building construction, especially in most situations, would be greatly objectionable.

Presence of water within the pores not only decreases the strength of the rock but also makes the stones very vulnerable to frost action, in cold and humid climatic conditions.

## **2.8 Density :**

It is defined as weight per unit volume of a substance. But in the case of rock it is not only the solid mineral matter which wholly accounts for the total volume of a given specimen. A part of the rock may comprise of pores or open spaces, which may be empty, partly filled or wholly filled with water. Accordingly, three types of density may be distinguished in rocks. They are a) Dry density, b) bulk density and c) saturated density.

1. **Dry density:** It is the weight per unit volume of an absolutely dried rock specimen, it includes the volume of the pore spaces present in the rock.

2. **Bulk density:** It is the weight per unit volume of a rock sample with natural moisture content where pores are only partially filled with water.

3. **Saturated density:** It is the density of the saturated rocks or weight per unit volume of a rock in which all the pores are completely filled with water.

The fourth type is also recognized as true density. It is the weight per unit volume of the mineral matter (without pores and water) of which a rock is made up. The most engineering calculations, it is the bulk density which is used frequently.

Bulk density values in gram/cubic cm for some common building stones are granite-2.7, basalt-2.9, sandstone-2.6, and limestone-2.2 to 2.6.

## **2.9 Abrasive Resistance :**

It is more a qualitative than a quantitative property. It may be broadly defined as the resistance which a stone offers to rubbing action of one kind or another. Determination of this is of considerable significance when stones are intended for use in situations where rubbing by natural or artificial causes is involved as a routine. Example a) stones used in paving along roads, b) Facing stones in buildings of arid region where strong sand laden winds are blown. These type of situations demand stones that have not only high abrasive resistance but also of essentially uniform composition. So that the wear is as uniform as possible.

Stones composed of more than one mineral like granite may look quite appealing. In such cases, when freshly used, but within short time, they may get pitted or disfigured because of unequal wear of the different mineral components.

## **2.10 Frost and fire resistance**

Many building stones show quick disintegration of building stones or rocks when used in situations involving frost formation (excessive cold) or heating. Frost causes disintegration by expansion of water on freezing within the rock pores.

In the case of fire, the unequal expansion in different mineral components and also at different depths from surface inwards may cause disintegration. This effect becomes more pronounced when the rock is first heated and then suddenly cooled by water by water. Heavy stones including granites crumble to pieces under such a treatment. It is easy to understand that rocks which are found porous and weak in strength are easily deteriorated in cold humid climates by frost action. Limestone and sandstones fall in this category. They show very poor frost resistance.

Fire resistance is especially determined when the stone is intended for use around stoves, heating places and in the wall of furnaces. Only compact and massive sandstones and quartzites suite reasonably well in fire and heating places.

### **3.0 Methods of Determining and Rock Properties :**

Subsurface rock properties are generally determined using one or more of the following methods:

- In-situ testing during the field exploration programme;
- Laboratory testing, and
- Back-analysis based on site performance data

#### **3.0 In-Situ Field Testing :**

The Geotechnical Engineers are expected to determine various soil and rock parameters under natural in-place conditions. This type of testing is useful for projects, where obtaining representative samples suitable for laboratory testing is difficult, such as those involving soft clays, loose sands and/or soils below the water table.

Common in situ tests are performed in conventional drilled borings, whereas specialized tests require a separate borehole or different insertion equipment. Field in situ borehole tests can be grouped into three categories:

##### a)Correlation Tests

- Standard Penetration Test (SPT)
- Dynamic Penetration Test (DPT)

##### b)Strength and Deformation Tests

- Penetrometers, such as Cone Penetrometer Test (CPT) and Piezocone
- Penetrometer Test (PQS)
- Pressure meters (PMT), such as Menard, Self-Boring, and Dilatometer
- stress or Shear Devices, such as Vane Shear and Borehole Shear Tests

##### c)Permeability Tests

- Pump Tests and Slug Tests
- Water Pressure Tests
- Hydraulic Conductivity Tests
- Percolation Tests

### **3.2 Laboratory Testing of Rock :**

Rock strength is measured by laboratory testing. Strengths are very different depending on the stress field applied to the rock. All rocks and soils are very much stronger inpossessing compression strength than in tensile strength.

The two common laboratory tests to determine the compressive strength of rock are:

- a) Uni-axial Unconfined Compression Test – In this method a cylindrical rock core is loaded axially until it fails.
- b) Tri-axial Confined Compression Test – In this method a cylindrical rock core is placed in a cell, subjected to all around (confining) pressure by hydraulic oil acting through a thin impermeable membrane, and loaded axially to failure.

There are a variety of tests used to determine the tensile strength of rock:

- Direct Pull Test - A cylindrical rock core sample is anchored at both ends and stretched.
- Brazilian Test - A relatively thin disk is load across the diameter until it splits.
- Beam Flexure Test - A thin slab of rock is loaded vertically when supported at three or four points along its length.

### **3.3 Back-analysis based on site performance data:**

Back-analysis is a quantitative approach to adjust soil or rock properties to match measureable site performance. Back-analysis is a method used to determine engineering properties of soil or rock. It is often used with geotechnical failures. When failures occur, back analysis can be used to model the conditions, and loads which resulted in failure. Back-analysis can also be used in some situations where failure has not occurred but the geotechnical performance can be quantified (e.g., deformations). Back-analysis is a quantitative approach to adjust soil or rock properties to match measureable site performance.

Most back-analyses in geotechnical engineering are based on methods that utilize field displacement monitoring data. Following are the methods of back analysis.

- Back-Analysis of Slopes
- Back-Analysis of Soil Settlement Resulting from Changes in Loading
- Back-Analysis of Foundations
- Use of Numerical Modeling for Back-Analysis

## **4.0 Geological characteristics of rocks**

### **4.1 Mineralogical composition :**

Rocks are made up of smaller units of the minerals. Their properties depend upon the nature and composition of these minerals. It has been observed that rocks composed chiefly of silica ( $\text{SiO}_2$ ) especially in free form, are the strongest in all respects. Quartzites are the strongest in all respects. Fresh Quartzite, Sand Stone and granite are some of the examples.

Carbonate rocks show a wide variation in their properties. A particular deposit of these rocks has to be tested by taking random representative samples before the stone is recommended for use in engineering construction of any importance. Presence of some minerals even in small quantities is to be viewed with caution while using in building stones. These minerals are mica, gypsum, sulphides, tremolite, flint and chert and clays. These destroy the inherent strength of the rock.

#### **4.2 Texture and Structure:**

Texture defines the size, shape and mutual relationship of the mineral compounds in a rock. Whereas structure determines the development of large scale features in the rock mass as a whole. Rocks may be coarse grained, medium grained or fine grained.

The fine grained equigranular textured rocks are better building stones compared to coarse grained and inequigranular rocks. In the later cases different compounds often tend to behave as separate units under the imposed loads and thereby reaction offered is of a complex and certainly weaker character.

Structurally speaking features like bedding planes, foliations, cleavage, joints and flow structures which might not be fully represented in small sized test specimens, but which may be present in rock masses on a large scale, have to be given due considerations.

#### **4.3 Resistance to weathering (Durability):**

It is essentially a geological character of a stone that is commonly determined by its composition, texture and structure on the one hand and the climate environment where the stone is ultimately used on the other hand.

A stone may remain almost fresh and untarnished for 500 years or more when used in the interior of a building. But the same stone used on the exterior might get pitted and weathered badly within 100 years. Good example is granite. Similarly, limestone used in building construction, in industrial townships may weather badly and quickly due to reaction with sulphurous acid polluted air. Whereas the same rock used only a little amount in temples and forts and historical buildings may last for centuries. An engineer and especially a town planner has to bear in mind this fact that rocks also live and sensitive to the environment in which they are placed.

Durability of a stone can be experimentally determined by subjecting the stone sample to disintegrating action of Sodium sulphate. Test specimens generally of 5cm side cubes, are dried perfectly and weighed. They are suspended in 14% solution of Sodium sulphate for 4 hours at 27 degree Celsius and then air dried and oven dried at 105 degree Celsius. The stone samples are subjected to 30 such cycles and loss of weight determined which gives a measure of the durability of the rock. Greater the loss in weight after these cycles, poorer is the durability of the stone.

**5.0 General characteristics of rocks:** In addition to these engineering and geological properties of rocks, there are certain other characteristics that may add value or otherwise to them. They are a) cost, b) colour.

**5.1 Cost:** It is an important consideration similar to engineering properties or geological character. A stone may be quite suitable for use in building construction on first two considerations, but still it may not find use for the simple reason that it is uneconomical. Cost of a building stone depends upon its availability, accessibility and workability. Good quality building stones are not available elsewhere.

Their transport from one place to another might be a very costly affair. The workability of a stone is understood the ease in effort and economy with which it can be extracted from its place of occurrence

and dressed to the desired dimensions and shapes. Harder and stronger rocks become costlier on these accounts.

**5.2 Color:** Color is the property of appearance and gets involved only where the stone is used in construction exposed to public view. For stones to be used in foundations or in situations where they are ultimately to be given covering, color of a rock has no relevance in its selection.

In the case of residential or official building, it becomes a property of major importance. The color of a rock is a geological character depending upon the type of rock and more precisely upon the composition of rock. Eg. Granites are light coloured, Basalt are dark, and Sandstone are lighter shades.

### **6.0 Modulus properties or Flexible strength or Elastic properties of rocks**

The elasticity of rocks indicates their deformation under loads. The deformation is recovered when loads are removed. It is determined in accordance with Hook's law which states that in elastic substances stress is directly proportional to strain.

It is expressed by the relationship

$$Q/E = E$$

Where Q = stress, E = Strain, E = Modulus of elasticity, It is also termed as young's modulus.

It is tested for rocks by loading test specimens usually a cylinder of L/D ratio 2, Under uniaxial compression and sometimes tension.

The axial deformation i.e. change in parallel to stress direction is determined at the application of each increment of load using strain gauges. This process of loading and determining the strain is continued till the specimen actually breaks.

That is the ultimate limit up to which the specimen could be deformed. The limit up to which it remains elastic i.e. recovers the original shape when the load is removed is reached slightly earlier.

Rocks are highly anisotropic so far as their elastic constants are concerned. They show all varieties ranging from perfectly elastic to practically inelastic. This depends on their composition, texture and structures. It is possible to broadly group the rocks into three categories, based on their Modulus of elasticity.

#### **6.1 Quasi elastic:**

These are rocks in which the stress-strain relationship is expressed by almost a straight-line till the point of failure. Such rocks include massive, densely packed uniformly structured varieties of igneous sedimentary and metamorphic groups such as Syenites, Diorites, Dolerites, gabbros, basalts and quartzites. Quasi elastic rocks show E values ranging from  $6 \times 10^5$  to the power of 5 to  $11 \times 10^5$  to the power of 5 kg/cm<sup>2</sup>.

#### **6.2 Semi elastic Rocks:**

Are coarse, grained slightly open packed with some porosity and very minor in any structure discontinuities. The semi elastic rock show E value range between  $4 \times 10^5$  to the power of 5 to  $6 \times 10^5$  to the power of 5 kg/cm<sup>2</sup>.



Coarse grained igneous rocks like granites, some massive compact sediments like Sandstones and dolomite may often show semi elastic properties. In this group the curve indicating the modulus of elasticity. Such a characteristic that is slope tends to decrease with increasing loads.

### **6.3 Non elastic Rocks :**

Are those in which stress strain relationship tends to break in two zones. A initial zone of steep slope followed by a curve of least slope. These are open textured coarse grained and rich in structural discontinuities. Values of E obtained with such rocks are commonly of the order of less than  $4 \times 10$  to the power of 5 kg/cm<sup>2</sup>.

### **7.0 Important Building stones**

Any type of rock that satisfies the above considerations may be used as a building stone. Granites, Sand stones, Limestones, Marbles and Quartzites and others like Dolerites, Syenites, Basalts and Gneisses etc. are some of them are not available, because they do not possess all the requisite properties.

Let us see one by one...

**7.1 Granites:** These are the most commonly used building stones of all the igneous rocks. They generally possess all the essential qualities of a good building stone showing very high crushing strength, low absorption values, least porosity, interlocking texture, variety of appealing colors, and susceptibility to perfect polish.

**Indian occurrence:** India has got good reserves of granite and granitic rocks. The archaic group of rocks of peninsular India are comprised chiefly of Gneisses and Granites

**7.2 Sandstone:** Massive sandstones consisting of closely interlocking and angular grains and free from structural defects find extensive use of building stones. Ferruginous and calcareous varieties should not be used for exterior work, especially in industrial towns. Argillaceous sandstones are generally weak in character. Massive varieties with siliceous cement possess sufficient strength and are easily workable.

**Indian occurrence:** India has got immense reserves of Sandstones fit for construction purposes. The most important supplies come from two important stratigraphical systems, namely the Vindhyan and Gondwana systems. Vindhyan sandstones are fine grained in texture and available in abundance in a variety of colours like white, cream and deep red and grey etc. They are easily quarried and economically workable.

These stones are available in a large area of the country for over 350,000 sq.kms extending from Bihar to Aravallis. Many buildings of Delhi, and Agra are built of these stones. No other rock formation of India possesses such assemblages of characters rendering it so eminently suitable for building or architectural work.

The gondwana formations of India have also yielded very good quality of sandstones. The fine grained sandstones of Cuttack (known as Athgarh sandstones) have been used most widely and famous temples of Jaganathpuri are built of them.

**7.3 Lime stones:** These sedimentary rocks are very extensively used as building stones. It is not due to their physical properties. It is due to the crushing strength. They may be weak showing values much below 300 kg/cm<sup>2</sup> or as strong as 1500 kg/cm<sup>2</sup> or even more. A similar variation in other property like absorption, specific gravity and porosity may be observed.

The use of limestones as facing stones even if they are sufficiently hard should be avoided in situations where

- a. The air is polluted with industrial gases
- b. The air from sea can approach them easily.

The reason for first precaution is that sulphuric acid vapours contained in the industrial gases react with calcium carbonate of limestone producing gypsum (calcium sulphate) crystals. This change involves an increase in the volume and results in disintegration of the surface layer of the rock. Salt crystals, may be formed from moist air from sea and cause dampness and disintegration of the stone.

**Indian occurrence:** Lime stones occur in many geological formations of this country. i. The cuddapah system outcropping in Andhra, Chennai, Delhi and Chattisgarh, ii) The Bijawar, Kondalite and Aravalli groups iii) The Vindhyan system of Madhya Pradesh, vi) The hill limestone, exposed at many places in northern India.

**7.4 Marbles:** These are metamorphic rocks that are used for ordinary structural work as well as for decorative purposes.

Marbles are varying in their texture, color and composition. Their absorption value is generally below 1% and normally they possess sufficient crushing strength.

They have been extensively used as decorative stones and this is because of their susceptibility to brilliant polish and beautiful colors.

**Indian occurrence:** Most important source of commercial marbles in the crystalline formations of Rajasthan. i) Makrana in Jodhpur-white and pink, ii) Kharva in Ajmer – green and yellow, iii) Kishengarh and Jaipur are famous for black and dense marbles.

**7.5 Slate:** It is another metamorphic rock, characterized by a perfect cleavage and because of this property it does not find any use in building stones except for paving roofing purposes.

**8.0 Conclusion :**

- It is a well-known fact that rocks play a vital role in constructing the structures which are destined to be strong, appealing and economical.
- All the factors which have been considered so far give a clear guideline for an engineer to choose the right type of naturally occurring rocks or stones to be used to build such structures.
- By choosing all the properties judiciously in conjunction with one another, it is possible to adhere to the safety regulations prescribed in building standards. A combination of laboratory testing of small samples, empirical analysis and field observations should be employed to determine the requisite engineering properties.
- Engineering properties of rocks are very essential properties to be determined in every project of civil engineering, construction engineering and structural engineering.