

# ENGINEERING BEHAVIOUR OF ROCKS AND SOILS (PROPERTIES)

## Abstract

Understanding the physical qualities of rocks and soils and how they relate to geological characteristics, general characteristics, and modulus properties of rocks and soils is the goal of this course. Geology offers organized knowledge of building materials and their characteristics. The stability of civil engineering structures including buildings, pavement constructions, dams, bridges, tunnels, and subway systems, among others, is influenced by the geological and geotechnical qualities of soils. It goes without saying that a proper understanding and assessment of the engineering properties of rocks and soils are essential to the safety, stability, and economy of engineering constructions. Thus, we explore the engineering behaviour (properties) of rocks and soils in this chapter.

**Keywords:** Rock, Soil, Hardness, Porosity, Permeability, Structure, Texture, Density, Fracture, Cleavage, Shear strength, Foundation, Stability etc.,

## Authors

### **Dr. G. Sivanatha Reddy**

Assistant Professor  
department of civil engineering JNTUA  
College of Engineering  
Pulivendula, an autonomous  
unit of JNT University in Anantapur.

### **B.Jahnavi**

B.Tech students  
department of civil engineering at the  
JNTUA  
College of Engineering Pulivendula  
(Autonomous), part of JNT University in  
Anantapur.

### **B.Supriya**

B.Tech students  
department of civil engineering at the  
JNTUA  
College of Engineering Pulivendula  
(Autonomous), part of JNT University in  
Anantapur.

## I. INTRODUCTION

The phrase "engineering behavior of rocks and soils" encompasses all the attributes of rocks and soils that hold significance in engineering applications, whether these materials have been extracted from their original geological formations or remain in their natural state in the ground. The initial category comprises all the characteristics that necessitate evaluation before selecting a rock for use as a construction material, road aggregate, or concrete component. The second set pertains to the inherent properties of a naturally occurring bedrock, which play a crucial role in determining its suitability as a construction site for a proposed engineering project.

Most construction materials come from naturally occurring rock and soil formations. However, modern ways using equipment and artificially created materials can replace it. As a result, one of engineering's goals is economy, which is why we should employ and utilize natural products.

To determine the essential engineering characteristics, it is advisable to employ a blend of laboratory examinations on small-scale samples, empirical assessments, and on-site observations. Rock properties can be classified into two primary categories: intact rock properties and rock mass properties. When it comes to evaluating the attributes of the entire rock, laboratory tests are performed on small samples, typically obtained from coring, natural outcrops, or sections exposed in existing excavations. Laboratory experiments are routinely conducted to establish common engineering parameters, including specific gravity, point load strength, compressive strength, tensile strength, shear strength, modulus, and durability.

The assessment of rock mass properties relies on a visual examination and description of the discontinuities present within the rock mass. To assess how these discontinuities will impact the behavior of the rock mass during the proposed construction, it is advisable to follow the approach outlined by the International Society of Rock Mechanics (ISRM 1978).

Rocks mechanically disintegrate or decompose chemically, resulting in the formation of soil. The physical, chemical, and engineering qualities of the soil that are used for the surface layers and subsurface that are affected by the strains from the loads exerted on it are very significant and necessary in civil engineering. Some of the most frequent foundation issues nationwide are settlement and sinking in the foundation. The weak bearing capacity of the soil, poorly compacted soil, variations in the amount of moisture in the soil, mature trees with roots, and other plants, as well as soil consolidation, are soil characteristics that cause foundations to settle. Therefore, determining the qualities of the soil is crucial in determining if it is suitable for building construction.

## II. ENGINEERING PROPERTIES OF ROCKS

Rocks are employed as construction materials in the vast majority of engineering applications. A rock that may be utilized safely as a rough unit or as a correctly cut and shaped (dressed) block, slab, column, or sheet in various situations in an engineering construction may be referred to as a building stone. The following physical characteristics of a rock are thought to be crucial for its usage as a building material.

- 1. Crushing Strength:** Crushing strength It also goes by the name of compressive strength of stone. It can be defined as the maximum force per unit area that a stone is capable of withstanding. The stone will fail if the force is greater than the compression strength.

Class	Description	Uniaxial compressive strength (Kg/cm <sup>2</sup> )
A	Very high strength (competency)	More than 2240
B	High strength (competency)	1120—2240
C	Medium strength (competency)	500—1120
D	Low strength (competency)	200—500
E	Very low strength (competency)	less than 200

- 2. Tensile Strength:** A rock's resistance to breaking is correlated with its tensile strength. It occurs after a certain level. Its strength is at that level. Either a direct or indirect determination may be made. the amount of tensile (pulling) force required to break a material. It is calculated as a force per square inch. By grasping the specimens at their ends, the direct technique would require complex ways to prevent bending while applying tensile stresses. An indirect technique is frequently used since precise measurements of tensile stresses are infrequently necessary.

The Brazilian test is the name of the indirect approach. It entails loading a test cylinder diametrically in order to develop tensile rupturing along the specimen's diametrical plane under the applied loads.

Increased loads are applied gradually until the cylinder breaks. Thus, the load P at rupture is known. The formula is used to compute transverse strength  $T_s$ .

$$T_s = 2P / \mu DL$$

D = diameter of the specimen

L = length of the specimen

- 3. Transverse Strength:** The ability of the stones to sustain bending stress is how it is characterized. In contexts where stones are often employed, such loads are incredibly uncommon. However, when a stone is meant to be used as a beam or lintel, its transverse strength is calculated as a rupture modulus using the relationship shown below.

$$R = 3WL / 2bd^2$$

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

This feature is practically assessed by loading transversely a bar-shaped test specimen, which is typically 20 cm long, 8 cm wide, and supported at both ends from below. It has been discovered that the transverse strength of stone is typically between one twentieth and one tenth of its compressive strength.

- 4. Porosity:** Porosity in rocks is a characteristic that arises from the arrangement, size, and shape of the rock's grains. It is quantified as the ratio of the aggregate volume of pore spaces to the overall volume of the rock sample, often expressed as a percentage. Low

porosity in rocks can be attributed to the presence of tightly interlocking crystals, angular grains with differing sizes, and a surplus of binding constituents.

On the other hand, if the cementing material is poorly characterized or is dispersed unevenly, the rock—which is formed of round or rounded grains—will be extremely porous. This is the case with sandstone.

Porosity plays a crucial role in the engineering assessment of rocks, especially in hydraulic structures. It characterizes the capacity of stones to absorb fluids, with higher porosity typically indicating lower density and, consequently, reduced compressive strength. Here are porosity values for several 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%), and Quartzite (0.1 to 0.5%).

- 5. Absorption Value:** It describes a stone's ability to absorb moisture when submerged in water for 72 hours or until fully saturated. It is typically represented as a percentage of the original dry mass weight. It might be acquired through the connection.

$$\text{Absorption value} = (W_s - W_o / W_o) * 100$$

- 6. Permeability:** Permeability, or a rock's capacity to transmit water, is an important consideration in construction materials. Some rocks, like sandstones and limestones, can exhibit high absorption rates, sometimes exceeding 10%. Employing such highly permeable rock types in construction, especially in most cases, would be highly undesirable. In cold and damp climates, the water present within the pores not only compromises the rock's strength but also makes it susceptible to frost-related damage.
- 7. Density:** It is described as a substance's weight in relation to its volume. However, when it comes to rock, it's not just the solid mineral substance that fully accounts for the specimen's overall volume. Rock may include pores or open holes that are either empty, partially or completely filled with water. As a result, there are three distinct forms of density in rocks. Dry density, bulk density, and saturated density are among them.

Four types of density measurements are essential in rock engineering:

- **Dry density:** This represents the weight per unit volume of a completely dried rock specimen, accounting for the volume of pore spaces within the rock.
- **Bulk density:** This measurement pertains to the weight per unit volume of a rock sample at its natural moisture content, with pores partially filled with water.
- **Saturated density:** This denotes the density of fully saturated rocks, representing the weight per unit volume of a rock with all its pores entirely filled with water. This type is also referred to as true density.
- **True density:** This is the weight per unit volume of the mineral matter making up the rock, excluding pores and water.

In most engineering calculations, bulk density is the parameter that is most frequently utilized.

Bulk density values in gram/cubic cm for some common building stones are granite-2.9, basalt-3.2., sandstone-2.2, and limestone-2.2 to 2.4.

### III. GEOLOGICAL PROPERTIES OF ROCKS

**1. Minerological Composition:** Quartz group, Feldspar group, Mica group, Pyroxene group, Amphibole group, etc. are the typical minerals that create rocks; consequently, silicate structures play a crucial part in the creation of rock as a source of strength. In terms of composition, Silica, Aluminium, Magnesium, Calcium, Phosphates, and Iron play crucial roles in the production of any rock.

Smaller units of the minerals make up rocks. Their characteristics are determined by the nature and make-up of these minerals. The strongest rocks in every way are those made primarily of silica ( $\text{SiO}_2$ ), especially when they are in free form.

Wide variations in their characteristics can be seen in carbonate rocks. Before a particular deposit of these rocks is suggested for use in any significant engineering building, it must be examined by taking random representative samples. When employing certain minerals in building stones, even in trace amounts, vigilance should be exercised. These minerals include chert, flint, mica, gypsum, sulphides, and tremolite. These reduce the rock's natural strength.

**2. Structure and Texture:** The size, form, and interrelationships of the mineral components within a rock are characterized by their texture. Large-scale feature development in the rock mass as a whole, however, is determined by structure. There are three different grain sizes in rocks: coarse, medium, and fine.

The arrangement of different mineral grains inside a rock type determines its design pattern. The rock type shows a spectrum of architectural patterns, from simple equally dispersed to weakly, moderately, and strongly foliated, and finally to heavily gneissic.

Compared to rocks with coarse grains and inequigranular textures, rocks with fine grains and equigranular textures make better building stones. The reaction that is supplied in the latter situations is complex and unquestionably weaker because distinct compounds frequently have a tendency to function as separate units under the applied pressures.

### IV. GEOTECHNICAL PROPERTIES OF SOILS

The main components of soil are minerals, which are created when parent material is worn or fragmented. In soil, both plants and animals play significant roles.

There are numerous ways in which soil composition and structure are altered by both plants and animals. Plants with roots use their roots to draw moisture and nutrients from the soil. Physical, chemical, and biological characteristics of soils define them. Additionally, soils provide excellent building materials for engineering projects. Another aspect of soils is its usage as a foundation, in buildings, and in industrial settings. Understanding the engineering qualities of soils and their importance is the goal of this module's study.

Black soils, Red soils, Laterite soils, Desert soils, Mountain soils, Alkaline soils, Marshy soils, Residual soils, Alluvial soils, Marine soils, Aeolian soils, Glacial soils, Clay soils, etc. are a few examples of the numerous types of soils found in our country. {10}

1. **Cohesion:** A material can't rupture or shear because of internal molecular attraction. Cohesion in fine-grained soils is the result of water films holding the individual particles of the soil mass together.

Cohesion is a characteristic of fine-grained soil with particles smaller than 0.002 millimeters. As moisture content rises, a soil's cohesiveness reduces. Well-compacted clays have stronger cohesion, which is unaffected by the external strain.

Standard compaction tests are challenging to conduct on cohesionless soils (also known as soils without any particles). Vibration application is the most efficient technique for compaction. Watering is a further tactic. The soil grains occupy a more stable position due to the seepage force of water that percolates through a cohesionless soil. However, using this procedure calls for a lot of water. They can be compacted either in a dry condition or in a saturated state to attain the maximum dry density. {1}

2. **Angle Of Internal Friction:** The angle of internal friction characterizes the resistance of soil mass grain particles to sliding. It is commonly believed that the magnitude of the angle of internal friction varies primarily with the density of the particles, which relates to how tightly they are packed, rather than with the normal pressure.

When comparing soils exposed to higher normal stresses with those exposed to lower normal stresses, the former will exhibit lower moisture contents and higher bulk densities at the point of failure. This can potentially lead to alterations in the angle of internal friction.

For clay, the actual internal friction angle is generally nonzero and can even reach up to 26 degrees. In granular soils, the angle of internal friction typically falls within the range of 28 to 50 degrees.

3. **Capillarity:** It is the ability of the soil to transport moisture around despite gravity's pull. Soil pores allow water to rise due to capillary attraction.

The greatest theoretical height of capillary rise is determined by the pressure that tends to push water into the soil; this force increases as the size of the soil particle decreases.

The capillary rise in wet soil can reach four or five times higher levels than in dry soil. The capillary rise of fine sand and soils is up to 1.2 m, that of coarse sand and gravel is up to 30 cm, and that of dry sand is very low. The capillary rise of coarse gravel is negligible. Although clays can have capillary increases of up to 0.9 or 1.2 m, their pure form is of very little utility. "1"

4. **Permeability:** The rate at which water flows through a soil under the influence of a hydraulic gradient is known as its permeability. Percolation is the term for the movement of moisture through the pores or gaps in the soil.

Pervious or permeable soils are those that are sufficiently porous to allow percolation to take place.

Which do not allow water to get through are referred to as "impervious" or "impermeable." The head of water directly relates to the flow rate.

Rather of being a property of particular soil particles, permeability is a property of the soil mass. In general, cohesive soil has extremely little permeability. Permeability is important to understand because it affects seepage, drainage, ground water, and how quickly structures slump in saturated soils.

**5. Specific Gravity:** Specific Gravity is defined as the ratio of the given volume of soil solids at a given temperature to the weight of equal volume of distilled water at the temperature. This test was conducted according to IS: 2720 Part-3-1980.

**6. Atterberg's Limits:**

- **Liquid Limit:** It is the amount of water in soil that corresponds to the arbitrary boundary between the soil's liquid and plastic states of consistency. According to IS, the liquid limit test was carried out.: 2720 Part-4-1970.
- **Plastic Limit:** It is the amount of water in the soil that corresponds to the arbitrary boundary between the plastic and semi-solid states of consistency. The plastic limit test was carried out on soil mixes that were run through 425 $\mu$  sieves in accordance with IS: 2720 Part-5- 1970. {2}

**7. Standard Proctor Compaction Test:** This test's goal is to ascertain the link between moisture content and dry density. After that, the soil's ideal moisture content (OMC) and maximum dry density (MDD) were calculated using the Standard Proctors Test. According to IS: 2720 Part-7-1980, the soil sample for the Proctor's compaction test was prepared. {2}

**8. Permeability Test:** Permeability of a soil is defined as the simplicity with which a fluid (often water) can pass through it. The rate of water flow across a unit cross-sectional area while flowing up a unit hydraulic gradient is what this term refers to. The head causing flow through the specimen stays constant during the test in a constant head permeameter. The IS: 2720 Part-17-1986 constant head permeability test for soils was carried out. {2}

**9. Laboratory Testing Of Soil And Rock:** An essential component of a geotechnical study is laboratory testing. The ultimate goal of laboratory testing is to use repeatable procedures to improve the visual observations and field testing carried out as part of the subsurface field exploration program and to ascertain how the soil or rock will behave under the conditions imposed by Engineering Properties of Soil and Rock. The optimum laboratory program will offer enough information to finish a cost-effective design without requiring too many experiments or spending too much money. Testing might range from straightforward soil classification tests to intricate strength and deformation tests, depending on the project's problems. {10}

## V. APPLICATIONS OF ROCKS AND SOILS PROPERTIES

Crushed or fractured rocks serve as essential aggregates in road and concrete construction. Similarly, these rocks can be employed to create railway ballast. Stone screens can naturally substitute sand in various applications. Limestone stands as the predominant component utilized in the production of cement and lime concrete.

Geotechnical design objectives start with the establishment or definition of the geological strata at the site in question, from which soil and rock characteristics are derived. Consequently, the geotechnical design property assessment and ultimate selection will primarily revolve around the specific geological strata identified at the project location. A geological strata is characterized by sharing the same geological depositional history, stress history, and degree of disturbance. Moreover, the stratum typically maintains uniformity in terms of density, source material, stress history, hydrogeology, and macrostructure throughout. It is imperative that the characteristics of each stratum align with its geological depositional, stress, and macrostructural history.

Common engineering qualities including specific gravity, point load strength, compressive strength, tensile strength, shear strength, modulus, and durability are often determined by laboratory experiments. Visual inspection and description of discontinuities within the rock mass are used to determine the characteristics of the rock mass.

When making the final property selection, it is crucial to account for the variability discussed in the previous section. This involves an assessment of the potential impact of such variability, or uncertainty, on the safety level of the design, depending on the extent of estimated or measured variability. If this uncertainty is expected to significantly affect the outcome, parametric analysis should be conducted, or additional data may be collected to help mitigate the uncertainty. However, it is not feasible to statistically combine all of these data sources to determine the most probable property value, as the data may include measurements from laboratory tests, field tests, performance records (e.g., from retrospective analyses), and previous experiences with the relevant geological units.

The ultimate assessment and determination of the design property necessitate engineering judgment grounded in expertise, with parametric analysis conducted when deemed essential. Subsequently, a decision must be made regarding whether the selected final design value should represent the interpreted average value of the property or a value positioned midway between that average and the most cautious property estimate. This decision hinges on the imperative consideration of design safety.

## VI. CONCLUSIONS

Any material utilized in the building industry, whether it be natural, geological, man-made, or otherwise, must meet two fundamental criteria, namely strength and economy. The texture and mineral makeup of rocks contribute to their strength, although weathering has introduced some weaknesses. In comparison to rocks isolated from deeper parts of the earth's surface, those close or at the earth's surface are more likely to be subject to weathering. Because rocks are natural materials, their physical and mechanical characteristics can vary greatly.



- This course explores the fundamentals of geological and geotechnical knowledge applied to Civil engineering structures.
- To educate civil engineering students in rock engineering concepts and approaches in the Planning and design of Engineering Structures with construction materials.
- Have knowledge of design and construction to safely control rock and soil for engineering behaviour.
- It is a well-known fact that rocks plays a vital role in constructing the structures which are destined to be strong, appealing and economical.
  
- Engineering properties of rocks are very essential properties to be determined in every project of civil engineering, construction engineering and structural engineering.

### Outcomes Of The Chapter:

- Learn about different physical, mechanical and engineering properties of rocks to be used for different construction purposes.
- Understand the relationship between rocks and Soils Engineering structures.
- Understand Rocks and Soils properties, as they influence on civil engineering works.
- An ability to identify the various properties act on engineering problems.
- An ability to recognition the various properties act on engineering structures for Safety, Stability and Economy.

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