*TITLE OF THE CHAPTER:*

**ENGINEERING BEHAVIOUR (PROPERTIES) OF ROCKS AND SOILS**

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**Abstract**:

*The aim of this lesson is to understand the physical properties of rocks and soils and their determination of geological characteristics, general characteristics and modulus properties of rocks and soils. Geology provides a systematic knowledge of construction materials and their properties. Geological and geotechnical properties of soils influence the stability of civil engineering structures like buildings, pavement constructions, Dams, bridges, Tunnels and subway systems etc., Obviously, the safety, Stability and economy of an Engineering structures are greatly depending up on the proper understanding and determination of the engineering properties of rocks and soils. Hence, in this chapter we discuss about engineering Behaviour (properties) of rocks and soils.*

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

**1. 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.

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.

Soils are formed due to mechanical disintegration or chemical decomposition of rocks. Soil characteristics are very important and essential in civil engineering and dependent on the physical, chemical and engineering characteristics employment for surface layers and subsurface that is affected by the stresses from the loads imposed on it. Settlement and sinking in foundation are some of the most common foundation problems experienced across the country. Soil conditions that cause foundation to settle are weak bearing capacity of soil, poorly compacted soil, changes in the level of moisture in the soil, mature trees with roots and other vegetation and soil consolidation. Therefore, determination of soil properties is the most important factor to check the suitability of the soil for construction of buildings.

**2. 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

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.

Class Description Uniaxial compressive strength (Kg/cm2

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. 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 calledthe 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 Ts is calculated by using the formula

TS=2P/µDL

D = diameter of the specimen

L = length of the specimen

2.3. 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=3WL/2bd2

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 property is determined practically by loading transversely a bar shaped test specimen generallyof 20cmsx8cmx8cm dimension and is supported at ends from below. It has been found that in stone, the transverse strength is generally 1/20th to 1/10 th of their compressive strengths.

2.4. 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 it 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%. {5}

2.5. 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 mass .It may be obtained from the relationship.

Absorption value = (WS-WO/WO)\*100

2.6. 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 verities 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. {5}

2.7. 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 area) Dry density, b) bulk density and c) saturated density.

* 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.
* 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.
* 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. Itis the weight per unit volume of the mineral matter (without pores and water) of which a rock s 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-2.9, basalt-3.2., sandstone-2.2, and limestone-2.2 to 2.4.

**3. GEOLOGICAL PROPERTIES OF ROCKS**

3.1. MINEROLOGICAL 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 (SiO2) 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 quantites 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.

3.2. STRUCTURE AND TEXTURE:

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.

It is the mutual arrangement of various mineral grains that imparts design pattern to the rock type. From simple evenly distributed to weakly, moderately and strongly foliated and then to strongly gneissic, the rock type exhibits a range of design patterns.

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 complexes and certainly weaker character.

**4. GEOTECHNICAL PROPERTIES OF SOILS:**

Soil is composed primarily of minerals which are produced from parent material that is weathered or broken into small pieces. Plants and animals have important roles to play in soil.

Both plants and animals change the composition and structure of soil in many different ways. Plants with roots obtain nutrients and moisture from soil through their roots. Soils are characterised by their physical, chemical and biological properties. In addition, soils are good materials used in engineering projects. Soil foundation, use of soil in constructions and industrial applications is another dimension of soils. The objective of studying this module is to know about the engineering properties of soils and their significances.

Generally various types of soils in our geographical country i.e. 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. {10}

4.1. COHESION:

It is the internal molecular attraction which resists the rupture or shear of a material. Cohesion is derived in the fine grained soils from the water films which bind together the individual particles in the soil mass.

Cohesion is the property of the fine grained soil with particle size below 0.002 mm. cohesion of a soil decreases as the moisture content increases. Cohesion is greater in well compacted clays and it is independent of the external load applied.

For cohesionless soils (or soils without any fines), the standard compaction tests are difficult to perform. For compaction, application of vibrations is the most effective method. Watering is another method. The seepage force of water percolating through a cohesionless soil makes the soil grains occupy a more stable position. However a large quantity of water is required in this method. To achieve maximum dry density, they can be compacted either in a dry state or in a saturated state. {1}

4.2. ANGLE OF INTERNAL FRICTION:

The resistance in sliding of grain particles of a soil mass depends upon the angle of internal friction. It is usually considered that the value of the angle of internal friction is almost independent of the normal pressure but varies with the degree of packing of the particles, i.e. with the density.

The soils subjected to the higher normal stresses will have lower moisture contents and higher bulk densities at failure than those subjected to lower normal stresses and the angle of internal friction may thus change. The true angle of internal friction of clay is seldom zero and may be as much as260.The angle of internal friction fro granular soils may vary in between 280 to 500. {1}

4.3. CAPILLARITY:

It is the ability of soil to transmit moisture in all directions regardless of any gravitational force. Water rises up through soil pores due to capillary attraction.

The maximum theoretical height of capillary rise depends upon the pressure which tends to force the water into the soil, and this force increases as the size of the soil particles decreases.

The capillary rise in a soil when wet may equal as much as 4 to 5 times the height of capillary rise in the same soil when dry. Coarse gravel has no capillary rise; coarse sand has up to 30 cm; fine sand and soils have capillary rise up to 1.2 m but dry sand have very little capillarity. Clays may have capillary rise up to 0.9 to 1.2 m but pure clays have very low value. {1}

4.4. PERMEABILITY:

Permeability of a soil is the rate at which water flows through it under action of hydraulic gradient. The passage of moisture through the inter-spaces or pores of the soil is called ‘percolation’.

Soils having porous enough for percolation to occur are termed ‘pervious’ or ‘permeable’.

which do not permit the passage of water are termed ‘impervious’ or ‘impermeable’. The rate of flow is directly proportional to the head of water.

Permeability is a property of soil mass and not of individual particles. The permeability of cohesive soil is, in general, very small. Knowledge of permeability is required not only for seepage, drainage and ground water problems but also for the rate of settlement of structures on saturated soils.

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.

ATTERBERG’S LIMITS

1. Liquid Limit: It is the water content corresponding to the arbitrary limit between liquid and plastic state of consistency of soil. The liquid limit test was conducted according to IS: 2720 Part-4-1970.

2. Plastic Limit: It is the water content corresponding to the arbitrary limit between plastic and semi-solid states of the consistency of the soil. The plastic limit test was conducted on soil-mixtures passing through 425µ sieves as per IS: 2720 Part-5- 1970. {2}

STANDARD PROCTOR COMPACTION TEST:

The objective of this test is to determine the relationship between water content and dry density and then to determine the Optimum Moisture Content (OMC) and the corresponding Maximum Dry Density (MDD) of the soil were determined using Standard proctors test. Preparation of soil sample for proctor’s compaction test was done as per IS: 2720 Part-7-1980. {2}

PERMEABILITY TEST

Permeability of a soil, the ease with which a fluid (usually water) flows through a soil, is expressed in terms of permeability. It is equal to rate of flow of water through a unit cross-sectional area under a unit hydraulic gradient. In the constant head permeaometer, the head causing flow through the specimen remains constant throughout the test. Constant head permeability test for soils was conducted according to IS: 2720 Part-17-1986. {2}

LABORATORY TESTING OF SOIL AND ROCK:

Laboratory testing is a fundamental element of a geotechnical investigation. The ultimate purpose of laboratory testing is to utilize repeatable procedures to refine the visual observations and field testing conducted as part of the subsurface field exploration program, and to determine how the soil or rock will behave under Engineering Properties of Soil and Rock imposed conditions. The ideal laboratory program will provide sufficient data to complete an economical design without incurring excessive tests and costs. Depending on the project issues, testing may range from simple soil classification testing to complex strength and deformation testing. {10}

**5. APPLICATIONS OF ROCKS AND SOILS PROPERTIES:**

Broken or crushed rocks are used as aggregates in concrete, in road constructions. Broken or crushed rocks are also used as railway ballast. Stone screenings are used as a natural substitute for sand. Limestone is the basic material for the manufacture of lime concrete and cement.

The development of soil and rock properties for geotechnical design purposes begins with developing/defining the geologic strata present at the site in question. Therefore, the focus of geotechnical design property assessment and final selection shall be on the individual geologic strata identified at the project site. A geologic stratum is characterized as having the same geologic depositional history, stress history, and degree of disturbance, and generally has similarities throughout the stratum in terms of density, source material, stress history, hydrogeology, and macrostructure. The properties of each stratum shall be consistent with the stratum’s geologic depositional and stress history, and macrostructure.

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.

**Final Property Selection Recognizing** the variability discussed in the previous section, depending on the amount of variability estimated or measured the potential impact of that variability (or uncertainty) on the level of safety in the design shall be assessed. If the impact of this uncertainty is likely to be significant, parametric analyses shall be conducted, or more data could be obtained to help reduce the uncertainty. Since the sources of data that could be considered may include measured laboratory data, field test data, performance data (i.e., from back-analyses), and other previous experience with the geologic unit(s) in question, it will not be possible to statistically combine all this data together to determine the most likely property value. Engineering judgment based on experience, combined with parametric analyses as needed, will be needed to make this final assessment and design property determination. At that point, a decision must be made as to whether the final design value selected should reflect the interpreted average value for the property, or a value that is somewhere between the most likely average value and the most conservative estimate of the property. However, the desire for design safety must be balanced with the cost effectiveness and constructability of the design.

**Conclusions:**

Any material natural, geological, manmade or otherwise, used in construction industry must satisfy two fundamental properties i.e. strength and economy. The strength of rocks comes from its texture, mineral composition and the weakness crept in due to alteration caused by weathering. Rocks sequestered from or near the earth surface are more likely to be affected by weathering as compared to rocks sequestered from deeper part of the earth surface. As rocks are not engineered materials hence their physical and mechanical properties can show extreme variations.

* 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 and mechanical 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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