Engineering Geology

Contents

Chapter 1 Engineering and Index Properties

In the field of engineering, the term "engineering property" refers to a broad concept that encompasses the discussion and practical determination of all properties of rocks and soils that are relevant to their engineering applications, whether they are extracted from their natural location or remain in their in-situ conditions.

Index properties are those properties of soils that are not of primary interest to geotechnical engineers but can serve as indicators of the soil's engineering properties.The particle size and relative density are the main index properties of coarse-grained soils. For fine-grained soils, Atterberg's limit and consistency are the primary index properties.

Engineering Properties of Rocks

• Naturally occurring rocks, including igneous, sedimentary, and metamorphic types, exhibit diverse physical properties and mineralogical compositions.

• In addition to their use as construction materials, rocks form the foundation of civil engineering projects such as dams, bridges, and tunnels.

• The strength characteristics of rocks, such as compressive, tensile, shearing, and abrasive strengths, are crucial to consider.

• The strength of a rock refers to its ability to withstand the load placed on it, which depends on factors such as hardness, density, texture, and structure.

• Compressive strength, also known as crushing strength, is the maximum force per unit area that a rock can withstand without rupturing.

• Any load beyond the compressive strength of the rock will result in failure or rupture of the material.

Sample no.	Rock type	Compressive strength (Mpa)	Abrasivity (%)
1	Shale	102.05	15.2
2	Dolomite	110.70	16.7
3	Sand stone	125.60	17.3
4	Limestone	149.92	18.8
5	Hematite	155.72	19.5
6	Dolerite	162.60	20.1
7	Soda granite	179.20	20.5
8	Black granite	187.72	21.4
9	Basalt	199.80	22.5
10	Gabbros	223.50	23.8

Table 1: Compressive strength of various rock types

• Tensile strength refers to the maximum stress that a rock material can withstand before breaking due to tension.

• Most rocks exhibit low tensile strength because of the presence of microcracks that develop during rock formation or deformation.

• The most common method for determining tensile strength is through the Brazilian Test.

• Typically, the tensile strength of rocks is about 1/10 to 1/8 of their compressive strength.

• In design, rocks should be subjected to minimal tensile stress to avoid failure.

• Rocks such as Granite, Basalt, and Quartzite are known for their good tensile strength.

• Shear strength describes the ability of rocks to resist deformation due to shear stress, which is accomplished through internal mechanisms like cohesion and internal friction.

• Cohesion measures the internal bonding of rock material, while internal friction is the result of contact between particles and is defined by the internal friction angle.

• Young's modulus is the modulus of elasticity that measures the stiffness of rocks.

• For small strains, Young's modulus is defined as the ratio of the change in stress to the strain.

• Rocks generally fail at small strains, typically around 0.2 to 0.4% under uniaxial compression.

• Brittle rocks, such as crystalline rocks, have low strain at failure, while soft rocks like shale and mudstone have relatively higher strain at failure.

• Rocks can exhibit either brittle or ductile behavior after the peak.

Engineering Aspects of Igneous and Metamorphic Rocks

• In their unaltered state, plutonic igneous rocks are generally strong and durable enough to meet most engineering requirements.

• The weathered products of plutonic rocks typically contain a significant amount of clay, although granitic rocks may also be porous with permeability comparable to medium-grained sand.

• The nature of weathering is affected by the climatic conditions in which it occurs. Granite, for instance, undergoes a significant reduction in strength upon weathering.

	Point load strength index (MPa)	Equivalent uniaxial compressive strength (MPa)
Extremely high strength	Over 10	Over 160
Very high strength	3–10	50–160
High strength	1–3	15–60
Medium strength	0.3–1	5–16
Low strength	0.1–0.3	1.6–5
Very low strength	0.03–0.1	0.5–1.6
Extremely low strength	Less than 0.03	Less than 0.5

Table 1: Point load strength classification

Foundation engineering may not encounter issues with older volcanic deposits, as ancient lavas can have strengths exceeding 200 MPa. However, certain basalts and dolerites can rapidly weather and break down, a phenomenon called **slaking**.

Smectite clays that swell and shrink during hydration and dehydration can cause or worsen the breakdown of these rocks. Repeated hydration and dehydration can mechanically disrupt small parts of the rock near its exposed surface, leading to flaking and surface cracking. Basalt containing 10%-20% of secondary montmorillonite is particularly prone to degradation. Some basalt disintegrates through crazing, which involves extensive micro fracturing that expands over time and transforms the rock into gravel-sized fragments.

Pyroclastic rocks can create highly variable ground conditions due to differences in strength, durability, and permeability, which depend on the degree of induration. While some agglomerates can support heavy loads and have low permeability, others are unsuitable for construction.

Slate, phyllite, and schist weather slowly, but regional metamorphism can cause extensive folding and deformation, leading to fractures and variable quality. Some schists, slates, and phyllites may offer excellent foundations for heavy structures, while others may be too poor regardless of their deformation or weathering.

The engineering performance of gneiss is similar to granite, with some gneisses being strongly foliated. The strength of rocks reduces with increasing weathering. Fresh, thermally metamorphosed rocks like quartzite and hornfels have high strength and provide stable ground conditions. Marble shares the advantages and disadvantages of other carbonate rocks.

Engineering Aspects of Sedimentary Rocks

• Sandstones exhibit a wide range of geo-mechanical properties due to differences in petrographical characteristics such as grain size distribution.

• Particle size measures do not have an impact on the compressive or indirect tensile strength of sandstones.

• The unconfined compressive strength of sandstone increases with increasing quartz content, while poorly cemented sandstones can have crushing strengths of less than 3.5 MPa.

• The density of sandstone generally increases with depth, resulting in decreased porosity and increased compressive strength.

• Sandstone strength is negatively affected by porosity, with higher porosity resulting in lower strength.

• Sandstones with high clay mineral or rock fragment content may experience significant strength loss when wet due to softening and expansion of clay minerals.

• Indirect tensile strength of sandstones, as measured by the point load test, tends to be less than one-fifteenth of their unconfined compressive strength.

• While sandstones are composed mainly of quartz grains that are highly resistant to weathering, other minerals present in lesser amounts may be vulnerable, such as feldspars becoming kaolinized.

• Mud rocks containing over 50% clastic grains of <60 mm size have geo-mechanical behavior that is dominated by the fine material, leading to weak strength and potential durability issues for engineering projects.

• Clay shales with high swelling properties due to the absorption of free water by certain clay minerals, such as montmorillonite, can cause structural damage to engineering structures.

• Cemented shales are stronger and more durable than compacted shales, with weak compaction shales having low cohesion and angle of friction.

• Sulphur compounds in shales and mudstones can cause structural damage due to expansion in volume caused by oxidation of minerals such as pyrite and marcasite to anhydrous sulphates.

• Durability of mud rocks is influenced by degree of induration, fracturing, lamination, grain size distribution, and mineralogical composition, particularly the nature of the clay mineral fraction.

• Engineering properties of carbonate sediments are influenced by grain size and post-depositional changes leading to induration.

• Porosity has a significant influence on the unconfined compressive strength of carbonate rocks, with increasing porosity resulting in decreasing strength.

• Carboniferous Limestone is generally very strong, while the Great Oolite, Jurassic, is only moderately strong.

• Dolomitized limestone has a lower compressive strength than non-dolomitized limestone due to increased porosity.

• On loading, the weakened cement between particles and reorientation of intact aggregations can cause fracture and loss of bonding, reducing the volume of voids.

• Anhydrite has high dry density and strength, while gypsum has moderate dry density and variable strength.

• Plastic deformation occurs earlier during loading in gypsum than in anhydrite, with Young's modulus being generally higher for anhydrite.

• Alabaster, the finest-grained material, showed the highest strength in both the point load test and unconfined compression test.

Engineering and Index Properties of Soils

Soils have several important engineering properties, including permeability, shear strength, and compressibility. Permeability refers to how easily water can flow through the soil's pores and is important for calculating seepage discharge in earth dams and other hydraulic structures.

Knowledge of permeability is also necessary for solving many engineering problems, such as predicting building settlement, estimating well yield, and preventing piping in filters. The hydraulic stability of soil masses is controlled by permeability, which varies greatly depending on soil type: gravels are highly permeable while stiff clays are the least permeable.

The Coefficient of Permeability (k) is a measure of average flow velocity under unit hydraulic gradient, with units ranging from mm/sec to m/day.

For example, clean gravel has very good drainage properties with k ranging from 10+1 to 10+2 mm/sec, while silty clay and clay have very poor drainage with k ranging from 10-8 to 10-5. Shear strength is the ability of soil to bear stresses without failure, and it is important for calculating factor of safety of earth slopes, determining bearing capacity of soils, and estimating lateral earth pressure on retaining structures.

Compressibility, on the other hand, deals with how much the soil's pores can change in volume under compressive loads. Compressibility characteristics are needed for computing settlements of structures founded on soils.

The Casagrande system, developed in 1948, is one of the earliest engineering classifications of soil and distinguishes between coarse-grained and fine-grained soils based on particle size.

Main soil type		Prefix
Coarse-grained soils	Gravel	G
	Sand	S
Fine-grained soils	Silt	M
	Clay	C
	Organic silts and clays	O
Fibrous soils	Peat	Pt
Subdivisions		**Suffix**
For coarse-grainedsoils	Well graded, with little or no fines	W
	Well graded with suitable clay binder	C
	Uniformly graded with little or no fines	U
	Poorly graded with little or no fines	P
	Poorly graded with appreciable fines or well graded with excess fines	F
For fine-grained soils	Low compressibility (plasticity)	L
	Medium compressibility (plasticity)	I
	High compressibility (plasticity)	H

Table 4: Symbols used in the Casagrande soil classification

Coarse-grained soils are classified into two principal types: gravels and sands. Well-graded soils have a particle size distribution that covers a wide range without any excess or deficiency in specific sizes.

Uniformly graded soils have a particle size distribution that covers a very limited range of particle sizes. Poorly graded soils have a particle size distribution that contains an excess of some particle sizes and a deficiency of others.

Constituents and Consistency of Soils

• Soil consists of two main components: solid grains and voids.
• The solid grains form the structure of the soil mass.
• Voids in the soil can be filled with air, water, or a combination of both.
• A partially saturated soil has voids filled with both air and water.
• A fully saturated soil has voids completely filled with water.
• In a dry soil, the voids are filled only with air.

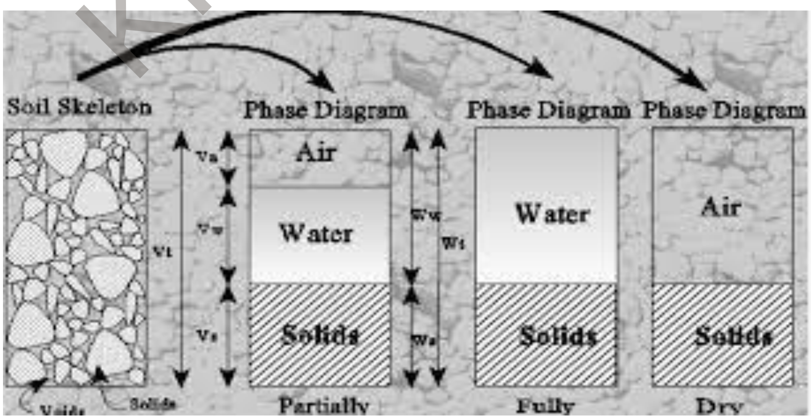

FIGURE1: Phase diagrams for dry soil, saturated soil and partially saturated soil

• In soil mechanics, consistency refers to the firmness of cohesive soils.
• Natural deposits of cohesive soils are typically described as very soft, stiff, very stiff, or hard, depending on their consistency.
• Consistency can be quantified using Atterberg limits and unconfined compressive strengths.

• In 1911, Swedish scientist Atterberg proposed a series of tests to determine the properties of cohesive soils and their consistency.
• Atterberg tests identify the range of plasticity, which is the ability of cohesive soils to change shape without rupturing, as well as other states.
• The water content at which the transition from one state to another occurs is called the Atterberg limit, and the tests that measure it are known as Atterberg limit tests.

States	**Limit**	**Consistency**	**Volume change**
Liquid		Very soft	↑
………. w_l	Liquid limit	Soft	
Plastic		stiff	Decrease in volume
…………..w_p	Plastic limit	Very stiff	
Semi solid			
……………..w_s	Shrinkage limit	Extremely stiff	↓
Solid		hard	Constant volume

Table5: Different states and consistency of soils with Atterberg limits

• The Liquid limit wl is the water content at which the transition state from the liquid state to a plastic state occurs. At this stage, all soils exhibit a certain small shear strength.
• The Plastic limit wp is the water content at which the transition from the plastic state to the semisolid state occurs. At this state, the soil rolled into threads of about 3mm diameter just crumbles.
• The Plasticity Index, Ip, is the range of water content between the liquid and plastic limits, which is an important measure of plastic behaviour. Ip = wl-wp.
• The Plasticity Index indicates the degree of plasticity of a soil. The greater the difference between liquid and plastic limits, the greater the plasticity of the soil.
• A cohesion less soil has a zero plasticity index. Highly plastic fat clays have a high plasticity index.
• Soils with organic content have low plasticity indices in comparison to soils with high liquid limits.

Plasticity index	**Plasticity**
0	Non-plastic
< 7	Low plastic
7-17	Medium plastic
>17	Highly plastic

Table6: Soil classification according to Plasticity Index

• The plasticity index and liquid limit are important factors that aid in understanding the consistency or plasticity of clay.
• Shearing strength is constant at liquid limits but varies at plastic limits for all clays.

• A high plastic clay (fat clay) has a higher shearing strength at the plastic limit, and the threads at this limit are difficult to roll.
• A lean clay can be easily rolled at the plastic limit and therefore has low shearing strength.
• In cases where the liquid limit is lower than the plastic limit, a negative plasticity index is obtained.
• The liquidity index (LI) is used to scale the natural water content of a soil sample to the limits. It can be calculated as the ratio of the difference between the natural water content, plastic limit, and liquid limit: LI=(W-PL)/(LL-PL), where W is the natural water content..

Different Tests

Laboratory tests are necessary to assess the engineering properties of rocks. The Uniaxial Compressive Strength (UCS) of rocks can be determined using both direct and indirect methods. Universal Testing Machine (UTM) is employed for testing the UCS.

The direct method involves placing NX-size cores, with a length-diameter ratio of 2.0 to 2.5, directly in contact with the steel plates of the UTM machine. The sample is loaded until it fails, and the compressive strength (σc) is calculated by ISRM (1981) using the formula: $\sigma c = P/A$, kgf/cm2, where σc is the uniaxial compressive strength of the rock in kgf/cm2, P is the load at failure in kgf, and A is the area of the cross-section of the specimen in cm2.

However, factors such as mineralogy, grain orientation, porosity, and external factors such as environment, specimen geometry, and rate of loading can affect the UCS of rocks. It should also be noted that UCS is a destructive testing method for rocks.

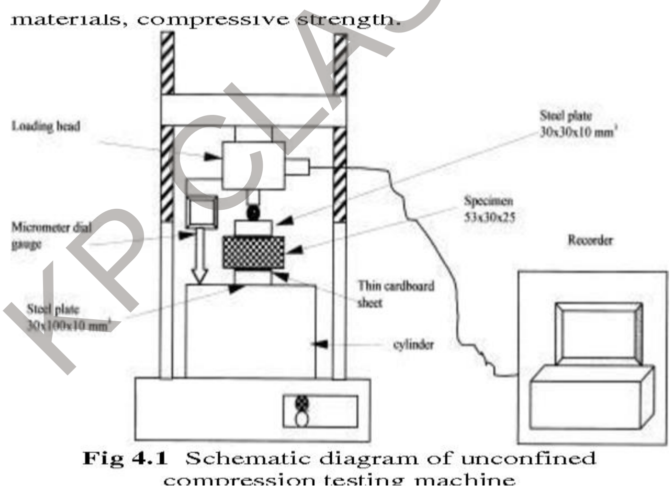

Figure 2: Schematic diagram of UCS testing machine

• The Schmidt Hammer Test is a non-destructive indirect method used to determine the uniaxial compressive strength of rocks based on the change in density caused by compression.
• The test may face difficulty when dealing with fractured and closely jointed rocks.
• The N-type hammer is commonly used in the Schmidt Hammer Test, which has an impact energy of 2.207Nm.

• Limitations of the Schmidt Hammer Test include the difficulty in testing highly fractured and closely jointed rocks, as well as its inapplicability to extremely weak rocks and non-homogeneous rocks.

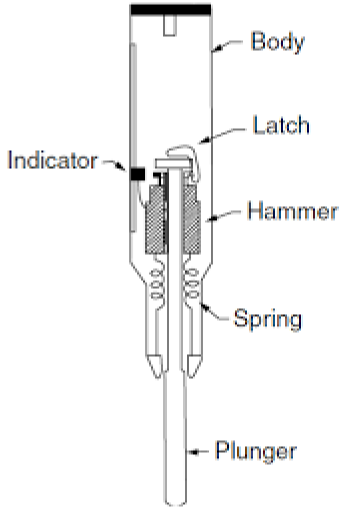

Figure3: Schematic diagram of a Schmidt Hammer

- **Point Load Test** is another **indirect method** for determining the UCS in rocks.

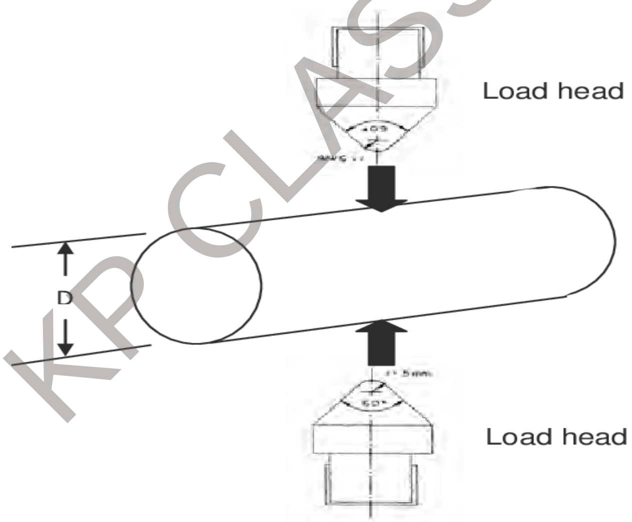

Figure4: Point load test on drilled core rocks.

- **Point load strength index, I_S** = **P/D2**, kgf/cm2. Here, Is= point load strength index, P= failure load (kgf), D=distance between the conical tips after failure of rocks (cm).
- **According to Bienianski (1975),** the **UCS** from **Is** for **irregular specimen, qc or σc = 22 × Is** and for **regular specimen**, **qc or σc = 24 × Is.**
- **Tensile strength** of rock was calculated as per **ISRM (1978),** using the formula: $\boldsymbol{\sigma t = 2P/\pi dt}$ kgf/cm2, (where, $\boldsymbol{\sigma t}$ $= tensile\ strength, \boldsymbol{d} = diameter\ pf\ specimen\ disc, \boldsymbol{t} = thickness\ of\ specimen, \boldsymbol{p} = failure\ load$) As per ISRM, thickness, t = 1.2-1.5 times of tensile crack.