PHYSICO-MECHANICAL PROPERTIES OF ROCKS

LECTURE 2

Contents

2.1. INTRODUCTION

Strength and deformation properties play a very important role while designing structures in rocks. Determining the appropriate strength parameters are important as the design should be in accordance with the type of structures, loading characteristics and characteristics of rocks in the bearing strata. The important design aspects and the shearing failure possibilities are to be checked before any superstructure or heavy temporary load allowed on the bearing strata. Appropriate tests to determine various strength properties for rock need to be planned before any final design.

In geotechnical engineering prediction of performance involves determination of properties of soil/rock and rock mass through laboratory or field tests. Laboratory tests have the limitations like variability and sample disturbance. Also, testing is done on small specimens and extrapolation of the measured properties for the entire site is often challenging. In contrast, insitu test provide the response of a larger mass under natural insitu condition. They provide more economical and rapid estimates of properties. The limitation includes poorly defined boundary condition, non-uniform and high strain rates imposed during testing and inability to control drainage condition etc. Despite various limitations both laboratory as well as insitu tests are essential part of any geotechnical design. The Figure 2.1 depicts the typical disturbed rock mass found at site. A typical rock mass found in the site which mostly comes with joints & discontinuities, fractures, fissures and many other weak planes and explains the complexity with the rock characteristics.

Figure 2.1: Typical rockmass encountered in the field

2.2. ROCK CORING AND LOGGING

Obtaining rock core is an expensive affair and should be done carefully. Proper logging methodology need to adopted and should maximise amount of data recorded. It should be presented in a readily understable form and involves the careful systematic logging of rock cores by a qualified engineering geologist. Details about the rock core drilling and sampling may be found out in ASTM standards (D2113-08) "Standard practice for rock core drilling and sampling of rock for site investigation". The corresponding Indian code IS 9179-1979 Indian Standard method for preparation of rock specimen for laboratory testing. The all sampling and logging operation should be as per the guidelines. Final log should include the general information, borehole number, location and orientation of borehole, drilling technique, contract details, drilling progress, drillers daily record, flush returns and standing water levels.

State of recovery of core need to properly recorded. Systematic rock sample description and rock grade classification is important. Expensive information may be lost if cores are not properly labelled in core boxes. Core boxes must be sound and robust (Figure 2.2). Usually rock cores are heavy, so must be an appropriate size to be handled by two people. The boxes are made 1.5m long and should be made of hard board for durability. Core box reads as a book i.e. shallow core start at top left and boxes must have site name, borehole number, contractors name and contract. Labels should appear on the box lid plus on the side. State of recovery of the core is dependent on the drilling methods used and needs to be taken into account when analysing core recovery.

Figure 2.2: Picture showing core box with cylindrical cores as recovered

The state of the rock recovered is a valuable indicator of the in situ conditions and mass behaviour. Logger decides on how to split the core into zones associated with different fracture spacing. the term total core recovery- it is the percentage of the rock recovered during a single core run and gives indication of material that has been washed into suspension of the presence of natural voids. Solid core recovery- percentage of full diameter core recovered during a single core run and gives indication of fracture state. Identification of man-made fractures (Figure 2.3) can be made with proper visual inspections. Natural discontinuities will normally be planar, discoloured and weathered. They usually form in sets and sometimes found to be in filled. Man made fractures will normally be looks irregular, fresh usually random.

Figure 2.3: Drilling induced fractures

Once the rock samples are recovered and the specimens are prepared, laboratory studies can be conducted. Basic rock parameters which are commonly derived from laboratory investigations for design application are mostly deformation modulus, compressive strength (intact and rock mass), shear strength characteristics (cohesion and friction), tensile strength and time dependent properties. The deformation modulus in the field helps in calculating the settlement and can be determined commonly using plate load test or pressure meter test. The compressive strength for intact rock as well as for the rock mass is helpful in calculating the bearing capacity of footing and may be estimated with the compressive strength test. Shear strength properties helps in finding out the shearing resistance of the interface of the structure and the foundation rock and also to check the stability of sliding block to avoid any shear failure. Tensile strength would help if there is stiffer layer underlying a weaker layer in the foundation strata, which may lead to flexural or punching failure. Many a time, settlement occurs with time as a result of rock creep or degradation due to weathering and hence need to be assessed the time dependent behavior of rock mass. A complete rock mass classification is also needed for the overall understanding the rock mass characteristics. The site characterization should include details on the structural discontinuities, joints and weakness plane, water table and other geological abnormities and need to be assessed carefully. Strength degradation on saturation and pore pressure effect need to be checked to know the stability during rains when the water table heights are relatively high. For such structures, stability against uplift force also needs to be checked.

2.3. PHYSICO-MECHANICAL PROPERTIES OF ROCK

Rock materials is basically aggregate of minerals, and may contain just a single or multiple minerals. E.g. rock granite mostly contain quarts, feldspar and hornblende. The performance of rock mostly depends on their physico-mechanical characteristics. The physical properties (or the index properties) helps in classifying the rock. The mechanical properties and the strength properties and tells about the performance of the rock material when subjected to a particular loading system. Some key features of rock material is,

- Strength of the rock is dependent on its physico-chemical composition. In addition to this, strength is also dependent on the method of testing, sample size , geometry, test procedure, loading rate, confining stress and degree of saturation.
- Physico-mechanical characteristics of same rock type may vary drastically from place to place and even point to point in a same geological formation.
- Rocks are strong in taking compressive load but relatively weak in taking tensile load.
- In the field, stresses mostly compressive in nature and usually it is attempted to reduce the tensile stress accumulation.
- Rocks behave mostly as brittle material when unconfined but may behave as ductile/plastic when high confining pressure is acted.

Table 2.1: List of some physical and mechanical properties of rocks

PHYSICO MECHANICAL PROPERTIES	
Physical Properties	**Mechanical Properties**
Mineralogical composition - mineral structure, texture.	Elastic Modulus/ Deformation modulus and Poisson's ratio
Specific gravity, density, unit weight	Uniaxial compressive strength
Porosity, void ratio	Tensile strength
Moisture content, degree of saturation	Shear strength Properties
Permeability	Point load strength
Swelling properties	Rock hardness
Anisotropy	
Electrical properties	
Thermal properties	
Velocity of Elastic waves	
Durability	

2.3.1 PHYSICAL PROPERY

2.3.1.1 Density, unit weight, specific gravity and water content

Density of the rock is the mass of rock per unit volume where as unit weight of the rock is the weight per unit volume. Highly porous rocks and relatively poor arrangement of grains (less packing) usually have relatively less densities and vice versa. The bulk unit weight considers the bulk (total) volume of rocks where as the solid unit weight considers volume excluding the pores, fissures. Obviously, for porous rocks the unit weight of solid would be relatively higher than the bulk unit weight as the value in the denominator is relatively lower due to exclusion of pores and micro fractures. Bulk unit weight depends on the type of rock, its porosity and geological processes that take place in it. Bulk unit weight of a rock may vary from region to region, some times in one location to another within the same geological formation.

Density, $\rho_s = \frac{Mass\, of\ solid}{Volume} kg/m^3$

Unit weight of solid, $\gamma_s = \frac{Weight\,(G)\, of\ dry\, rock\, sample}{True\, volume\,(V)} kg/m^3$

True volume signifies the grains without pores and fissures included.

Bulk unit weight, $\gamma_o = \frac{Weight\,(G)\, of\ dry\, rock\, sample}{Volume\,(V_o)\, of\ the\, skeleton\,(including\ pores\, and\ fissures)} kg/m^3$

Table 2.2: Average bulk unit weight for some common rocks

Rock	**Average Bulk unit weight (kN/m^3)**
Granite	27
Basalt	30
Gneiss	27
Marble	27
Schist	26
Sandstone	26
Hard coal	15

The water content of rock specimen can be calculated directly by dividing mass of pore water to mass of sample. For the determination of porosity and density saturation and calliper technique, saturation and buoyancy, mercury displacement and grain specific gravity technique are usually followed.

2.3.1.2 Saturation and Buoyancy technique

Applicable only to non-friable coherent rocks that can be machined and rocks that do not swell or disintegrate when they are oven dried or when immersed in water. Atleast three specimens selected such that minimum size should be of mass 50g or minimum dimension should be ten times greater than maximum grain size whichever is greater. Apparatus required: Oven, Desiccator, Vernier, Vacuum saturation equipment, Sample container, Balance, Immersion bath and Wire basket.

Procedure:

- The sample is washed in water to remove dust and then is saturated in water for 1 hour with a vacuum pressure of 0.8 kPa
- Determine the mass of wire basket submerged into immersion bath, M_1
- Transfer the mass of sample into wire basket into immersion bath and determine the mass. M_2
- Determine the mass of container which should be in clean and dry with lid, M_3
- Remove the sample from immersion bath and surface dry it with moist cloth. Place the sample into the container with lid and determine their mass, M_4
- Take out the lid and place the sample with container into the oven @ 105°C for 24 hours
- Place the sample in desiccators and allow it cool for 30 minutes
- Determine the mass of dry sample with container provided with lid, M_5

Calculations:

Saturated-Submerged mass, $M_{sub} = M_2 - M_1$ (kg)

Saturated-Surface dry mass, $M_{sat} = M_4 - M_3$ (kg)

Dry mass, $M_s = M_5 - M_3$ (kg)

Bulk volume, $V = \dfrac{M_{sat} - M_{sub}}{\rho_w}$ (m^3)

Pore volume, $V_v = \dfrac{M_{sat} - M_{sub}}{\rho_w}$ (m^3)

Porosity, $n = \frac{V_v}{V} \times 100\,(\%)$

Dry density, $\rho_d = \frac{M_s}{V}$ (kg/m^3)

Relative density, $G_m = \frac{\rho}{\rho_w}$

2.3.1.3 Porosity

Rocks contain voids in the form of pores, joints (fissures) etc. The voids may be inter connected or separated from one another. If they are inter connected and pressure gradient exists – rock can conduct fluids or gases. Porosity is an intrinsic property and is the ratio of the volume of openings (voids) to the total volume of material.

$$\text{The Porosity 'n'} = \frac{\mathrm{V_v}\ \text{(Pore volume)}}{\mathrm{V_o}\ \text{(Bulk volume)}} \quad \text{in } \%$$

Porosity represents the storage capacity of the geologic material. The primary porosity of a sediment or rock consists of the spaces between the grains that make up that material. The more tightly packed the grains are, the lower the porosity. Using a box of marbles as an example, the internal dimensions of the box would represent the volume of the sample. The space surrounding each of the spherical marbles represents the void space. The porosity of the box of marbles would be determined by dividing the total void space by the total volume of the sample and expressed as a percentage. The primary porosity of unconsolidated sediments is determined by the shape of the grains and the range of grain sizes present. In poorly sorted sediments, those with a larger range of grain sizes, the finer grains tend to fill the spaces between the larger grains, resulting in lower porosity. Primary porosity can range from less than one percent in crystalline rocks like granite to over 55% in some soils. The porosity of some rock is increased through fractures or solution of the material itself. This is known as secondary porosity.

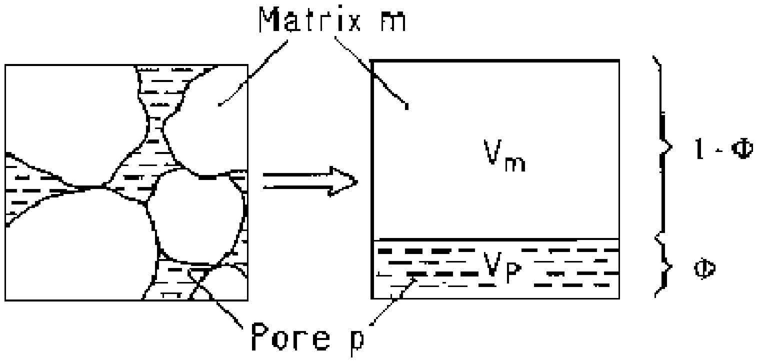

Figure 2.4: Visual representation of a porous rock

High porosity	↑	Highly porous marine sediments
		Unconsolidated sediments
		Sandstones
		Carbonate rocks
Low porosity	↓	Fractured igneous rocks, other dense rock types

Usually igneous or metamorphic rocks will have very low porosity (0-2%) where as sedimentary rocks like sandstones will have very high porosity (upto 40%). Many factors which affect porosity like, grain size distribution, grain shape and arrangement, degree of cementation of grains, applied pressure etc. Porosity decreases with increase of pressure and therefore, deep seated deposit with large overlying pressure may tend to have relatively low porosity compare to surface depositions.

Porosity may be represented with void index which can be found using quick absorption technique. Void index defined as the mass of water contained in a rock sample after one hour period of immersion, as a percentage of its initial dry mass. The index is correlated with porosity and also with such properties as degree of weathering or alteration. The test should only be used for rocks that do not appreciably disintegrate when immersed in water. The void index is evaluated from the ratio of difference between the saturated and dry weight of rock to dry weight of rock expressed in terms of percentage.