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1. Learning Outcomes

After studying this module you shall be able to:

- Know different uses of rocks in construction industry.
- Learn about different physical and mechanical properties of rocks to be used for different construction purposes.
- Understand different aspects of site or foundation rocks.
- Identify rock mass properties controlling behaviour of rock mass in case of loading and unloading.

2.1 Introduction

In construction industry rocks are being used as the construction material and as founding ground. The "Rock Material" refers to the intact rock within the framework of discontinuities at the level of texture i.e. mineral boundaries. While the "Rock Mass" refers to insitu rocks encompassing all the discontinuities and alteration induced by weathering. Different rocks extracted from the rock masses are used as construction material, elsewhere. While rock masses are subjected to construction insitu i.e. over them in case of buildings and damsas founding ground or inside, as tunnel or any accommodating structures. Some important uses of rocks and rock masses are:

Aesthetic Uses: Ornamental stone carvings, statue or mural making, artefacts and in beautification of buildings.

Building Stones: For making columns, walls, flooring, roofing, cladding of buildings and as pavement slabs.

Dimension Stones: As large framework blocks in construction of fort walls, bridge piers, retaining walls, lighthouses, abutments, dams, sea walls, jetties, dikes etc.

Aggregates: For making plaster, mortar, concrete etc.

Road Metal: As base course, load bearing course, wearing course of road.

Rail Ballast: Stones as side and bottom cushion for rail tracks.

Energy Dissipaters: Along shores, river bends, water fronts, spillway dentitions to minimise wave and current energy to prevent erosion.

Site Rocks: Atplaces where rocks are exposed on or closer to the ground surface will act as site rocks having foundation of supra-structures over them and may accommodate structures inside them.

As such even a weakest rock may be stronger than the strongest soil. Hence, founding small structures on rocks are not a big problem. But, laying the foundation of mega structures i.e. skyscrapers, dams, retaining walls, dikes etc. may exert immense loading stresses. Hence,geotechnical properties of even a strong site rocks becomes very important. Construction of underground structures, bunkers, subways, tunnels, power stations etc. involves not only redistribution of stresses in rock mass due to excavation and unloading but also concentration of stresses along the openings become important, hence need proper scrutiny, analysis before construction and measures for safety and longevity of structures.

The above mentioned uses of rocks demand different kinds of aesthetic, physical, mechanical and to some extent chemical properties termed as geotechnical properties. These properties depend broadly on physical appearance, strength and stability of constituent mineral, mode of interlocking of these minerals and presence of bedding/foliation plane and fractures induced by deformation a rock mass has undergone. Some important geotechnical properties such as *strength,* for rocks to be used as dimension stones in heavy structures, *impactstrength* for road metal, *abrasionresistance* for rail ballast, *inertness* to chemical reactions for aggregates, *appearance* for rock cladding and *softness* for rock carvings and in making of artefacts.

2.2 Rock Material

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 imparted due to alteration caused by weathering and deformation. 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. The important physical and mechanical properties of rock as material are discussed in the following sections. Rocks are not engineered materials hence their properties can show extreme variations from place to place or from site to site. Hence proper assessment of rocks for specific uses in terms of physical and mechanical properties are must to ensure safety, strength and longevity of structures within the purview of economy. The important physical properties are colour, anisotropy, hardness, porosity, permeability, density, durability and thermal properties. The mechanical properties of rocks include elastic and strength properties. Chemical properties may not play direct role in deciding the selection of construction material but for its use as aggregate does require some chemical specifications.

2.2.1 Physical Properties

The physical properties are also called as index properties as they are used for identification and classification of rocks. These properties are inherited at the time of formation of rocks but may be subjected to change in the environment of weathering.

2.2.1.1 Colour: The colour of a rock only matters when it is used for aesthetic purposes or for flooring and rock cladding. The colour of rocks depends on the minerals present and is termed as *leucocratic*, *mesocratic* and *melanocratic*for light, medium and dark colours respectively. The true colour of rocks can only be seen on freshly broken surface as the long exposed part of rocks get stained in brown to grey colours due to weathering. For denoting the colour of rocks -*Rock Colour Charts* can be used.

2.2.1.2 Anisotropy: In a rock if constituent minerals are randomly oriented then rock is saidto have *isotropic fabric* and if minerals show some preferred orientation then rock is said to have *anisotropic fabric*. Different properties of anisotropic rocks become directionalfor example it may have different strength along different directions or it may have different permeability in different directions as compared to isotropic rocks which will have these same all along (Fig. 2.1 a, b).

Figure 2.1: (a) Rock granite with isotropic and (b) Rock granite gneiss with anisotropic fabric

Most of igneous, non-foliated metamorphic and sedimentary rocks show isotropic fabric. Few volcanic rocks formed by cooling of flowing lava show anisotropic fabric due to alignment of minerals during flow. All foliated metamorphic rocks will show anisotropic fabric. Some sedimentary rocks with sediment deposited under high current velocity may also show anisotropic fabric.

2.1.1.3 Hardness: Hardness of a rock depends upon the hardness of minerals present in a rock. A mono-minerallic rock e.g quartzite will have similar hardness all through the rocks while polymineralic rock will show average value. It is easy and common to use Moh's hardness scale for knowing the relative hardness of rocks after seeing the overall mineral composition. Another scale known as Vicker's scale is used to get absolute hardness values based on micro indentation hardness.

Table 2.1: Moh's (MH) and Vicker's (VH) Hardness Scale

Minerals	*Talc*	*Gypsum*	*Calcite*	*Fluorite*	*Apatite*	*Orthoclase*	*Quartz*	*Topaz*	*Corundum*	*Diamond*
MH	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
VH	**24**	**36**	**109**	**189**	**526**	**795**	**1120**	**1427**	**2060**	**10,060**

2.2.1.4 Density: It is defined as the mass per unit volume of the rock. It can be expressed as dry density, bulk density and saturated density. When rock is completely dry i.e. pores contain only air, then it is dry density, when sample is in normal condition i.e. rock may have some moisture and air, then it is bulk density and when sample is completely saturated with water then it is termed as saturated density. The density of rocks differs because of different constituent minerals, their interlocking and porosity. The density of commonly found rocks varies from 2.60 to 2.80. High density rocks are usually stronger than the low density rocks. The density of common rocks and other engineering materials are as follows:

Table 2.2 Dry densities of commonly found rocks and other construction materials.

Rocks	Density (gm/cc)	Rocks	Density (gm/cc)	Other Materials	Density (gm/cc)
Basalt	2.75 - 3.00	Schist	2.45 - 2.75	Gravel	1.40 - 1.70
Dolerite	2.70 - 2.90	Conglomerate	2.35 - 2.65	Sand	1.40 - 1.60
Granite	2.60 - 2.70	Sandstone	2.20 - 2.40	Clay Brick	1.60 - 1.80
Rhyolite	2.50 - 2.65	Limestone	2.10 - 2.70	Wood	0.40 - 0.60
Quartzite	2.40 - 2.50	Shale	2.25 - 2.55	Steel	7.50 - 8.50

Gneiss	2.50 - 2.60	Gypsum	2.20 - 2.35	Light Concrete	1.25 - 1.80
Marble	2.55 - 2.75	Coal	0.75 - 2.00	Heavy Concrete	1.80 - 2.50

2.2.1.5 Porosity: The relative proportion of voids and solids in terms of percentages is called as porosity. The voids may have into them, water, air, oil, gas etc. Completely dry rocks will have only air (gas) and completely saturated rock will have only water or oil in pores. Other related parameters are *Degree of Saturation*,defined as the volume of water in total volume of voids (V_W / V_V) and *Moisture Content*, defined as weight of water in total weight of solids (W_W / W_S). A rock sample submerged under water or taken from below the ground water table will have very high degree of saturation. The moisture content of a rock sample increases with depths to which civil engineering works are carried out, due to the presence of subsurface moisture and groundwater. It can be calculated by drying a saturated rock sample in oven at 105 to 110 ^{0}C for 24 hours and noting the weight loss.Most of the sedimentary rocks being granular are generally porous, foliated metamorphic rocks show negligible porosity along foliation planes while igneous and nonfoliated metamorphic rocks are practically non porous. Some volcanic rocks may possess porosity owing to the presence of vesicles.

Weathering may increase the porosity of rocks. Rocks with high porosity will showlow density and low strength as compared to their nonporous counterparts. High moisture content and high degree of saturation make rocks weak especially in cold regions where ice may form in pores and due to increase in volume may create internal stresses leading to breaking of rocks.

2.2.1.6 Permeability: The interconnection of pores in a rock will constitute primary permeability. Being theoretically porous, sedimentary rocks show permeability though very low. The presence of micro discontinuities such as fractures, lamination and foliation planes may enhance the porosity and will be called as secondary permeability. The permeability as such is not required in day to day uses of rocks as material. An approximation can be made that rocks with high porosity will have high permeability and vice-versa.

Insitu or field permeability is more important and is usually higher than the rocks tested in lab because of the presence of micro discontinuities (table 2.3). The field values may go much higher depending upon the number of joints per unit volume,nature of their aperture and their interconnection. The field permeability can be measured using radioactive tracers and their movement from one bore hole to other or may be worked out by measuring the water loss through different sections of a bore hole.

Table 2.3Lab and field permeability of some common rocks.

Rock Type	Laboratory Test (cm/sec)	Field Test (cm/sec)
Sandstone	3×10^{-3} to 8×10^{-8}	1×10^{-3} to 3×10^{-7}
Limestone	1×10^{-5} to 8×10^{-13}	1×10^{-3} to 1×10^{-8}
Dolostone	1×10^{-4} to 8×10^{-12}	1×10^{-3} to 1×10^{-7}

Shale	1×10^{-9} to 5×10^{-13}	1×10^{-8} to 1×10^{-11}
Basalt	1×10^{-12} to 2×10^{-14}	1×10^{-3} to 1×10^{-8}
Granite	1×10^{-7} to 1×10^{-11}	1×10^{-4} to 8×10^{-9}
Schist	1×10^{-7} to 1×10^{-9}	1×10^{-6} to 1×10^{-8}
Quartzite	1×10^{-10} to 8×10^{-15}	1×10^{-9} to 1×10^{-11}

2.2.1.7 Durability: Durability can be defined as resistance to natural deterioration. Rocks are naturally subjected to weathering and erosion, in *insitu* condition as well as when they are placed as construction element due to exposure, hence are liable to deteriorate with time,resulting into overall reduction of strength. One can see in historical monuments, discolouration, loosening of grains, chipping, exfoliation and spalling. The durability of rocks at its natural exposure as well as the site of its use is controlled by overall climate of the area, structures, texture and mineral composition of rocks. The mode and depth from which rock material has been sequestered will also control its quality. The surficial material will be of low quality as compared to material excavated from deeper mines. Nowadays due to increasing atmospheric pollution, acidic rain has become a common phenomenon in urban areas which is detrimental to exposed parts of the buildings including rocks. Rocks which are porous, coarse grained and rich in feldspar carbonate and clay minerals are affected more. To measure the durability of rocks *Slake Durability Test* can be used (Fig.2.2).

Figure 2.2: **Slake Durability Test apparatus**

For this 500 gm of oven dry rocks are broken in to 10 equi-sized pieces, weighed and kept in a drum made of 2 mm sieve mesh with 140 mm diameter and 100 mm length, submerged half in water bath.

The drum is rotated at the rate of 20 revolutions per minute for first cycle of 10 minutes. The sample is taken out from the drum, subjected to drying in oven at 110 ^{0}C and weighed again to see how much percent is the loss in weight. The sample is dried again and is subjected to same process for second cycle, again to get weight loss denoted as I_d(table 2.3).

Table 2.3: Durability Classification based on Slake Durability Test

Group	% Retained after first cycle	% Retained after second cycle
Very High Durability	> 99	> 98
High Durability	98 - 99	95 - 98
Medium to High Durability	95 - 98	85 - 95
Medium Durability	85 - 95	60 - 85
Low Durability	60 - 85	30 - 60
Very Low Durability	< 60	< 30

2.2.1.8 Thermal Properties: Thermal properties of rocks as engineering material is important where ever some kind of heating is involved such as in furnaces, strategic storage facility, power houses etc. The resistance to fire is also related with this property. Sudden and frequent change in temperature can expand and contract rocks depending upon their coefficient of thermal expansion, inflicting micro cracks and make the rocks weak (table 2.4).

Table 2.4: Coefficient of thermal expansion of some common rocks (Griffith 1936).

Rocks	Coefficient of thermal expansion/^{0}C	Rocks	Coefficient of thermal expansion/^{0}C
Granite	34×10^{-7} to 66×10^{-7}	Sandstone	36×10^{-7} to 65×10^{-7}
Basalt	22×10^{-7} to 35×10^{-7}	Gneiss	34×10^{-7} to 44×10^{-7}
Diorite	31×10^{-7} to 35×10^{-7}	Marble	34×10^{-7} to 51×10^{-7}
Gabbro	20×10^{-7} to 30×10^{-7}	Quartzite	60×10^{-7} to 62×10^{-7}
Limestone	24×10^{-7} to 68×10^{-7}	Schist	34×10^{-7} to 43×10^{-7}
Dolomite	22×10^{-7} to 66×10^{-7}	Slate	45×10^{-7} to 49×10^{-7}

2.3 Strength

Rocks possess strength due to coherence of constituent mineral(s). A mono-minerallic rock with random (isotropic) fabric will show similar strength all around but a polymineralic rock may show variation in strength from section to section. So is the case with rocks having oriented (anisotropic) fabric. In general rocks are very strong under compressive forces as compared to under shear forces followed by flexural and tensile stresses.

2.3.1 Compressive Strength

Rocks are usually subjected to up right vertical loading, for example a rock used as a block in bridge pier will be subjected to compressive strengths. As such compressive strength of most rocks is greater than the applied engineering loads, except some clay rich and less indurate sedimentary rocks. The most standardised way of defining compressive strength is *Unconfined Compressive Strength* of dry rocks. The other methods are *ConfinedCompressive Strength*, *Point Load Strength*, *Schmidt Hammer Strength* and *Geological Hammer Strength*.

2.3.1.1 Unconfined Compressive Strength Test: Unconfined Compressive Strength (UCS) can be worked out with the help of a machine known as Universal Testing Machine. For this rocks cut in shape of cube with 5.5 cm long edge or cylinder of > 5.4 cm diameter or more with diameter to length ratio of 2 to 3 are used. The top and bottom face of sample should be made parallel and smooth before loading it between flat steel plates of machine. The load is not applied instantaneously because it will give higher strength; rather load is applied slowly so that test can continue for more than 5 minutes minimum before failure. The load at failure is noted and is divided by the area of the sample face to get the compressive strength. To standardise the test length to diameter ratio of cylindrical sample is reduced to 1, by a formula:

$$q_u = \sigma_c \text{ (ob) } / \ 0.778 + 0.222 \ (D/L) \qquad \text{Equation 2.1}$$

Where, $\mathbf{q_u}$ is compressive strength, $\boldsymbol{\sigma_c}$ is observed compressive strength, D and L is diameter and length of the sample.

The UCS can be related to physical properties porosity and dry density. The rocks with dry density in between 2.5 to 2.9 t/m^3 and porosity 1 to 3% may have UCS in the range of 150 to 250 MPa while rocks with dry density in between 1.5 to 2.5 t/m^3 and porosity 5 to 15% may have UCS in the range of 50 to 150 MPa. Igneous rocks with very small sized minerals are stronger than their coarse counterparts. Non foliated metamorphic rocks will have higher compressive strength as compared to foliated ones. Geologically older sedimentary rocks due to high indurations and cementation will be stronger than the young sedimentary rocks provided that they are not weathered.

2.3.1.2 Confined Compressive Strength Test: Rocks when subjected to lateral compression apart from vertical compression they give confined compressive strength (CCS). The rocks which are confined from all the sides may experience this kind of stress. For Confined Compressive Strength or *TriaxialTest*,a small core of rock is extracted from the main rock body by using diamond drill cutter. The end surfaces are made smooth and parallel on grinding wheel. Its length

(l_o) and diameter (d_o) with a ratio of 2 to 3 are measured by using micrometre to two significant numbers after decimal. The specimen is jacketed in thin copper or aluminium foil in such a way that pressure fluid present in pressure vessel should not enter in to sample. The sample is kept in steel pressure vessel screwed to the anvil and fitted in to upper piston holder. The sample is subjected to axial compression (σ_1, maximum principal stress) parallel to the length of the sample through piston while horizontal radial compressive stresses (σ_2 and σ_3, intermediate and minimum principal stresses, but are equal here), as confining pressure are applied through fluids in steel vessel. The expected result is shortening of the sample along the length and stretching of sample in the middle part before the development of cracks or failure. The experiment can be carried out on many different samples by changing confining pressure and calculating the vertical stresses required to break the sample(table 2.5).

Table 2.5:Results of triaxial testing under different confining pressure

Parameters	Specimen 1	Specimen 2	Specimen 3
Confining Pressure	29 MPa	104 MPa	209 MPa
Differential Failure Stress	125 MPa	320 MPa	555 MPa
Max. Principal Stress σ_1	154 MPa	424 MPa	764 MPa
Max. Principal Stress σ_3	29 MPa	104 MPa	209 MPa

From the table it can be seen that with increasing confining pressure the requirement of vertical stresses to break the rock also increases. The vertical and lateral loads can also be plotted graphically known as Mohr's Diagram to determine shear strength, *Angle of Friction*(**Φ**) and *Cohesion* (**c**). For this circles are drawn on a graph with normal stress($\boldsymbol{\sigma_N}$), *x* axis and shear stress on *y* ($\boldsymbol{\sigma_S}$) axis. For each sample circles are drawn on x axis, at a distance of $(\sigma_1 + \sigma_3)/2$ from the origin with a radius of $(\sigma_1 - \sigma_3)/2$. Then a tangent (Mohr's envelop) is drawn touching all the circles, the angle of inclination of this line is called as the angle of friction and the distance it touches the Y axis from the origin is called as cohesion (Fig. 2.3). The angle of fracture from the vertical stress is also important which normally increases with increasing confining pressure. The shear and normal strength can also be calculated for a particular fracture angle (**θ**), by reading x, y coordinates along any point on the perimeter of the circle, located with the help of drawing a radius at **2θ** (Fig. 2.3).

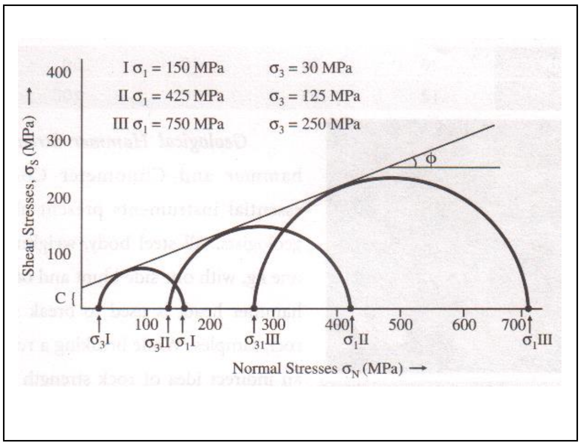


Fig. 2.3: Mohr stress diagram with three different confining pressure setup

The Confined Compressive Strength actually replicates strength of rocks naturally placed underground, which increases greatly with depth because of increasing confinement and go beyond any significant engineering loading on or near the earth surface conditions.

2.3.1.3 Point Load Strength Test: This can be worked out directly, easily and rapidly in the field itself by using a portable machine. For this square or rectangular or cylindrical shape sample can be used. By applying some corrections point load strength can be workedout. Even an irregular rock lump can be used with approximate dimensions close to 1:1:2. The machine consist of two 60 steel points with a tip of 10 mm diameter which can be lower down and pressurized the sample with the help of hand held hydraulic jack. Denoted by I_S, is usually close to UCS/20. If very low values are recorded then it may be due to the presence of micro cracks in the sample.

$$I_s = P / D^2 \qquad \text{Equation 2.2}$$

2.3.1.4 Schmidt Hammer Strength: It is a hand held cylindrical shape instrument which operates on spring loaded piston shaped hammer (Fig. 2.4). The spring can be loaded and locked by pushing the piston inside by pressing against the rock sample or any hard surface. The loaded spring can be again released by pressing against the sample surface, where it makes rebound which is recorded on the recording panel on instrument itself.

Figure 2.4: Schmidt Hammer

The rebound values are related to hardness/compactness/density of the sample which can be indirectly correlated to the UCS as:

Schmidt Strength	20	30	40	50	60
UCS (MPa)	12	25	50	100	200

A very easy to use rapid field test to identify weak, weathered, porous and fractured rocks as Schmidt rebound values reduce significantly with increasing porosity, weathering and fracturing of rocks. Schmidt hammer is also used as non-destructive testing method for knowing in situ strength of other engineering materials.Geological hammer can also be used to have an indirect idea of rock strength in field (table 2.6).

Table 2.6: Indirect strength of rocks based on breaking by geological hammer

Rock Strength	Probable Strength (MPa)	Breaking Characteristics
Very Very Strong Rock	> 150	Impossible to break by hammer
Very Strong Rock	150 - 100	Firm hammering to break
Strong Rock	50 - 100	Easy hammering to break
Moderately Strong Rock	12.5 - 50	Dent with hammer pick
Moderately Weak Rock	5.0 - 12.5	Fractured by hammer pick
Weak Rock	1.5 - 5.0	Crumbles in pieces by pick blows

Very Weak Rock	0.6 - 1.5	Break by hand
Weathered Rocks or Stiff Soil	0.3 - 0.6	Indent by finger nails
* *As per International Society of Rock Mechanics a material with UCS < 1.0 MPa is characterized as soil.*		

2.3.1.5 Shear Strength: Shear Strength (Ss) of rock is defined as the capacity of rock to withstand shearing stresses. It can be worked out indirectly by Triaxial Test and with the help of Mohr's diagram, as described above. The shear strength has two components *cohesion* due to interlocking and *friction resistance* along the fracture. Both increases with increase in confining pressure. Mathematically shear strength is calculated by using an equation, called as *Coulomb's Law*.

$$Ss = \text{Cohesion} + \text{normal Stress} \times \tan \Phi \quad \text{Equation2.3}$$

Direct shearing strength of rock samples can also be known by ***Ring*** or ***Punch Shear*** test (Fig. 2.5a) by using a formula:

$$\sigma_s = P / A \text{ or } P / \pi d t \qquad \text{Equation 2.4}$$

Shear Box test (Fig. 2.5b) can be used to get the direct values of shear strength by a formula:

Normal Stress $\sigma_n = P \times \sin 45^0 / A$ Equation 2.5

Shear Stress $\sigma_s = P \times \cos 45^0 / A$ Equation 2.6

Normally shear strength vary from UCS/6 in strong rock to UCS/2 in soft clay.

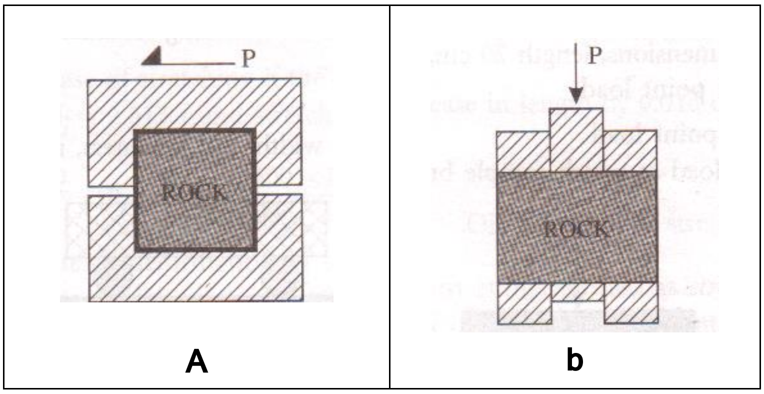
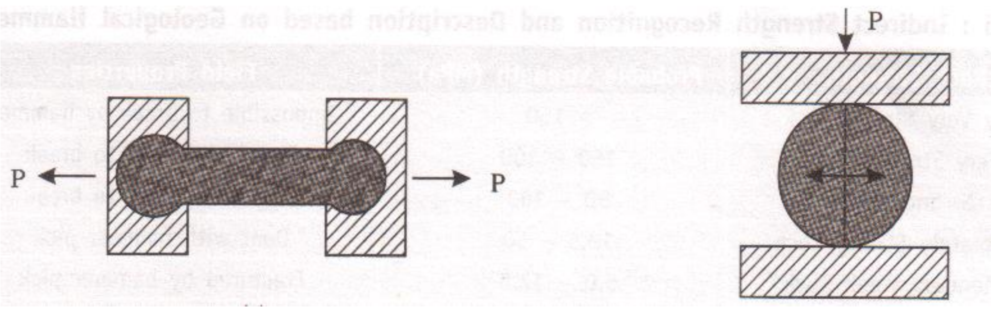


Fig. 2.5: Schematics for measuring shear strength using (a) Shear box and (b) Ring Shear setup.

2.3.1.6 Tensile Strength: Rocks are very weak under tensile stresses and are rarely subjected to direct tensile stresses. Tensile stresses may be induced indirectly when rocks are used as slabs or beams. The direct tensile strength can be worked out by Dog Bone Test, where rock sample is dressed in "bone" shape to hold and pull the specimen from two ends. The sample preparation and perfect testing is very cumbersome (Fig. 2.6).



(a)

(b)

Fig. 2.6: Schematics of (a) direct tensile or "bone" test and (b) indirect Brazilian test.

Measuring indirect tensile stresses are more prevalent using ***Brazilian Test*** and/or by applying empirical formulae:

$$\sigma_t = 0.0675\ P/D^2 \qquad \text{Equation 2.7}$$

$$\sigma_t = 0.0476\ \sigma_u + 1314 \qquad \text{Equation 2.8}$$

Where, σ_t is tensile stress in kN/m^2, P is vertical load at failure in kN, D is diameter in m of cylindrical sample and σ_u is compressive strength in kN/m^2.

2.3.1.7Brazilian Test: Itis performed by using a core disc with length to diameter ratio of 0.5. The core sample with smoothened outer surface is placed between two loading plates of compression testing machine (Fig. 2.6 b). The compressive force is applied at the rate of 2kN/sec so that the experiment can be extended to some 5 minutes before failure take place. The sample experiences tensile (indirect) stresses in direction perpendicular to the direction of compressive stress and can be calculated by a formula:

$$\sigma_t = 2P / \pi DL \qquad \text{Equation 2.9}$$

2.3.1.8Flexural Strength: Transverse strength of rocks comes into play when it is subjected to bending loads. Usually the transverse strength varies from UCS/10 to UCS/20. It is determined by loading a bar by three point load (Fig. 2.7a) or four point load (Fig. 2.7b) on a beam shaped rock with dimensions, length 20 cm, width 8 cm and thickness 8 cm using formulae:

Three point load $\sigma_f = 3\ PL / 2\ BD^2$ Equation 2.10

Four point load $\sigma_f = 3\ PA / BD^2$ Equation 2.11

Where, P is load at which sample breaks, L, B, D are length, width and thickness respectively.

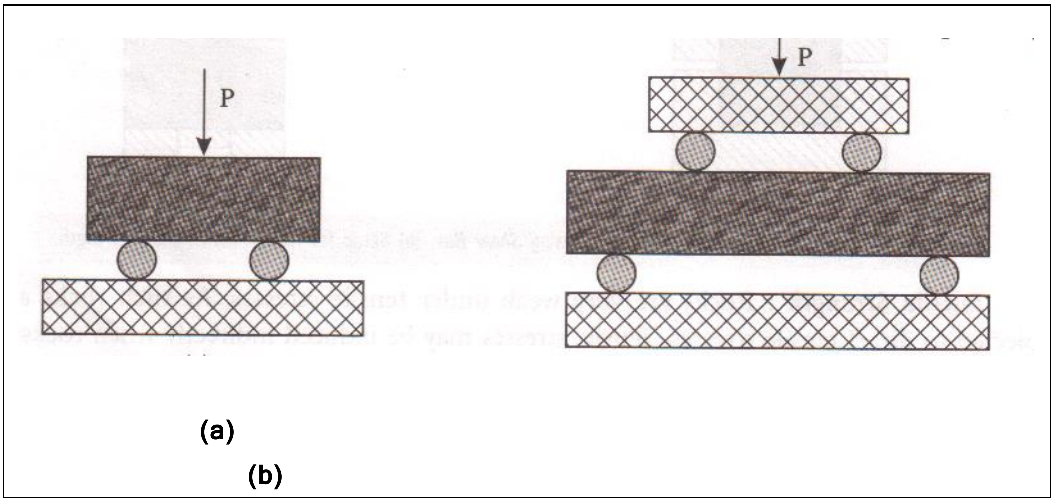


Fig. 2.7: Schematics of (a) three and (b) four point flexural strength test

2.4 Elastic Properties

Elastic properties of rocks relate stresses with corresponding strain. These parameters can be worked out by performing deformation tests and can also be extrapolated for insitu rock masses because it will be difficult to perform similar test for site rocks. The important elastic properties or constants are *Modulus of Elasticity* and *Poisson's*

Ratio.Many of these constants can be calculated by observing the deformation process on a sophisticated instrument which can measure minute deformations related to uniaxial and triaxial loading and unloading.

2.4.1 Modulus of Elasticity

The straight line nature of stress and strain diagram means strain increment per stress increment (Fig. 2.8). As and when stresses are withdrawn, sample comes in to its original size and shape i.e. strain is recovered. Though we may not be able to observe deformations but it does take place, in form of contraction of molecular spacing, crystal lattice deformation and microscopic displacements along mineral boundaries. This indicates *elastic*or spring like behaviour of rock, suggestive of rocks ability to absorb or recover minute non-rigid body deformations. Such materials are said to follow *Hook's Law* stated as:

$$\sigma = Ee \quad \text{OR} \quad E = e / \sigma$$

Where, σ is stress, e is strain and E is termed as *Modulus Ratio* or *Young's Modulus*.

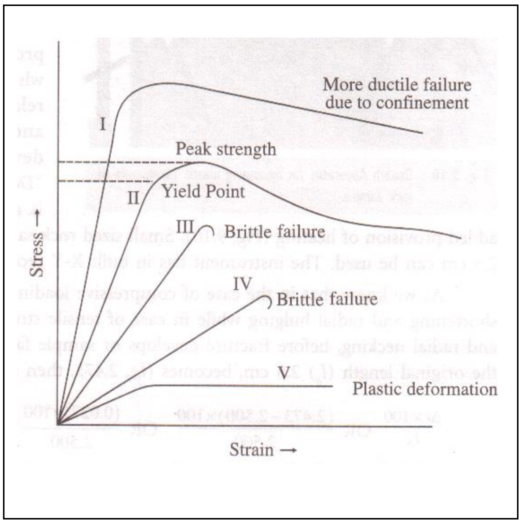


Figure 2.8: Stress-strain diagram showing different types and stages of deformation

The Young's modulus varies from rock to rock i.e. the shape of slope may not be straight rather it may have curve at start as well as at the end. Slope of these curves will be different for different rocks meaning thereby natural differences in resistance of rocks or *stiffness* to elastic deformation (Fig. 2.8). The modulus ratio can be calculated by getting a best fit line either by drawing a tangent from origin to the start of the curve called as *initial tangent modulus* **(E_i)**, or drawing a tangent at the straighter part of the curve termed as *secant* or *tangent modulus* **(E_{sec})** or a tangent at half of the failure load called as E_{50}.

The value of E denotes its strength, homogeneity, isotropy and continuity. It is very important especially for pressure tunnels and abutments of arch dams. Granite, gabbro, basalt, rhyolite, quartzite etc. are termed as *Quasi Elastic* with E = 6 10^5 Kg/cm^2 to 11×10^5, Coarse grained granite, dolomite, marble etc. are termed as Semi Elastic with E = 4×10^5 Kg/cm^2 to 6×10^5, sandstone, schist, phyllite, limestone are termed as *Non Elastic* with E = 4×10^5 Kg/$cm^{2.}$

Another important term is *Modulus Ratio***,** defined as E / UCS which is almost 300 for most of the rocks, but strong rocks such as basalt, quartzites and dense limestone termed as stiff or strong rocks may have this value greater than 500 and weak rocks such as mudstone and shale less than 100.

2.4.2 Poisson's Ratio

We know that rock sample under compressive stresses gets shortened in length with accompanied increase in cross sectional area. The ratio of lateral strain and axial strain within the elastic limit is called as *Poisson's Ratio*denoted by(**ʋ**). In mathematical form:

ʋ = Lateral Strain (ἐ) / Axial Strain (ε) **OR** ***∆l/l/∆d/d*** **OR**

∆dl / ∆ld

Most of the rocks show **ʋ** value ranging from 0.05 to 0.25. Weathered, soft and porous rocks show very low values as compared to non weathered, non porous and hard rocks. Some rocks do not show immediate increase in lateral dimensions despite the fact that axial shortening start taking place, the reason is ascribed to presence of micro cracks and pores into which grains/minerals start moving in causing decrease in length but no accompanied increase in diameter.

2.5 Specific Properties of Rock Material for Different Uses

2.5.1 Aesthetic Uses: Rocks have been used from time immemorial for various kinds of aesthetic work in palaces, churches, temples, forts and other monuments. Even in present times rocks are being used to increase the aesthetic value of buildings. The availability of instruments and modern machines have made sequestering and working with stones much easier. The important properties of rocks for such uses include pleasing colour(s), strength, elasticity and softness. For longevity and resistance to weathering, non porous nature and absence of flaws or micro cracks in building stones are also important. The common rocks used for such purpose includes soapstone,serpentine, marble, limestone and sandstone.

2.5.2 Building and Dimension Stones

In rocky areas it is very common to have each and every part of building made of rocks i.e. foundation, column, wall, floor, roof etc. as irregular to square and rectangular blocks as a replacement of brick or as slabs for paving and ceiling. Mostly local available rocks such as granite, basalt, gneiss, quartzite, sandstone and limestone blocks (UCS > 50 MPa) found naturally and due to presence of equally spaced joints are of three dimensional/regular shapes, are in frequent use. But, if the building is large and the structure is of importance, then rocks are dressed properly in regular geometrical shapes, with sharp straight edges and smooth surface. The regions away from rocky areas also use rocks in buildings as structural element, as polished flooring slab or tiles and for cladding of buildings from outside to give it beautiful look. Raw pieces of rocks with sand and cement mortar are very commonly used for making boundary walls known as *ashlars masonry*. Flagstones 40 to 50 mm thick separated along the bedding planes of sandstone or limestone have been used traditionally as flooring and paving slabs. Slates 5 to 10 mm easily splitting along foliation plane using hammer and chisel have been used as roofing material due to its high tensile and flexural strength. The governing factors for using rocks in buildings are: (i) Need, (ii) Availability, (iii) Workability,(iv) Cost and (v) Durability

2.5.2.1 ***Need*** of rocks for its use in building construction arises because of its easy availability, beauty and strength. It can be opted as structural element such as beam and column, solely due to its strength. Now a day rocks are being used in plenty even in areas far from rocky regions especially due to its aesthetic values. Due to mechanisation in mining and easy transportation, it has become possible to bring rocks of required type, look, size and strength to any place even from outside the country. Granite, gneisses, charnockite and marble of different varieties are being frequently used for increasing the strength and beauty of buildings.

2.5.2.2 ***Availability*** of a particular group of rocks depends upon the geology of that region. Usually rocks available in nearby areas are used such as Red Fort in Delhi is made of red sandstone from Vindhyan Hills of Uttar Pradesh and Rajasthan, Quartzites of Delhi and nearby areas of Haryana. Similarly marble in famous Taj Mahal has been procured from Makrana, Rajasthan while sandstone of Fatehpur Sikri is local rocks belonging to Vindhyan Hills. In south India granite and gneisses have been used extensively. In Himachal Pradesh and Jammu and Kashmir quartzites, porphyritic basalt and slates are being used heavily. But, in some situations depending upon the purchasing power of an organisation or of an individual, even rocks from outside the country can be procured. At the same time marble from Rajasthan and Granite from South India are being exported worldwide for their beauty and strength.

2.5.2.3 ***Workability*** is an important factor which as such increases the cost of using rocks especially in areas away from the rocky regions. Lot of breaking, cutting, chiselling, dressing are involved leading to loss of time and wastage of material. The workmanship is also a very important factor for using rocks as building stones.

2.5.2.4 ***Mineral composition*** not only controls the strength of rocks but also its durability. Rocks with high content of ferro-magnesian minerals usually have low hardness, fair bad in all kind of climate. Hardness of minerals controls the overall strength and resistance to abrasion of rocks. Minerals like muscovite, biotite, pyrite, calcite, dolomite, talc are weak minerals which can be easily chipped out and become avenues for further damage. Rocks with high content of quartz and for some degree feldspar fair good due to their high hardness. Loss of polish and presence of pitted surface is good indicator of rocks getting deteriorated.

2.5.2.5 ***Structure*** i.e. presence of bedding plane, lamination, foliation, joint and micro cracks will definitely make rocks weak. These planes will not only act as discontinuity surface but also act as pathways for water, frost and storage of deleterious material. Therefore sedimentary and foliated metamorphic rocks which invariably consist of such discontinuity planes will be more vulnerable to deterioration as compared to non foliated metamorphic and igneous rocks.

2.5.2.6 ***Texture*** is another very important factor of rocks as it controls the interlocking, induration and cementation of minerals apart from the presence of inter mineral voids i.e. porosity. Porous rock will be weak as compared to non porous rocks in terms of strength in dry condition and also in wet condition as it will undergo weathering at faster rate due to solution action of water. Igneous aphanitic rocks will be stronger than the porphyritic rock followed by phaneric rocks. Non foliated metamorphic rocks will be stronger than foliated ones as far as compressive strength is concerned but it has been found that flexural or tensile strength of foliated metamorphic rocks are more than non foliated ones. Silica and iron oxide cemented clastic sedimentary rocks are stronger than the carbonate cemented and clay cemented sedimentary rocks. In non clastic rocks chert and limestone are strong rocks but in dry climate. Strength again is an important property for building stones similar to Dimension Stones. Other important properties include:

2.5.2.7 ***Resistance to abrasion*** offered by rocks to mechanical wear and tear. This property can be tested by using *Dorry's Test* (explained later).

2.5.2.8 ***Resistance*** **to** ***frost and fire*** is a very important property of rocks to be used as building material.Porous rocks or rocks with micro cracks in very cold regions absorb moisture and due to repeated frosting and thawing result into further cracking of rocks due to volume increase and with time rocks become weak. Non porous and flaw less rocks will fair good in regions of cold climate.

Mono-minerallic rocks are good in resisting fire due to homogeneity in coefficient of thermal expansion of constituent minerals. Poly-minerallic rocks suffer disintegration due to haphazard increase in size of minerals due to different coefficients of thermal expansion of different minerals. Similarly fine grained rocks fair well as compared to coarse grained rocks in case of heating due to fire.

2.5.2.9 ***Durability*** of the rocks will not only provide strength but also ensure the longevity of the building. The rocks mined from their place of origin as fresh rocks will now be placed under new milieu of weathering and erosion at their site of use. Hence the selection of rocks should take into account not only strength and weakness of rocks but also the climatic set up of the site in terms of maximum and minimum diurnal and seasonal temperature variation, humidity, rain fall, industrial pollution etc. Durabilityof rocks to be used for flooring and wall cladding are supposed to retain polish and resist wear and tear. These properties are a function of strength, resistance to weathering and abrasion and depend upon mineral composition, primary and secondary structures, porosity and texture.Slake Durability Test can be used to assess the above mentioned properties where in small rock pieces are subjected to milling under water and their weight loss is measured.

There is another test which can be used to work out the effect of weathering especially of frosting, wherein pieces of building stone around 5 cm^3 is dried and weighed. It is then submerged in 14% $NaSO_4$ at 29^0C for 4 hours. After this it is washed and dried first in air then in oven at 150^0C. This completes one cycle;samples are subjected to thirty cyclesand are finally weighed. If weight loss is less than 5% then the rock is excellent, 5 - 10%, good, 10 - 15%, fair, 15 - 20% poor and greater than 20% very poor.

2.5.2.11 ***Appearance*** is related to the users liking. This property of rocks is mainly controlled by mineral composition as minerals with different colours will impart colour. Some specific texture and proper polishing will enhance this property.

2.6 Aggregate for Concrete

It is a construction material which when bounded with cement as a conglomerated mass forms concrete, mastic, mortar and plaster. *Coarse aggregate* used as part of concrete is natural rock pieces or crushed rocks that are retained on ¼ inch sieve. Fine aggregate comprises sand or crushed rocks passing through ¼ inch sieve. Here the emphasis is given to coarse aggregate whose physical, mechanical and chemical properties are important for durability and strength of concrete. Aggregates can be mined from glacio-fluvial, alluvial and fluvial terrace deposits or by crushing rocks. In natural aggregate deposits quality control is difficult as it may have mixed rock types. Artificially crushed aggregates have almost similar quality because of the fact that single rock mass is being quarried and crushed. As aggregates constitute75% volume of concrete its property is largely controlled by the soundness and effectiveness of aggregate-cement bond.

2.6.1 Physical Properties: The important physical properties are size, gradation, shape, surface texture, and coatings of aggregates. These properties show marked difference in natural and crushed aggregates.

2.6.1.1 Size: Within the coarse aggregate size may differ as per the requirement of concrete. For ease in working with concrete or to control slump in concrete the usual size varies from 30 to 50 mm. It is easy to get aggregate of required size from aggregate crushers because of screening facility as compared to natural aggregates where there is always a chance of mixing of different sizes.

2.6.1.2 Gradation: The grading defines the presence of different sizes of rock pieces in an aggregate deposit. Limited size range makes an aggregate poorly graded while presence of different sizes makes it well graded. The well graded aggregate will increase the workability as well as require lesser amount of cement. Grading can easily be controlled in artificially crushed aggregate by proper mixing as compared to natural aggregates whose grading depends upon the energy during its deposition.

2.6.1.3 Shape: The shape of natural aggregates are controlled by the mode and distance of transportation apart from the presence of parting planes such as bedding, lamination, foliation or cleavage planes. The breaking along these parting planes will make aggregates two dimensional. The rocks devoid of such partings will have equal probability of wear and tear from all the side resulting into three dimensional shapes. For example mineral quartz with no cleavage plane will be three dimensional in shape irrespective of being rounded or angular as part of sand or gravel deposits as compared to feldspar minerals which have two strong cleavage planes which will make it two dimensional. With same analogy granite, basalt and quartzite rocks which are devoid of any partings will give three dimensional aggregate while gneiss, schists, phyllites, sandstone, limestone etc. with parting planes may give two dimensional aggregates. The equant shape aggregate are better than the one dimensional ones. Apart from being equant the spherical shape of aggregate may increase workability of concrete mix, require less cement as compared to harsh, irregular and sharp edged aggregates which not only decrease the workability but also increased cement content.

2.6.1.4 Surface Texture: The outer most surface of the individual aggregate pieces are different from its interiors because of the fact that it is this surface which remain in direct contact with processes of weathering and erosion. The outer surface is usually smooth, pitted, weak, scaly and porous. This results in weak bonding with cement and is a very common problem with natural aggregates. Artificially crushed aggregates are usually free from this problem as its surface are freshly broken hence are clean, rough and strong.

2.6.1.5 Coatings: Due to transportation of natural aggregates, weathering and due to continuous percolation of water through the aggregate deposits decantation of clays and precipitation of salts and growth of organics take place around the rock pieces. All these cause development of weak coating around aggregates which not only act as a deleterious material but are also detrimental for cement and inhibits bond making with aggregate. Again this problem is less common in artificially crushed aggregates.

2.6.2 Mechanical Properties: The important mechanical properties desirable for rocks to be used as aggregate include hardness, toughness, crushing strength, hydrophobic and binding properties.

2.6.2.1 Hardness: When two or more pieces of rocks in contact with each other move then they rub each other and may produce powder depending upon their resistance to abrasion. As such aggregate once get set with cement and form concrete they rarely undergo such process. But still rocks with high resistance to abrasion are better choice as aggregate because it is the high strength rocks only which will have higher resistance to abrasion which is actually controlled by mineral content and their interlocking or induration. *Dorry's* or *LosAngele's AbrasionTests* can be used for knowing the abrasive hardness (explained later).

2.6.2.2 Toughness: On one hand concrete rarely undergo repeated or dynamic loading but on the other hand it is the most important load bearing element, where aggregates are subjected to continued load throughout its life. Hence, toughness is important parameter for aggregates to be used in making of durable high strength concrete. *Aggregate Impact Test* can be used to work out this property (explained later).

2.6.2.3 Crushing Strength: Crushing strength of aggregate is important in a sense of deformation under self-weight/load or under dynamic load which may act from time to time. A standard *Crushing strengthTest*, can be employed (explained later) to measure this property.

2.6.2.4 Binding Properties: To make concrete, aggregates are to bind with cement which is usually made by pulverization, calcinations of limestones and mixing of alumina, called as *OrdinaryPortlandCement* (OPC). Tests carried out on felsic rocks i.e. rich in quartz and feldspar (granite, quartzite) suggest much better chemical affinity with OPC, as compared to mafic rocks (basalt, gabbro) as far as binding is concerned. While, mafic rocks have much better binding with tar, due to presence of iron and ferro-magnesian minerals such as haematite, magnetite, pyroxene, amphibole etc.

2.6.2.5 Hydrophobic Properties: The cement used for binding aggregate, works at its best when optimum amount of water, which is used in the mix for hydration process to take place and for concrete to get desired strength. Excess water will be detrimental for hydration process involved in controlling the setting process of concrete and may lead to bleeding. While low amount of water will reduce the slump hence workability of concrete emplacement. Vesicular volcanic igneous, foliated metamorphic and porous sedimentary rocks are hydrophilic rocks as they absorb water which may not only impede the process of setting but also being excess to the system may become alkaline solution and start forming silica gel. All non porous rocks are hydrophilic as they cannot absorb water hence good for aggregate.

2.6.3 Chemical Properties:The rocks used as aggregate should behave as inert material. Apart from aggregate which is comprised of minerals (chemical compounds), cement and water too has chemical potential. Unwanted chemicals, using water as carrier can come from any quarter. Water being very good solvent can dissolve different elements and can easily become chemically acidic, basic or organic solutions by dissolving different materials and become harmful to making of concrete. That is why it has been said that the water which is fit for human consumption should be used for making concrete also. Some chemicals should especially be watched as they are highly detrimental for concrete and can sneak in to concrete either during its making or afterwards through micro pores or micro fractures. Presence of *clay* and *mica* in sand being weak, absorptive, and expansive can be detrimental for strength of concrete. *Pyrite* found in sand weathers and dissolved in water releases sulphur and forms weak sulphuric acid and enhances rusting process in reinforcement. *Salts* can precipitate from water or may come from sand especially in arid climate may result into efflorescence in concrete, expansion of cracks in concrete and corrosion of reinforcement. Similarly *Sulphates and Sulphides* are commonly found as gypsum ($CaSO_4$), pyrite (FeS_2) in sand. The iron, sulphide and sulphates both can get oxidised and hydrated resulting into volume expansion especially in warm humid tropical climate. Sulphates dissolved in water can form sulphuric acid which may not only react with cement and aggregate material but also result in corrosion of reinforcement. *Organic substances*from dead flora and fauna can easily come in through sand are also deleterious for concrete or mortar. Water used for making concrete from standing water body having algae, and plant growth should also be used with caution. The presence of organics inhibits hydration process of cement and concrete may not achieve full strength.

2.6.3.1Alkali aggregate reaction:Alkalis (Na_2O and K_2O) are common chemical components of many minerals present in rocks used as coarse aggregate as well as a component of sand used as fine aggregate. For example feldspar, KAl_3SiO_8; plagioclase, $NaAlSi_2O_8$; muscovite, $KAl_3Si_3O_8(OH,F)_2$ etc., can release sodium and potassium into water which have high reactivity with free silica i.e. silica not properly bound in crystal lattice of silicate minerals. The reaction between alkali solution and free silica forms a gel like solution. This reaction is called as *alkali-aggregate reaction*. Being high in volume and low in density it creates internal osmotic stresses leading to cracking of concretes. Being low in density, it starts rising along micro-cracks, until it reaches the outer surface of the concrete, leaving it cracked. The free silica is common in aggregate as well as in sand if they are rich in different crypto-crystalline hydrous silica, $SiO_2.nH_2O$ (opal, chalcedony), amorphous glass with free silica (tridymite) in volcanic rocks.

Hence, the rocks with high content of feldspar, plagioclase, muscovite, biotite and tourmaline such as granite, grano-diorite, rhyolite etc. should be avoided as aggregate as they may release alkalis in water. While presence of volcanic rocks such as tuff, andesite, rhyolite etc. may have chances of high free silica content hence should be avoided. Petrographic examination of rocks can be used to assess rocks with high content of cryptocrystalline and amorphous silica which should not go beyond 5% by volume.

2.7Road Metal

Rocks are extensively used in construction of roads. Road metal forms the most important part of roadways, runways and highway as base course, load bearing course and wearing course. The weight of running and standing wheels subject rocks to compressive stresses while impact by landing aircrafts tests the toughness of rocks. The horizontal smearing forces due to running wheels test abrasion resistance of rocks.

2.7.1 Classification: The rock materials used in construction of highway-runway construction are classed as:

(i) *Load Bearing*: Carry vehicular load and transmit to sub base material or lower sub grade courses. 45 – 90 mm sized graded rocks are usually preferred in lower most layers followed by 45 – 63 mm layer. The best rocks if available are quartzite, basalt, dolerite and granite.

(ii) *Binder*: Used as filler as well as binding material over the load bearing rocks. It may be fine to coarse sized material comprising clay, silt, crusher dust, hydrated lime, brick kiln dust etc. depending the type of road and availability, mixed in presence of optimum amount of moisture.

(iii) *Void Filling Material*: Powder like fine grained material but may not have the binding property. Rock dust, limestone dust, ground silica, brick slag etc. are used to fill the irregularity of the lower course.

(iv) *Wearing Course*: 22.4 - 53 mm sized graded chips of rocks cemented with Portland cement or bitumen forms the top of the roads hence should be of rocks which are non porous and with high resistance to abrasion. The best rocks are quartzite, granite and basalt.

As such two kinds of roads are made namely Rigid Pavement made of concrete mix with reinforcement and Flexible Pavement made of bituminous mix. The rigid pavements are made mostly in regions with high rainfall or in areas of water logging but are not successful for highways. The flexible pavement are more common and has the tendency to slightly flex when load by vehicle is exerted, passed on lower layers and then reverts back to original condition as the wheel load is withdrawn. The rock material used for rigid pavement should be those which can bind well with Ordinary Portland Cement such as quartzite and granite while for flexible pavement it should bind well with bitumen such as basalt and dolerite. The important properties to be tested for road material include attrition, abrasion, toughness and stripping.

2.7.1.1 Attrition Test: *Deval's Testing Machine*, an apparatus with two cylinder of 20 cm diameter and 34 cm length inclined to 30^0 and fixed along an axis about which it can rotate @ 30 revolution per minute (Fig. 2. 10). 5 kg (M_1) of 60 mm sized rocks, washed and dried at 100 - 115 ^{0}C are put in two cylinders and are subjected to rotation for 5 hours. The process of rotation will subject rocks undergo attrition. After five hours rocks are taken out of cylinder and sieved through 1.5 mm sized mesh. The retained material is reweighed (M_2) percentage of loss in wear is obtained by formula:

$$\text{Percentage of wear in attrition} = \frac{M_1 - M_2}{M_1} \times 100$$

The loss due to attrition and wear, if is less than 3% then the rock is good and if almost 3% then just while more than 3% loss will make a particular rock unsatisfactory.

Figure 2.10: Deval's Test apparatus for attrition testing

***2.7.1.2 Abrasion Test*:** *Los-Angels' Abrasion Test* is used for testing resistance to abrasion of coarse rocks used as road material. The machine (Fig. 2.11) consists of circular drum of 70 cm diameter and 50 cm length mounted on a horizontal rotary axis.

Figure 2.11: Los Angeles Test apparatus for attrition testing

Iron balls of 48 mm diameter and 390 to 445 gm weight, used as *abrasive charge* along with rock pieces to be tested. The size of charge ball varies with size of rock pieces whose weight varies from 5 to 10 kg ($\mathbf{M_1}$) depending upon its grading. The drum is rotated at the speed of 30 - 33 revolution/minute for 500 times. The aggregates are taken out and are sieved through 1.7 mm mesh. The retained rock pieces are washed and weighed ($\mathbf{M_2}$) in terms of percentage as:

$$\text{Los} - \text{Angels' abrasion value } = \frac{M_2}{M_1} \times 100$$

Larger is the value weaker is the rock material and vice-versa (table 2.7).

Table 2.7 Permissible Los-Angels' abrasion values for use of rock material for roads.

S. No.	Los-Angels' abrasion value (%)	Recommended Uses
1	50	Base course for bitumen bound macadam roads
2	40	Base course for water bound macadam (WBM) roads
3	40	Bituminous penetration macadam roads
4	35	Bituminous surface dressing (Pre-mix carpeting)
5	30	Bituminous concrete road
6	15	Cement concrete

***2.7.1.3 Toughness Test*:** The rocks as road metal are subjected to dynamic loading frequently due to wheel loads. Rocks may undergo crushing if weak. Hence they should be tested for their toughness by *Aggregate Impact Tester* (Fig. 2.12).

Figure 2.12: Aggregate Impact tester

Rock pieces passed through 12.5 mm and retained on 10 mm sieve, 5 kg in weight (**M_1**) are put in cylindrical mould of 10.2 cm, internal diameter and 5 cm of height. The impact hammering is imparted by 15 kg, 10 cm diameter hammer falling from a height of 40 cm. After three blows material is taken out, sieved through 2.36 mm mesh. The mass of the material passed (fines) is taken as M and expressed in percentage for *Impact Toughness* as:

$$\text{Impact toughness value } = \frac{M_2}{M_1} \times 100$$

Higher is the amount of fines weaker will be the rock and higher will be the impact toughness value. The value should be less than, 30% for rocks to be used as surface course, 40% for base course and 50% for sub base course.

2.7.1.4. Stripping Test: A qualitative testing for adhesion of bitumen to the surface of road metal is carried out by mixing 5% bitumen binder at specified temperature. Coated rocks are immersed in water for 24 hours. Some bitumen may come off and float. The percent uncoated surface is assessed by visual inspection. It should not be more than 25% of the total surface area as per IRC recommendations.

2.8 Rail Ballast Railballast act as side and bottom cushion for rail track andtransfer the train load to sub grade apart from holding the track at place. Mostly crushed rocks or natural rock debris are used as rail ballast. Sometimes, blast furnace slag is also used depending upon its availability in huge quantity from ore smelting industries.

Toughness, crushing strength and resistance to abrasion are important mechanical properties which should be ensured while deciding the rock type for rail ballast.

Some physical properties such as density, porosity of rocks and size grading to ensure proper drainage through them are also important. The requirement of strength properties are more in case of rail ballast as compared to road metal. The resistance to abrasion is also important because the powder generated during rubbing of ballast with each other at times when they are subjected to vibration of tracks during movement of trains. The powder when comes in contact of moisture becomes hard and act as cement between ballasts. The cemented ballast becomes rigid and the very purpose of cushioning is lost. That is why non porous rocks and drainage is important. Rail ballast is subjected to cleaning from time to time to remove this powder. Quartzite, basalt, dolerite, granite and hard silica cemented sandstones fair good while limestone, dolomite, pegmatite and mica rich metamorphic rocks fair bad as rail ballast.

2.8.1 ***Resistance to Abrasion***: Itis measured as *coefficient of hardness* by using *Dorry's Abrasion Testing Machine* (Fig.2.13).

The weighted dry sample of 2.5 cm diameter and height is kept in one of the funnel under the pressure of 12.25 kg weight in such a way that its lower part touches the rotating disc. From the other diagrammatically opposite funnel sand is poured at constant rate. The revolution of disc is set @ 28 revolution/minute and after 1000 rotations sample is taken off and re-weighed as:

$$Coefficient\ of\ hardness = 20 - [\frac{\text{loss of mass in gm}}{3}]$$

Figure 2.13Dorry's Abrasion Test machine

2.9Energy Dissipaters: Along shores to counter wave action, along river bends to counter water current, below falling water of spillways where the force of water is very high and to prevent erosion on upstream side of earth dams, rocks are used as energy dissipaters and as protection veneer. These rocks are also called as *Rip Rap*(Fig. 2.14 a). The rocks with interlocking texture, non porous nature, high hardness and toughness values showing resistance to weathering will be good for this job. Concrete *tripods* and *tetra pods* are also used for the same purpose, a typical scene around many coastal areas (Fig. 2.14 b).

Figure 2.14 (a) Rip Rap around a sea promontory in Kozhikode and (b) Tripods made of concrete in Goa, laid along wave fronts to prevent erosion.

2.10Site Rocks

There are three kinds of ground on which buildings are founded i.e. consolidated ground (rocky), semi-consolidated ground (weathered rock and/or soil) and unconsolidated ground (soil). Most of us are familiar with soil as the ground where structures are founded after calculating probable load exerted by the structure and bearing capacity of the soil horizons. While in areas where there is thin to thick veneer of weathered material or soil, structures depending upon their size and importance are founded on soil or can be placed on the rock after stripping the soil off or through pile foundation. Similarly in rocky areas roads, rails, buildings, bridges, dams etc. directly rest on rocks. As we know that even the weakest rocks are stronger than the strongest soil hence, can easily bear the normal engineering loads. But for big and mega structures rocks too cannot be taken for granted and need all kind of engineering scrutiny. The area of influence on rocks will depend upon the size of the structure for example buildings, groins, retaining wall or bunkers will involve lesser area as compared to subsurface power stations, tunnels, dam and reservoirs which will involve much larger area. Bigger is the structure, larger the area of influence, more the variation of rock mass countered will require much greater engineering scrutiny i.e. site characterization.

The strength of rock masses are subjected to forces in two different ways for example laying foundation of skyscrapers, retaining walls, groins, dams, etc. will involve loading on rock mass while construction of underground structures such as bunkers, subways, tunnels, power stations, mines etc. involves excavation hence unloading of rocks. In both the cases stresses are generated other than the residual stresses already present in rock mass. All these stresses combined, test elastic and strength properties of rock mass. For the safety of the structure detailed site characterization and evaluation of rock mass in terms of their engineering behaviour is of utmost importance. The detailed and systematic analysis of site characterization will be dealt in detail in the next chapter while methods of rock mass evaluation are being dwelt upon in the following sections.

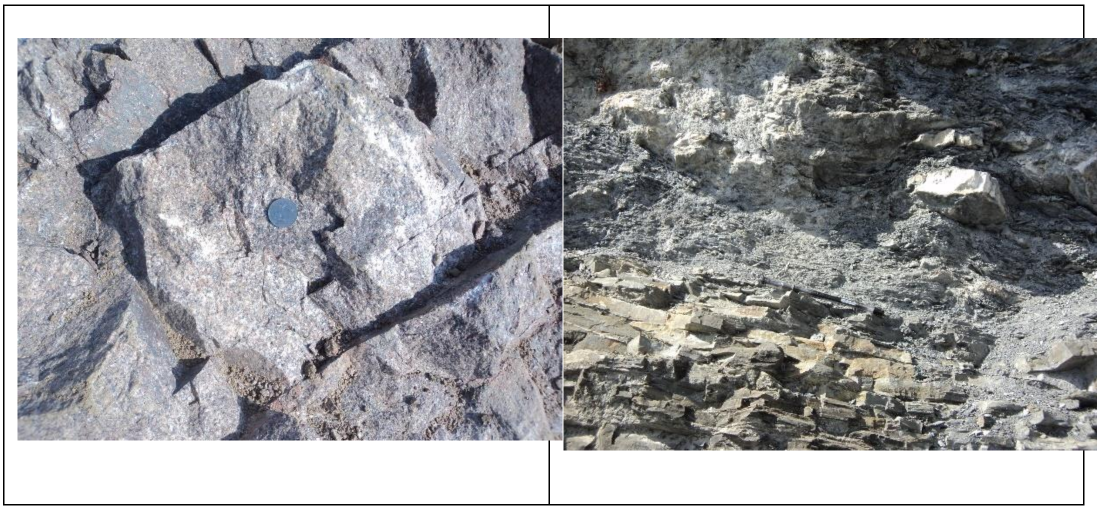
2.10.1 *Rock Mass*

Depending upon the construction project, planning is required from the logistic, designing and operational point of view. In the case of rocky ground the most relevant and critical rock mass parameters are to be identified for a particular project. This will help in making parlance amongst rationale and feasibility of the project, site geology as well as design objectives. To achieve these objectives the first step is to identify and classify a rock mass in a way that can be understood by all the players involved in the project, may it be a geologist, civil engineers involved in design and in operation, contractors, supervisors and even to some extent workers. This has led to development of engineering classification of rock mass to:

1. Identify the most significant parameters influencing the behaviour of rock mass.
2. To divide rock mass formation of the site into groups with similar behaviour or quality.

3. Provision of key factors of each rock mass class identified for ready reference.
4. Generate quantitative data and guidelines for engineering design.

As we know that the in-situ rock mass is an assemblage of intact rock blocks (Fig 2.15 a) separated by natural discontinuities such as joints, bedding and foliation planes, shear zones and faults. These blocks may vary from fresh unaltered rocks to intensely weathered disintegrated rocks. To applied stresses during construction the rocks will respond on the basis of their own strength as well as rock blocks. Hence we have to consider the characteristics of rock material as well as inter action amongst different rock blocks along discontinuities. If discontinuities are widely spaced with respect to the area of engineering structure then rock material properties will be up front, in case discontinuities are very closely spaced then the onus shall be on fracture properties (Fig 2.15 b). In most of the engineering classification of rock mass discontinuities have been found to play key role.



a **b**

Figure 2.15(a) Rocks with joints at comparatively larger distance in granite (Lalitpur) as compared to (b) closer joints in slates (Nainital).

The other important factors which play important role in overall behaviour of rock mass is presence of ground water and in the case of deep excavations *insitu* stress field is also important.

The compilation of information and data are fundamental to empirical design approach used in rock engineering throughout the world and are continual processes starting from preliminary site investigations to operational stage. These classifications are based on practical experiences and have improved from time to time with advancement in construction technology. It started with one of the first and renowned Terzaghi's Rock Load Theory devised in 1947 for designing support for tunnels to the most latest one given by Hack et al. (2002) to address the problem of characterization of joints. The main aim was to move from qualitative analysis to quantitative one because for designing civil engineers need numbers not the 'adjectives'. Various rock mass classifications originated, covered various geo engineering projects related to tunnels, chambers, mines, slopes, dam, foundations, excavations etc. Some of the important rock mass classifications are listed in table 2.8.and will be discussed in coming modules.

Table 2.8: Important Engineering Classification of Rock Mass

Classification Name	Originator/Year	Country	Applications

1. Rock Load Theory Terzaghi/1946 USA Tunnelling/Steel Support

2. Stand-Up Time Lauffer/1958 Austria Tunnelling

3. New Austrian Tunnelling Method Pacher et al./1964 Austria Tunnelling

4. Rock Quality designation/RQD Deere et al./1967 USA Core Logging/Tunnelling

5. Rock Structure Rating Concept Wickham et al./1972 USA Tunnelling

6. Rock Mass Rating System/RMR Bieniawski, 1973 South Africa Tunnel, Mine, Slope,Foundation

7. Rock Mass Quality/'Q' System Barton et al./ 1974 Norway Tunnels, Chambers

8. 'Q' System Extension Kirsten/1982 South Africa Excavability

9. 'Q' System Extension Kirsten/1983 South Africa Tunnelling

10. Strength -Size Franklin/1975 Canada Tunnelling

11. Basic Geotechnical Description ISRM/1981 General Communication

12. Unified Classification Williamson/1984 USA General Communication

13. Rock Mass Jointing Palmstrom/2001 Norway Joint Characterization

14. Slope Stability Probability Hack et al. 2002 Holland Slope Stability

SUMMARY

The rocks are used as construction material from time immemorial and also as founding ground. Its use in different parts of small dwellings to large buildings is very much evident around us. Their large scale uses in making forts, bridges, dams, retaining walls, historical and cultural murals have shown its versatility as construction material. The modern day construction industry thriving on concrete heavily depends upon rock aggregate and cement sequestered from rocks. One cannot think of construction of roads and laying of railways without the rocks used in bulk.

A large part of the world and of our own country has rocky ground exposed or present at very shallow depths, under the thin veneer of soil, hence amenable to become founding ground. At places the rocks are forming insurmountable edifices, or to ease out traffic congestion tunnels are the only option. Many other underground works from power stations to strategic storage etc. are made through rocks. As such even a weakest rock may be stronger than the strongest soil. Hence, founding small structures on rocks are not a big problem. But, laying the foundation of mega structures which may exert immense amount of loading hence geotechnical properties of even a strong site rock becomes very important.

The above mentioned uses of rocks demand different kinds of physical, mechanical, chemical and aesthetic properties termed as geotechnical properties, broadly depend on physical appearance, strength and stability of constituent mineral, mode of interlocking of these minerals and presence of bedding/foliation plane and fracture. These broad geotechnical properties are basically related to mineral composition, texture and structures in rocks. Of many different geotechnical properties some are very important for specific uses such as strength, for rocks to be used as dimension stones in heavy structures, impactstrength for road metal, abrasionresistance for rail ballast, inertness to chemical reactions for aggregates, appearance for rock cladding and softness for rock carvings etc.

Similarly, construction of structures over the rocks or underground structures involves proper studies in terms of its bearing capacity, shearing strength, redistribution of stresses in rock mass due to loading or unloading, etc. need proper scrutiny, analysis and construction measures for safety and longevity of structures.

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. Same rock quarried from two different places may have profound variations. Hence proper assessment of rocks for specific use in terms of physical and mechanical properties is a must to ensure aesthetics, safety, strength and longevity of structures within the purview of economy. The important properties can be classed into physical which include colour, anisotropy, hardness, density, porosity and permeability. The important mechanical properties are compressive, shear, flexural and tensile strengths. The elastic properties such as modulus of elasticity and Poisson's ratio are also important depending upon the uses of rocks. Resistance to attrition, abrasion, weathering, fire and frost are some specific properties.

Chemical Properties are not very important but the structures in contact with saline water or rocks used in industrial construction where they may come in contact with acidic, basic or organic fluids need to be properly selected. In normal construction conditions where concrete is being used the problem of alkali aggregate reaction should always be taken care off.

When rocks are to be used as founding ground (site rocks) or subjected to excavation for underground structures detailed planning and analysis are for designing, construction and operation. As we know that the in-situ rock mass is an assemblage of intact rock blocks separated by natural discontinuities such as joints, bedding and foliation planes, shear zones and faults. These blocks may vary from fresh unaltered rocks to intensely weathered disintegrated rocks. To applied stresses during construction the rocks will respond on the basis of their own strength as well as rock blocks. Hence one has to consider the characteristics of rock material as well as inter action amongst different rock blocks along discontinuities. If discontinuities are widely spaced with respect to the area of engineering structure then rock material properties will be up front, in case discontinuities are very closely spaced then the onus shall be on fracture properties. In most of the engineering classification of rock mass discontinuities have been found to play key role. The other important factors which play important role in overall behaviour of rock mass is presence of ground water and in the case of deep excavations *insitu* stress field is also important.

The most relevant and critical rock mass parameters are to be identified for a particular design and project. This will help in making parlance amongst rationale and feasibility of the project, site geology as well as design objectives. To achieve these objectives the first step is to identify and classify a rock mass in a way that can be understood by all the players involved in the project, may it be a geologist, civil engineers involved in design and in operation, contractors, supervisors and even to some extent workers. Engineering rock mass classifications based on compilation of information and data relevant to particular construction project can build a complete conceptual model of founding rocks to work out all geological complexities and geotechnical properties which may control the stability of the structure. The main aim is to move from qualitative analysis to quantitative one to be used in designing by civil engineers. Various rock mass classifications originated, covered various geo-engineering projects related to tunnels, chambers, mines, slopes, dam, foundations, excavations etc. The compilation of information and data are fundamental to empirical design approach used in rock engineering throughout the world and are continual processes starting from preliminary site investigations to operational stage. These classifications are based on practical experiences have improved from time to time with advancement in construction technology from “Karl Terzaghi’s Rock Load Theory” to present day rock mass classifications involving finite element methods. The engineering classification of rock mass on the basis of most significant parameters influencing the behaviour of rock mass and its division into groups with similar behaviour or quality becomes a key factor to generate quantitative data and guidelines for engineering designs.

Frequently Asked Questions

Q. 1. What do you understand by "rock material" and "rock mass"? List its uses.

The "Rock Material" refers to the intact rock within the framework of discontinuities at the level of its texture. The "Rock Mass" refers to *insitu* rocks encompassing all the discontinuities, alteration induced by weathering and residual stresses. It is from the rock mass, rocks are extracted and are used as construction material, elsewhere. While rock masses are subjected to construction over, as founding ground or inside them as manmade cavities, in *insitu* conditions. Some important usages of rock materials are as building stones for making columns, walls, flooring, roofing, polished slabs, cladding of buildings, pavement slabs. As dimension stones for construction of fort walls, bridge piers, retaining walls, lighthouses, abutments, dams, sea walls, jetties, dikes etc., as large blocks. As aggregates for making plaster, mortar, concrete. As Road Metal for base and wearing course. As Rail Ballast for side bottom cushion for rail tracks. Energy Dissipaters along shores, river bends, water fronts, spillway dentitions to lessen the wave and current energy to prevent erosion.

Rock Mass can be defined as site rocks which will have foundation over it or will host any underground structure. Here it not only has properties of that very rock material but also involves its weathering state, in-situ stresses, all kinds of discontinuities and related parameters. These parameters can be identified and measured to model a rock for any particular construction project in rocks.

Q. 2. Discuss about different physical properties of rock as construction material.

The physical properties are also called as index properties as they are used for identification and classification of rocks. These properties are inherited at the time of formation of rocks but may be subjected to change in the environment of weathering. The important physical properties are:

Colour: The colour of a rock only matters when it is used for aesthetic purposes or for flooring and rock cladding. The colour of rocks depends on the minerals present and is termed as *leucocratic*, *mesocratic* and *melanocratic* for light, medium and dark colours respectively. The true colour of rocks can only be seen on freshly broken surface as the long exposed part of rocks get stained in brown to grey colours due to weathering. For denoting the colour of rocks *Rock Colour Charts* can be used or following numeral can be allotted to convey the true rock colour.

Anisotropy: In a rock if constituent minerals are randomly oriented then rock is said to have *isotropic fabric* and if minerals show some preferred orientation then rock is said to have *anisotropic fabric*. Anisotropic rock shows directional properties for example it may have different strength along different directions or it may have different permeability in different directions as compared to isotropic rocks which will have these same all along.

Hardness: Hardness of a rock depends upon the hardness of minerals present in a rock. A mono-minerallic rock will have similar hardness all through the rocks while poly-minerallic rock will show average value. It is easy and common to use Moh's hardness scale for knowing the relative hardness of rocks. Another scale known as Vicker's scale is used to get absolute hardness values based on micro indentation hardness.

Porosity: The relative proportion of voids and solids in terms of percentages is called as porosity. The voids may have into them, water, air, oil, gas etc. Completely dry rocks will have only air (gas) and completely saturated rock will have only water or oil in pores. Other related parameters are *Degree of Saturation* and *Moisture Content*. Porosity is controlled by texture of rocks. Most of the sedimentary rocks being granular are generally porous, foliated metamorphic rocks show negligible porosity along foliation planes while igneous and non foliated metamorphic rocks are practically non porous. Some volcanic rocks may possess porosity owing to the presence of vesicles. Weathering may increase the porosity of rocks. Rocks with high porosity show low density and low strength. High moisture content and high degree of saturation also make rocks weak.

Permeability: The interconnection of pores in a rock constitute *Primary Permeability* and being porous only sedimentary rocks show permeability that too very low. The presence of micro discontinuities such as fractures, lamination and foliation planes may enhance the porosity and permeability (secondary). The permeability as such is not required in day to day uses of rock material and an approximation can be made based on its porosity. In situ or field permeability is more important and is usually higher than the rocks tested in lab because of the presence of micro discontinuities. The field values may go much higher depending upon the number of joints per unit area their aperture and their interconnection.

Density: It is defined as the mass per unit volume of the rock. It can be expressed as dry density, bulk density and saturated density. When rock is completely dry i.e. pores contain only air, then it is dry density, when sample is in normal condition i.e. rock may have some moisture and air, then it is bulk density and when sample is completely saturated with water then it is termed as saturated density. The density of rocks differs because of different constituent minerals and/or porosity. The density of commonly found rocks varies from 2.60 to 2.80.

Durability: Durability can be defined as resistance to natural deterioration. Rocks on their places of exposure are subjected to weathering and get deteriorate, resulting into overall reduction of strength. The durability of rocks at its natural exposure as well as the site of its use is controlled by overall climate of the area, structures, texture and mineral composition of rocks. The mode and depth from which rock material has been sequestered will control its quality. The surficial material will be of low quality as compared to material excavated from deeper mines. The material can further deteriorate with time depending up on the climatic setup of the place it is being used. One can see in historical monuments, discolouration, loosening of grains, chipping, exfoliation and spalling. Nowadays due to increasing atmospheric pollution, acidic rain has become a common phenomenon which is very injurious to exposed parts of the buildings including rocks. Rocks which are porous, coarse grained and rich in feldspar carbonate and clay minerals are affected more. To measure the durability of rocks *Slake Durability Test* can be used.

Q. 3. Discuss about different mechanical properties of rocks as construction material.

The most important mechanical property of rocks is its strength. Rocks possess strength due to coherence and interlocking of constituent mineral(s) as well as its mineral constituents. A mono-minerallic rock with random (isotropic) fabric will show similar strength all around but a poly-minerallic rock may show variation in strength from place to place more so if it has oriented (anisotropic) fabric. A rock may be subjected to different kinds of forces; in general rocks are very strong under compressive forces and are very weak under tensile forces. The shear and flexural strength lies in between. Different strength properties are also controlled by direction of force with respect to inherent layering in form of bedding, foliation and lamination planes.

The Compressive Strength of most rocks is greater than the applied engineering loads, except some clay rich and less indurate sedimentary rocks. The most standardised way of defining compressive strength is Unconfined Compressive Strength (UCS) of dry rocks. The other methods are ConfinedCompressive Strength, Point Load Strength, Schmidt Hammer Strength and Geological Hammer Strength.

Rocks used as construction material are rarely subjected to confining conditions. The Confined Compressive Strength actually replicates strength of rocks naturally placed underground, which increases greatly with depth because of increasing confinement and go beyond any significant engineering loading on or near the earth surface conditions.

For ready reference Point Load Strength is very important as it can be worked out readily on small sized samples without much dressing by using a portable machine. The values of point load strength can be collated and compared with that of UCS, using standard nomograms.

For indirect measurement of rocks in in-situ conditions Schmidt Hammer is very handy. It is a hand held cylindrical shape instrument which operates on spring loaded piston shaped hammer. The rebound values recorded are related to hardness/compactness/density of the sample which can be indirectly correlated to the UCS. The breaking effort using Geological Hammer weighing 800 grams to one kg, with one side blunt and other side tapering hammer head also gives indirect idea of rock strength.

Rocks are very commonly subjected to shearing stresses. It can be worked out using direct shear box test or punch shear test. The indirect method using Triaxial Test can also be used to determine two important parameters cohesion due to interlocking and friction angle of the fracture. Both the parameters increase with increase in confining pressure.

Rocks are very weak under tensile stresses and are rarely subjected to direct tensile stresses. Tensile stresses may be induced indirectly when rocks are used as slabs or beams. The direct tensile strength can be worked out by Dog Bone Test, but sample preparation and perfect testing is very cumbersome. Measuring indirect tensile stresses are more prevalent using Brazilian Test performed on a rock cylinder where compressive forces are resolved perpendicular to its direction into tensile stresses.

Some other mechanical properties are elastic properties where responses of rocks are measured at given level of stresses to corresponding strain. The important elastic properties or constants are Modulus of Elasticity and Poisson's Ratio. Many of these constants can be calculated by observing the deformation process on a sophisticated instrument which can measure minute deformations related to uniaxial and triaxial loading and unloading. The value of modulus of elasticity (E), denotes its strength, homogeneity, isotropy and continuity. The rocks can be classified as Quasi Elastic with E = 6×10^5 Kg/cm^2 to 11×10^5, Semi Elastic with E = 4×10^5 Kg/cm^2 to 6×10^5 and Non Elastic with E values less than 4×10^5 Kg/cm$^{2.}$

The Poisson's ratio (υ), relates lateral strain and axial strain within the elastic limit of any material. Most of the rocks show υ value ranging from 0.05 to 0.25. Weathered, soft and porous rocks show very low values as compared to non weathered, non porous and hard rocks. Some rocks do not show immediate increase in lateral dimensions despite the fact that axial shortening start taking place, the reason is ascribed to presence of micro cracks and pores into which grains/minerals start moving in causing decrease in length but no accompanied increase in diameter.

Q. 4. What are the basis and parameters of "Engineering Rock Mass Classifications"?

In the case of rocky ground as the founding rock few relevant and critical rock mass parameters are to be identified depending upon the nature of construction project. To achieve these objectives the first step is to identify and classify a rock mass in a way that can be understood by all the players involved in the project, may it be a geologist, civil engineers involved in design and in operation, contractors, supervisors and even to some extent workers.

In case of rock mass five major aspects are important which are as follows:

(a) Weathering state of rock mass and its continuity in subsurface.

(b) Incidence and nature of joints present in rock mass

(c) Presence of shear zones, fault plane and zone

(d) Presence of groundwater in rock mass

(e) Residual stresses in rock mass and their vertical / horizontal continuity with respect to the alignment of the proposed structure.

Of these five aspects joints play the dominant role in controlling the behaviour and response of rock mass to civil engineering loading or unloading. Based on the detailed analysis of above parameters, following aspects are needed to be worked out:

I. Identify the most significant parameters influencing the behaviour of rock mass.

II. To divide rock mass formation of the site into groups with similar behaviour or quality.

III. Provision of key factors of each rock mass class identified for ready reference.

IV. Generate quantitative data and guidelines for engineering design.

Q. 5. What are important "Engineering Rock Mass" classifications and their uses?

Engineering rock mass classifications refer compilation of information and data to build a complete conceptual model of founding rocks to work out all geological features and geo mechanical properties which may control the stability of the structure. The compilation of information and data are fundamental to empirical design approach used in rock engineering throughout the world and are continual processes starting from preliminary site investigations to operational stage. These classifications are based on practical experiences and have improved from time to time with advancement in construction technology. It started with one of the first and renowned Terzaghi's Rock Load Theory devised in 1947 for designing support for tunnels. It was followed by Core Recovery Percent and Rock Quality Designation (RQD), given by Deer in 1967, Geomechanics Classification (RMR), of Bieniawski in 1972 and Rock Mass Quality (RMQ) given by Barton et al in 1973. These classifications were modified and were extended to many other specific projects.

The main aim was to move from qualitative analysis to quantitative one because for designing civil engineers need numbers not the 'adjectives'. Various rock mass classifications originated, covered various geo engineering projects related to tunnels, chambers, mines, slopes, dam, foundations, excavations etc. Some of the important rock mass classifications and their uses are as follows:

Classification Name	Originator/Year	Country	Applications
1. Rock Load Theory	Terzaghi/1946	USA	Tunnelling/Steel Support
2. Stand-Up Time	Lauffer/1958	Austria	Tunnelling
3. New Austrian Tunnelling Method	Pacher et al./1964	Austria	Tunnelling
4. Rock Quality designation/RQD	Deere et al./1967	USA	Core Logging/Tunnelling
5. Rock Structure Rating Concept	Wickham et al./1972	USA	Tunnelling
6. Rock Mass Rating System/RMR	Bieniawski, 1973	South Africa	Tunnel, Mine, Slope,Foundation
7. Rock Mass Quality/'Q' System	Barton et al./ 1974	Norway	Tunnels, Chambers
8. 'Q' System Extension	Kirsten/1982	South Africa	Excavability
9. 'Q' System Extension	Kirsten/1983	South Africa	Tunnelling
10. Strength -Size	Franklin/1975	Canada	Tunnelling
11. Basic Geotechnical Description	ISRM/1981		General Communication
12. Unified Classification	Williamson/1984	USA	General Communication
13. Rock Mass Jointing	Palmstrom/2001	Norway	Joint Characterization
14. Slope Stability Probability	Hack et al. 2002	Holland	Slope Stability

Multiple Choice Questions (Quiz)

1. The rock with maximum compressive strength is

(a) Granite (b) Basalt (c) Sandstone (d) Limestone

2. Which of the following rock has anisotropic fabric?

(a) Dolomite (b) Dolerite (c) Schist (d) Breccia

3. Which of the following rock will have maximum flexural strength?

(a) Slate (b) Quartzite (c) Shale (d) Conglomerate

4. Which of the following properties are tested to workout weatherability of rock material?

(a) Punch Shear (b) Impact Strength (c) Slake Durability (d) Los Angels

5. Which rock mass classification is based on drilling and core recovery?

(a) RSR (b) Strength - Size (c) Unified Classification (d) RQD

Suggested Readings:

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