LECTURE 3

PHYSICAL PROPERTIES Contd...

2.3.1.4 Permeability

Permeability is a measure of the ease with which fluids will flow though a porous rock and is also an intrinsic property. Just as with porosity, the packing, shape, and sorting of granular materials control their permeability. Although a rock may be highly porous, if the voids are not interconnected, then fluids within the closed, isolated pores cannot move. The degree to which pores within the material are interconnected is known as effective porosity. Rocks such as pumice and shale can have high porosity, yet can be nearly impermeable due to the poorly interconnected voids. In contrast, well-sorted sandstone closely replicates the example of a box of marbles cited above. The rounded sand grains provide ample, unrestricted void spaces that are free from smaller grains and are very well linked. Consequently, sandstones of this type have both high porosity and high permeability.

Permeability is part of the proportionality constant in Darcy's law which relates discharge (flow rate) and fluid physical properties (e.g. viscosity), to a pressure gradient applied to the porous media:

$$v = \frac{\kappa}{\mu}\frac{\Delta P}{\Delta x}$$

Therefore:

$$\kappa = v\frac{\mu \Delta x}{\Delta P}$$

Where,

v = superficial fluid flow velocity through the medium (i.e., the average velocity calculated as if the fluid were the only phase present in the porous medium) (m/s)

κ = permeability of a medium (m^2)

μ = dynamic viscosity of the fluid (Pa s)

ΔP = applied pressure difference (Pa)

Δx = thickness of the bed of the porous medium (m)

In general rocks have very low permeability, less than 10^{-8} cm/s which in jointed rock mass is much higher around 10^{-4} cm/s even with very narrow aperture of joints <0.1mm. So the permeability in rocks depends on the number and kind of pores and joints present, pressure of water, direction etc. Some common rock types and their permeability co-efficient values are given here.

Table 2.3: Permeability coefficient for some common rock types

Rock type (intact)	**K_γ (cm/s)**
Sanstone	0.2-6 X 10^{-9}
Granite	0.5-2 X 10^{-10}
Limestone	1-12 X 10^{-12}
Schist	0.5-1.5 X 10^{-10}

Relation to hydraulic conductivity

The proportionality constant specifically for the flow of water through a porous media is called the hydraulic conductivity; permeability is a portion of this, and is a property of the porous media only, not the fluid. Given the value of hydraulic conductivity for a subsurface system, *k*, the permeability can be calculated as:

2.3.1.5 Electrical resistivity

Ability of rocks to conduct electrical current is called the electrical conductivity 'G' and the reciprocal of electrical conductivity is the electrical resistivity 'ρ'. Electrical resistivity is an intrinsic property of a material and the unit of measurement is the ohm meter (Ω.m). Resistivity is a measure of the ability of current to flow through a volume of earth material, which is the product of the resistance multiplied by a geometric factor to account for the subsurface volume. The apparent resistivity is the average resistivity over an equivalent uniform half-space. There exist a wide range of typical electrical resistivity of earth materials (Table 2.4). Electrical properties of rocks are affected by rock composition, clay and mineral content, porosity; fluid type, salinity and saturation, temperature; and grain size distribution etc. Obviously, rocks with metal oxides (hemaitites, bouxites etc) will have very low resistivity to electrical current. The different resistivity characteristics of rocks has tremendous application in the site investigation and prospecting.

Table 2.4: Typical electrical resistivity of earth materials

Material	**Resistivity (Ω.m)**
Clay	1-20
Sand (wet to moist)	20-200
Shale	1-500
Porous limestone	100-1,000
Dense limestone	1,000-1,000,000
Metamorphic rocks	50-1,000,000
Igneous rocks	100-1,000,000

2.3.1.6 Velocity Of Elastic Waves

Velocity of elastic waves generated artificially in a rock media is very helpful in characterizing the ground as different rock types posses different velocity. Moreover, in a same rock type, the velocity may change depending on the joint characteristics. This velocity of propagation in proportional to the quality of rock mass and usually massive igneous rocks will have relatively higher velocity, than metamorphic rocks and then the sedimentary rocks. The velocity of elastic waves depends upon many factors like, mineral composition, porosity, temperature, depth, direction etc.

Table 2.5: Typical elastic wave velocity of some rocks

Rock	Velocity (m/s)
Granite	4600-6200
Basalt	5500-6500
Gabbro	6400-7500
Gneiss	3500-7000
Marble	3700-7000
Sandstone	1500-4500
Shale	2000-4000
Limestone (Soft)	1700-4200
Limestone (Hard)	3000-6500

2.3.1.7 Thermal Properties

Thermal properties of rocks are described by means of coefficient of heat conductivity (λ) or by the thermal resistivity ξ (=1/ λ) or coefficient of thermal expansion.

Thermal expansion

The strain associated with one degree temperature change is called the coefficient of thermal expansion with dimension /°K, /°C or /°F. The thermal strain can be expressed as follows,

$$e = \alpha (T - T_o)$$

where, T_o is a reference temperature and T is the current temperature T.

When,

$T > To$ heating takes place. Here the thermal strain is positive and extension takes place.
$T < T_o$, cooling takes place. Here the strain is negative and contraction occurs. Values for the coefficient of thermal expansion of several rock types are given in Table 1.

Table 2.6:. Coefficient of thermal expansion for different rock types (Berest and Vouille, 1988)

Rock type	**α (10^{-6}) K^{-1}**
Basalt	5.4
Limestone	2.5-20
Granite	7.5-9
Sandstone	10
Marble	5.4-7

The longitudinal stress is equal to

$$\sigma = -\alpha\, E(T - T_o)$$

where, E is the Young's modulus of the material assuming isotropic behaviour. The stress is compressive if T>To (heating) and tensile if $T<T_o$ (cooling). For rocks, thermal contraction and extension are not the same in all directions since rocks are aggregates of mineral grains with different degrees of thermal expansion. Because of anisotropic expansion of various mineral grains, stresses develop in the grains or at the grain interfaces. Combination of normal and shear stresses will result in separation between the grains or across inter-granular cracks, i.e. thermal cracking.

Thermal resistivity

Most rocks obey *Fourier's law* relating the heat flux vector q ($J/m/s^2$) to the thermal gradient,

$$q = -K_t\, .\nabla T$$

where, K_t is the *thermal conductivity* and is expressed in W/m/K or J/m/K/s. It represents the ability of a material to transport thermal energy. The *specific heat* C_p (in J/kg/K) is the capacity of a material to store thermal energy. The *thermal diffusivity* k_t (in m^2/s) is the ability of a material to level temperature differences. These three thermal properties are related as follows,

$$k_t = \frac{K_t}{\rho C_P}$$

where, ρ is the density (kg/m^3).

For most rocks, K_t varies between 0.5 and 4.2 W/m/K, and C_p varies between 500 and 1000 J/kg/K. Values of K_t and k_t for an "average" rock is around 3 W/m/K and 1.5x10^{-6} m^2/s. The thermal conductivity of geologic materials like rock is usually low requiring sensitive measuring systems with high heat input and temperature gradient. Thermal resistivity depends upon,

- Decreases with increase of rock density
- Decrease as the moisture increases
- Decreases with increasing temperature
- Increases with joints

2.3.1.8 Slake durability test

This test is intended to assess the resistance offered by a rock sample to weakening and disintegration when subjected to two standard cycles of drying and wetting in a slaking fluid usually water. A representative sample is selected comprising of ten rock lumps, each with a mass of 40 - 60 g to give total sample mass of 450-500g.The slake-durability index is calculated as percentage ratio of final to initial dry sample weights. The test is conducted to know the resistance offered by a rock sample to weakening and disintegration when subjected to two standard cycles of drying and wetting in a slaking fluid (generally tap water @ 20°C). The test is conducted in a drum of size of 100mm thickness and 140mm diameter made from 2mm wire mesh which can withstand 105°C when sample is transferred from oven. The drum is coupled with motor drive capable of rotating drum at 20rev/min.

Representative sample

- Sample comprises of ten rock lumps each having mass of 40-60g of weight so that the total weight of the sample will be 400-600g

- Sample should be spherical in shape and corners should be rounded off during preparation

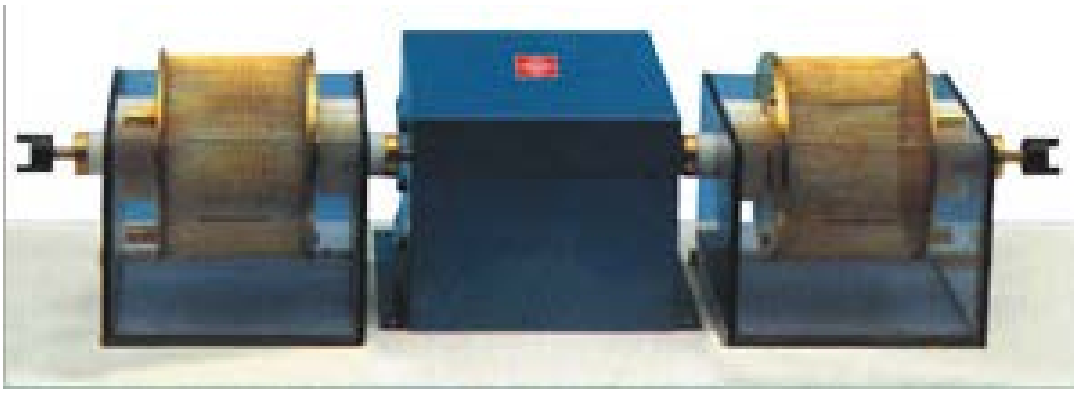

Figure 2.5: Slake durability apparatus

Procedure

- The sample should be placed in dry drum and dried to constant temperature of 105°C at oven and their weight is recorded, A
- The lid shall be placed and drum is mounted with motor
- It is filled with slaking fluid usually tap water and is rotated at a speed of 20rev/min for a period of 10 min.
- Remove the drum from the motor and keep retained sample in the drum with it in oven for 24 hours and their weight is recorded, B
- Now mount the drum into the motor and the procedure in second and third step is repeated for 10 min. After that weight of the drum with retained portion if sample is taken, C
- The drum shall be brushed clean and its weight is recorded, D

Calculation:

Slake durability index (second cycle) $= \dfrac{C-D}{A-D} \times 100\,(\%)$

A tentative sub-division of the slake-durability scale may be used for classification as given in table below.

Table 2.7: Different durability group based on the percentage retained

Group	% retained after first 10min cycle	% retained after 2nd 10min cycle
Very high durability	>99	>98
High durability	98-99	95-98
Medium high durability	95-98	85-98
Medium durability	85-95	60-85
Low durability	60-85	30-60
Very low durability	<60	<30