Tensile Strength:-

Tensile strength of rock material is normally defined by the ultimate strength in tension, i.e., maximum tensile stress the rock material can withstand. Rock material generally has a low tensile strength. The low tensile strength is due to the existence of microcracks in the rock. The existence of microcracks may also be the cause of rock failing suddenly in tension with a small strain. Tensile strength of rock materials can be obtained from several types of tensile tests: direct tensile test, indirect tensile strength and Brazilian test. The most common tensile strength determination is by the Brazilian test.

The uniaxial tension test, as illustrated in Figure (3), is not as a rule used in engineering practice as direct test is not commonly performed due to the difficulty in sample preparation. Also, it is difficult to perform, and the rock does not fail in direct tension in situ (Harrison and Hudson, 1997).

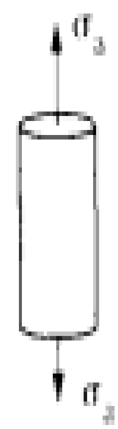

Figure 3. Uniaxial tension (Harrison and Hudson, 1997)

The indirect tensile strength is the one measured when the tensile stress is generated by compressive loading. (The tensile strength of the rock is very much lower than the compressive strength, so that such indirect tests are possible, for the same reason, it is not possible to have indirect compression tests.). Through the testing configurations, the maximum tensile stress can be calculated from elasticity theory as a function of the compressive force and specimen dimensions. The tensile strength is, therefore, the maximum tensile stress calculated to be present in the specimen at failure (Harrison and Hudson, 1997).

Since the main problems in tensile testing of rock and similar materials are concerned with the very low strains which occur before failure, procedures generally attempt to apply an even, direct stress by a loading system which avoids twisting or bending the specimen. The ISRM method (Ulusay and Hudson, 2007) specifies cores at least of NX size (54 mm), with the ends prepared smooth and flat as for the compressive strength test. Metal end caps of the same diameter are then cemented to the test specimen, and after hardening, the end caps are loaded by a chain linkage system. The number of tests possible depends on the specimens available, but at least five is preferred for calculating an average.

With the ASTM D3967 (2008b), the BTS specimens are drilled, cut, and then inspected to meet dimension tolerances including; smoothness of the cylindrical surface of the specimen shall be within 0.50 mm over the full length of the specimen; the perpendicularity of the specimen ends to the axis of the specimen shall not depart from a right angle by more than 0.5°. The BTS specimens are prepared with the thickness to diameter (t/D) ratio of 0.5.

In the Brazilian tensile stress test, according to elasticity theory, is developed across the vertical diameter of short cylinders diametrically line loaded. The specimen size is again specified as at least NX core, so that if cross drilling of cores is to be considered these must be at least HX size (approx. 70 mm).Spot loading of the short cylinders used (length of half diameter) must be avoided, and a layer of adhesive paper strip (masking tape) is wrapped round the specimen before loading in a slightly curved jig, as shown in figure (4). The tensile strength is calculated from the formula (Ulusay and Hudson, 2007):

$$T_0 = \frac{2P}{\pi D t}$$

Where T_0 is the tensile strength in MPa, P is the load at failure in kN, D is the diameter in mm and t, the thickness of the specimen also in units of mm.

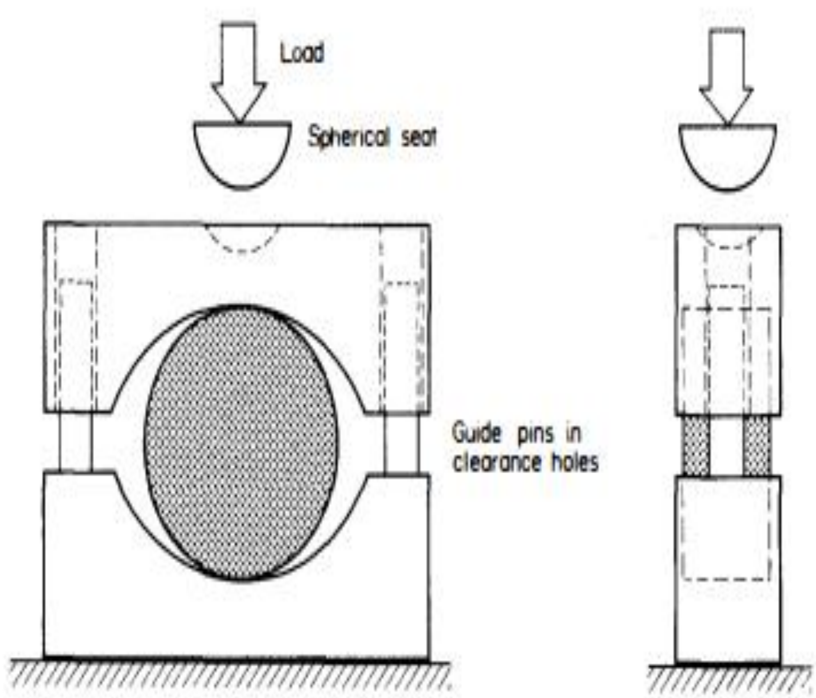

Figure 4. Apparatus for ISRM Brazil test (ISRM, 2007) from (Hudson, 1993)

Flexural Strength or Bending Test:

The flexural strength or modulus of rupture is a measure of the outer fiber tensile strength of a material. This can be determined by loading a cylindrical specimen in a three point loading device to fracture (Refer Figure 2.7)

$$R_o = \frac{8F_c L}{\pi D^3}$$

R0 is flexural strength of rock in kg/cm2

Fc is the applied compressive load at failure in kg

L is length between the bearing edges of the lower plate in cm

Unconfined Shear Strength:

Indirect shear test is properly known as punch shear test. Usually, shear test are single shear test, double

shear test, punch shear test, torsion shear test (Figures 5).

Usually, the measured shear strength is not inversely proportional to the cross-sectional area.

1. For single shear test, the shear strength S_o is:

$$S_o = \frac{F_c}{A}$$

Where Fc is the force in the direction of the plane ‘A’ necessary to cause failure.

A = cross-sectional area of specimen

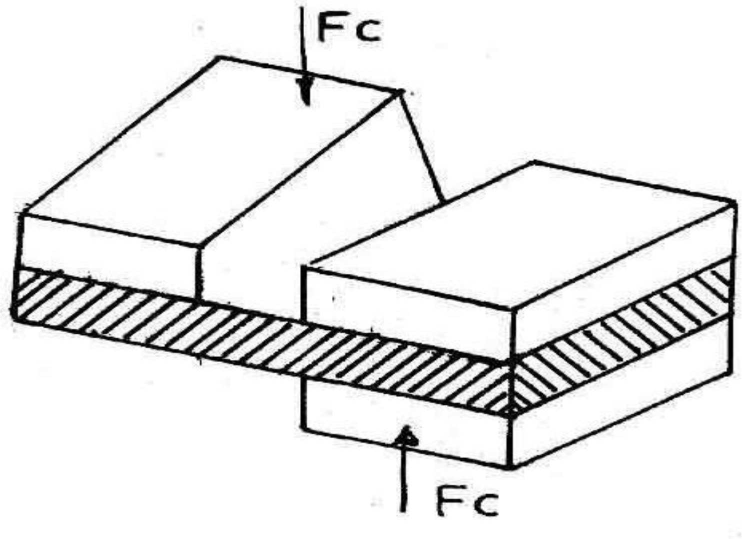

Figure 5. Single Shear Test

2. For Double Shear test, the shear strength So is (Figures 6):

$$S_o = \frac{F_c}{2A}$$

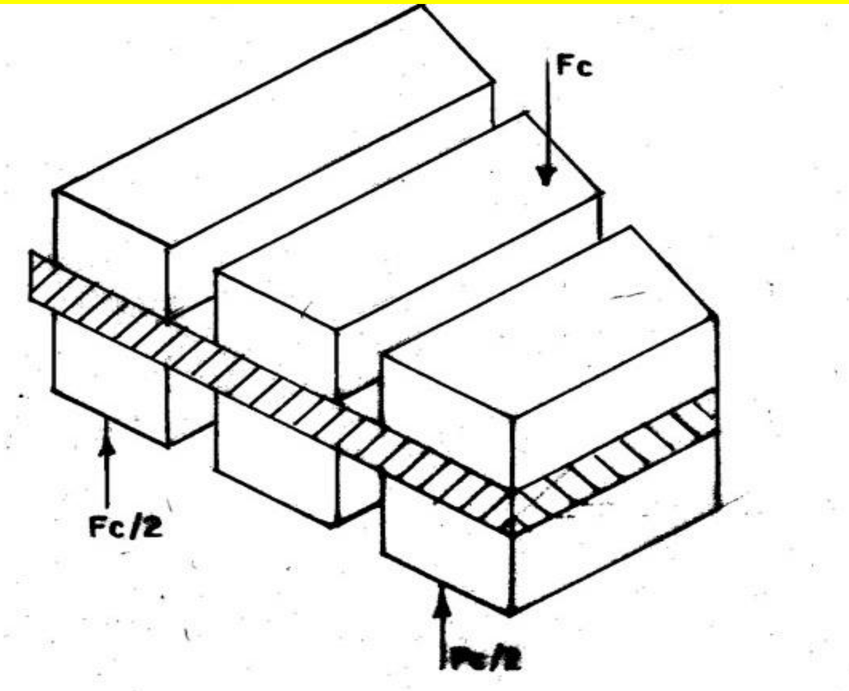

Figure 6. Double Shear Test

3. For Punch Shear test, the shear strength So is (Figures 7):

$$S_o = \frac{F_c}{2\pi ra}$$

where, a = thickness of the specimen and

r = radius of punch

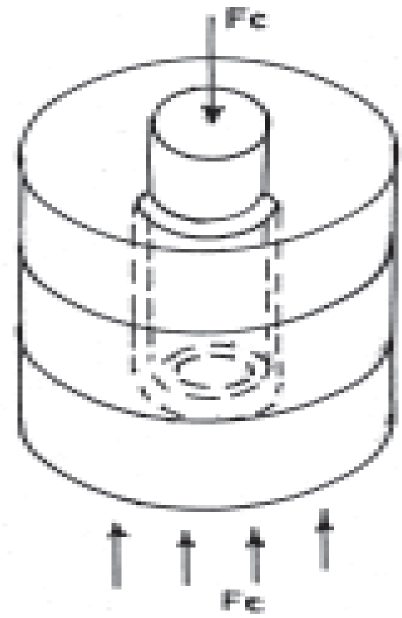

Figure 7. Punch Shear Test

4. For Torsional Shear test, the shear strength So is (Figures 8):

$$S_o = \frac{16\,M_c}{\pi D^3}$$

where, Mc = applied torque at the failure

D = Diameter of the cylinder

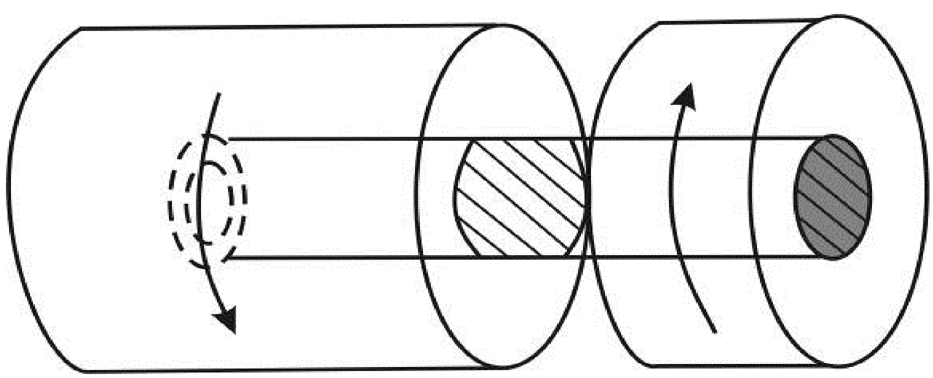

Figure 8. Torsional Shear Test

Rock Mechanics Properties

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 IS, 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.

Is = P / D2 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

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:

$Ss = \text{Cohesion} + \text{normal Stress} \times \tan \Phi$ 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:

$\sigma s = P / A$ or $P / \pi d t$ 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 σn = P × sin 450 / A Equation 2.5

Shear Stress σs = P × cos 450 / 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:

$\sigma t = 0.0675 P/D2$ Equation 2.7

$\sigma t = 0.0476 \sigma u + 1314$ Equation 2.8

Where, σt is tensile stress in kN/m2, P is vertical load at failure in kN, D is diameter in m of cylindrical sample and σu is compressive strength in kN/m2.