

In-situ shear strength parameters- A case study

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Abstract

The strength parameters of rock mass are playing a challenging role in the design of engineering structures in or on rock mass. It is difficult to determine the accurate shear strength parameters of rock masses in the laboratory as the samples need to be undisturbed and sufficiently large to be representative of the discontinuum rock mass. Hence, in-situ direct shear tests are conducted to find out the shear strength parameters in terms of cohesion 'c' and angle of friction ' ϕ '. Present paper deals with in-situ direct shear tests conducted at dam axis drift of Kirthai H. E. Project (Stage-II) for rock over rock (Granite Gneiss) interface. In-situ shear tests (rock over rock interface) have been conducted in the drift at different but constant normal load to evaluate shear strength parameter, cohesion 'c' and friction angle ' ϕ ' of the rock mass. By using best fit line method in the plot of shear stress v/s normal stress, 'c' and ' ϕ ' are determined. Interestingly higher angle of friction ' ϕ ' has been observed in the present investigation. The strength of a rock mass depends not only on the nature of the rock material (intact rock), but also on the discontinuities that separate the intact rock blocks. In many cases, the behaviour of a rock mass is controlled by sliding along discontinuities. The present study is focused to highlight the probable reason for this peculiar observation.

1. Introduction:

All rock masses contain discontinuities such as bedding planes, joints, shear zones and faults. At shallow depth, where stresses are low, failure of the intact rock material is minimal and the behaviour of the rock mass is controlled by sliding on the discontinuities. The aim of performing in-situ direct shear tests is measurement of peak and residual shear strength parameters of a discontinuity in rock as a function of normal load. Shear strength parameters, 'c' and ' ϕ ' in design of rocky structures, particularly stability analysis of rock slopes and also stability of dam foundation are of paramount importance.

An in-situ direct shear test is the simplest method in determining the shear parameters, 'c' and ' ϕ ' and due to large dimensions of test blocks in comparison to laboratory samples, in-situ tests lead to more precise and accurate results. For determining shear strength of rock to rock contact surface of the abutments of a dam, four set of in-situ direct shear tests have been conducted inside the left bank drift which have been excavated at dam site. In order to analyse the stability of this system of individual rock blocks, it is necessary to understand the factors that control the shear strength of the discontinuities separating the blocks. A natural discontinuity surface in hard rock is never as smooth as a sawn or ground surface of the type used for determining the basic friction angle. The undulations and asperities on a natural joint surface have a significant influence on its shear behaviour. Generally, this surface roughness increases the shear strength of the surface, and this strength increase is extremely important in terms of the stability of excavations in rock (GharouniNik, M.2010).

2. Factors Influencing Shear Strength of Rock in situ:

Shear strength parameters (cohesion 'c' & friction angle ' ϕ ') of rock mass in situ test finding is invariably lower than laboratory test results. A number of factors influence the insitu values. Among of these the most important factors are particle shape and roughness of grain surface (friction angle typically increases with increasing angularity and surface roughness), grain quality (weak rock materials such as shale have lower friction angles compared to strong rock materials such as granite), grain size (friction angle increases or decreases with increase in grain size), grain size distribution (friction angle typically decreases with decreasing coefficient of uniformity C_u), specific gravity (related to mineralogy), state of compaction or packing (friction angle typically increases with increasing density or decreasing void ratio), applied stress level (friction angle decreases with increasing confining stress, resulting in a curved strength envelope passing through the origin instead of the classical straight line), definition of failure conditions (drained or untrained), degree of saturation. These factors compete with each other, complicating their effect on friction angle, has been studied by various researchers (Hawley, 2001; Holtz and Kovacs, 2003). This study shows effect of angle of inclination of bedding on shearing stress.

3. Brief Description of Project Studied:

Kirthai H.E. Project Stage-II is conceived as a run off the-river-scheme with diurnal storage of 8.5 million cumecs to run 6 units of 165 MW each (total generation of 990 MW). The scheme envisages having 121 m high concrete gravity dam, 4.289 km long head race tunnel (HRT), underground power house near Lidrarinala and 352.50 m long tail race tunnel (TRT) with a diameter of 11.25 m. At the Kirthai H. E. Project (Stage-II), all the geological components are in the Pias Granites which is intruded within the Kishtwar Window. The Kishtwar Window is a conspicuous structural element of Higher Himalaya. Kishtwar Window exposes Dul Quartzite enveloped by Salakhala Formation, which is tectonically overlain by the high grade metamorphites along the Trace of Main Central Crystalline Thrust. The rocks of Kishtwar Window are overriding the younger Salakhala Formation along Kiaji Thrust. Geological cross section along the dam axis of Kirthai H. E. Project Stage-II is shown in figure 1.

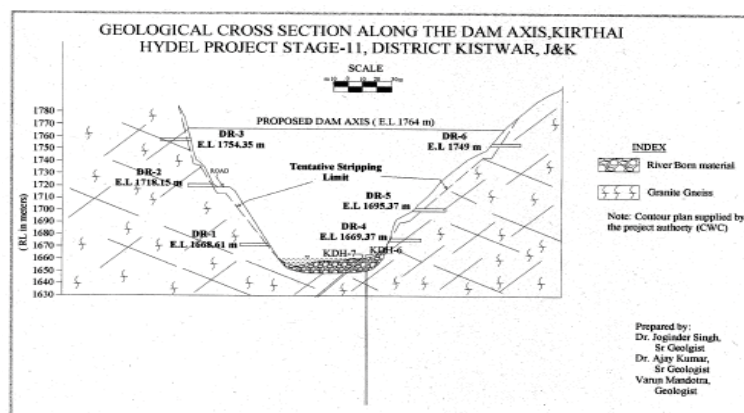


Figure 1 Geological cross section along the dam axis of Kirthai H.E. Project Stage-II

4. In-Situ Direct Shear Test Procedure:

In-situ shear tests were conducted in the left bank drift site of Kirthai H. E. Project Stage –II. Four set of rock blocks for rock/rock interface has been prepared. The test block shall be cut to the required dimensions (700 mm X 700 mm X300 mm) using methods that avoid disturbance or loosening of the weak discontinuity to be tested (IS 7746:1991, ISRM: 1981). The base of the test block should coincide with the plane to be sheared. Frame consisting of 20 mm thick mild steel plate was used to envelop the prepared rock block to avoid any unwanted failure of rock block other than predefined shear plane during testing. MS plates of 20 mm thickness were used to prepare side and top reaction pads, strengthened by R.C.C. The care is taken to keep the top and side reaction pads concentric with the block. Vertical load is applied by 200T capacity hydraulic jack and aluminium alloy hollow cylinders were used to fill up the gap between the top reaction pad and the hydraulic jack. The shear load is applied by another 200 T capacity hydraulic jack from the side reaction pad, at an angle of 15° with the horizontal in order to pass the resultant force through the centre of the test block. This is achieved by two wooden wedges placed across the jack. The application of shear force is kept until the failure occurs.

Each block is tested for a particular normal stress of rock block which is kept constant during the test. The shear force and displacement of block are measured and recorded during the test. The vertical, horizontal and lateral displacements of the block, produced during the test are measured by nine dial-gauges (four for normal displacement, three for shear displacement and two for lateral displacement) each of 0.01 mm least-count. The observations are recorded till failure and continued even after the failure to the extent possible to get the information regarding residual frictional resistance. Set up of equipment and schematic diagram for in-situ shear test is shown in figure 2 and figure 3 respectively.

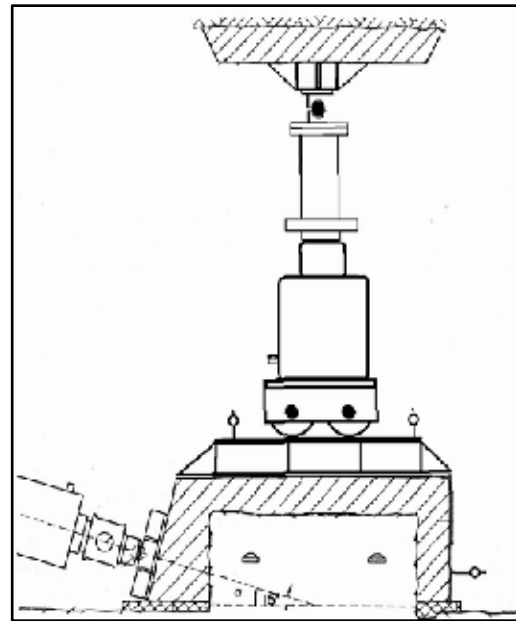


Figure 2 Photograph of shear test set-up Figure 3 Schematic diagram of shear test set up

5. Calculations:

Normal stress and shear stress are obtained from normal load and shear load recorded during the test conducted. The shear stress and normal stresses are calculated from the following equations:

$$\text{Shear Stress, } \tau = \frac{P_s}{A} = \frac{P_{sa} \cos \alpha}{A}$$
$$\text{Normal stress, } \sigma_n = \frac{P_n}{A} = \frac{P_{na} + P_{sa} \sin \alpha}{A}$$

Where,

P_{sa}	=	Applied shear load
P_s	=	Total Shear force
P_n	=	Total Normal force
A	=	Area of test block
P_{na}	=	Applied normal Load
α	=	Inclination of applied shear force

As α is 15° in this case, the applied normal force is reduced after each increase in shear force by an amount $P_{sa} \sin \alpha$ in order to maintain the normal stress approximately constant. At failure and after failure (residual), the shear stress is plotted against the normal stress for each test and the “curve of best fit” is drawn using linear regression analysis. From the equation of straight line obtained, the intercept on the Y- axis gives cohesion ‘c’ of the rock mass and the slope of the line gives the friction angle ‘ ϕ ’ of the rock mass.

6. Test Results and Discussion:

Four shear tests on rock to rock interface were conducted in the drift on left bank of the dam axis. The tests were conducted at different but constant normal load. Normal load of the order of 10, 20, 30 and 40 tonnes was applied in these tests. The blocks were overturned after shearing and the actual area of shear was measured. The normal and shear stresses were calculated considering this measured area. Shear stress versus displacement plot is shown in figure 4. Peak and residual shear stresses were plotted against the normal stress to get the peak and residual shear strength parameters of rock to rock interface given in figure 5. From the “curve of best fit” using linear regression, values of peak shear strength parameters viz. cohesion ‘c’ and friction angle ‘ ϕ ’ were found as 0.49MPa and 65.96° , respectively for rock to rock interface. Similarly, residual shear strength parameters ‘ c_r ’ and friction angle ‘ ϕ_r ’ were found to be 0.33MPa and 53.81° respectively.

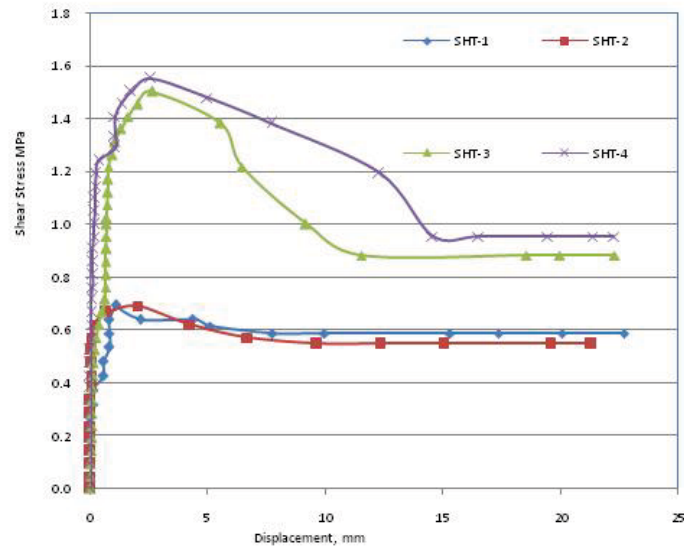


Figure 4 Shear stress v/s displacement curve

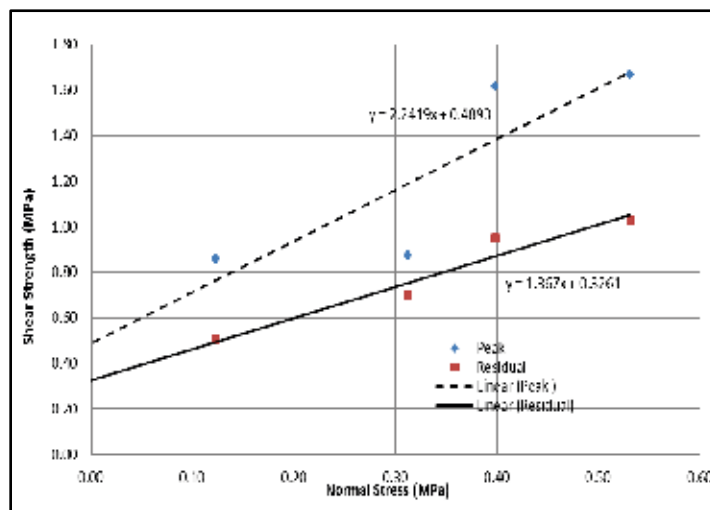


Figure 5 Shear stress v/s normal stress

Table 1 presents the detailed test results. The photographs of some typical overturned rock blocks are shown in figures 6a and 6b.

Table 1
 Test results

Drift/Trench		Rock Type	Shearing Interface	Peak Shear Strength parameters		Residual Shear Strength parameters	
No.	Location			Cohesion, 'c' (MPa)	Angle of Friction, 'ø' (degrees)	Cohesion, 'c _r ' (MPa)	Angle of Friction, 'ø _r ' (degrees)
DR-2	Left Bank	Granite Gneiss	R/R	0.49	65.96	0.33	53.81



Figure 6 Overturned rock blocks tested at normal load (a) 30T and (b) 10T

The actual point of contact is important (Mishra et al. 2013) and as peak shear strength is obtained, the actual point contact stress levels are high due to the small contact areas. Barton recognizes the effect of roughness and particle size on shear strength. As roughness increases so does friction angle. Interfaces, which could be the weakest point in the system, also can be evaluated similar to rock fill, rock pile, and rock joints (Barton 2008).

7. Conclusion:

The complexity of the investigated rock materials highly influence the shear strength of the rock mass, therefore the parameters influencing direct shear strength have to be carefully investigated. The most important ones are the surface roughness, the presence, the type and thickness of the infill material, the direction and angle of the shear, the inclination of the shear surface with respect to the shear direction, the magnitude of the normal load acting on the surface, the dilation, the area of the sheared surface, the scale effect, the inhomogeneity, the microstructure of the rock fabric, and the form of the mineral crystallisations. Joints, bedding planes, faults, and other recurrent planar fractures radically alter the behaviour of rock. As joints are generally not randomly distributed, their effect is to create pronounced anisotropy in the properties of the rock mass, in particular, anisotropy of strength.

The shape of the damage zones depends on the local geometry of the fracture surface, including the size and shape of the asperities, as well as on the mechanical parameters of the rock. In addition, a critical further step is to find an expression to quantify contact area across the joint that describes how contact varies during shearing and with changes in applied normal load. The samples with rough surface showed the highest resistance, due to the high surface roughness. The smaller the surface roughness became the lower the internal angle of friction.

Cohesion & angle of friction depend upon the angle of inclination when shearing stress is acting at an angle to bedding. The angle of friction increases as the beds dip in the opposite direction of shearing stress. The cohesion values are higher for the beds dip in the direction of shear stress. In present study it was observed that the beds dip approximately 20° with the direction of shear stress which causing increase in friction angle and lower value of cohesion.

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