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In-situ Block Shear Test at Tanahu Hydropower Project, Tanahun District Western Development Region, Nepal

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ABSTRACT

The in-situ direct shear tests were conducted at the powerhouse drifts AP-2 site of the Tanahu Hydropower Project with five different blocks sheared in three consecutive normal loading stages. The peak shear strength and residual shear strength data showed that cohesion of rock mass Cpeak was 0.52 MPa and Cres was 0.51 MPa. The friction angle of rock mass showed that Phi_{peak} was 38.7º and Phi_{res} was 37.0º. The rock mass having greater than 0.51–0.52 Mpa was placed in class I – class II (very good rock to good rock), and cohesion of rock mass ranged from 37.0º to 38.7º was placed in Class II (good rock).

Keywords: In-situ direct shear test, Tanahu Hydropower Project, Peak shear strength, Residual shear strength,

INTRODUCTION

Tanahu Hydropower Limited (THL) is a subsidiary company of Nepal Electricity Authority (NEA) having installed capacity of 140 MW (SRCL, 2012; OYO Corporation, 2012). The Project site is situated 150 km west of Kathmandu on the Seti River near Damauli, Tanahu District, Gandaki Zone. In-situ geotechnical investigation is essentially required to clearly understand the mechanical behavior of the rock mass and to determine the engineering parameters which are required for an optimum design of structures like caverns, tunnels, shafts and dams, etc.

The whole project area is located in the Nurpul Formation, Dhading Dolomite and Benighat Slate of the Lesser Himalaya. Phyllite, quartzite, dolomite and slate are the main rock units of that area. One strike slip fault extends just upstream part of the head works. The proposed powerhouse site (block shear tested area) is located at the right bank of the Seti River just opposite to the Belbas Village (Fig. 1). The powerhouse lies on the foothill side of the slope, which is sub vertical to vertical. The area is composed of slate and dolomite. The latter acts as a cap rock for that area having thickness of about 30 m. Slate is main lithology for underground powerhouse area. It is dark grey to black, slightly weathered, and moderately fractured with quartz veins. Shear tests of all the five blocks were conducted on slate with quartz veins for calculation of principle stresses.

METHODOLOGY

Block shear test is used to determine the shear strength of rock mass, which is the maximum shear stress that the material can withstand before failure occurs. This is a very important for underground structural design and to estimate the support quantity. The in-situ direct shear test (Block Shear Test) on rock mass was conducted with three continuous stages of normal loading. The additional stages were conducted by increasing and decreasing the applied normal stress within the limit of maximum normal stress of 4.0 MPa. The test procedures were followed as per the guidelines of IS: 7746 (1991). In this test, peak and residual direct shear strength were measured as a function of stress normal to the shear plane, by conducting at least five tests on the same test horizon with each specimen tested at a different but constant normal stress.

Block Preparation

Proper cleaning of the drift floor from debris and excavation muck was done at the selected locations. The rock-to-rock test blocks were carved to the required dimensions (700 x 700 x 350 mm) from the parent rock mass using manual chisel and hammer to avoid disturbance or loosening of the natural rock (Fig. 2).

Test Setup

After adequate curing of the test block, the site was prepared for starting the shear tests. After dewatering, the block was cleaned and the base sides of the block were made free from any broken rock pieces so that the block was free to move in shear direction. A shear mould of 25 mm thick MS plates was encapsulated on the shear block to maintain the integrity of the block throughout the test. A 10-mm layer of fine sand was applied on top of the shear block to fill any void and undulations and ensure a perfect contact of loading plate with the block. A 25 mm thick mild steel plate of 700 mm x 700 mm size was placed on the block centrally for uniform distribution of normal load. Another plate of similar size was placed over it with an adequate roller arrangement sandwiched in between to allow free and smooth sliding movement in shear direction.

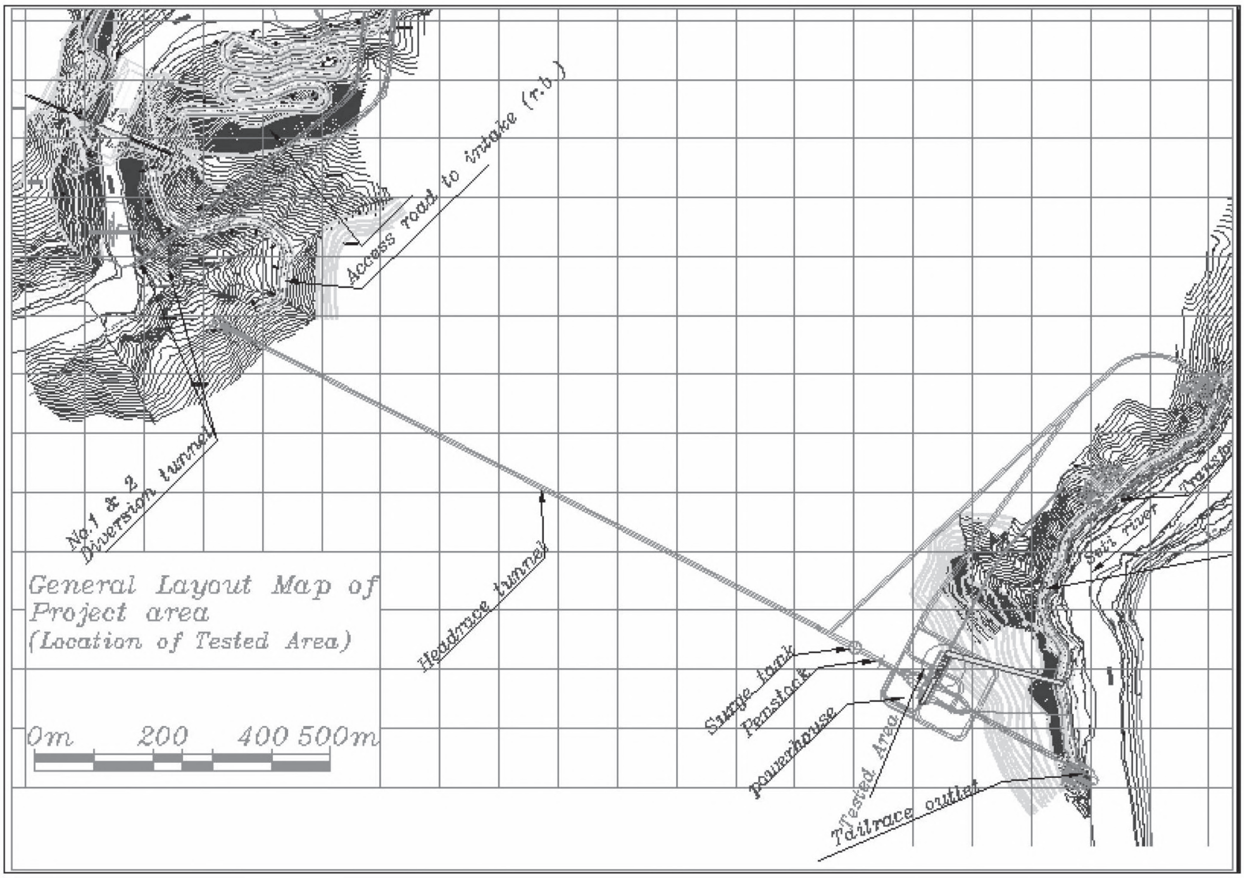


Fig. 1: Location of tested area at general layout map of Tanahu Hydropower Project (SRCL, 2012; OYO Corporation, 2012)

Fig. 2: Block Preparation

Then a remote controlled hydraulic jack of 2000 kN capacity was placed centrally over top plate. A reducer plate was also placed on the top of this plate similar to the size of the jack (Fig. 3). Spacer columns of appropriate length were placed over ram of the jack to reach normal reaction pad. The normal load was transferred from the normal reaction pad at crown through a spherical ball seat arrangement to maintain verticality of the normal load during the test. The contact between the normal pad and the column was made by displacing the jack. The hydraulic jack of suitable capacity for applying shear force was placed parallel to the base of the block due to practical hindrances, in spite of a 15-degree inclination. The jack applying shear force was positioned such that the line of action of the force passed as close as possible to the center of the shear area. Reducer plates are also used on the shear reaction pad to disperse the load evenly into the wall. The normal load and the tangential force were applied such that their line of action intersected just above the centroid of the shear area at the base of the block. To record the displacements of the block, dial gauges having least count of 0.01 mm and a travel of 50 mm were used. Four dial gauges were placed to record normal (vertical) displacement, two for recording shear (horizontal) displacement. The dial gauges were fixed from a datum bar supported on stands located sufficiently away from the test blocks and the reaction pads.

Fig. 3: Setup the Block Shear Test Machine (ATES, 2017)

Consolidation of Test Blocks

After completing the loading set up the consolidation of the fully saturated shear blocks was done. All displacement gauges were checked for rigidity, adequate travel and freedom of movement, and a preliminary set of load and displacement readings was recorded. The consolidation stage of testing was carried out at designated loads to allow pore water pressure in the rock and filling material adjacent to the shear plane to dissipate under full normal stress before shearing. Normal load was then raised to the full value specified for the particular stage of the test, recording the consequent normal displacements (settlements) of the test block as a function of time as well as applied loads. The consolidation stage was considered complete when the rate of change of normal displacement recorded at each of the four gauges was less than 0.05 mm in 10 minutes. Due to highly foliated slates dipping around 20–30 degrees, immediate settlements were observed in the blocks and consolidation of the rock blocks was attained in less than 60 minutes as per above criteria.

Shearing of Test Blocks

After the consolidation of the test blocks the shear stage was initiated. Both shear displacement gauges were checked for rigidity, adequate travel and freedom of movement, and a preliminary set of load and displacement readings were recorded. The shear force was then applied in increments in such a way as to control the rate of shear displacement and the normal displacements. An increment of about 50 kN was given initially to check the strength of the test block. Based on displacement observed the further increments were modified. Shear and normal displacements of the block for each increment of shear load were recorded. The verticality of the loading column was monitored and maintained during the entire shearing process. The peak shear force was attained when no further increment in shear load was observed with increase in shear displacement. Due to very high applied normal load a sudden drop in shear force was not observed. This implies that the rock mass might have undergone a ductile failure. After reaching peak strength, the shear displacement readings were continued to be recorded to adequately define the shear stress-shear displacement curve and to attain the peak and residual shear strength of the shear blocks. Having established a residual strength for the 1st stage, the normal stress was increased or decreased as per the designated multi stage testing schedule. The test blocks were reconsolidated or stabilized under each increased or decreased normal stresses, respectively. The shearing was then continued to obtain additional peak or residual shear strengths under increased or decreased normal stresses, respectively.

Calculations and Interpretation

The shearing behavior of blocks tested with increasing normal loading stages was different from those with decreasing. Therefore, the failure envelope of all test blocks could not be plotted together for stage 2 and 3. The Mohr-Coulomb failure envelops was plotted for all three stages, respectively. However, for stage 2 and stage 3, different envelopes were plotted based on normal loading trend of the respective blocks.

The shear and normal stresses were computed from the applied forces as follows:

$$\text{Shear stress, } \tau = P_s/A' \qquad (1)$$

$$\text{Normal stress, } \sigma = P_n/A' \qquad (2)$$

where,

P_s = applied shear force,

P_n = applied normal force,

A' = area of shear surface corrected to account for shear displacement

Graphs of shear strength vs. normal stress were plotted from the combined results for all the five test specimens. Shear strength parameters i.e. cohesion and angle of friction were estimated using Mohr-Coulomb shear strength failure criterion, for both Peak and Residual plots, respectively as shown in Fig. 4.

A best fit straight line was adopted for plotting peak and residual failure envelops to be on conservative side.

DIRECT SHEAR TEST OBSERVATIONS

One example of block shear test at Test Block no. 02

Block-2 was tested under increasing normal stress of 0.5 MPa, 1 MPa and 2 MPa in its 1st, 2nd and 3rd stages, respectively. All the three stages were successfully conducted with maximum shear displacement of 10.95 mm. The Peak and residual shear stresses were recorded for all the 3 stages (Figs. 5).

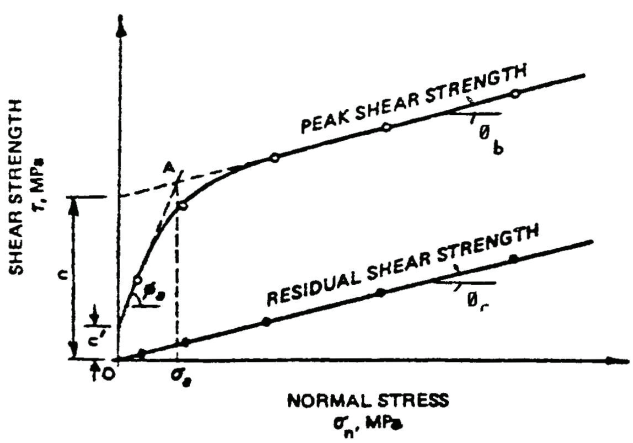
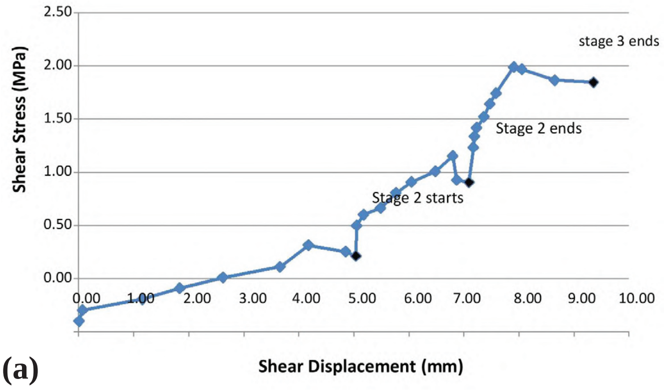
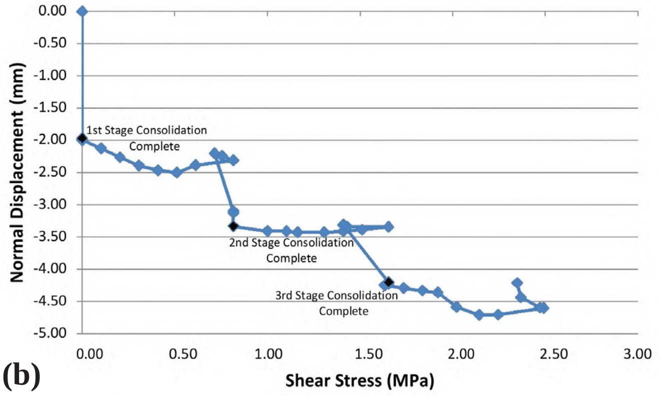


Fig. 4: Idealized Mohr Coulomb Failure Envelop (theoretical) (IS: 7746, 1991)



(a)



(b)

Fig. 5: (a) Shear stress vs. shear displacement curves for block no. 02 and (b) Shear stress vs. normal displacement curves for block no. 02

DIRECT SHEAR TEST RESULTS

The crude data obtained from the testing was processed, analysed and remarked. The peak and residual shear strengths in all stages are identified from the data trends in all stages of all blocks. Peak shear strengths of stages 2 and 3 are applicable in blocks tested with increasing normal stress only. This is because the increasing normal stress enhances the interlocking of asperities in later stages which will result in new peak and residual shear strength. However, the decreasing normal stress will only release the interlocking and the shear strength will decrease in later stages resulting in residual strength. The shear displacement in respective stages is also recorded for respective blocks.

In case of a planar failure surface, corrected shear area will be lower than original area of the base of block which can be corrected by measuring from the inverted blocks. However, planar failure surfaces are not observed in any block, therefore shear correction is not applied on the test blocks to determine stresses on a conservative side.

Generally, all shear blocks show shearing along a highly rough failure surface in combination with crushing of asperities. It is also evident that entire rock mass of the block has taken part in the shearing which is supposed to occur on a horizontal plane.

The peak and residual shear strengths obtained in respective stages at respective normal stresses are presented along with shear displacements and loading remarks in Table 1. The peak shear strength and residual shear strength data show that cohesion of rock mass C_{peak} is 0.52 MPa and C_{res} is 0.51 MPa. The friction angle of rock mass shows that Phi_{peak} is 38.70 and Phi_{res} 37.00.

Table 1: Peak and residual shear strengths obtained in respective stages (ATES, 2017)

Block No.	STAGE	Normal Stress (Mpa)	Peak Shear Stress (MPa)	Residual Shear Stress (MPa)	Average Cumulative Shear Displacement (mm)	Remarks
1 RD- 208 m	1	3.5	1.73	1.65	4.53	Decreasing Normal Trend
	2	2.5	-	1.43	3.02	
	3	0.5	-	0.84	9.03	
2 RD- 212 m	1	0.5	0.82	0.78	5.03	Increasing Normal Trend
	2	1	1.65	1.41	2.06	
	3	2	2.49	2.35	2.26	
6 RD- 216 m	1	2.5	2.43	2.31	2.05	Decreasing Normal Trend
	2	1.5	Not Applicable	1.49	2.34	
	3	1		1.02	8.21	
3 RD- 226 m	1	2	2.43	2.31	21.28	Increasing Normal Trend
	2	3	3.27	2.96	8.47	
	3	4	The stage could not be achieved as setup collapsed after 2nd stage			
RD- 236 m	1	3	2.82	2.65	6.78	Decreasing Normal Trend
	2	2	Not Applicable	1.84	5.49	
	3	1.5		1.33	4.77	

Table 2: In-Situ Shear Parameters of Rock mass at Powerhouse Drift, Tanahu HPP, Nepal (ATES, 2017)

Stage No.	**1**				**2**				**3**			
Max. Normal Stress	**3.5 MPa**				**3.0 MPa**				**2.0 MPa**			
Shear Parameter / Loading	Peak		Residual		Peak		Residual		Peak		Residual	
	C (MPa)		Ø(^{0})		C (MPa)		Ø(^{0})		C (MPa)		Ø(^{0})	
Increasing					0.84	39.01	0.63	37.78	Stage could not be achieved			
Decreasing	0.52	38.71	0.51	36.97	Not applicable		0.44	34.99	Not Applicable		0.40	31.80

Accordingly, failure envelops are plotted for all applicable normal loading trends for respective stages. The results in terms of peak and residual shear strength parameters, i.e. cohesion and friction angle of “rock mass” are obtained and presented in Table 2.

CONCLUSIONS

The in-situ Block Shear Tests were conducted at the powerhouse drifts AP-2 site of Tanahu HPP. In total five different blocks were sheared in three consecutive normal loading stages. The resulting shear parameters of rock mass in different stages of normal stress variations are presented in Table 1.

-The peak shear strength and residual shear strength data show that cohesion of rock mass C_{peak} is 0.52 MPa and C_{res} is 0.51 MPa. The friction angle of rock mass shows that Phi_{peak} is 38.70 and Phi_{res} 37.00.

-The cohesion of rock mass greater than 0.51 MPa–0.52 MPa is placed in class I to class II (very good rock to good rock) and Cohesion of rock Mass ranges between 37.00–38.70 is placed in Class II (good rock).

-The rating value shows that rock of that area is under class II (good rock), full face excavation, 1–1.5 m advance; complete support 20 m from face. Rock bolt is of 20 mm diameter, fully grouted, and locally, with bolts in crown 3 m long with spacing 2.5 with occasional wire mesh.

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