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Shear Strength Behviour of Jointed Mass at 15° Orientation

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Abstract: ***The analysis of engineering behavior of jointed rock is typical and depends upon various properties of jointed rock such as elastic, frictional, surface roughness and adhesion properties. Stability analysis in jointed rock is often governed by the stability of a critical joint. In such cases, it is assumed that no interaction exists between the rock and the joint; the joint can therefore be considered isolated. The engineering characteristics of the joint plane are necessary for assessing instability. The direct shear test is a suitable experiment to determine these parameters. In the present study an attempt has been made to study a jointed mass under direct shear test. The specimen has been made large enough so they have negligible scale effect. Due to ease in working and reproducibility of results a model material has been used. The jointed mass is prepared with the help of cement sand mortar having ratio 1:3 and water cement ratio 0.5. The orientation of the joint was kept as 15˚. During the direct shear tests normal stress was kept constant. The shearing displacement and the normal displacements were recorded with respect to shearing stress for orientation of 15˚ joint. The shear behaviour of jointed mass under low normal stress condition was analyzed for the present study and found that instantaneous cohesion increases as increase in normal stress and instantaneous friction angle decreases as increase in normal stress.***

1. Introduction

The shear strength and deformational behavior of jointed rock masses is important for stability of slope, design of foundations, underground openings and anchoring systems. Generally rock is not homogeneous and isotropic due to the presence of discontinuities, which makes the strength behaviour more complex.

The assessment of the shear behaviour of jointed rock mass has been attempted by several researchers. Patton (1966) was the first person who introduced the phenomenon of interlocking and influence of asperities of the joints. Later this criterion was extended by Barton et al. (1973), Ladyani and Archumbault (1972), Bandis (1983) and Johnston and Kodikora (1994).

The studies show that irregularities have an appreciable influence upon the shearing resistance of rock masses. In rock masses, different types of modes of shear failure can take place along the rock surfaces having various orientations. On conducting the shear test in laboratory, the normal stress has been generally held constant. This experimental boundary condition corresponds in situ to a rock block slide at the surface. When two non-planer surfaces are at the verge of sliding, they tend to dilate if the boundary conditions are favorable for such type of deformation. In the present study, the behaviour of rock joints under direct shear test at constant normal load is studied. It is very difficult to use the natural rock joints because of its complicated topography. So artificial rock joint was created at 15° orientation angle with the help of model material.

2. Model Material Used

Due to ease in working and reproducibility of the results model material has been used for the experimental study. To select a suitable model material trial testing was done on plaster of Paris. Finally, based on suitability, cement sand mortar (ratio 1:3, water cement ratio 0.5) was selected as the model material for the present study. Keeping the above in mind the following specific experimental studies were planned on cement sand (ratio 1:3, water cement ratio 0.5) as model material.

Preparation of the Jointed Specimen

Direct shear tests were conducted on the jointed specimen having orientation (θ=15˚) of joints with respect to shearing direction. Angularities were present perpendicular to the joint plane, which are in the shearing plane of the jointed specimen (Fig. 1). Spacing between the joints was kept as 50 mm. Preparation of the jointed specimen was done under the following procedure

1) Wooden moulds of size 30mm x 30mm x 15mm were prepared.
2) Slits were cut in the wooden walls at 15˚ with horizontal orientation and spacing. Steel sheets were inserted inside the slits (Fig. 1) to create the joints in the model material.
3) Additional steel sheets were used perpendicular to joint plane to form the angularities.
4) Cement sand mortar having cement sand ratio 1:3 and water cement ratio 0.5 was poured in the mould. The mould was vibrated for about 20-30 seconds.
5) Specimen was allowed to set in the mould for 24 hours, after that it was placed under curing.
6) Testing was done on the specimen after 28 days of curing.

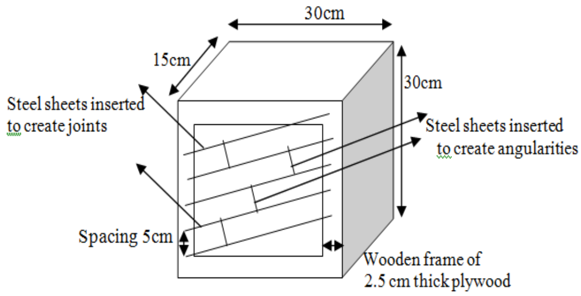

Fig. 1

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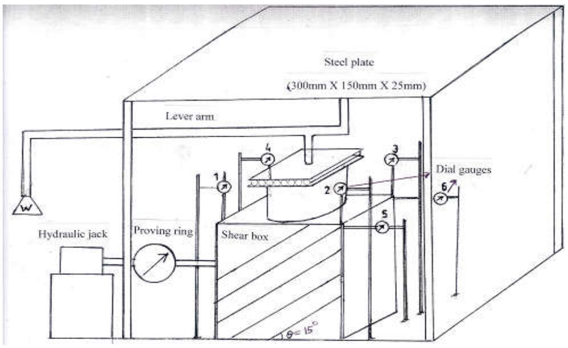


Fig. 1a Schematic diagram of Large shear box

Physical and Engineering Properties of Model Material

Physical and engineering properties of the model material was found out and tabulated in Table 1.

Table 1: Physical and engineering properties of model material

Properties of model material	Value
Specific gravity (G)	2.584
Dry density (γ_d) KN/m^3	18.37
Saturated unit weight (γ_{sat}) KN/m^3	21.27
Void ratio (e)	0.4066
Porosity (n) %	28.9
UCS, σ_{ct} (MPa)	6
Brazilian strength, σ_{ti} (MPa)	1.167
Point load strength (MPa)	1.394
Void index	0.16
Cohesion C_i (MPa)	1.047
Friction angle Φ_i	55.56°
Deere Miller classification	EL

Tests on joints

Shear Stiffness

To find the shear stiffness of joints, direct shear tests were performed on the specimen of size 60 mm x 60 mm x 12.5 mm by placing two such specimens one over other (Fig.2) at low normal stress, along a joint. The normal stress was kept constant in each test. The shear stress vs shear displacement curves were plotted and maximum shear stiffness is calculated by drawing tangents to most linear part of each curve and tabulated in Table 2.

Table 2: Maximum shear stiffness at different normal stresses

Determination No.	1	2	3	4
Normal Stress (MPa)	0.1	0.2	0.3	0.4
Shear stiffness (MPa/mm)	0.028	0.031	0.062	0.064

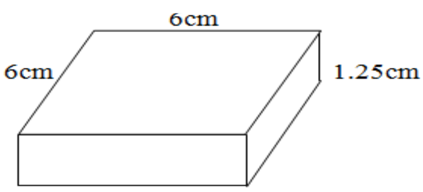


Fig.2

Normal Stiffness

To determine the normal stiffness, cores of diameter 42 mm and height 25 mm were casted. A set of four such cores were kept one above the other (Fig. 3) and load was applied normal to the joints. Normal stress vs deformation behaviour of this set of cores up to failure was observed. The average axial stress vs axial deformation curves of intact and of the jointed specimen are plotted (Fig. 4).

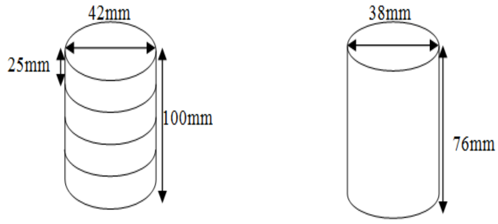


Fig.3 Fig.4

Joint closer was calculated by subtracting the intact material deformation from the joint deformation, and divide by number of joints (Fig. 5). The curve shows the variation between normal stress on the joint closer. The variation between normal stress and joint closer of these tests is shown vide Figure 6.

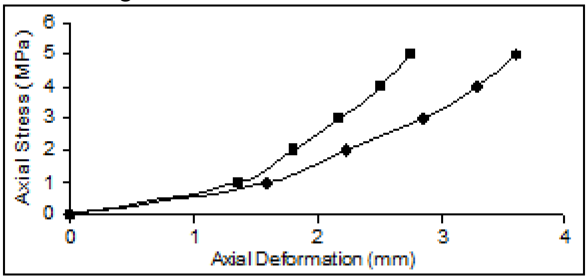


Figure 5: Normal stress vs deformation curve for intact and jointed mass

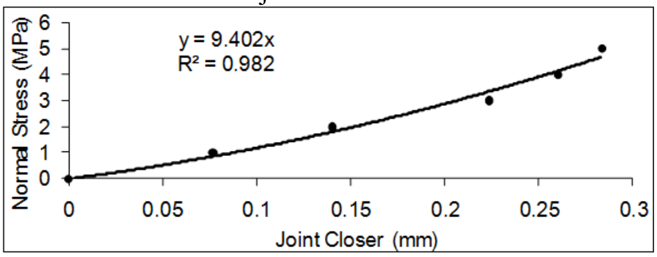
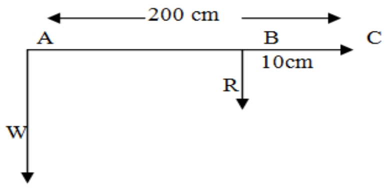


Figure 6: Variation of normal stress vs joint closer

Direct Shear Testing of Jointed Mass

Direct shear tests were performed on the specimen of jointed mass, and the following procedure were adopted:

1) Direct shear tests were conducted on specimens having 15°orientation of joint with respect to shearing direction. Direct shear tests were also conducted for infilled joints. China clay powder was used to fill between the joints having orientation θ=15°.Test were conducted under constant normal load condition.
2) To minimize the scale effect, specimen size 300 mm x 300 mm x 150 mm was selected. A model material was selected because of ease of workability and reproducibility of the results.
3) The casted jointed specimen was carefully placed in the shear box so that the joints make an angle 15˚ with the direction of shear. Sand was used to level the top surface of jointed specimen. A steel plate of the size 300 mm x 150 mcm x 25 mm was placed on the sample. Roller was placed between the spaced and the steel plates (Fig.6).
4) The spacing of the joints was kept constant. Normal load was applied on the specimen through the lever arm. The calibrated normal load was 20 times the load placed at the end of lever arm on the hangar.



Taking moment about C :
R x 10 = 200 W
R = 20 W

5) Shear force was applied to the specimen by the Hydraulic Jack (Fig. 7). Shear stress, shear displacement and normal displacement (dilatation) were recorded during the test.

To measure the shear load, proving ring (least cont. 1 Div = 10.526 kg) of 100 kN was used. Four dial gauges (least count 1 div.= 0.01mm) were used to measure the dilation and two dial gauges were used to measure the shear displacement. Average value of the dial gauge readings was adopted to measure the dilations on the shear displacement (Fig. 6). As shear force was applied to the specimens, for every 100 Division of dial gauge No. 5 readings of the entire dial gauges and the proving ring readings were recorded.

3. Observations

Direct shear tests were conducted on the jointed specimens of 15° orientation. Direct shear tests were also conducted for infilled joints with china clay powder with orientation θ=15°. The values of peak shear strength and peak dilation are presented in Table 3 and Table 4.

Table 3: Observation of direct shear test for jointed specimen, θ=15°

Sample Observation	CS-1 σ= ν αΠΜ 61.0	CS-2 σ= ν αΠΜ 42.0	CS-3 σαΠΜ 23.0= ν	CS-4 σ= ν αΠΜ 04.0	CS-5 σ= ν αΠΜ 84.0
1.Initial compression (mm)	1.2	1.6	1.4	1.8	1.8
2.Peak shear stress (MPa)	0.187	0.246	0.334	0.318	0.43
3.Peak dilation (mm)	1.95	2.05	1.09	1.1	1.35
4.FailureMode	sliding	sliding	sliding and tensile splitting	sliding and tensile splitting	sliding and tensile splitting.

Following modes of failure have been observed during the present study,

a) Sliding along the joint plane.
As the shear load applied on the jointed specimen, it slides along the joints. The specimen failure was initiated due to sliding along the joints.

b) Tensile splitting by vertical fracture planes passing through specimen.
The term tensile splitting implies failure of material due to tensile stresses developed inside the specimen. At the high normal stress, the failed specimen shows minute cracks, roughly vertical in direction.

c) Opening of angularities.
Opening of angularities are also observed during direct shear test. This is because of the frictional difference between the two asperities plane, due to this frictional difference relative movement takes place between the asperities plane and angularities opens.

Table 4: Observation for direct shear test on infilled jointed specimen, θ=15°

Sample Observation	CS-1 σ= ν αΠΜ 61.0	CS-2 σ= ν αΠΜ 42.0	CS-3 σαΠΜ 23.0= ν	CS-4 σ= ν α ΠΜ 04.0
1.Initial compression (mm)	4.6	5	5.4	5.4
2.Peak shear stress (MPa)	0.06	0.134	0.14	0.18
3.Peak dilation (mm)	2.88	2.5	2.38	2.22
4.FailureMode	sliding	sliding	sliding and tensile splitting	sliding and tensile splitting

Shear Strength Parameters of the Jointed Mass

Joints without infilling

The failure envelopes for an asperity angle θ =15° is presented in Fig. 8. The instantaneous cohesion and friction angle values are computed by drawing tangents at different normal stress levels. The results obtained are presented in Tables 5.

Table 5: The Instantaneous cohesion and friction angles for θ = 15°

σn (MPa)	Instantaneous cohesion Cj (MPa)	Instantaneous friction angles Φj (degree)
0.16	0.022	44.19
0.24	0.059	40.35
0.32	0.072	36.03
0.40	0.12	31.17
0.48	0.17	25.76

It is observed that the failure envelopes for 15° orientation used in the present study are non linear and pass through origin. In general, it was observed that, instantaneous cohesion increased with increase in the normal stress (Fig. 9). Whereas the instantaneous friction angle Φj decreased with increase in the normal stress (Fig.10).

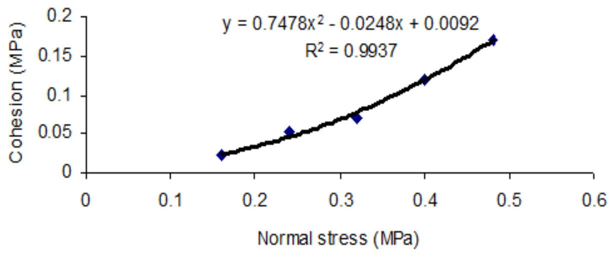


Figure 9: Variation of instantaneous cohesion with normal stress, θ = 15°

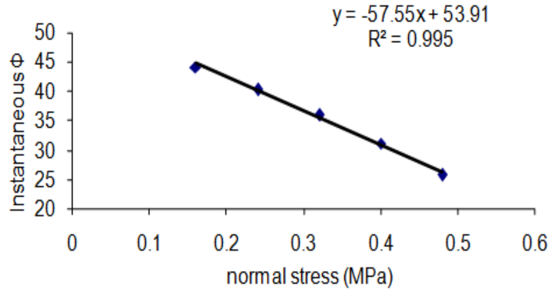


Figure 10: Variation of instantaneous angle of friction Φj with normal stress, θ =15˚

Joints with infilling

It is interesting to see that there is a reduction of the order of 50% in the peak shear strength in almost all the cases of normal stress adopted. The failure envelope for the infilled joint is presented in Fig. 11. The variation of the instantaneous cohesion and friction angle is also shown in the Fig. 12. It is also observed that the failure envelope do not pass through origin and indicates a cohesion intercept for zero normal stress. The results obtained are presented in Table 6.

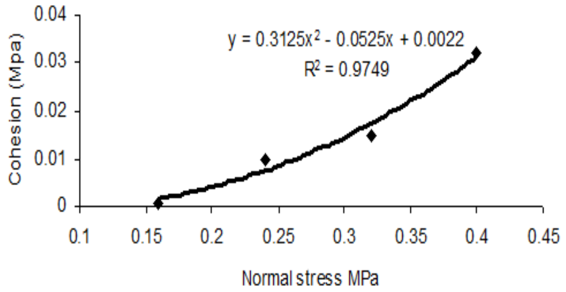


Figure 11: Variation of instantaneous cohesion with normal stress for infilled joints,

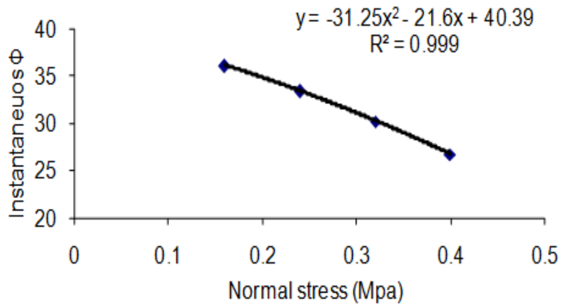


Figure 12: Variation of instantaneous angle of friction Φj with normal stress for infilled joints, θ =15˚

Table 6: Instantaneous cohesion and friction angle for infilled joint for orientation θ = 15°

σn (MPa)	Instantaneous cohesion cj (MPa)	Instantaneous friction angles Φj (degree)
0.16	0.0018	36.21
0.24	0.0074	33.38
0.32	0.0174	30.42
0.40	0.0312	27.12

4. Conclusion

The present study is only on single joint set & single joint frequency. The joints may have number of different orientation and discontinuity. The toppling and rotational behaviour of jointed mass is also neglected in the present study. Apart from these limitations the following conclusions were drawn from the present study which reflects shear strength parameters of jointed mass.

1) Instantaneous cohesion increases as increase in normal stress for jointed mass at 15° orientation.
2) Instantaneous friction angle decreases as increase in normal stress for jointed mass at 15° orientation.
3) Peak shear strength of infilled joints i.e. joints filled with dry china clay powder found to be decreased about 50% for the same orientation θ = 15˚ with respect to without infilled joint.

References

[1] B. Nicholas, "Review of a New Shear Strength Criterion for Rock Joints" 7(4) pp. 287 – 332, Engineering Geology, 1973.

[2] Bandis S.C., Lumsden A.C. and Barton N.R., "Fundamental of Rock Joint Deformation", 20(6) pp. 249–268, Int J Rock Mech Sci Geomech Abstr, 1983.

[3] Johnston W.I, Kodikara K.I , "Shear Behaviour Of Irregular Triangular Rock Concrete Joints" 31, pp. 313-322, Int J Rock Mech Sci Geomech Abstr, , 1994.

[4] Patton F.D., "Multiple Modes of Shear Failure in Rock", 1, pp. 509-513, Proc. Ist Cong., Int. Soc. Rock Mech. Lisbon, 1966.

[5] Sharma S.K., "Characterization of Model Material For Shear Strength Behaviour Of Jointed Rocks", M.Tech Dissertation, IIT Roorkee, India, 2003.

[6] Ladanyi B. and Archambault G, "Evaluation of Shear Strength of a Jointed Rock Mass", pp. 249 – 260 French Proc. 24th Int. Geotechnical Cong., Montreal, , 1972.