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Shear Behaviour of Rock Joints

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Abstract: ***Rocks in natural state always consist of joints and presence of intact rock is very difficult because some weathering action is always taking place in nature .Compared to intact rocks the weathered rocks has very less crushing and shearing strength ,thus this requires the study of strength parameter of rock masses. In jointed rocks, the shear displacement is accompanied with vertical movement or dilation and this property plays an important role and should be known to design engineers . For experimental work it is very difficult to use actual rock present in field therefore artificial samples of rocks are prepared .The material used for preparations of sample should be easily and cheaply available in market for example mortar ,POP etc. can be used but we have considered POP . The joints can be prepared at any angle but in this analysis the joints are taken unequal with asperity geometry of 15°-30° and 15°-45° .The geometry of 15°-30° represent that the facing angle is 30°. The sample are prepared with POP at the moulding water content of 50% by weight then direct shear test is conducted at 14 days of air dried curing and test is done in conventional direct shear test machine. The direct shear test can be conducted in CNL or CNS condition. In CNL condition, the normal stress is kept constant but in actual the normal stress does not remain constant, in field CNS condition occurs. In CNS condition stiffness remains constant ,the result obtained from CNS condition gives higher value of shear stress but this condition of testing is not adopted because the equipment developed in the past for CNS boundary condition was either having difficulty in changing the boundary conditions or it was not useful for wide variety of rock joints. The orientation of rock during testing plays an important role in resisting shear stress. Direct shear stress carrying capacity for 15°-45° asperity sample as compared with 15°-30° asperity sample will more and dilation will also more in case of 15°-45° asperity sample as compared with 15°-30° asperity sample. In case of 15°-45° asperity sample and 15°-30° asperity sample, the peak shear displacement increases up to 0.4MPa normal stress but it drastically reduced at 0.5 MPa because at this value the normal stress tries to prevent the horizontal displacement and finally the result obtained experimentally are compared with well known equation of Barton(1973), Bandis(1982) and Patton's(1966) and Shrivastava and Rao (2012) criteria.***

Keywords: Asperity, Dilation, shear stress, horizontal displacement.

1. Introduction

Rock mechanics is the theoretical and applied science of the mechanical behaviour of rock and rock masses. Compared to geology, it is that branch of mechanics which concerned with the response of rock and rock masses to the force fields of physical environment. Rock is the material which may be intact or which may be in the disintegrated form. Their form has very high influence over the engineering properties .The strength is high in intact rock and very low in the jointed rock .The frequency of loading is also a very important parameter which defines the strength of rock. For designing any structure or analyzing rock, the characterization of material is very important in rock mechanics. The aim of this research is also to study the shear and dilation behaviour of artificial rock joint (prepared by Plaster of Paris) , to model the shear behavior using experimental results and also tells which theory gives most realistic result compared with experimental results .

Rock mechanics, as applied in engineering geology, mining, petroleum and civil engineering practice, is concerned with the application of the principles of engineering mechanics to the design of the rock structures generated by mining, drilling, reservoir production, or civil construction activity, e.g. tunnels, mining shafts, underground excavations, open pit mines, oil, road cuts, waste repositories, and other structures built in or of rock. It also includes the design of reinforcement systems, such as rock bolting patterns, which is concerned with the mechanical responses of all geological materials, including soils.

2. Literature Review

Researches over shear behavior is conducted on rock by many researchers from time to time .Shear strength of rock increases with the increase in normal stress and asperity angle of joint (Patton's 1966).The shear strength generally follows the different pattern at low normal stress as compared with shear strength at high normal stress. During shearing the sample have tendency to dilate .Dilation can be defined as the relative movement of rock joint and can be measured as inverse tangent of ratio of vertical displacement to Horizontal displacement .Shear strength of sample is dependent on surface area of plane formed by the joint and the rate of dilation (Ladanyi and Archambault 1970),as the area and rate of dilatancy increases the shear strength will increases .

Barton also gave the criteria for determination of shear strength, he suggested that the shear strength of jointed rock not only depends upon the joint area but also depends on JCS, JC and on basic friction angle (Barton 1973-1976).

For determination of shear strength Shrivastava and Rao (2010), Shrivastava and Rao (2011) and Shrivastava and Rao (2013) proposed the expression for the determination of shear strength. He proposed that shear strength is proportional to basic friction angle and effective asperity angle .He also suggested the expression for the determination of effective asperity angle.

The shear strength of sample is obtained at particular horizontal displacement which is known as Peak shear displacement and expression is given for determination of the peak shear displacement (Bandis et. al. 1981).As the researches are conducted new expression are suggested by different scientist .According to Asadollahi ,peak shear displacement is depended on the length of sample ,normal stress under which testing is done and JCS value of sample.

Our aim of study is the determination of shear parameter of rock by preparation of artificial sample .In this study the result obtained from the experiments are represented in graphical form . Graphs are plotted between i)dilaton and shear displacement ii)shear stress and shear displacement and then the results are obtained and comparision is made with results obtained from different theories like Barton's theory, Barton-Bandis theory ,Bandis theory and with Shrivastava and Rao(2012) criteria.

3. Experimental Work

Experimental work consists of characterization of material used for the preparation of sample and finally direct shear test is conducted on the sample. Material characterization of Plaster of Paris is done in which UCS test, Specific gravity test, Initial setting time, Final setting time tests are performed.

3.1. Material Used

It is very difficult to obtain the core of rock sample in field and conducting experiments on it, therefore behaviour of rock joints is simulated by molding artificial rock joints using some model material. Model material should be such that uniform, identical and homogeneous joint specimen can be prepared in order to understand the failure mechanism, deformation behavior and strength of rock joints. It has been observed that the POP is the best material for the preparation of the artificial rocks sample. POP is a type of building material obtained from Gypsum plaster ($CaSO_4.0.5H_2O$) hemihydrates by heating gypsum at a temperature of about 300°F. Plaster of Paris of Sakrani Brand has been used for this study.

Specific gravity test-The specific gravity of POP used is determined by Le-Chatelier flask and the specific gravity is obtained as 2.08.

3.2. Initial and final setting time determination

The initial and final setting time of POP is determined according to the IS 4031 (Part5): 1988 .Initial setting time is determined so as to know the time up to which the paste can be remoulded or should be placed in the mould. Final setting is determined to know the minimum time upto which the paste should not be disturbed.

Table No.1: Shows Initial and Final Setting Time of POP

Water Content % by Weight	Initial Setting Time (min)	Final Setting Time(min)
30	5.2	7.5
40	8.1	11.2
50	12.5	15.8

3.3. UCS Test

UCS tests was conducted on the samples prepared by 30%, 40% and 50% water content (by weight) of Plaster of Paris for 7 days of curing and 14 day of curing (air dried curing) on the sample of 50% water content.

Comparison of UCS values at different water content at 7 days of curing:

Table 2: Shows UCS values for different w/c at 7 days of curing

W/C Content	UCS Values
30%	11.5MPa
40%	10.0MPa
50%	7.0MPa

Compressive strength for 50% water content after 14 day curing: Uniaxial Compressive Strength of Plaster of Paris for 50% water content after 14 curing is 11.2MPa.

Finally the 50% water content and 14 days of air dried curing is selected for the preparations of the sample for direct shear test.

Direct shear test is conducted on the samples and the peak shear stress values are obtained for samples under different normal stress.

i) **For 15°-30° asperity sample-** Direct shear test is conducted on rock sample prepared at an asperity angle of 15°-30° .The shear stress values are obtained at different normal stresses and strength envelope is drawn .This shear stress values obtained from experiment are compared with shear stress values obtain from different theories.

Table 3: Shows shear stress values at different normal stress

Normal Stress (MPa)	Experimental Result (MPa)	Patton's Equation of τ_p (MPa)	Barton's Equation of τ_p (MPa)	Shrivastava and Rao (2012) τ_p (MPa)
0.05	0.210	0.130	0.156	0.185
0.1	0.467	0.250	0.244	0.344
0.2	0.630	0.510	0.396	0.605
0.3	0.800	0.750	0.532	0.813
0.4	0.924	0.990	0.650	0.985
0.5	1.055	1.270	0.777	1.130

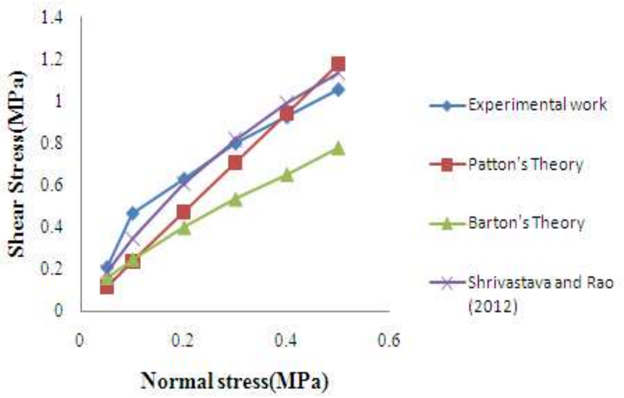

Figure 1: Graph shows peak shear stress under different normal stresses for different theories.

ii) **For 15°-45° asperity sample**-Direct shear test is conducted on rock sample prepared at an asperity angle of 15°-45° .The shear stress values are obtained at different normal stresses and strength envelope is drawn. This shear stress values obtained from experiment are compared with shear stress values obtain from different theories.

Table 4: Shows shear stress values at different normal stress

Normal Stress (MPa)	Experimental Result (MPa)	Patton's Equation of τ_p (MPa)	Barton's Equation of τ_p (MPa)	Shrivastava and Rao (2012)
0.05	0.250	0.355	0.476	0.099
0.1	0.480	0.710	0.469	0.194
0.2	0.770	1.420	0.614	0.370
0.3	1.130	2.130	0.759	0.531
0.4	1.410	2.846	0.896	0.680
0.5	1.600	3.557	1.025	0.818

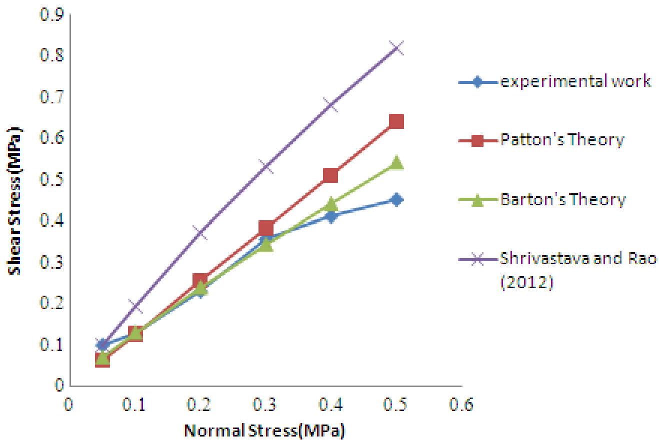

Figure 2: Graph shows peak shear stress under different normal stresses for different theories

4. Comparison of Peak Shear Displacement

Peak shear displacement is defined as the shear displacement at which the sample is likely to be fail or the displacement beyond which the stress value is decreasing .

i) **For 15°-30° asperity sample-** Direct shear test is conducted on rock sample prepared at an asperity angle of 15°-30° .The peak shear displacement values are obtained at different normal stresses and strength envelope is drawn .This peak shear displacement values obtained from experiment are compared with values obtain from Barton-Bandis theory.

Table 5: Shows Peak shear displacement values at different normal stress

Normal Stress (MPa)	Experimental Result (mm)	Barton-Bandis Theory (mm)
0.05	1.76	0.74
0.1	3.11	0.74
0.2	3.11	0.74
0.3	3.21	0.74
0.4	3.65	0.74
0.5	2.57	0.74

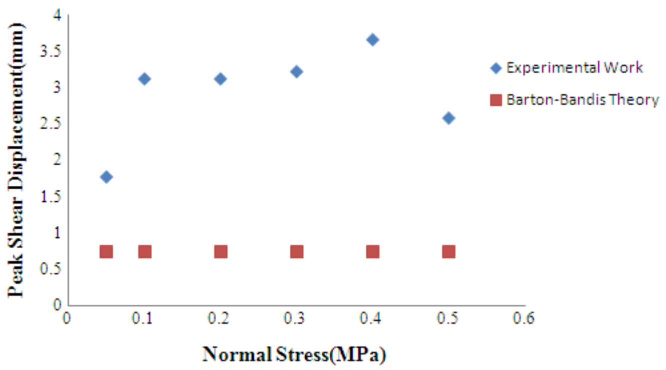

Figure 4: Graph shows peak shear displacement under different normal stresses for different theories

ii) **For 15°-45° asperity sample-** Direct shear test is conducted on rock sample prepared at an asperity angle of 15°-45° .The peak shear displacement values are obtained at different normal stresses and strength envelope is drawn .This peak shear displacement values obtained from experiment are compared with values obtain from Baton-Bandis theory.

Table 6: Shows Peak shear displacement values at different normal stress

Normal Stress (MPa)	Experimental Result (mm)	Barton-Bandis Theory (mm)
0.05	1.53	0.81
0.1	2.75	0.81
0.2	3.00	0.81
0.3	3.25	0.81
0.4	3.63	0.81
0.5	3.46	0.81

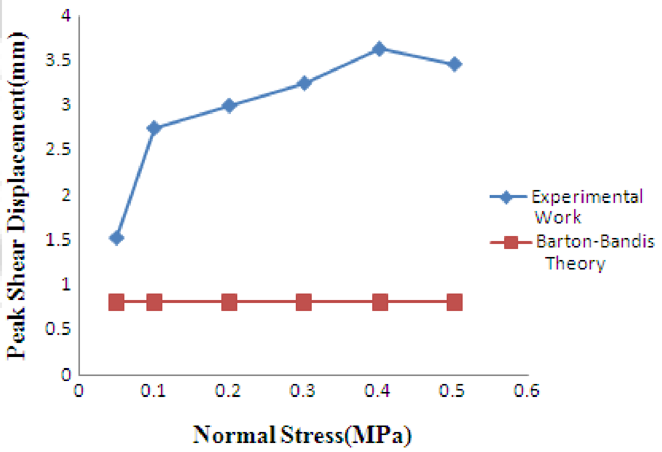

Figure 5: Graph shows peak shear displacement under different normal stresses for different theories

5. Results

From the experimental result and comparison with the Barton's theory, Patton's theory and with criteria suggested by Shrivastava and Rao (2012) we have following points as Results

1) Peak shear stress increases with the increase in the asperity angle(facing asperity angle) . With increase of facing angle (i) from 15° to 45°, the peak shear stress increases by 127.27% to 269.2% .This is the fact because

as the asperity angle increases it provides greater interlocking.

2) Peak shear stress increases with the increase in the normal stress, it is observed that the peak shear stress increases by 9% to 122.3% with the increase in normal stress from 0.05 MPa to 0.5 MPa.
3) Peak secant dilation angle decreases with increase in normal stress .It is observed that peak secant dilation angle decreases by 2.5% to 47.3% .This is the fact as the normal stress increases the tendency of upward movement will decreases.
4) Peak secant dilation angle for 15°-30° and 15°-45° asperity sample calculated from experimental values are coming higher than the values obtained from the Barton's equation.
5) Peak shear displacement increases with increase in the normal stress upto 79.7% with increase in normal stress upto 0.4 MPa but Peak Shear Displacement decreases suddenly for 0.5 MPa because this is very high Normal Stress at which sample is subjected to the shear stress and vertical stress both so it will leads to the failure of sample at comparatively low value of Peak Shear Displacement.
6) The experimental result are nearer to the values obtained by Barton's theory, therefore Barton's theory gives more realistic representation.

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