Effect of confined and unconfined stress on jointed rocks

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The behaviour of rockmass depends on the loading behaviour and their surroundings. The Chunar sandstone of Vindhyan System has been tested in confined and unconfined stress conditions with different joint orientations 30°, 45°, 60° and 90°. It is found that uniaxial compressive strength increases as the value of joint orientation increases. It has also been observed that strength of specimens having joint orientation 90° is highest under the same confinement. As the confinement increases the strength increases at the same angle of joint orientation.

Homogenous rockmass are rarely found in nature. It almost always contains different types of discontinuities which are in form of joints, faults, folds, fissures, igneous intrusions etc. Among them, joints are one of the basic structural characteristics of rockmasses which influences their mechanical response and behaviour. Investigations of rockmasses shear strength at discontinuities is of immense practical importance, especially in relation to mining excavations and civil engineering constructions. This has given impetus to clarify the mysteries and complexities of rock behaviour for safe and economical design and construction of structures. The mechanical behaviour of jointed rockmass depends upon the factors like mechanical behaviour of individual elements constituting the system, sliding characteristics of the joints, configuration of the system and operating stress field.

The triaxial shear parameters of rock is of special importance in calculating the bearing capacity of foundation rock for surface structures, in determining the strength of mine pillars and other problems related to underground structures. These underground structures and pillars are sometimes subjected to hydrostatic condition and they behave in confined state of stress where loading is from all the three directions.

A joint drastically effects the bearing capacity of a rockmass. This is of vital importance while considering a rockmass as a foundation to a big structure or as an abutment to a large bridge or an arch dam. If a joint favours unstable condition, it may lead to disaster on rockmass failure. On the other hand, an opposite angle of orientation will lockup the rock, enhancing the stability and bearing capacity, but it will undergo a greater amount of deformation on consolidation of joints under the applied stress.

The problem of defining the rock behaviour under unconfined state, i.e., uniaxial loading, however, is not devoid of practical interests. Rock structures like mine pillars, pillars under a bridge, barrier pillars are subjected to unconfined loading.

Study of confined and unconfined loading of rocks could help to improve the communition of rocks and design of more stable structures, eliminating accidental failures. Significant work has been done by various researchers about the behaviour of rock in confined and unconfined states but very little work has been reported on jointed rocks, hence this work has been taken up keeping in view the heterogeneity of rock, to understand the phenomenon of failure in both the confined and unconfined states. The present investigation aims to determine the strength of rock specimens in both confined and unconfined states at different angles of discontinuity (joint) with the direction of loading, for understanding the failure mechanism in these states, find out the relationship between the cohesion (c) and the angle of internal friction (φ) of rocks at different angles of joints and develop a relation between unconfined and confined strength for intact and jointed rockmass.

Review of Literature

A number of empirical strength criteria for
anisotropic/jointed rocks were proposed earlier based on classical Navier-Coulomb and Griffith failure theories. These theories due to their limitations, cannot be used for determining the strength of jointed rockmass. The stress-strain behaviour under uniaxial and triaxial loading conditions was first investigated by Burdine. He suggested that the strength of rocks is strongly dependent on the grain size, their packing, intra-granular relationship, presence of matrix and other binding materials. Shen and Stephenson developed a conceptual model to analyze the behaviour of a rock specimen containing a joint and rock bridges during loading cycle. Singh simplified the joints in the rockmass as a joint system which completely cuts the rockmass into regular blocks. Based on this assumption, he obtained an analytical solution to describe the elastic behaviour of a jointed rockmass.

Sheroy and Choubey described that the five triaxial parameters $\sigma_c, \sigma_p, \tau_c, \tau_p$ and $\mu (\mu = \tan \phi)$ may be interrelated for a given triaxial strength equation. A change in any of these parameters cannot be made independent of each other. They suggested the following relations:

$$\sigma_c = 1.8 \tau_c (\mu + \sqrt{1+\mu^2})$$

and

$$\sigma_p = 1.67 \tau_p (\sqrt{1+\mu^2} - \mu)$$

The orientation of the joint planes plays a crucial role in alteration of the deformation properties of the medium as compared to intact rockmass. The failure of rockmass around excavation often occurs when the strength of the joints and other discontinuities is exceeded. This phenomenon is more common in areas having hard rocks.

**Experimental**

**Procedure**

In the present study, confined and unconfined testing methods were employed to determine the uniaxial compressive strength of the jointed rock specimens. Triaxial tests were conducted for specimens in varying confining pressures allowing the failure to follow the path of least resistance. The rock selected for the experiment was Chunar sandstone of Vindhyan System because of its homogeneity, hard and compact nature and easy availability. All the specimens were obtained from the same block of Chunar sandstone. Specimens were prepared as per ISRM standards.

Cylindrical specimens were obtained by diamond core drilling from the Chunar sandstone block and artificial joints were simulated at angles of 30°, 45°, 60° and 90° by cutting the specimens at the required angle by diamond coated saw blade and joining them by special adhesive. Intact specimens were also tested.

![Graph](image-url)
Testing

For triaxial testing, samples having joints at 0° (intact), 30°, 45°, 60° and 90° were tested at four different confining pressures of 5, 7.5, 10 and 12.5 MPa. This conning pressure was maintained with the help of a hand operated oil pressure pump. Then the specimen was loaded along its axis on the servo-controlled auto feedback testing machine (MTS). For unconfined testing, specimens having joint angles as stated earlier were loaded uniaxially on the MTS Servo Controlled Stiff Testing Machine. Axial load versus deformation curves were obtained from the MTS Machine for both the confined and unconfined tests.

Results and Discussion

Strength envelopes at maximum principal stresses obtained from the tests are shown in Figs 1 - 5. At the angle of orientation β=90°, value of angle of internal friction (ϕ) obtained was 50° and cohesion was 12

![Graph 1](image1)

**Fig. 2**—Coulomb’s strength envelope for jointed rock specimen having joint plane orientation of 30°.

![Graph 2](image2)

**Fig. 4**—Coulomb’s strength envelope for jointed rock specimen having joint plane orientation of 45°.
MPa (Fig. 5) which almost agrees with those of intact specimens where $\Phi$ is $50^\circ$ and cohesion is 9MPa (Fig. 1). When $\beta=30^\circ$, the value of $\Phi$ obtained is $0.22^\circ$ and cohesion is 0.9 MPa (Fig. 2) from which it could be inferred that the failure resulted mainly from the sliding along the weak structural plane and new surfaces are rarely formed. The value of $\Phi$ obtained can be understood as value of sliding friction rather than internal friction. When $\beta=45^\circ$ and $60^\circ$ the value of $\Phi$ and cohesion is $0.9^\circ$ and 15 MPa, 26$^\circ$ and 24 MPa respectively (Figs 3 and 4) which meant that the failure resulted from not only the sliding along the joint plane but also due to cross connection of weak planes with the development of new failure surfaces in the rock. As $\beta$ increased from $30^\circ$ to $90^\circ$, the value of $\Phi$ increases assuring that the failure mode...
transformed from sliding failure to that of making new failure surfaces.

Relationship between axial stress and orientation angle

The angle of orientation of the joint plane with the principal stress direction greatly influences the strength properties of rock.

The experimental results for the axial stress, at different orientation angles have been plotted in Fig. 6. It can be seen that the strength for specimens having $\beta=90^\circ$ is the highest, under the same confinement. The strength shows a decreasing trend with decrease in $\beta$. Out of all the orientation angles tested, the strength had least value in case of $\beta=30^\circ$. 

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Fig. 6—Variation of axial stress with different orientation angles at different confining pressures

Fig. 7—Variation of stress-strain at various confining pressures (Joint angle 30°)
where it reduces to approximately 10% of the intact rock strength. It appears that the variation of strength of jointed rock is related to their failure forms. If $\beta$ is high, the strength is higher because the failure forms are mainly due to the damage of rock blocks themselves. However, if $\beta$ satisfies the condition for sliding failure, the strength reduces sharply.

A distinguished observation was that at $90^\circ$ orientation, the strength of jointed rock was slightly more than that of intact rock. It appears that because of the reduction in size of the specimen ($L/D$ ratio 1:1) on division into two (equal halves), the two blocks behave independently. One block acts as a platen for the other. The resultant end constraint might have caused the increase in the strength.

A load-deformation curve till failure was obtained.
at various angles of joint orientations, with the help of this curve strains at various stress level were calculated. Stress-strain curves obtained from these values are shown in Figs. 7-10.

It is observed that in almost all the cases the curve follows a more or less linear path. It is seen in the plot that as the confinement increases, the stress increases.

At 30° joint orientation the maximum stress was 16.5 MPa at 12.5 MPa confinement and minimum was 8.9 MPa at 5 MPa confinement (Fig. 7). Similarly maximum stress at joint orientation of 45°, 60° and 90° was 39.5, 106.3, and 167.3 MPa at 12.5 MPa confinement and minimum stress was 31.3, 89.2 and 106.5 MPa at 5 MPa confinement respectively (Figs. 8-10).
Rock behaviour during unconfined loading

The load-deformation curves obtained from the stiff testing machine were analyzed to find out the stress-strain behaviour of rock at each joint orientation. Stresses were calculated at various strain values for the intact as well as jointed rock specimens. Maximum stress for intact rock specimens was found to have a value 46.9 MPa (Fig. 11). The rock samples tested at 30° joint orientation shows a linear line more or less parallel to the deformation axis at a constant load which indicates that the shear strength was almost constant throughout the test. It can be concluded that at 30° joint orientation, sliding initiated at very low strain, new fracture surface was rarely developed. At 45° joint orientation the stress-strain curve shows that the strain reached the maximum level when stress was 17.2 MPa and after that sliding was observed. At 90° joint orientation, the stress-strain curve are similar to that of intact rock because the loading and joint direction are perpendicular to each other. The peak axial stress in case of joint orientation of 90° is more than that of intact rock specimen. This is because of the reduction in size of the specimen (L/D ratio 1:1), the rock divides into two equal blocks, each block behaving almost independently. One block acts as a platen for the other. The resultant end constraint might have caused the increase in the strength.

Conclusions

The following conclusions can be drawn from the results obtained:

(i) The strength of the rock specimens having joints showed a wide variation in the inclination of the weak plane.

(ii) At the joint angle 30°, the specimen shows least strength. The strength increases as the joint angle increases.

(iii) In the confined state, the maximum strength was found at joint orientation of 90°.

(iv) Maximum angle of internal friction was found at joint orientation of 60° and minimum angle of internal friction was found at joint orientation of 30°.

(v) The unconfined compressive strength is also dependent on the joint angle. The maximum strength was found at 90° whereas lowest at 30°. In both the cases, i.e., confined and unconfined, 30° angle was found more crucial for sliding as compared to the other joint angles.

(vi) It was found that joint angle and uniaxial strength relation indicates a linear decrease in stress with decrease in joint orientation.

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References