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**"Technical Note"**

# STRENGTH AND DEFORMATION PROPERTIES OF A SCHIST ROCK IN ISFAHAN*

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**Abstract–** In most parts of the city of Isfahan, at depths of 5 to 20 meters from the ground surface, schist is the predominant rock. This schist is a layered rock with variable thickness of 3 cm or more. Triaxial tests were conducted on the specimens with various anisotropic angles under confining pressures of 0, 7 and 15 MPa, and axial stress-axial strain were measured and plotted for various conditions.

The results obtained reveal the effects of schistosity on the strength and deformability of the rock very clearly. The modulus of deformation of this rock varies with the anisotropic angle. For zero orientation, the modulus of deformation increases to a maximum. The results show that the friction angle and cohesion are affected by the anisotropic orientation, which is more important for the cohesion than the friction angles. It is not possible to apply failure criteria such as Mohr–Coulomb and Hoek–Brown for this rock without consideration of anisotropy orientation.

**Keywords–** Schist rock, anisotropy, triaxial test

## 1. INTRODUCTION

Rock masses are rarely homogeneous, isotropic and intact, as commonly assumed for other engineering materials [1]. Failure of rock masses, particularly near the surfaces, usually results from sliding along a single discontinuity or a combination of discontinuities [2].

Determination of the strength and deformation properties of Isfahan schist is of paramount interest because many large factories, dams, conveyance tunnels, airports, and heavy buildings are under study and construction. For the purpose of measuring the strength and deformation properties of this rock, triaxial tests were conducted on specimens with various anisotropic angles under confining pressures of 0, 7 and 15 MPa, and axial stress-axial strains were measured and plotted for various conditions.

The procedure used for preparation of test specimens was in accordance with the ISRM suggested methods [3]. The specimens were cored to a nominal diameter of 45 mm and a length of 90 mm. All specimens were kept at room temperature and were room dry when tested. In order to prepare cylindrical specimens containing different anisotropic angles (layers with different orientations), with respect to the specimen axis, the surfaces of schist blocks were cut and oriented at angles of $0^0$ , $30^0$ , $45^0$ , $60^0$ , and $90^0$ relative to an axis perpendicular to each surface.

## 2. EXPERIMENTAL RESULTS

Table 1 shows the peak strength for different directions and confining pressures. The peak strength for zero and $90^0$ orientations are almost the same for different confining pressures. The confining pressure has increased the peak strength and improved the schist rock deformability. However, this effect is not the same for various anisotropic directions, nor is the same trend seen.

In order to assess the deformation characteristic of schist rock for various anisotropic directions and under different confining pressures, secant deformation modulus was measured at fifty percent of peak strength.

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Figure 1 shows the deformation modulus variations for different confining pressures. The effect of confining pressure on the deformation characteristics of this schist is clearly observed. For zero degree orientation this effect is much more significant. The rate of increase in this direction is higher than the other directions. The lower rate of increase corresponds to $90^0$ and $60^0$ orientations. Despite the fact that the peak strength in the $45^0$ direction is the lowest amount among the other orientations, the corresponding deformation modulus for this orientation is higher than the $60^0$ and $90^0$ directions, and the rate of increase is also higher in this orientation.

Figure 1 shows that the increase in confining pressure leads to the hardening of the schist specimens. This trend is not the same for different anisotropic angles. The increase in confining pressure resulted in a reduction in the rate of increase in the deformation modulus.

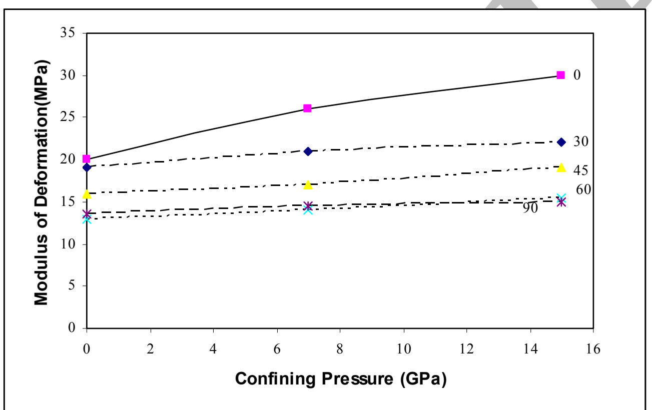


Fig. 1. Modulus of deformation-confining pressure plots for various bedding angles

Table 1. Peak strength (MPa) for different anisotropic directions and confining pressures

| Axial stress ($\sigma_1$) in MPa | | | |
|---|---|---|---|
| $\beta^\circ$ | $\sigma_3 = 0$ | $\sigma_3 = 7$ | $\sigma_3 = 15$ |
| 0 | 86 | 150 | 205 |
| 30 | 61.49 | 115.34 | 160.59 |
| 45 | 47.6 | 94.5 | 139.3 |
| 60 | 61.22 | 112.4 | 161.81 |
| 90 | 84.95 | 143.09 | 209.26 |

## 3. DISCUSSION OF RESULTS

For the purpose of exploring the effects of anisotropic directions on the mechanical parameters of the schist rock, the results were analyzed and strength envelops were determined using both Mohr-Coulomb and Hoek –Brown failure criteria. It is observed that C, $\phi$, m and s for the $45^0$ anisotropic orientation are minimum in comparison to other orientations. Figures 2 and 3 illustrate the corresponding envelops. A comparison of strength envelops for two failure criteria reveals that up to 10 MPa normal stress, the envelops for each anisotropic direction nearly coincide with each other. That is, a linear failure criterion may be used for low normal stresses, and therefore, a constant magnitude of C and $\phi$ for each particular anisotropic direction is acceptable.

It has been shown [4 & 5] that the variation of strength and parameters of C and $\phi$ for anisotropic rocks are as follows:

$$\sigma_1 - \sigma_3 = \frac{2(C + \sigma_3\, Tan\phi)}{Sec\phi - Tan\phi} \tag{1}$$

$$C = a - b[Cos2(\beta_{\min,C} - \beta)]^n \tag{2}$$

$$tg\ \phi = c - d[Cos2(\beta_{\min,\phi} - \beta)]^m \tag{3}$$

a, b, c, d, m and n are constant parameters which are determined for each anisotropic rock. $\beta_{\min C}$ is the anisotropic direction in which C is minimum, and $\beta_{\min\phi}$ is the anisotropic direction in which $\phi$ is minimum. As is observed, for $\beta = 45^\circ$ both C and $\phi$ are minimum. Analysis of the data and substituting Eqs. (2) and (3), the following relations are obtained.

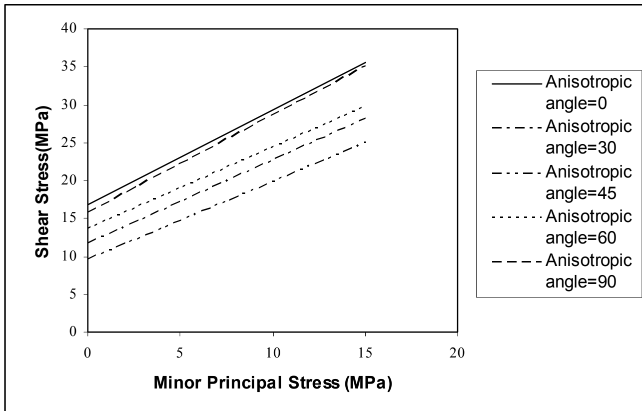


Fig. 2. Mohr-Coulomb envelops for various anisotropic directions

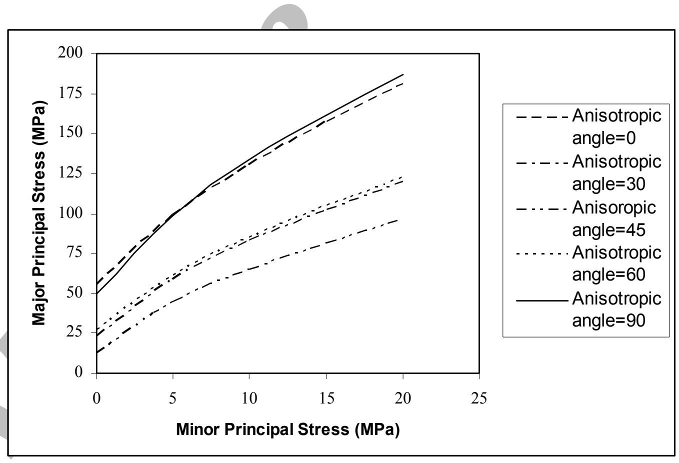


Fig. 3. Hoek-Brown envelops for various anisotropic directions

$$C = 163.2 - 66.7[Cos(45 - \beta)]^4 \tag{4}$$

$$tg\phi = 1.2731 - 0.2387[Cos\ 2(45 - \beta)]^2 \tag{5}$$

The following cosine functions may be used for these two parameters as appropriate mathematical models

$$m = e - f\,Cos2(\beta_{\min,m} - \beta), \quad \beta_{\min,m} = 45^\circ \tag{6}$$

$$s = g - h\,Cos2(\beta_{\min,s} - \beta),\ \beta_{\min,s} = 45^\circ \tag{7}$$

Analysis of data for the above functions resulted in the following equation:

$$m = 14.19 - 7.75\ Cos2(45 - \beta) \tag{8}$$

$$s = 0.38 - 0.272\ Cos2(45 - \beta) \tag{9}$$

Figures 4 and 5 show the variations of m and s with respect to anisotropic directions. As m refers to the type and quality of the rock and s refers to the degree of fracturing and opening of the joints, for an anisotropic rock mass high variations of these parameters are not expected. It is concluded that the approximation of m and s as representative of anisotropic rock mass is not possible, and therefore, Hock-Brown failure criterion is not applicable for discontinuous and anisotropic rocks.

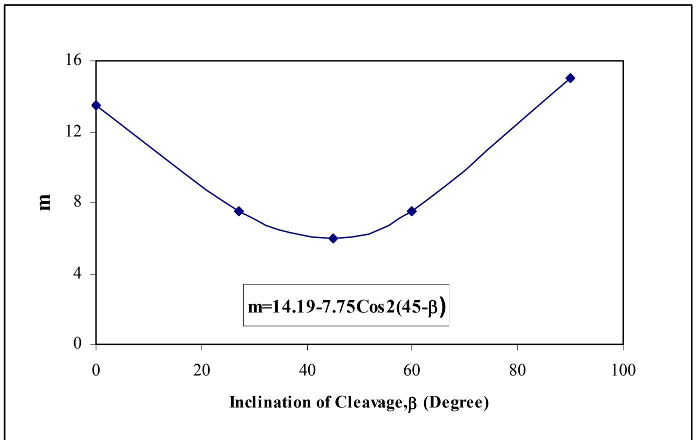


Fig. 4. Variation of m *vs* anisotropy direction

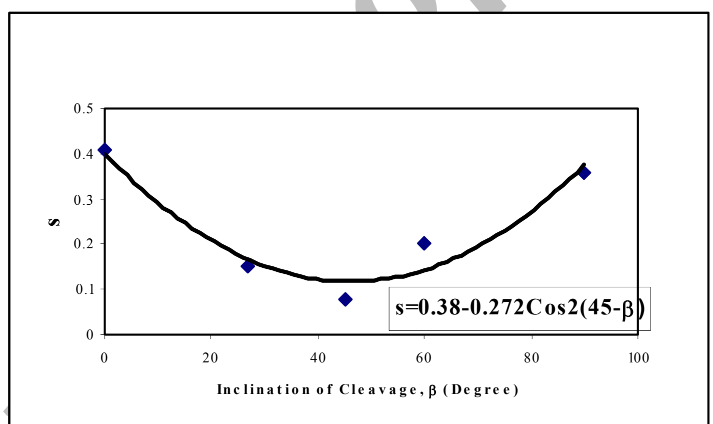


Fig. 5. Variation of s *vs* anisotropy direction

## 4. CONCLUSIONS

This experiment reveals that Isfahan schist has highly variable properties and it is significantly anisotropic. It does not show a unique strength, but orientation dependence. Behavioral parameters such as C, $\phi$, m and s are not unique, but variable for each direction and each level of confinement. Therefore, it is not possible to predict the failure of this rock by the usual failure criteria such as Mohr-Coulomb and Hock-Brown.

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