STRENGTH AND DEFORMATIONAL RESPONSES OF SCHISTOSE ROCKS

By

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DEDICATED TO

MY

PARENTS

CERTIFICATE

This is to certify that the thesis entitled, "STRENGTH AND DEFORMATIONAL RESPONSES OF SCHISTOSE ROCKS" being submitted by Mr. Mohammad-Hossein Nasseri Behrestaghi to the Indian Institute of Technology, Delhi, for the award of the degree of DOCTOR OF PHILOSOPHY is a record of the bonafied research work carried out by him. Mr. Nasseri Behrestaghi has worked under our guidance for the submission of this thesis which to our knowledge has reached the required standard.

The thesis or any part thereof has not been submitted to any other University or Institution for the award of any degree or diploma.

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ABSTRACT

To understand the physico-mechanical behaviour of intrinsically anisotropic rocks, some investigators emphasized the necessasity of conducting a number of triaxial test at a minimum of three orientations in order to predict the strength of anisotropic rocks at other orientations. Besides the need for predicting the strength, no precise attempt was made to understand and predict the behaviour of deformation modulus, stress-strain response, shear strength behaviour with minimum pre-evaluation experimental data. A non-linear strength criterion based on Mohr-Coulomb approach for intact and anisotropic intact rocks proposed by Ramamurthy and co-workers has shown better results as compared to a number of other available failure theories. With these findings in view, the present investigation is an attempt

i) to evaluate the nature and engineering bahaviour of the four varieties of schists with inherent anisotropies obtained from two Hydroelectrical project sites of Himalayan region, no such studies were carried out earlier on these rocks.

ii) to compare the responses of these four schists with that of similar rocks studied earlier by other researchers.

iii) to verify the applicability of the non-linear criterion proposed by Ramamurthy and co-workers for prediction of triaxial compressive strength of the schists with minimum pre-evaluation experimental data of two triaxial tests at $\beta = 90^\circ$ and uniaxial compressive tests of $\beta = 0$, 30 and 90°.

iv) to propose an empirical criterion to predict the deformation modulus, stress-strain behaviour and shear strength behaviour at different confining pressures (σ_3), and orientations (β) of anisotropic schistose rocks.

In this study, the nature of Quartzitic, Chlorite, Quartz mica and Biotite schists was broughtout using thin section, X-ray diffraction and Scanning Electron

Microscopic studies. The physical and strength properties were estimated using ISRM and Indian Standards (IS) test procedures.

Anisotropic strength behaviour of the schists was studied through testing of specimens with varying orientation (ß) of schistosity with respect to the major principal stress, at an interval of 15° i.e. 0, 15, 30, 45, 60, 75 and 90°. Triaxial tests were conducted at σ_3 = 5, 15, 35, 50 and 100 MPa at all the above orientations.

The schists under investigation have exhibited maximum compressive strength at ß=90° and the minimum between 30 to 45° showing "U-Shape" anisotropy curve similar to that of other schistose and metamorphic rocks. It has been observed that the anistotropic curve showing the variation of deformation modulus with ß for anisotropic rocks is either "U-Shape" or "Irregular Shape". Two of the more competent schists i.e. Quartzitic and Chlorite schists fall under former class whereas other two less competent schists i.e. Quartz mica and Biotite schists can be catagorised under later class.

The Brazilian and axial point load strengths increase at different rate for the four schists as ß varies from, 0 to 90° (with respect to loading direction); whereas diametral point load strength behave contrary to this. Quartzitic schist exhibits maximum anisotropic ratio in terms of compression, tension and strain measurement. Biotite schist shows minimum anisotropic ratio in compression.

The strength prediction made on the basis of modified criterion proposed by Ramamurthy and co-workers shows a good agreement with the experimental data of schistose rocks for all orientations and confining pressures, using the triaxial test data only at ß=90° and uniaxial compressive strength at 0, 30, and 90° orientations. The criterion slightly underpredicts the strength at 50 and 100 MPa of σ_3 for Quartzitic schist in the region ß<45 degrees. Using same strength criterion Ramamurthy and co-workers have shown a close agreement between the predicted strength and actual one for number of anisotropic rocks tested by numerous researchers. Keeping in view the non-linear increment of deformation modulus at different confining pressures for different orientations (ß), following empirical relationships have been proposed to predict the variation of deformation modulus at any orientation other than ß = 90° and for complete range of confining pressure (σ_3):

$$\frac{E_{t90}}{\sigma_3} = B_{e90}\left(\frac{\sigma_{c90}}{\sigma_3}\right)^{\alpha_{e90}} \tag{1}$$

Two more equations have been found to hold good to obtain the constant B_{ej} and α_{ej} at an orientation other than ß=90°. The uniaxial compressive strength at various orientations, σ_{cj}, is a scaling parameter for the non-dimensional parameters B_{ej} and α_{ej};

$$\frac{\alpha_{ej}}{\alpha_{e90}} = \left(\frac{\sigma_{cj}}{\sigma_{c90}}\right)^{1-\alpha_{e90}} \tag{2}$$

$$\frac{B_{ej}}{B_{e90}} = \left(\frac{\alpha_{e90}}{\alpha_{ej}}\right)^{1 \text{ to } 3} \tag{3}$$

These two key equations enables to determine the values of α_{ej} and B_{ej} at various orientations through the values of α_{e90} and B_{e90} obtained with only two to three triaxial tests at ß = 90°, which is the same minimum test requirement proposed by Ramamurthy and co-workers to predict the strength behaviour of anisotropic rocks.

The analysis showed that the power in the proposed Eqn. (3) varies form 1 to 3 for schists in general and being 3 for Quartzitic and Chlorite schists, and 1.5 for Quartz mica and 1.1 for Biotite Schist.

Using predicted values for strength and deformation modulus values were obtained in the present study in a non-linear hyperbolic formula proposed by Kondner et al. It has been found that the predicted stress-strain curves agree well with the experimental stress-strain curves of these schists.

To predict the shear strength behaviour of isotropic and anisotropic rocks with confining pressure, Mohr-Coulomb envelopes of more than 50 isotropic and 10 anisotropic rocks were constructed and analysed. Cohesive strength c, at each 'confining pressure (σ_3) was found and the value of c_o i.e. cohesion corresponding to uniaxial compressive strength was evaluated. The following relationship has been proposed to predict c at any confining pressure in brittle range.

$$\frac{c}{\sigma_3} = B_c \left(\frac{c_o}{\sigma_3} \right)^{\alpha_c} \tag{4}$$

Based on the analysis of data obtained for isotropic rocks an average value of 0.6 has been suggested for α_c of all types of rocks. Using 0.6 as α_c in the above equation B_c has been found to be 1.5 for argillaceous, 1.8 for arenaceous, 2.1 and 3 for chemical and igneous rocks respectively.

By extending the above cited equation for predicting the value of c for anisotropic rocks, it has been proposed to replace the parameters c_o, B_c and α_c with c_{oj}, B_{cj} and α_{cj}. These new parameters can be obtained through uniaxial compressive test and two triaxial compression tests at lower σ_3 at each of 0, 30 and 90° orientations respectively. The following equations are used to obtain the predicted c_{oj}, α_{cj} and B_{cj} for orientations other than 0, 30 and 90°.

$$c_{oj} = A_{oj} - B_{oj} \cos 2(\xi - \beta) \tag{5}$$

$$\alpha_{cj} = A_{cj} - B_{cj} \cos 2(\xi - \beta) \tag{6}$$

$$B_{cj} = A_{cj} - B_{cj} \cos 2(\xi - \beta) \tag{7}$$

Through the predicted values of strength and c at any confining pressure the value of angle of internal friction (ϕ) can be determined.

Predicted value of c at different σ_3 and β for a number of anisotropic rocks, match well with the observed values.

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