

CONSTITUTIVE MODELLING OF A SCHISTOSE ROCK IN THE HIMALAYA

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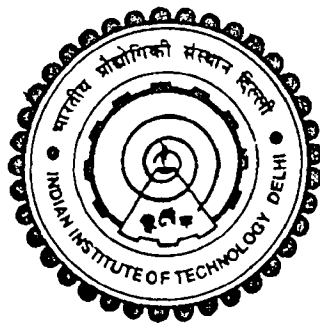
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Submitted

in fulfilment of the requirements of the degree of

DOCTOR OF PHILOSOPHY

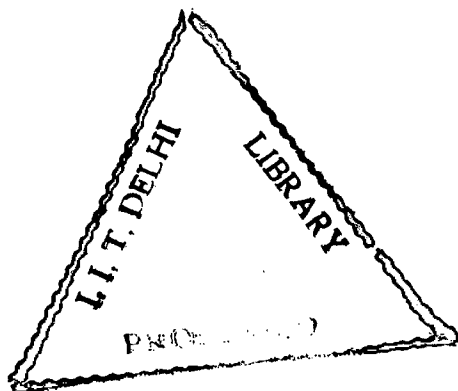
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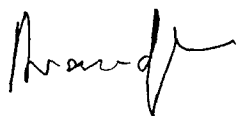
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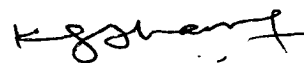
CERTIFICATE

This is to certify that the thesis entitled “**CONSTITUTIVE MODELLING OF A SCHISTOSE ROCK IN THE HIMALYA**” being submitted by **Mr. Mahmoud Hashemi Esfahanian** to the Indian Institute of Technology, Delhi is a record of bonafide research work carried out by him under our supervision and guidance. The thesis work, in our opinion, has reached the standard, fulfilling the requirements for **DOCTOR OF PHILOSOPHY** degree. The research report and the results presented in this thesis have not been submitted, in part or full, to any other University or Institute, for the award of any degree or diploma.



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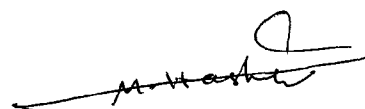
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A handwritten signature in black ink, appearing to read 'M. Hashemi', with a long horizontal stroke extending to the left.

M. HASHEMI

ABSTRACT

A number of river valley projects are being developed in the Himalayan region of Indian subcontinent. The rock mass in nature includes such complex geological features as joints, faults, foliations, discontinuities and shear bands, which affect its behaviour under different stress conditions. The behaviour of an engineering structure in the rock mass is often studied using finite element method (FEM). Meaningful results can be obtained from these analyses only if realistic characterisation (constitutive modelling) of the rock mass is used in the analysis. The characterisation of the rock behaviour is often based on the standard testing of rock in the laboratory, which is generally restricted to obtaining stress-strain behaviour up to peak/failure using stress-controlled loading. Rocks are known to exhibit softening behaviour after the peak stress. The complete stress-strain behaviour of the rock including softening is required to develop realistic constitutive models.

Keeping in view the present state of research, the following objectives have been identified for the research programme :

- (i) To conduct experimental investigation in order to study the stress-strain-volume change response including post-peak behaviour of a rock
- (ii) To model the complete stress-strain behaviour including post-peak behaviour (softening) and to verify the predicted values with the experimental data.
- (iii) To conduct finite element (FE) analysis of an underground powerhouse cavern using the constitutive model in (ii) and to compare the results with the observed results.

For the research programme, a hydropower project (Nathpa-Jhakri Power Project) in the Himalayan region has been chosen. Three types of rock samples, viz., quartz mica schist, biotite schist and quartz mica schist with quartz veins, from the project site have been used for testing. The powerhouse cavern has been adopted for the investigation.

A series of triaxial compression tests have been conducted on rock samples to capture complete stress-strain behaviour. An experimental setup consisting of a servo-controlled loading system, a high-pressure triaxial cell, hydraulic pressure unit and a data acquisition system has been assembled. The servo-controlled system has an MTS actuator which has been installed on a locally fabricated loading frame. The data acquisition system has been developed locally to capture the axial and lateral strains in the sample as well as load in the servo-controlled system.

For modelling the behaviour of the rock, the disturbed state concept (DSC) approach developed by Desai and his coworkers has been adopted. A computer program PRMDSC has been developed to determine the material parameters of intact rock from the test results, and to predict the stress-strain-volume change response using the single point method (SPM).

From the parameters obtained for the intact rock, it can be concluded that,

- (i) The ultimate parameters, γ and β are the lowest for quartz mica schist and the highest for quartz mica schist with quartz veins, showing the former as the weakest and the latter as the strongest rock among the three rock types.
- (ii) As the rock becomes stronger, the disturbance parameters, A and Z decrease, and the ultimate disturbance parameter, D_u , increases.

A finite element analysis code DSC-SST-2D has also been used to simulate the strain-controlled triaxial tests and to predict stress-strain-volume change response of the rock. The predicted stress-strain-volume change responses (by FEM and SPM) have been compared with the observed experimental results. The predictions are found to be satisfactory. The predicted results by SPM and FEM are identical to each other, as expected. The behaviour of the rocks shows that,

- (i) The axial strain at peak is close to 1% for quartz mica schist, and close to 0.5% for the other two rock types.
- (ii) The volumetric strain generally decreases in initial portion and shows dilation thereafter with increase of axial strain.

The material parameters of the rock mass have been obtained for the constitutive model based on the DSC approach, from the intact rock parameters, using a procedure proposed by Ramamurthy. From the parameters obtained for the rock mass, it is observed that,

- (i) The ultimate parameters γ and β , for the rock mass show 33% and 17% reduction as compared to the intact rock.
- (ii) The Young's modulus and uniaxial compressive strength for the rock mass are decreased by 22% and 16% as compared to the intact rock, respectively.
- (iii) The value of bonding stress, $3R$, shows 11% reduction as compared to the intact rock.

The powerhouse cavern has been analysed using the computer code DSC-SST-2D and the DSC approach. From the results of the finite element analysis, it is found that,

- (i) The sidewalls undergo large deformations as compared to the crown and the invert part. The invert undergoes large deformations as compared to the crown, due to a large release of the insitu stress with respect to the crown.
- (ii) Higher stresses are observed in a small zone near two corners of the cavern in the bottom part. This again is due to a large release of the stress in this zone.
- (iii) The plastic strains are low in major parts of the sidewalls and the crown. The maximum plastic strains occur in the bottom portion of the cavern, due to a large stress release in the corner portion.
- (iv) The predicted maximum deformation in the sidewalls by FE analysis is close to the predicted maximum movement using Unified Distinct Element Code (UDEC).

The instrumentation data have been obtained from the project authority for the powerhouse cavern. The details of instrumentation, interpretation and comparison are presented and discussed. A correlation has been established between the registered instrumentation data and the levels of excavation. The comparison of the observed and the predicted deformations based on the correlation shows that the predicted deformations generally lie within the range of the observed instrumentation data.

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