Rock Mechanics

a) Practical Equivalent Continuum Model and Applications to Large Underground Openings in Jointed Rock Mass

An Equivalent Continuum Model (ECM) has been developed by establishing new sets of statistical relationships between the uni-axial compressive strength and elastic modulus of jointed rock mass versus the joint factor. These relations were arrived from statistical analysis of large amount of experimental data collected from different sources in literature and also carrying out some selected experiments. This experimental data covers a wide range of intact rock and joint fabric. Equivalent continuum model has been developed for the jointed rock by incorporating the statistical relationships arrived which expresses the joint rock properties as a function of intact rock properties and joint fabric.

Numerical simulations of jointed rock masses in under ground openings and mines were carried out using equivalent continuum approach in FLAC 2D and 3D (Figure 35). Different strength criteria available for jointed rocks were incorporated in the numerical analysis code. A comparative study of the existing empirical strength criteria for jointed rocks was made to give a better insight in understanding the different failure criteria. Several large scale underground openings in jointed rock mass (such as Shiobara power cavern, Tokyo; Nathpa Jhakri power house; Kiirunavara mine slope) have been simulated using the developed practical equivalent continuum model and the obtained results compared very well with the field measurements of deformation in those structures at different locations.

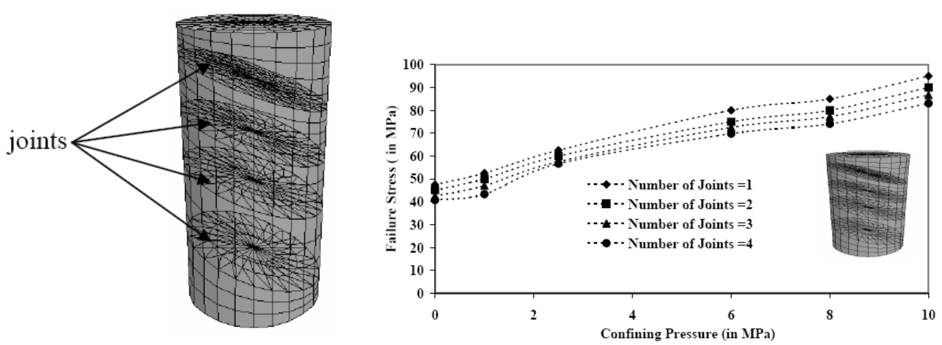


Figure 35: FLAC 3D Simulation of jointed rock sample of Agra Sandstone subjected to triaxial compression

b) Static And Seismic Analysis of Rock Slopes In Himalayas

Two case studies of large rock slopes in Himalayas are taken up for stability analyses. These slopes constitute the abutments of bridges that are being constructed as a part of the railway line between Katra and Laole in Jammu and Kashmir where it is crossing the rivers Chenab and Anjikhad. Numerical modeling is done using the equivalent continuum approach in FLAC along with the generalized Hoek-Brown failure criterion. Static and dynamic stability analyses are carried out for the rock slope at Chenab, which is about 359 m in height (Figures 4.36 and 4.37). The slope is situated in Seismic Zone V, according to the seismic zonation map of India, which means that the assessment of stability of the slope under earthquake induced dynamic shaking conditions is very much essential. The dynamic analysis is carried out using both pseudo-static and time response approaches. In case of time response analysis, the slope is subjected to the maximum credible earthquake for the region and the stability is studied in terms of displacements along the slope. Kinematic analysis is done using the stereographic projections of the joint sets to identify the possibility of wedge failure. For the slope portions close to the foundations, as per IS 1448: 1997, considering a planar wedge failure analysis the lengths of rock bolting scheme has been worked out (Figure 38).

Figure 36: Rock slopes at Chenab **Figure 37: Rock slopes at Anjikhad**

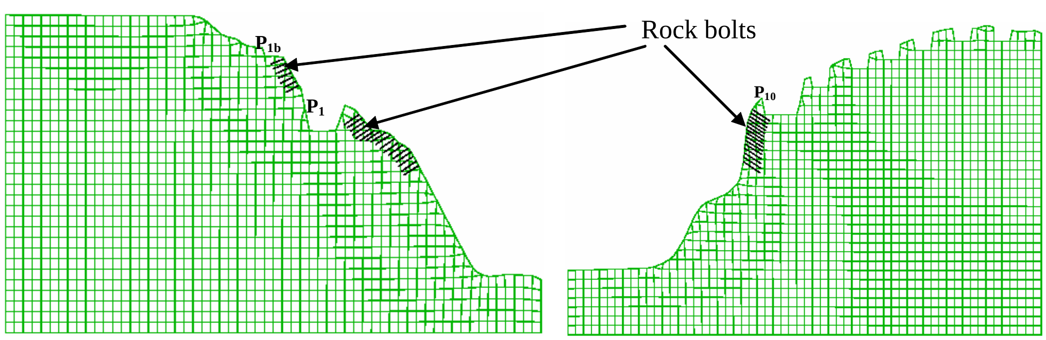
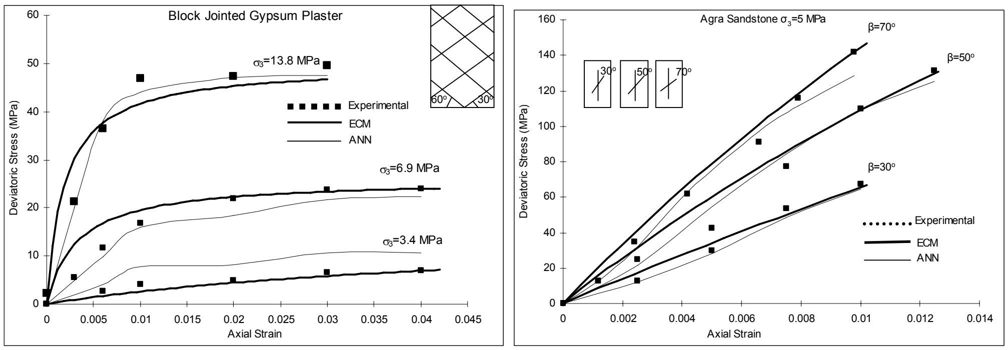


Figure 38: Rock bolting scheme proposed for Anjikhad slopes

c) Prediction of Stress-Strain Behaviour of Rocks Using ANN

The application of Artificial Neural Networks (ANN) for predicting the stress-strain response of jointed rocks under different confining pressures is studied. Rocks of different compressive strength with different joint properties (frequency, orientation and strength of joints) are considered in this study. The database for training the neural network is formed from the results of triaxial compression tests on different intact and jointed rocks with different joint properties tested at different confining pressures reported by various researchers in the literature. The network was trained using a 3 layered network with feed forward back propagation algorithm. About 85% of the data was used for training and remaining15% was used for testing the network. Results from the analyses demonstrated that the neural network approach is efficient in capturing the stress-strain behaviour of intact rocks and the complex stress-strain behaviour of jointed rocks (Figure 39). A single neural network is demonstrated to be capable of predicting the stress-strain response of different rocks, whose intact strength vary from 11.32 MPa to 123 MPa and spacing of joints vary from 10 cm to 100 cm for confining pressures ranging from 0 to 13.8 MPa.



a) Block jointed Gypsum Plaster **b) Agra Sand stone**

Figure 39: Comparison of stress-strain curves predicted by ECM and ANN with experimental measurements for jointed rocks