AN EQUIVALENT CONTINUUM ANALYSIS OF A LARGE-SCALE CAVERN EXCAVATION IN JOINTED ROCK MASS

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INTRODUCTION

With the main purpose to validate the equivalent continuum model developed for jointed rock mass, the present work considers a well-documented case study - excavation of large-scale cavern in jointed rock mass for Shiobara power station in Japan. An equivalent continuum model developed by Sridevi and Sitharam (1998) has been used in the present study for the analyses of large-scale cavern. This case study as reported by Horii et al., (1999) was selected for our modeling using equivalent continuum model as the complete field information along with instrumented data of deformations were available for possible analysis and comparison with the results of equivalent continuum model.

EQUIVALENT CONTINUUM MODEL

This paper deals with the finite element modeling of jointed rock mass as an equivalent continuum. In the finite element modeling the jointed rock properties are represented by a set of relationships, which express the properties of the jointed medium as a function of joint factor and the properties of the intact rock. The tangent elastic modulus of the intact rock is represented by a confining stress dependant hyperbolic relationship. Joint factor for a given jointed rock is estimated based on the joint fabric. Jointed rock has been represented as equivalent continuum using the statistical relations for strength and moduli of jointed rock mass arrived based on large set of experimental data on jointed rocks. Based on the analysis of large experimental data, the relations expressing the tangent modulus of the jointed medium as a function of joint factor and the tangent modulus of the intact rock has been established. The statistical relationships used in this analysis are as given below (Sridevi and Sitharam, 2000):

$$\frac{E_j}{E_i} = a + b\exp\left(-\frac{J_f}{c}\right) \qquad (1)$$

Where, E_j is the tangent modulus of jointed rock, E_i is the tangent modulus of intact rock, and, J_f is the joint factor. The coefficients a, b and c are arrived based on statistical analysis of large set of data and the constants used in this analysis are functions of confining pressures. Based on the field information available in this case study, joint frequency $J_n = 5$, inclination parameter $n = 0.05$ and joint strength parameter $r = 0.90$ were estimated from which the joint factor (J_f) is calculated using the relationship $J_f = \frac{J_n}{n \times r} = 111.11$. Where, J_n is number of joints per meter depth, 'n' is the inclination parameter depending on the orientation of the joint β, 'r' is the roughness parameter depending on the joint condition. The values of 'n' and r' are given elsewhere in the form of table. Nonlinearity in the finite element analysis has been incorporated in the form of material nonlinearity of both the intact and jointed rock. Incremental method is used for the solution of the non-linear problem and in the incremental procedure, load is increased in series of steps, or increments. The model has been validated with element tests for variety of joint orientations and number of joints with the experimental results. The Cavern along with the surrounding rock has been analyzed using the above approach at the completion of the whole excavation.

RESULTS AND DISCUSSIONS

Figure 1 shows the cross section considered for the analysis along with the location of displacement measurement lines along which field data was available. The discontinuous rock body is modeled using four node quadrilateral elements, the properties of each element defined in terms of some combination of the properties of the intact rock and those of the joints. Figure 2 shows the finite element mesh (200m × 200m) used for the above problem. The problem is analyzed for the initial stresses existing in the surrounding rock and the overburden stress due to the weight of the rock above the cavern. The results of the finite element analysis have been plotted in terms of relative displacement at the completion of whole excavation along the each measurement line. The field measurement values of relative displacement after Horii et al. (1999) are also plotted for comparison. The relative displacement versus distance from the cavern wall along the measurement lines BI10 to BI19 were observed and due to lack of space only along line BI10 and BI11 displacement results have been presented as shown in figs. 3 a and 3 b along with the measured values. It can be seen from figures 3a and 3b that the relative displacement values obtained using the equivalent continuum model are higher than the measured values of relative displacement. The measured values of relative displacement reduce sharply at a distance of 5m to 20m from the cavern wall. The values of relative displacement obtained using equivalent continuum analysis reduce gradually at points away from the cavern wall. The trend of numerical results obtained is similar to the measured values in the field along all the measurement lines. Comparison is much better along measurement lines at bottom of the cavern. The relative displacement values along the cavern wall reduce gradually from the top of the cavern to the bottom of the cavern. The displacement values are more on the left side of the cavern when compared to the right side of the cavern showing that the displacement is anti-symmetric (see Figures 3a and 3b).

Keywords: Jointed rock mass, Joint factor, Equivalent continuum model, Cavern excavation simulation, Numerical model
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CONCLUSIONS

The characteristic behavior of rock mass around the cavern has been modeled effectively using the equivalent continuum model. The numerical results similar to field measurements show that the displacement is antisymmetric and larger at the left side of the cavern wall. Also displacement drastically increases near the cavern wall at the upper part of the left side and also displacement is almost constant near the cavern wall. From the above discussions it can be concluded that the equivalent continuum model can be applied to complex practical problems without much sacrifice on the accuracy and efficiency. The model is simple, as it only requires the properties of intact rock and the joint properties for estimating the joint factor. It can be seen from the above analysis that in the absence of extensive experimental data the equivalent continuum model can be used to get a fair estimate of the behavior of the cavern and the surrounding rock.

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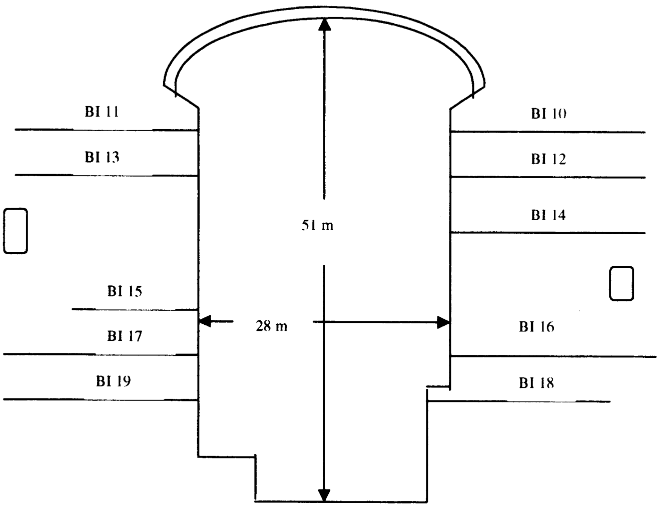

Fig.1. Cross-section of cavern and location of field measurement lines for displacement.

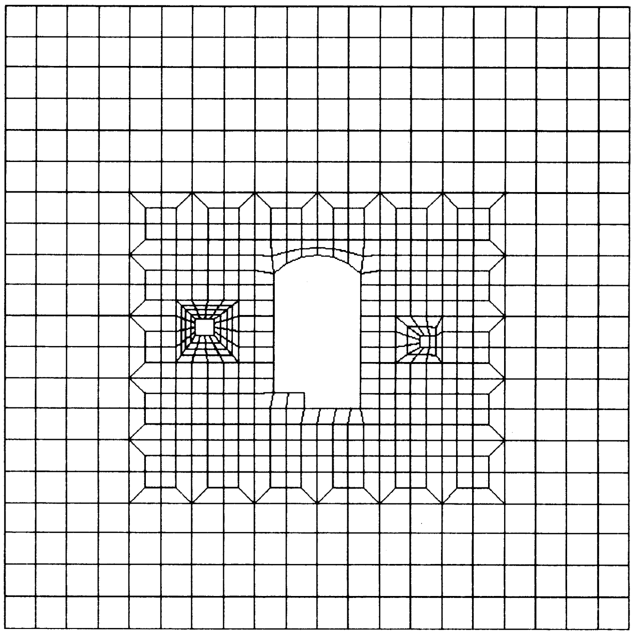

Fig. 2. Finite Element mesh adopted

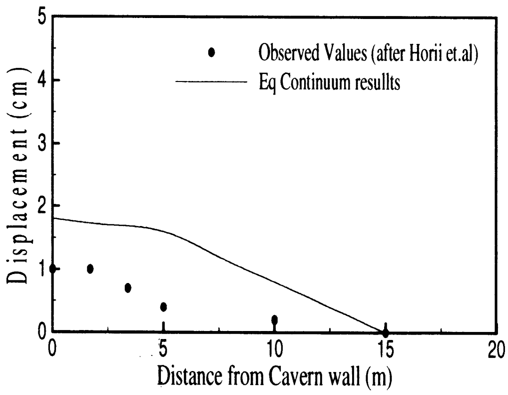

Fig. 3a. Relative displacement plot along the measurement line BI10

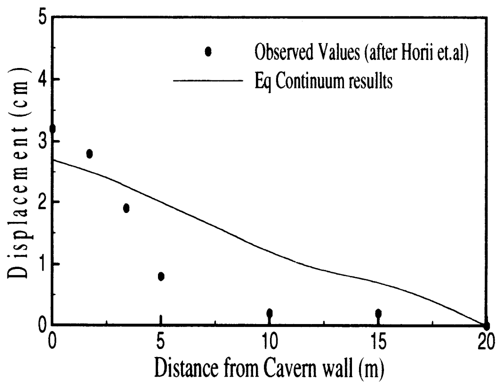

Fig. 3b: Relative displacement plot along the measurement line BI11