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Numerical analysis of boundary conditions to tunnels

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ABSTRACT: This paper presents the results of numerical analysis of boundary conditions to tunnels excavated in rock masses obeying Hoek–Brown failure criterion. In numerical analysis, a 2D finite element program with software Phase2 is utilized together with the convergence-confinement method. Three boundary types box, circle and hull and different expansion factors is considered for modeling. The results of the evaluations show that the best expansion factor for modeling of tunnels is equal to 7 and the external boundaries circle, hull and box to cause maximum displacement around tunnels, respectively.

***Keywords*:** Numerical analysis, Tunnel, Boundary conditions.

INTRODUCTION

Tunneling often disturbs the natural state of rock masses and produce interaction of different rock mass parameters and boundary conditions. Initial changes in rock mass parameters or boundary conditions will cause more changes of other parameters. The interaction of parameters is a dynamic and cyclic process, until a new equilibrium state is reached. For this purpose, a rock engineering interactive mechanism has been suggested to model the dynamic and cyclic behavior of rock mass and the boundary conditions (Hudson, 1991).

The three common external boundary types are box, circle and hull. The box external boundary will in general be a rectangle. It will be a square if the horizontal and vertical extents of your excavation are equal. The circle external boundary actually generates a regular 10-sided polygon approximating a circle around the excavation. The hull produces an external boundary which is a magnified version of the excavation. It will work for multiple excavations, although it is more appropriate for a single, convex excavation. The expansion factor determines how far the automatically generated external boundary will be projected relative to your excavation dimensions (Rocscience, 1999).

The main motivation for this study is to analysis the tunnels in order to find the best expansion factor and also, to investigate the effect of external boundary on the displacement around tunnels.

Geomechanical properties of the rock masses

The rock mass properties such as the rock mass strength (σcm), the rock mass deformation modulus (Em) and the rock mass constants (mb, s and a) are calculated by the Rock-Lab program defined by Hoek (2002). This program has been developed to provide a convenient means of solving and plotting the equations presented by Hoek (2002).

Table 1. Geomechanical parameters of granitic rock masses obtained by using Roclab software

Input and output of Roclab software						
Hoek-Brown classification Hoek Brown Classification				Hoek-Brown criterion Hoek Brown Criterion		
σ_{ci}(Mpa) Intact Uniaxial compressive strength	GSI Geological strength index	m_i Constant Hoek-Brown criterion for intact rock	D Disturbance Factor	mb Hoek-Brown criterion	s	a
250	35	32	0.00	3.140	0.0007	0.516
Parameters of the Mohr - Coulomb equivalent Mohr-Coulomb Fit		Rock Mass Parameters Rock Mass Parameters				
C (Mpa)	φ (degree)	σ_t (Mpa)	σ_c(Mpa)	σ_{cm}(Mpa)	E_{rm}(Mpa)	
Cohesion	Friction angle	Tensile strength	Uniaxial compressive strength	Golobal strength	Deformation modulus	
0.760	66.86	-0.058	6.020	56.201	12049.49	

In Rock-Lab program, both the rock mass strength and deformation modulus are calculated using equations of Hoek , 2002, and the rock mass constants are estimated using equations of Geological Strength Index (GSI) (Hoek , 2002) together with the value of the granite material constant, mi (Table 1). Also, the value of disturbance factor (D) that depends on the amount of disturbance in the rock mass associated with the method of excavation, is considered zero for the rock masses, it means these rocks would not be disturbed more than this during blasting.

Finally, the shear strength parameters of the rock mass (C and φ) for the rock masses are obtained using the relationship between the Hoek–Brown and Mohr–Coulomb criteria (Hoek and Brown, 1997) and are presented in Table 1.

Numerical analysis of boundary conditions to tunnels

Numerical analyses of boundary conditions in the rock masses are accomplished using a two-dimensional hybrid element model, called Phase2 Finite Element Program (Rocscience, 1999). This software is used to simulate the three-dimensional excavation of a tunnel. In three dimensions, the tunnel face provides support. As the tunnel face proceeds away from the area of interest, the support decreases until the stresses can be properly simulated with a two-dimensional plane strain assumption. In this finite element simulation, based on the elasto-plastic analysis, deformations and stresses are computed. These analyses used for evaluations of the tunnel stability in the rock masses. The geomechanical properties for these analyses are extracted from Table 1. The Hoek and Brown failure criterion is used to identify elements undergoing yielding and the displacements of the rock masses in the tunnel surrounding.

To simulate the excavation of tunnel in the granite rock masses, a finite element models is generated with three common external boundary types, namely box, circle and hull (Fig. 1 to 3). The outer model boundary is set at distances of 3 times to 9 times the tunnel radius (expansion factor = 3 to 9) and six-nodded triangular elements are used in the finite element mesh. The tunnels diameter is 4 meters and the hydrostatic stress condition (K_0 =1) is considered for these models.

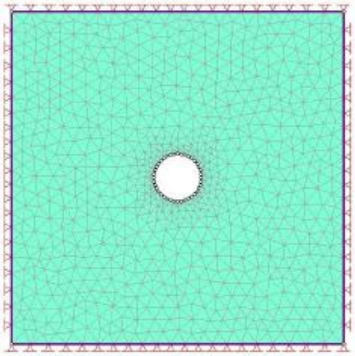

Figure 1. The modeling of circular tunnel with external boundary of box and expansion factor of 5

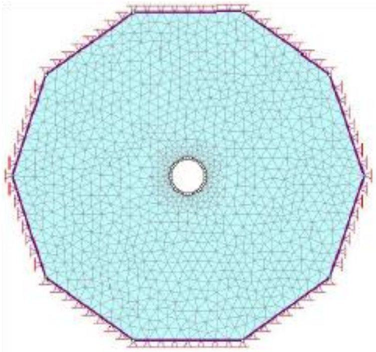

Figure 2. The modeling of circular tunnel with external boundary of circle and expansion factor of 5

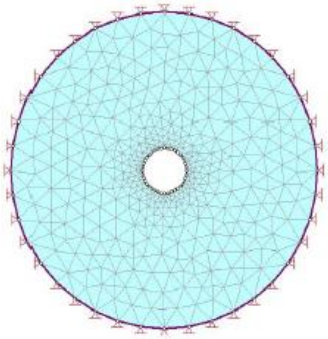

Figure 3. The modeling of circular tunnel with external boundary of hull and expansion factor of 5

By run of models, the maximum tunnel wall displacement far from the tunnel face is determined for each tunnel (for example Figs. 4 to 6) and the obtained results are shown in Figs. 7 to 9.

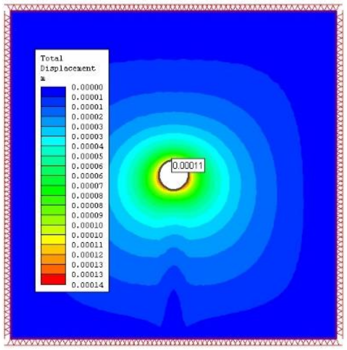

Figure 4. The displacement around circular tunnel with external boundary of box and expansion factor of 5

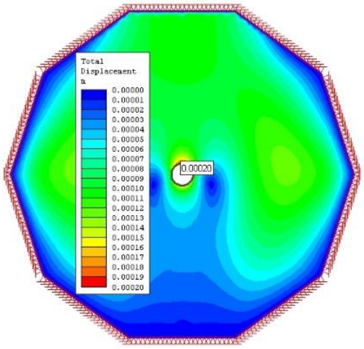

Figure 5. The displacement around circular tunnel with external boundary of circle and expansion factor of 5

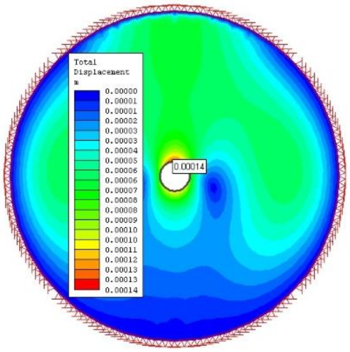

Figure 6. The displacement around circular tunnel with external boundary of hull and expansion factor of 5

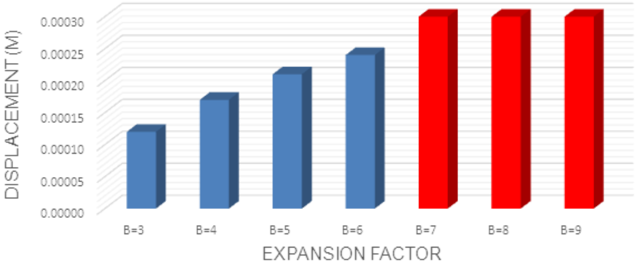

Figure 7. The displacement of circular tunnels with external boundary of box in different expansion factors

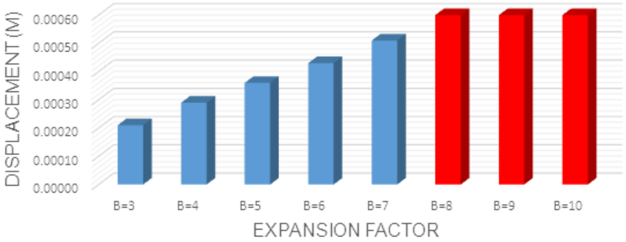

Figure 8. The displacement of circular tunnels with external boundary of circle in different expansion factors

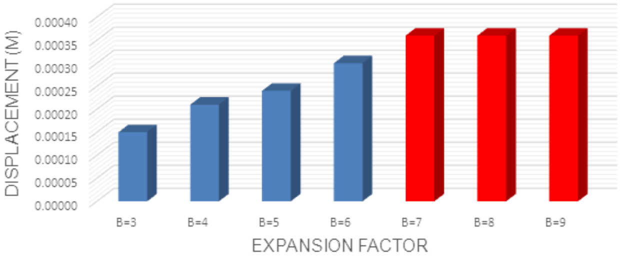

Figure 9. The displacement of circular tunnels with external boundary of hull in different expansion factors

As the above diagrams show, in all cases, the maximum displacement around tunnels has increased with increasing of expansion factor. Increasing displacement in tunnels with external boundary of box is to expansion factor of 7, in tunnels with external boundary of circle is to expansion factor of 8, and in tunnels with external boundary of hull is to expansion factor of 7. This implies that when modeling tunnels, the outer model boundary should be set at distance of 7 times the tunnel radius. Furthermore, the external boundaries circle, hull and box to cause maximum displacement around tunnels, respectively. This indicates that in modeling of tunnels, with expansion of the external boundary, the displacement around tunnels has increased.

CONCULSION

This study provides an estimation of the boundary conditions in tunnels and could be used as initial parameter for modeling of tunnels. The following conclusions could be noted:

- The best expansion factor for modeling of tunnels is equal to 7.
- In modeling of tunnels, the shape of the external boundary is important and the external boundaries circle, hull and box to cause maximum displacement around tunnels, respectively.
- In modeling of tunnels, with expansion of the external boundary, the displacement around tunnels has increased.

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