WALIA journal 31(S1): 172-174, 2015
Available online at www.Waliaj.com
ISSN 1026-3861

The three-dimensional strain in cylindrical tunnels

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Abstract: The numerical analysis of tunnels often performs in plane strain condition. However, since the condition of stresses around the advancing face of a tunnel is three-dimensional, the axisymmetric analysis would be useful in circular tunnels for determine the extent of three-dimensional strain in the end of tunnels. In this paper, the extent of three-dimensional strain in cylindrical tunnels was investigated. For this purpose, the cylindrical tunnels with different diameters in dolerite rocks were modeled using the Phase2 software and in each model, the displacement in different distances from the tunnel face were determined. The results show that by increasing distance from the face of tunnels, the displacement has been increased and near the tunnel face, the strain is three-dimensional. Furthermore, by increasing diameter of tunnels, the extent of three-dimensional strain has been increased and by increasing K_0 over 1, the plane strain conditions have been achieved so far beyond the tunnel face.

Key words: *Axisymmetric analysis; Cylindrical tunnels; Three-dimensional strain*

1. Introduction

Analysis of displacements around circular tunnels excavated in isotropic rock masses has been one of the main problems in geotechnical engineering. By excavating a tunnel, the convergence and ground pressure on the tunnel lining increase with time. These are because the advance of the tunnel face and the time-dependent response of the surrounding rocks. In order to describe the time-dependent deformation in tunnels, multiple numerical methods have been developed (Ghaboussi and Gioda, 1977; Gioda, 1981; Cividini et al., 1991; Peila et al., 1995). Also a closed-form solution in order to determine tunnel wall displacements and ground pressure imposed on tunnel supports presented by Sulem et al., 1987.

The condition of stresses around the face of a tunnel is three-dimensional. At a section in a rock mass, which is at distance of two and a half tunnel diameters ahead of the face, the stress state is equal to the in-situ stress status. At the tunnel face, the rock mass provides a support pressure that is approximately 25% of the in-situ stress. Due to the three-dimensional stress condition at tunnel faces, application of two-dimensional numerical analysis to the design of tunnel support systems is erroneous. Most two-dimensional numerical formulations for excavation analysis assume plane strain conditions. However these conditions are only applicable to tunnel sections far from the face. Therefore, in near of the face should be use axisymmetric analysis.

The axisymmetric analysis allows analyze a 3-dimensional excavation which is rotationally symmetric about an axis, and therefore, because of the rotational symmetry, we are analyzing a symmetric 3-dimensional problem. A typical use of the axisymmetric modeling option is to analyze the strain state around the end of a circular tunnel. The mathematical formulation of an axisymmetric finite element is similar to plane strain problems. By symmetry, the two components of displacement in any plane section of the excavation through its axis of symmetry define exactly the state of strain (Rocscience, 1999).

This paper proposes a simple and practical numerical procedure to determine the distribution of strain around cylindrical tunnels excavated in dolerite rock masses using axisymmetric analysis.

2. Geomechanical parameters of dolerite rocks

In this study, the geomechanical parameters of the dolerite rocks were obtained using Roclab software (Hoek et al. 2002). These parameters are obtained based on The Hoek-Brown failure criterion and it is presented in Table 1.

3. Modeling of cylindrical tunnels

To study the extent of three-dimensional strain in tunnels, the cylindrical tunnels with diameters 2, 3, 4, 5, 6, 7, 8, 9 and 10 meters were modeled in axisymmetric state by Phase2 software (for example, as Figs. 1 and 2). In the models, the hydrostatic stress conditions have been considered.

By run the made models, the displacement in different distances from the face of tunnels were determined and presented in Fig 3.

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Table 1: Geomechanical parameters of dolerite rock mass obtained by using Roclab software

Input and output of Roclab software						
Hoek-Brown classification				**Hoek-Brown criterion**		
Hoek Brown Classification				**Hoek Brown Criterion**		
σ_{ci}(Mpa)	**GSI**	**m_i**	**D**	**mb**	**s**	**a**
Intact Uniaxial compressive strength	Geological strength index	Constant Hoek-Brown criterion for intact rock	Disturbance Factor	Hoek-Brown criterion		
30	65	15.6	0.00	4.469	0.0205	0.502
Parameters of the Mohr - Coulomb equivalent		**Rock Mass Parameters**				
Mohr-Coulomb Fit		**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	
2.142	38.81	-0.137	4.259	8.946	8205.40	

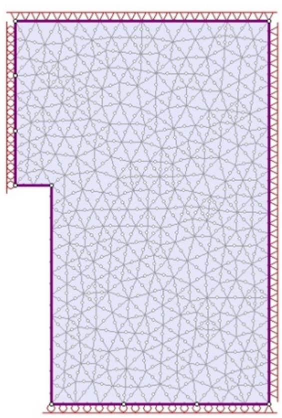

Fig. 1: Modeling of the cylindrical tunnel with diameter 2 meters for axisymmetric analysis

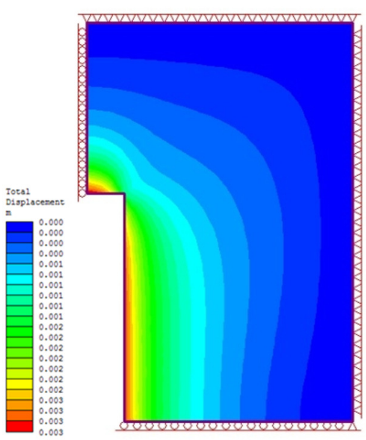

Fig. 2: Total displacements in around the cylindrical tunnel with diameter 2 meters

The diagram in Fig. 3 shows the values of displacement around the cylindrical tunnels with different diameters and in different distances from tunnels face. As can be seen, the displacement levels off and becomes constant at a certain distance away from the tunnel face. This curve is useful in that it can be seen the distance at which end effects can be ignored, and plane strain conditions can be assumed.

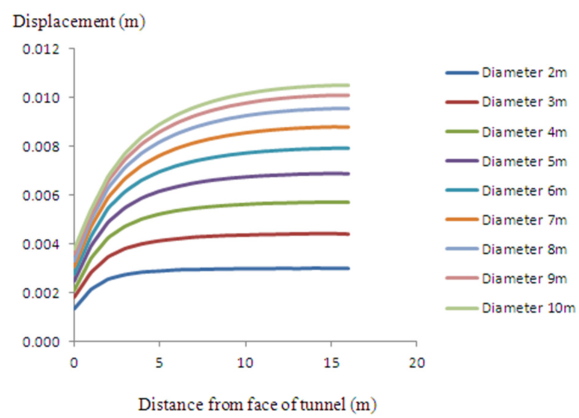

Fig. 3: The values of displacement around the cylindrical tunnels for different distances from tunnels face

The diagram shows that near the tunnel face, the strain for all of diameters is three-dimensional, but away from the tunnels face there is plane strain conditions. For example, in cylindrical tunnel with diameter of 2 meters, at a distance of about 4 meters from the tunnel face there is three-dimensional strain, and then the strain becomes two-dimensional. Also, by increasing distance from the face of tunnels, the displacement has been increased. Furthermore, by increasing diameter of tunnels, the extent of three-dimensional strain has been increased.

The next stage, the cylindrical tunnels with diameters 2, 3, 4, 5, 6, 7, 8, 9 and 10 meters were modeled in axisymmetric state and in non-hydrostatic stress conditions. In this stage, the effect of K_0 ratio which were considered 1.2 and 1.5, on the convergence of tunnels was evaluated and the results was shown in Figs. 4 and 5. The K_0 is defined as the ratio between the major horizontal stress (σh) and the vertical stress (σv) (Goodman, 1989), being σv the weight of overburden.

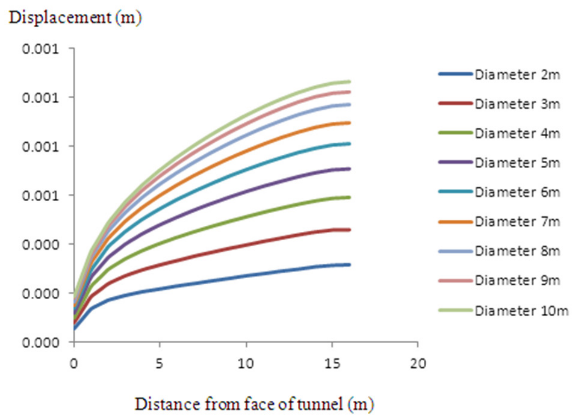

Fig. 4: The values of displacement around the cylindrical tunnels for different distances from tunnels face (K_0=1.2)

The diagram in Fig.4 shows that at a considerable distance from the tunnel face, the strain is three-dimensional, and compared to previous models (Fig. 3) the plane strain conditions has been achieved so far beyond the tunnel face. For example, in cylindrical tunnel with diameter of 2 meters, at a distance of about 15 meters from the tunnel face there is three-dimensional strain, and then the strain becomes two-dimensional. However, the three-dimensional strain rate gradually reduce away from the tunnels face, until at a distance of about 15 meters, the strain becomes entirely two-dimensional. Compare this diagram with the previous diagram (Fig. 3) can be concluded that non hydrostatic stress condition has reduced the total displacement around the cylindrical tunnels. In addition, as in the previous diagram, by increasing diameter of tunnels, the extent of three-dimensional strain has been increased.

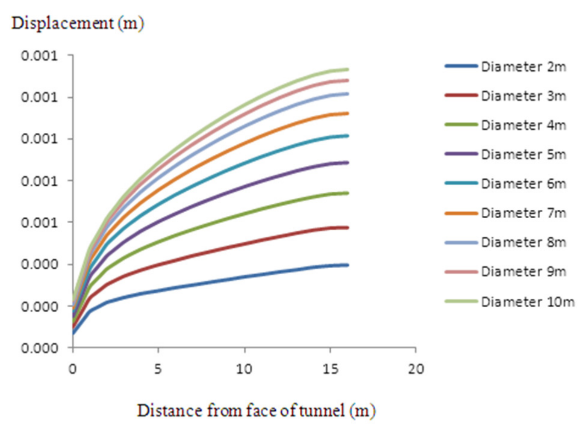

Fig. 5: The values of displacement around the cylindrical tunnels for different distances from tunnels face (K_0=1.5)

The diagram in Fig. 5 shows that at a considerable distance from the tunnel face, the strain is three-dimensional, and as in previous diagram (K_0=1.2), the plane strain conditions has been achieved so far beyond the tunnel face. The displacement in this diagram is very similar to the previous diagram. It suggests that increasing K_0 over a certain extent, does not effect on the strain in cylindrical tunnels.

4. Conclusion

In this research that with aim to analysis the extent of three-dimensional strain in cylindrical tunnels is done the following results are obtained:

- The near the face of cylindrical tunnels, the strain is three-dimensional, but away from the tunnels face there is plane strain conditions.
- By increasing distance from the face of tunnels, the displacement has been increased.
- By increasing diameter of tunnels, the extent of three-dimensional strain has been increased.
- When cylindrical tunnels are under hydrostatic stress condition (K_0=1), the displacements is much more than the condition which K_0 is more than 1.

By increasing K_0 over 1, the plane strain conditions have been achieved so far beyond the tunnel face.

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