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The Effect Of Depth And Diameter Of Tunnels On The Axial Force Of Rock Bolts

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Abstract— **This paper presents numerical analysis the effect of depth and diameter of tunnels on the axial force of rock bolts by means of elasto-plastic finite element method. The circular tunnels are modeled with diameter of 4, 6, 8, 10 and 12 meters and in depth of 5, 10, 25 and 35 meters in the shale rocks. The tunnels are supported by end anchored rock bolts with length of 3 meters and spacing of 2 meters. The axial force of rock bolts are measured for each of depth and diameter of the tunnels. The results of the evaluations show that with increasing the depth and diameter of the tunnels, the axial force of rock bolts has increased because the total displacement around tunnels has been increased. The impact of tunnel depth in increasing the axial force of rock bolts is greater than its diameter.**

Keywords— Axial force; Rock bolt; Tunnel; Phase2

1. INTRODUCTION

One of the ways to stabilizing of tunnels is application of rock bolts. A rock bolt is a long anchor bolt, for stabilizing rock excavations, which may be used in tunnels or rock slopes. It transfers load from the unstable exterior to the confined interior of the rock mass. The rock bolts are almost always installed in a pattern, the design of which depends on the rock quality designation and the type of excavation [1]. Rock bolts work by knitting the rock mass together sufficiently before it can move enough to loosen and fail by unravelling. The rock bolts can become seized throughout their length by small shears in the rock mass, so they are not fully dependent on their pull-out strength.

Rock bolts have been used for years to reinforce the surface and near surface rock of excavated or natural slopes. They are used to improve the stability and load bearing characteristics of a rock mass. When rock bolts are used to reinforce a fractured rock mass, the rock bolts will be subjected to tension, shear and compressive forces. The studies have been done by researchers [2, 3, 4] to reinforce the slopes with rock anchoring. A general rule for rock bolts is that the distance between rock bolts should be approximately equal to three times the average spacing of the planes of weakness in the rock mass, and the bolt length should be twice the bolt spacing [5].

Tunnels excavate in various rock masses and ground conditions with different modes of behaviour. The way the rock masses surrounding a tunnel behave is very important. The behaviour of ground largely depends on the shape and size of underground excavation. The ground behaviour can be assessed via ground conditions with various project features. The rock masses whose strength is lower than the surrounding stress can be considered as weak rocks. The behavior of weak rocks in tunnels has led to problems during the construction of a number of projects. The ratio of rock mass strength to the in situ stress value specifies that deformations induce stability problems in the tunnel. The analysis of circular tunnels excavated in weak rocks under hydrostatic stress fields has been one of the principal sources of knowledge.

In this research in order to study the effect of depth and diameter of the tunnels on the axial force of rock bolts, the circular tunnels with different depth and diameter are modeled.

2. THE PHYSICAL AND MECHANICAL CHARACTERISTICS OF THE SHALE ROCKS

The rock mass properties such as the rock mass strength (σ_{cm}), the rock mass deformation modulus (Em) and the rock mass constants (mb, s and a) were calculated by the RocLab program defined by [6] (Table 1). This program has been developed to provide a convenient means of solving and plotting the equations presented by [6].

In RocLab program, both the rock mass strength and deformation modulus were calculated using equations of [6]. In addition, the rock mass constants were estimated using equations of Geological Strength Index (GSI) [6] together with the value of the shale material constant (mi). Also, the value of disturbance factor (D) that depends on the amount of disturbance in the rock mass associated with the excavation method was considered equal to 0.2 for the shale rocks in Table 1.

Table 2. Geomechanical parameters of shale 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		
35	32	6	0.2	0.404	0.0003	0.520
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	
0.079	54.04	-0.026	0.522	2.700	495	

The Hoek-Brown failure envelope of shale rock masses for different depths is obtained and presented in Figs. 1 to 4.

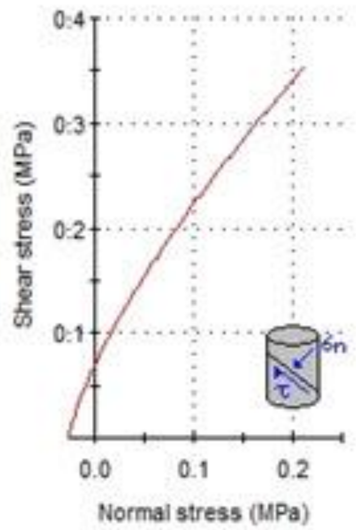

Fig.1. The Hoek-Brown failure envelope of shale rock masses in the depth of 5 meters

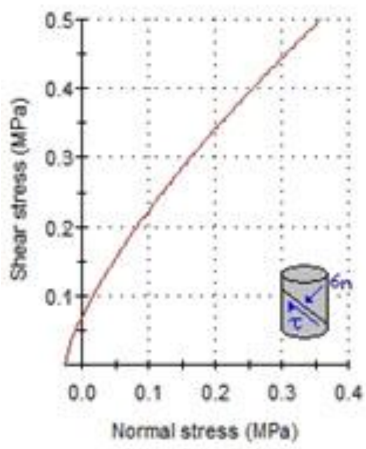

Fig. 2. The Hoek-Brown failure envelope of shale rock masses in the depth of 10 meters

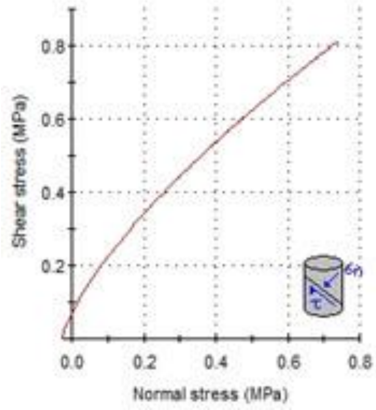

Fig. 3. The Hoek-Brown failure envelope of shale rock masses in the depth of 25 meters

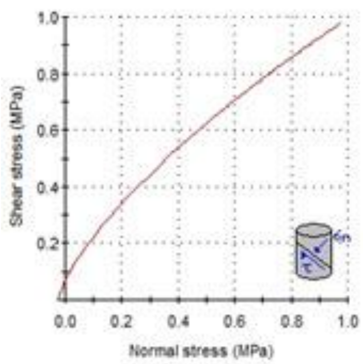

Fig.4. The Hoek-Brown failure envelope of shale rock masses in the depth of 35 meters

As you can see, by increasing depth of rock masses, the shear and normal stress in the Hoek-Brown failure envelope has increased.

3. NUMMERICAL ANALYSIS

Numerical analyses are done using a two-dimensional hybrid element model, called Phase2 Finite Element Program [7]. This software is used to simulate the three-dimensional excavation of a tunnel. 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 generalized 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 tunnels in the shale rock masses, a finite element models is generated for circular tunnels with diameter of 4, 6, 8, 10 and 12 meters and in depth of 5, 10, 25 and 35 meters. The six-nodded triangular elements are used in the finite element mesh (Figs. 5 to 9). The end anchored bolts with length of 3 meters and spacing of 2 meters is used for reinforcement of tunnels.

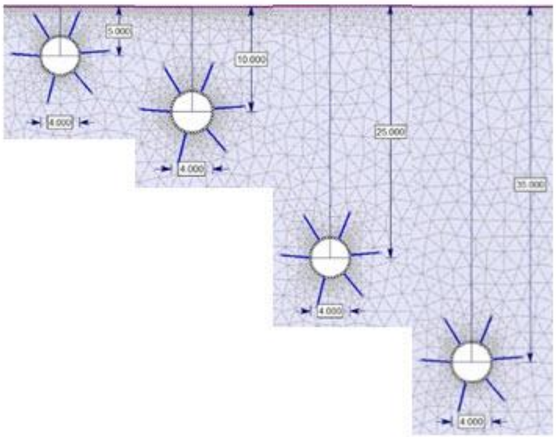

Fig. 5. The modeling of the circular tunnel with a diameter of 4 meter and in depths of 5, 10, 25 and 35 meters

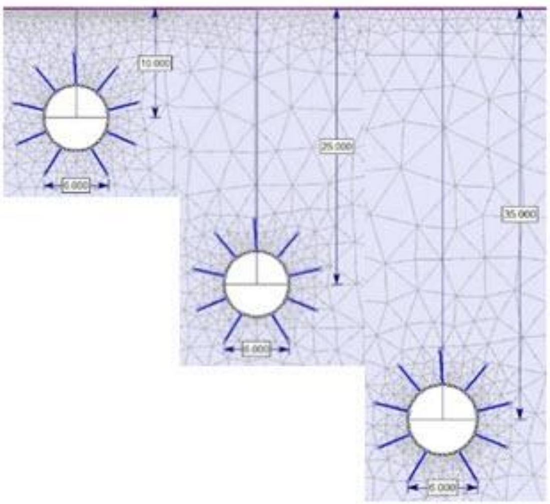

Fig. 6. The modeling of the circular tunnel with a diameter of 6 meter and in depths of 10, 25 and 35 meters

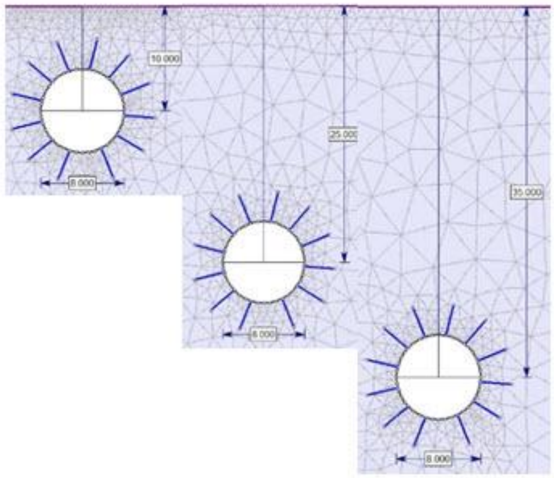

Fig. 7. The modeling of the circular tunnel with a diameter of 8 meter and in depths of 10, 25 and 35 meters

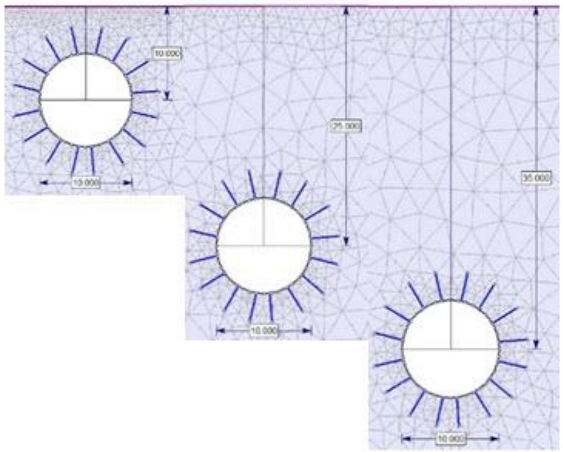

Fig. 8. The modeling of the circular tunnel with a diameter of 10 meter and in depths of 10, 25 and 35 meters

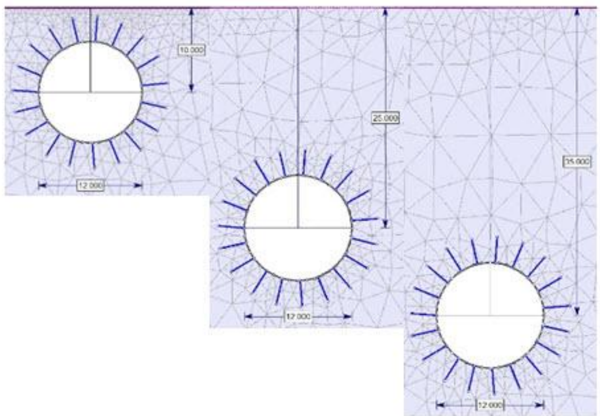

Fig. 9. The modeling of the circular tunnel with a diameter of 12 meter and in depths of 10, 25 and 35 meters

By run the models, the axial force of rock bolts is determined (for example Figs. 10 and 11) and is shown in Fig. 12.

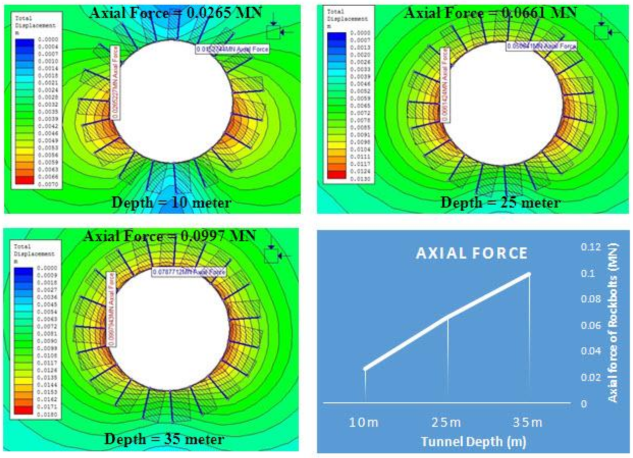

Fig. 10. The axial force of rock bolts for the circular tunnel with a diameter of 10 meter and in depths of 10, 25 and 35 meters

As the above figure shows, with the same diameter of tunnels, the axial force of rock bolts has increased with increasing depth of the tunnels. The overburden height increases the applied stress around the tunnels also growths and thus the axial force of rock bolts will increase. As can be seen, with increasing depth of the tunnels, total displacement the top and bottom of tunnels has increased. In order to prevent the displacement, the rock bolts has been stretched and hence, the axial force of them has increased.

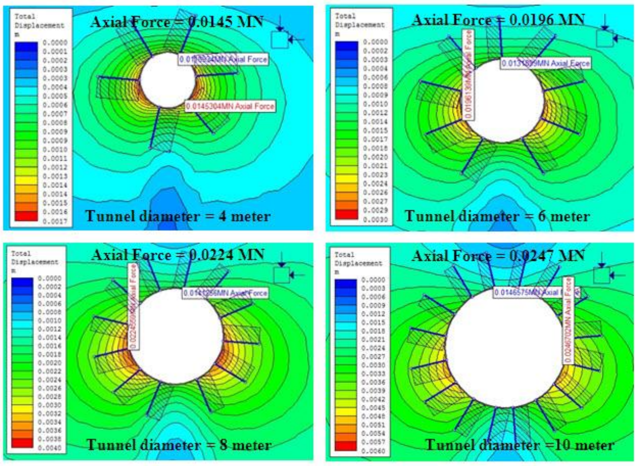

Fig. 11. The axial force of rock bolts for the circular tunnels with diameter of 4, 6, 8 and 10 meters and in a depth of 10 meter

As the above figure shows, with the same depth of tunnels, the axial force of rock bolts has increased with increasing diameter of the tunnels. As you can see, with increasing diameter of tunnels, the total displacement around tunnels has increased and therefore, the axial force of rock bolts has increased since, the rock bolts must prevent displacement of tunnel

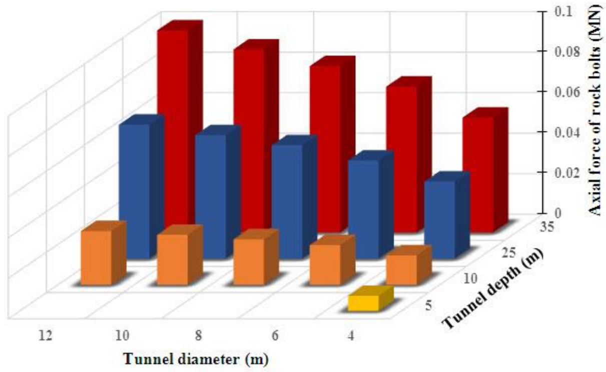

Fig. 12. The axial force of rock bolts in terms of diameter and depth of tunnels

Based on the above diagram it can be seen that with increasing the depth and diameter of the tunnels, the axial force of rock bolts has increased. It is important to note that the growth of rock bolts axial force by increasing the diameter of the tunnel is very small for shallow tunnels. As the depth of tunnels increases, the growth rate of axial force has also increased with larger the diameter of the tunnels. So, the impact of tunnel depth in increasing the axial force of rock bolts is greater than its diameter.

4. Conclusions

The results of the evaluations show that by increasing the depth and diameter of the tunnels, the axial force of rock bolts has increased. By increasing depth and diameter of tunnels, the total displacement around tunnels has increased. In order to prevent the displacement, the rock bolts has been stretched and hence, the axial force of them has increased. The impact of tunnel depth in increasing the axial force of rock bolts is greater than its diameter.

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