International Journal of
Science and Engineering Investigations vol. 5, issue 54, July 2016
ISSN: 2251-8843

The Effect of Earthquake Acceleration on the Yielding of Rock Bolts in the Tunnels

Vahid Hosseinitoudeshki[1], Saeed Mojtabazadeh Hasanlouyi[2]
[1,2]Department of Civil Engineering, Zanjan Branch, Islamic Azad University, Zanjan, Iran
([1]toudeshki@gmail.com, [2]mojtabazadeh@chmail.ir)

Abstract- In this study, through pseudo-static analysis with the help of finite element modeling software phase2, the effect of earthquake acceleration on the yielding of rock bolts in the tunnels is evaluated. The circular tunnels are modeled in depths of 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 and the earthquake with magnitude of 8 on the Richter scale is considered for dynamic mode. The results of the evaluations show that the distribution of the stress around the tunnels resembles an ellipse and the long-axis of this ellipse follows the direction of horizontal seismic coefficient (K_h). The compressive stresses parallel to short-axis of ellipse and the tensile stresses along the long-axis of ellipse have been formed which is very important and can influence the stability of rock bolts. Furthermore, by increasing the depth of tunnels, the tensions around the tunnels has increased and it leads to increasing the number of yielded rock bolts.

Keywords- *Earthquake acceleration, Rock bolt, yielding, Tunnel, Phase 2*

I. INTRODUCTION

Tunnels are vital underground structures that can withstand earthquakes. Although underground structures, in comparison to surface structures are of high safety regarding seismic waves, historical evidence and earthquake reports show that these structures are vulnerable to waves which result from earthquake and outbreak of damage and destruction is possible.

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 (Gale et al., 2004).

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 (Kliche 1999, Wyllie and Mah 2004, Ramamurthy 2007) 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 (Hoek and Wood 1988).

Excavating underground structures in rock mass, causes stress changes in the underground environment and this phenomenon can cause displacements in these areas. Also the displacements caused by excavation may cause induced stress on the support system of the tunnels and finally can end with instability of the tunnel surrounding area (Solak 2009).

Furthermore, applying the earthquake to the tunnel can cause compressive and tensile stresses that lead to squeezing in rock mass. The term “squeezing” refers to the large long-term deformations of rock masses that formed by tunnel excavation. Squeezing can leads to the destruction of a temporary tunnel supporting system or even to a complete closure of the tunnel cross section (Kovári 1998).

This paper attempts to evaluate the effect of seismic loading on the yielding of rock bolts in the circular tunnels.

II. THE PHYSICAL AND MECHANICAL CHARACTERISTICS OF THE SHALE ROCKS

The physical and mechanical properties of the shale rocks are determined from cores obtained of boreholes in a tunnel. The specific gravity of these rocks is equal to 2.65 and the minimum and maximum of UCS varies from 33 to 37 MPa, respectively, and the average value is equal to 35 MPa.

The rock mass properties such as the rock mass strength (σ_{cm}), the rock mass deformation modulus (E_m) and the rock mass constants (mb, s and a) were calculated by the RocLab program defined by (Hoek et al., 2002) (Table 1). This program has been developed to provide a convenient means of solving and plotting the equations presented by (Hoek et al., 2002).

In RocLab program, both the rock mass strength and deformation modulus were calculated using equations of (Hoek et al., 2002). In addition, the rock mass constants were estimated using equations of Geological Strength Index (GSI) (Hoek et al., 2002) 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 I. GEOMECHANICAL PARAMETERS OF SHALE ROCK MASS OBTAINED BY USING ROCLAB SOFTWARE

<table>
<tr><th colspan="7">Input and output of Roclab software</th></tr>
<tr><th colspan="4">Hoek-Brown classification</th><th colspan="3">Heok-Brown criterion</th></tr>
<tr><td>σ_{ci} (MPa)</td><td>GSI</td><td>m_i</td><td>D</td><td>M_b</td><td>s</td><td>a</td></tr>
<tr><td>Intact Uniaxial compressive strength</td><td>Geological strength index</td><td>Constant Hoek-Brown criterion for intact rock</td><td>Disturbance Factor</td><td colspan="3">Heok-Brown criterion</td></tr>
<tr><td>35</td><td>32</td><td>6</td><td>0.2</td><td>0.404</td><td>0.0003</td><td>0.520</td></tr>
<tr><td colspan="2">Parameters of the Mohr-Coulomb equivalent</td><td colspan="5">Rock mass Parameters</td></tr>
<tr><td colspan="2">Mohr-Coulomb Fit</td><td colspan="5">Rock Mass Parameters</td></tr>
<tr><td>C (MPa)</td><td>φ (Degree)</td><td>σ_t (MPa)</td><td>σ_c (MPa)</td><td>σ_{cm} (MPa)</td><td colspan="2">E_{rm} (MPa)</td></tr>
<tr><td>Cohesion</td><td>Friction angle</td><td>Tensile strength</td><td>Uniaxial compressive strength</td><td>Global strength</td><td colspan="2">Deformation modulus</td></tr>
<tr><td>0.079</td><td>54.04</td><td>-0.026</td><td>0.522</td><td>2.700</td><td colspan="2">495</td></tr>
</table>

The Hoek-Brown failure envelope of shale rock masses for different depths is obtained and presented in Figs. 1 to 3.

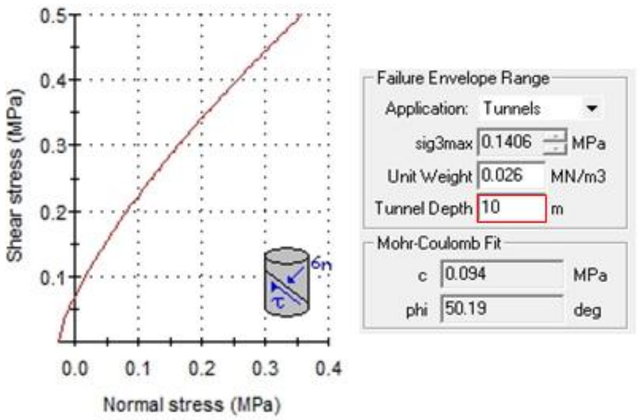


Figure 1. The Hoek-Brown failure envelope of shale rock masses in a depth of 10 meters

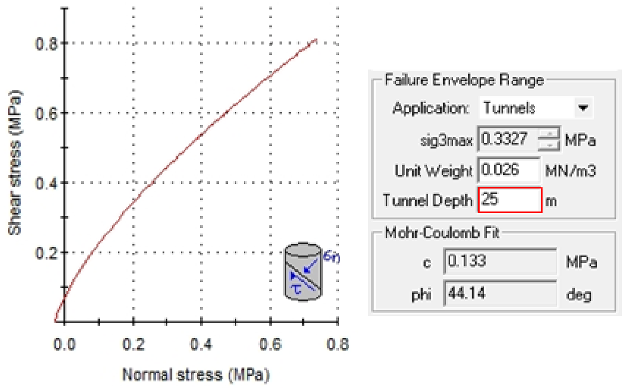


Figure 2. The Hoek-Brown failure envelope of shale rock masses in a depth of 25 meters.

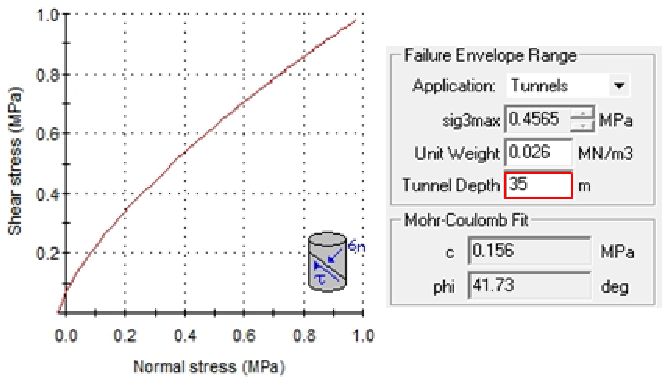


Figure 3. The Hoek-Brown failure envelope of shale rock masses in a depth of 35 meters.

In order to achieve more accurate results, material properties defined for each depth of tunnels, separately.

III. NUMERICAL ANALYSIS

Numerical analyses are done using a two-dimensional hybrid element model, called Phase2 Finite Element Program (Rocscience, 1999). This software is used to simulate the two-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 analyzes is 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 10 meters and in depths of 10, 25 and

35 meters. The six-nodded triangular elements are used in the finite element mesh. The end anchored bolts with length of 3 meters and spacing of 2 meters is used for reinforcement of tunnels and the earthquake magnitude applied to models is 8 on the Richter scale. The tunnels modeling with diameter of 10 meters and in different depths are shown in Fig. 4.

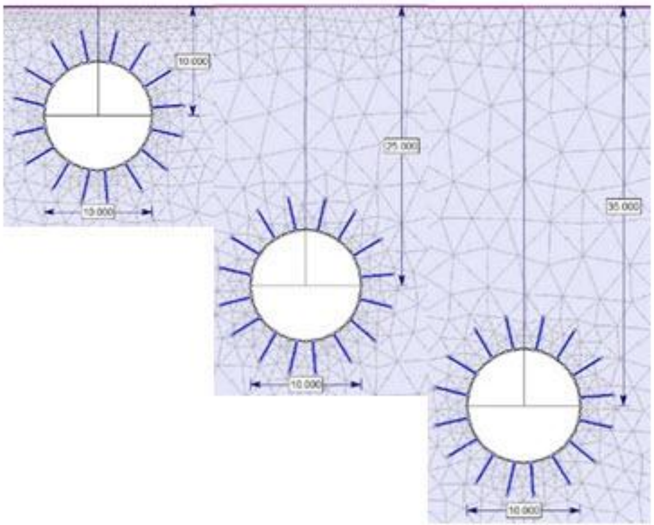
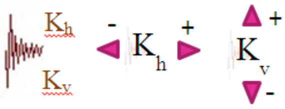


Figure 4. The modeling of the circular tunnels with a diameter of 10 meters and in depths of 10, 25 and 35 meters

It's necessary to mention that in Phase 2 software, when horizontal seismic coefficient (K_h) is positive, it applies to right side and when it's negative, applies to left side. For vertical seismic coefficient (K_v), positive value means up side and negative value means down side.



In this research, horizontal seismic coefficient (K_h) and vertical seismic coefficient (K_v) both have negative values that help to show the effect of seismic coefficients direction on the variations of stress contours around the tunnel and number of yielded rock bolts in the tunnels.

Run the models in the static and pseudo-static modes, clarify the state of major principal stress (σ_1) contours around the tunnel and the yielded rock bolts which are shown in Figs. 5 and 6.

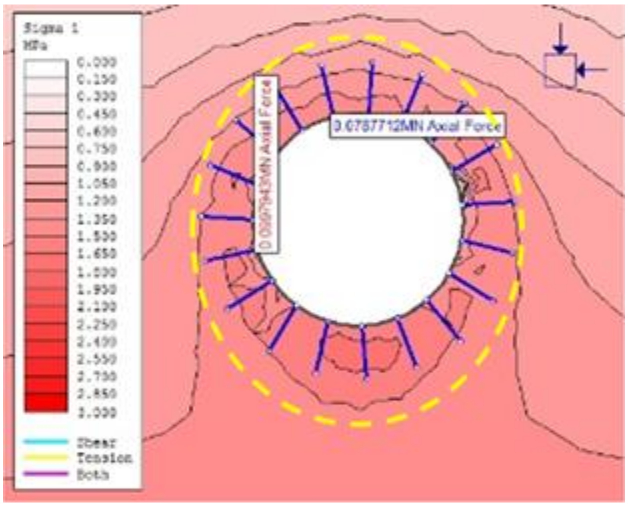


Figure 5. The state of major principal stress (σ_1) contours around the tunnel with a diameter of 10 meters and at a depth of 35 meters in static mode.

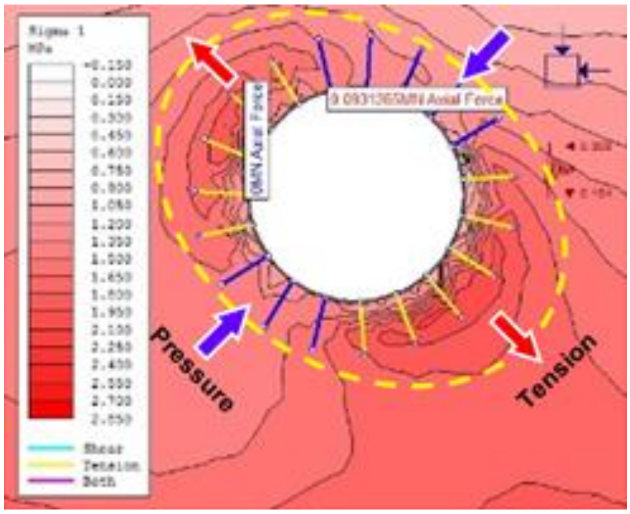


Figure 6. The state of major principal stress (σ_1) contours around the tunnel with a diameter of 10 meters and at a depth of 35 meters in pseudo-static mode.

As the results show, the distribution of the major principal stress (σ_1) around the tunnel generally resembles an ellipse. Also the major principal stress (σ_1) before applying the earthquake (static mode) is in equilibrium which shown with a yellow dotted line around the tunnel and the long-axis of ellipse is parallel to the vertical axis (Fig. 5). But when earthquake applies to the model (pseudo-static mode), the long-axis of ellipse inclined to the left side (Fig. 6). In fact, in this condition the stress contours followed the direction of horizontal seismic coefficient (Kh) which is applied to the left side. Furthermore, as you can see, the compressive stresses parallel to the short-axis of ellipse and the tensile stresses along the long-axis of ellipse have been formed in pseudo-static mode which is very important and can influence the stability of tunnel with destruction of the rock bolts. Fig. 6 shows the eleven yielded rock bolts (yellow colored rock bolts) of the nineteen rock bolts along the tension direction due to peak capacity in tensions has exceeded. For other depths of the tunnels, the results are obtained in a similar way but with less intensity. The examples of actual damages due to stresses around the tunnel for Bolu tunnel in Turkey and URL tunnel in Canada is shown in Figs. 7 and 8. In these tunnels, the location of the actual damaged section is coincides with the two zones of high tension stresses which is consistent Phase2 software results.

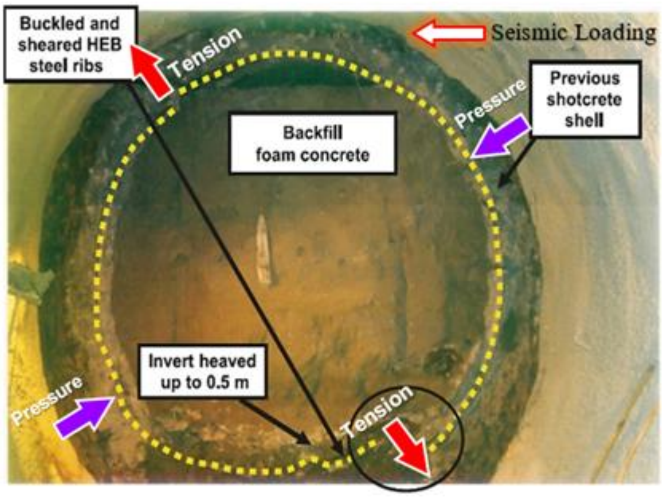


Figure 7. The location of the damaged section for Bolu tunnel due to tension stresses around the tunnel in dynamic mode (Tshering, 2011). It's assumed that the photo is taken in the direction of tunnel advancement.

According to the results, we can say that the tension path is along the minor principal stress (σ_3) and the pressure path is along the major principal stress (σ_1). Thus, it can be concluded that the tension stresses are due to high pressure in σ_1 path. The schematic and actual section of URL tunnel is shown in Fig. 9.

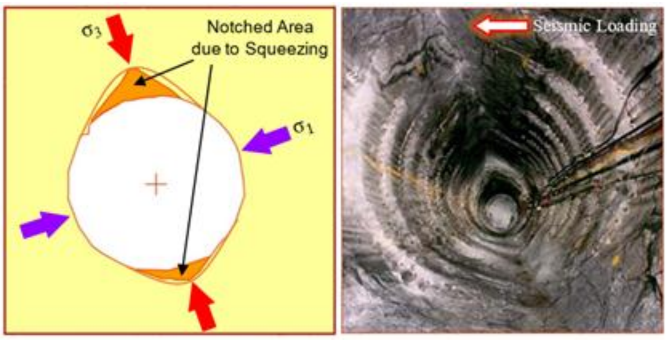


Figure 8. Schematic and actual deformation of URL tunnel due to stresses around the tunnel in dynamic mode. Red arrows indicate minor principal stress path and purple arrows indicate major principal stress path (Reed et al., 1995).

As Fig. 8 shows, high pressure in major principal stress (σ_1) path leads to deformation of tunnel section, squeezing and forming of notched area in minor principal stress (σ_1) path.

Another result evaluated in this research is about the magnitude of tension stresses for different depths of tunnels. Analyses show that the tension stresses around the tunnel will be greater with increasing the tunnel depth. Figs. 9 to 11 show tension stresses around the tunnel with a diameter of 10 meters and in depths of 10, 25 and 35 meters.

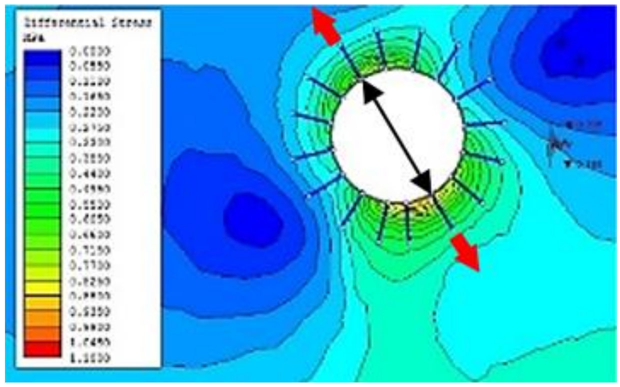


Figure 9. Tension stresses around the tunnel with a diameter of 10 meters and in depths of 10 meters.

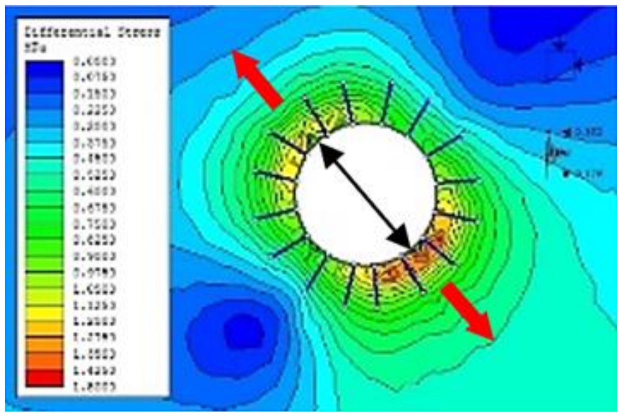


Figure 10. Tension stresses around the tunnel with a diameter of 10 meters and in depths of 25 meters.

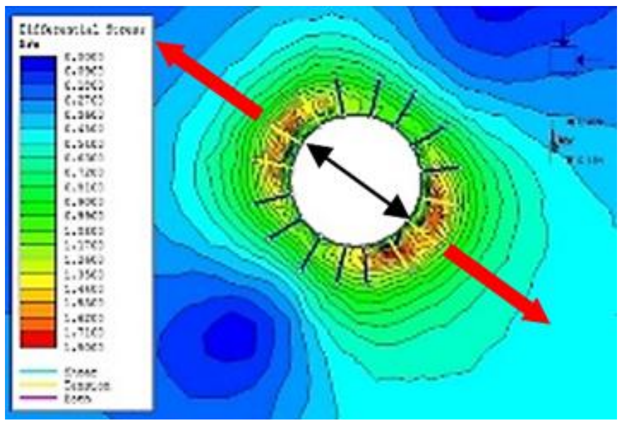


Figure 11. Tension stresses around the tunnel with a diameter of 10 meters and in depths of 35 meters. The yielded rock bolts are yellow.

Numerical analyses show that with increasing the tunnel depth, concentration of stresses around tunnel has increased which it is shown with concentration of stress contours in Figs. 9 to 11. Furthermore, when tunnel excavated in depths of 10 and 25 meters, there is no yielded rock bolts, but in a depth of 35 meters we can see six yielded rock bolts which is due to increasing the tension stresses around the tunnel. The size of red arrows in the above figures indicates the magnitude of tension stresses.

IV. CONCLUSIONS

The results of the evaluations show that the distribution of the major principal stress (σ_1) around the tunnels resembles an ellipse. The major principal stress (σ_1) before applying the earthquake is in equilibrium and the long-axis of ellipse is parallel to the vertical axis. But in pseudo-static mode, the long-axis of ellipse inclined to the left side because in this condition, the stress contours follow the direction of horizontal seismic coefficient (K_h) which is considered with negative value. Also, the compressive stresses parallel to short-axis of ellipse and the tensile stresses along the long-axis of ellipse have been formed when earthquake is applied to the tunnels which is very important and can influence the stability of rock bolts. Furthermore, by increasing the depth of tunnels, the major principal stress (σ_1) around the tunnels has increased which leads to increasing the minor principal stress (σ_3) and tensions around the tunnels. Increasing the tensions around the tunnels finally leads to increasing the number of yielded rock bolts.

REFERENCES

[1] W.J. Gale, C. Mark, D.C. Oyler, and J. Chen, “Computer Simulation of Ground Behaviour and Rock Bolt Interaction at Emerald Mine 2004”. Proc 23rd Intl Conf on Ground Control in Mining, Morgantown, WV, Morgantown, WV: West Virginia University, 27-34, 2004.

[2] E. Hoek, and D.F. Wood, “Rock Support”, Mining Magazine,159, 4, 282-287, 1988.

[3] E. Hoek, C. Carranza-Torres, and B. Corkum, “Hoek–Brown Failure Criterion—2002 Edition”. Rocscience, 2002.

[4] A.C. Kliche, “ Rock slope stability”. Society for Mining Metallurgy. USA, 1999.

[5] K. Kovári, “Tunnelling in Squeezing Rock”, Tunnel, 5/98, 12-31, 1998.

[6] T. Ramamurthy, “Engineering in rocks for slopes, foundation and tunnels”, Prentice Hall of India Private Limited, New Delhi, India , 2007.

[7] R.S. Read, C.D. Martin and E.J. Dzik, “Asymmetric borehole breakouts at the url”, In Proceedings, 35th U.S. Symposium on Rock Mechanics, Lake Tahoe, 879-884, 1995.

[8] Rocscience, “A 2D finite element program for calculating stresses and estimating support around the underground excavations”. Geomechanics Software and Research. Rocscience Inc., Toronto, Ontario, Canada, 1999.

[9] T. Solak, “Ground behavior evaluation for tunnels in blocky rock masses”, Tunnelling and Underground Space Technology, 24, 323-330, 2009.

[10] T. Tshering, “The Impact of Earthquakes on Tunnels in different Rock Mass Quality”, University of OSLO, Department of Geosciences, 2011.

[11] D.C. Wyllie, and C.W. Mah, “Rock slope engineering”, Fourth edition. London, Spon Press , 2004.