Seismic behavior evaluation of drilling foothills’ effect on tunnel maintenance system using numerical modeling

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ABSTRACT: Dynamic stresses caused by seismic waves are added to static stresses existing in tunnel lining or underground space and its surrounding rocks. Increasing stresses raise the probability of crushing and peeling state in underground space environment. Seismic stresses decrease static in-situ stresses and increasing it can cause slip, relocation or even structural failure. In this article inductive effect of drilling foothill under horizontal quasi static force on an existing complex tunnel maintenance system in foothill has been studied. Thus by the use of Phase2 software, a finite difference method, a domain at 45 degree slope and 100 meters height has been modeled, where a tunnel with diameter of 10 meters has been drilled. Results indicate that values of axial forces and axial stresses in rock bolt are increased due to drillings in foothill under quasi static force. Values of axial forces, bending moment and shear-stress maintenance cover, show a considerable increase. These issues indicate the importance of seismic design and its high effect on underground space endurance and stability.

Key words: Horizontal quasi static force, Maintenance cover, Foothill drilling

INTRODUCTION

Studying potential stability and instability of underground structures are in fact assumed as an introduction of their maintenance system design. New innovation and initiations into rupture control systems create the possibility of accelerating the progress of tunneling. Rock masses existing in depth of the earth, are affected by stresses called in-situ stresses. Main factors of in-situ stresses are layers’ weight and region’s tectonic activities. After constructing the tunnel (or any other underground hole), stress’s condition gets disorganized and its condition around the hole, gets a new formation which differs from its first condition. Produced stresses due to tunnel drilling are called “induced stress” (Hoek and Brown, 1998). Vulnerability of underground structures against earthquakes may be made by earth’s rupture during the earthquake and also by vibrations resulted from earthquake. Most of the underground space damages due to earthquakes are because of the slips produced in the entrance of the tunnel. Earth’s rupture during earthquake mostly includes fault, earth slip and liquefaction liquefaction (DadashzaheSayyar et al., 2003). In these cases, rock’s fracturing and dilapidation in drilling’s lining and border can result in stability. This may appear as a gradual convergence of drilling, collapse and falling of arch, cracking and layering of walls, or even ultimately may appear as an abrupt fracturing and explosion of rock (Madani, 2002). The most basic subject in studying tunnel maintenance system is analyzing instability condition. These studies may show that there is no need to install maintenance system or vice versa; temporary maintenance system should be installed immediately. Instability may occur under these conditions: (1) fractures of rock masses around tunnels due to high effects of stresses on them. (2) Movement and falling of large segments of rock as a result of existing geological structures (structural instability). (3) Combination of fractures due to induced stresses and structural instability. (4) Instability resulted from other factors like seismic forces.
Modeling and data analysis method

In this article we have discussed the effect of different foothill drillings with inducing horizontal quasi static force (0.3 g) on combination maintenance system. Assuming it to be in the mountain foothill, drilling a tunnel occurs with diameter of 10 meters in every step of modeling. In order the slope difference to be effective in every step of modeling, the distance between centers of tunnels to perpendicular bisector of foothill’s surface, is assumed to be of fixed quantity. On the surface of every foothill, one 10 meters trench is made on upstream, midstream and downstream section. A trench with the dimension of 6*9 meters is also made in foothill’s heel section and each drilling’s effect on tunnel maintenance system is assessed. It should be mentioned that before drilling foothill and heel, implemented modeling, using mentioned diameter and slope, has analyzed by the program, and its results are compared with the models after drilling.

In order to do data analysis, the numeral method is being used. First, the rate of in-situ stresses in the area ($K_0$) is considered regarding the tectonic stresses of the area, and in-situ stress around tunnel’s environment has been determined. Thereafter appropriate behavioral model has been recognized considering the environment’s condition and information. Then with the help of Rock Lab software, rock mass strength parameters (compressivestrength, elastic module, tensile strength, etc.) have been obtained. Material used in modeling is Tuff rock which has been used in constructing the great tunnel of Tehran-Shomal freeway (Yassaghi et al., 2005). Then with the help of Phase2 software we can conduct the modeling and finally through analyzing the program’s outputs, we can get the results and conclusions. Phase2 software is a product of Rocscience Software Company. It uses finite element method for calculating stresses and relocations around underground drilled spaces. This software can be used by mine, civil, rock, mechanic engineers, and etc., and by the use of different graphs and curves it can solve many problems (Hoek et al., 1993).

It can be noted that the result of the forces and stresses obtained from outcomes, are in the form of maximum and minimum limit values to ease the comparing. Middle values are calculated and collected values for gaining result are the basis of action. In table 1 (that rock mass properties including rock mass strength ($\sigma_{cm}$), rock mass transformation module ($E_m$), and rock mass constants ($a$, $s$, and $mb$) have been calculated by the program) input and output parameters in Rock Lab program have been described.

<table>
<thead>
<tr>
<th>Hoek Brown Criterion</th>
<th>Hoes Brown Classification</th>
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</thead>
<tbody>
<tr>
<td>$\sigma_{cm}$ (Mpa)</td>
<td>GSI</td>
</tr>
<tr>
<td>single axis</td>
<td>Hoek Brown constant</td>
</tr>
<tr>
<td>pressure strength</td>
<td>Criterion for</td>
</tr>
<tr>
<td>Mohr-Coulomb Fit C</td>
<td>geology</td>
</tr>
<tr>
<td>stickiness</td>
<td>mass rock</td>
</tr>
<tr>
<td>$\Phi$ (degree)</td>
<td>tensile strength</td>
</tr>
<tr>
<td>95</td>
<td>47</td>
</tr>
<tr>
<td>16</td>
<td>0.4</td>
</tr>
<tr>
<td>1.502</td>
<td>0.0011</td>
</tr>
<tr>
<td>0.575</td>
<td>0.798</td>
</tr>
<tr>
<td>51.21</td>
<td>-0.07100</td>
</tr>
<tr>
<td>3.030</td>
<td>15.245</td>
</tr>
<tr>
<td>1646.77</td>
<td>0.798</td>
</tr>
</tbody>
</table>

In order to element the model, meshing 6-node finite element networks (second level from relocation and numeral integrating from 3 Gauss points) has been used in all models. Tunnel lining system, consists of armed concrete parts (Concrete shotcrete and steel section), rounding all over the tunnel’s peripheral part, and rock bolt is in tunnel lining sewed to surrounding rocks of the environment. Rock bolts are used in all tunnel models, with 1 meter space between them and 2 meters length. Tunnel’rock bolt and lining properties are described in table 2. By defining the modeling parameters, two-dimension model is depicted in figure 1. It should be noted that due to the redundancy of existing models, trenches of foothill and heel are also depicted. Programs’ output, before and after drilling, will be presented in the next part for comparison between the effect of induced drilling stresses and quasi static force on maintenance system.
In this section the results of numeral data are being assessed. Comparing outputs before and after drilling in upstream, midstream and downstream sections as well as heel trench, a signal difference can be seen. Resulting effect of drillings and quasi static force in different parts causes a considerable increase for all values of stresses, forces and bending moments. As much as these changes increase, it shows more effect of induced stress on tunnel system which subsequently results in increasing instability in complex maintenance system. Regarding the variety of program’s output and plentitude of stress data, force and bending moments of lining complex system and rock bolt, presenting visual data is being forgone, and numeral results are going to be discussed. To ease the comparison between output results of the program and, studying and analysis of data, average values of forces, stresses and bending moments have been calculated and illustrated in comparative graphs (figures 2 to 7). Furthermore in every graph, changes have been illustrated, before and after drilling, and implementing quasi static forces simultaneously. On horizontal axis there are values before drilling and values after drilling (downstream, midstream, upstream and heel, respectively) that will be explained.

### Table 2—Properties of maintenance cover

<table>
<thead>
<tr>
<th>properties of maintenance covering, connecting rod</th>
<th>properties of maintenance concrete</th>
<th>properties of rockbolt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance (m)</td>
<td>Thickness (m)</td>
<td>0.6</td>
</tr>
<tr>
<td>Depth (m)</td>
<td>Young module (Mpa)</td>
<td>0.2</td>
</tr>
<tr>
<td>Surface cut (m2)</td>
<td>Poisson’s ratio</td>
<td>0.013</td>
</tr>
<tr>
<td>Young Module (Mpa)</td>
<td>Pressure strength (Mpa)</td>
<td>200000</td>
</tr>
<tr>
<td>Poisson’s ratio</td>
<td>Tensile strength (Mpa)</td>
<td>0.25</td>
</tr>
<tr>
<td>Pressure strength (Mpa)</td>
<td></td>
<td>400</td>
</tr>
<tr>
<td>Tensile strength (Mpa)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Data examination and analysis

In this section the results of numeral data are being assessed. Comparing outputs before and after drilling in upstream, midstream and downstream sections as well as heel trench, a signal difference can be seen. Resulting effect of drillings and quasi static force in different parts causes a considerable increase for all values of stresses, forces and bending moments. As much as these changes increase, it shows more effect of induced stress on tunnel system which subsequently results in increasing instability in complex maintenance system. Regarding the variety of program’s output and plentitude of stress data, force and bending moments of lining complex system and rock bolt, presenting visual data is being forgone, and numeral results are going to be discussed. To ease the comparison between output results of the program and, studying and analysis of data, average values of forces, stresses and bending moments have been calculated and illustrated in comparative graphs (figures 2 to 7). Furthermore in every graph, changes have been illustrated, before and after drilling, and implementing quasi static forces simultaneously. On horizontal axis there are values before drilling and values after drilling (downstream, midstream, upstream and heel, respectively) that will be explained.
 relocation counter in every position) is under this part of drilling, because of setting most of stress free due to downstream drilling and more sensitivity of foothill’s slip wedge (gable). General increment process in the two graphs above is, relatively, alike for axial forces and stresses. Graphs in both cases, relatively show the same 1.99 increment in relation to before drilling level, which consequently causes instability in rock bolt maintenance system. Axial forces of lining cover are presented in figure 4. Existing axial forces in comparison with before drilling level (as well as changes in axial force of rock bolt’s cover) have a relative increment in different levels of foothill drilling and heel's trench.

![Fig. 2. Axial force values changes graph in rock bolt](image1)

![Fig. 3. Axial stress values changes graph in rock bolt](image2)

![Fig. 4. Axial force values changes graph in lining](image3)
It should be noted that values of these forces, in relation to increment of other forces values, stresses and bending moments in other sections, have lower level increment in relation to before drilling cases. As it can be understood from related graph, we observe a slighter slope, this is due to minimum induced stresses and quasi static seismic acceleration of different drillings in foothill and heel on lining axial forces in relation to other parts. In
figure 5, tunnel's lining cover of bending moment graph, the referred values after drilling levels (in every drilling) in relation to before drilling sections have been illustrated. In both above mentioned graphs, maximum increment of force values and bending moment in lining section of the tunnel, can be seen in downstream and heel of the drilling. In figure 6, considering lining shear forces graph, significant increment in after drilling level can be noticed. Maximum force increment is also seen in heel and downstream trench, in relation to mid and upstream trenches. This shows more freeing stresses in downstream and heel, and consequently causes more occurred slip wedge (regarding general relocation counter in the model) and finally inducing more shear force in this part of the drilling.

In this section we are going to assess Liners bending moment, using safe factor obtained from maintenance system capacity. For a defined safe factor (S.F=3), safe factor's pushes according to the force, are illustrated against bending moment for lining armed concrete (in two distinct graphs for shotcrete and steel profile). Safe factor's push graphs are illustrated in figures 8 to 12.
If calculated values are included inside the push, they get higher safe factor than push values and vice versa, if they are included outside the push, they get lower safe factor than push values. Similarly, the lower the safe factor of the calculated values of bending moment gets, the more unstable the system becomes; and the higher the safe factor is assigned inside envelope boundary, the lower the induced instability would consequently be included in Liners maintenance cover. Regarding safe factors of push graphs in above figures, it can be noticed that these factors will relatively experience a significant decrease after drilling levels. Regarding the graphs above, in 10 meters of diameter tunnel (foothill, 45 degrees slope), safe factor for drilling downstream in Liners cover of shotcrete section, decrease from 2 to 1.7; in steel cut (profilel-beam 260*101) from 2.6 to 1.9; in midstream drilling, Lingers cover of shotcrete section from 2 to 1.75 and in steel cut from 2.6 to 2; in upstream drilling for shotcrete section from 2 to 1.6 and profile section of Liners from 2.6 to 2 and finally in heel drilling for Liners shotcrete section from 2 to 1.7 and steel profile section from 2.6 to 2. Resulted values from safe factors push also show that stresses arising from drillings and seismic force, decrease the safe factors in all over the drilling sections that eventually and generally cause instability in complex maintenance system.

CONCLUSION

In this article, a numeral study has been made on quasi static horizontal force's effect and induced stress caused by different foothill and heel drilling on complex maintenance system constructed in foothill. The results of the analysis show that generally due to the drilling of different varieties of foothill and seismic acceleration, tunnel's complex maintenance system (including maintenance covering and rock bolt) are affected by induced stresses and their values are of importance. Examining the data resulted graphs, maximum induced stress (on maintenance system) is in foothill's downstream and heel's trench; and its minimum is located in midstream section. Besides, the effect of increase in stress values, forces and bending moment in complex maintenance system, would be on shear force, axial force of tunnel's lining system, respectively. Regarding the importance of discussed subject in this article, and considering that seismic behavior, is not confined to a particular part of the tunnel or underground space and the damage can be done throughout the tunnel's route or its space. Thus, it's suggested that a careful attention through all construction levels and tunnel's maintenance installation, should be paid to the effect of seismic forces arising from earthquake and future possible drillings on foothill around underground spaces for different purposes, and (as for example) with the installation of some accurate devices in every level of drilling the slope of the site, It would be possible to record every slip and relocation and prevent every increasing instability and future possible dangers due to it.
REFERENCES


