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Numerical Assessment of Support and Reinforcing Techniques of Alborz Tunnel

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Abstract

Despite the development of numerous excavation methods and reinforcement of tunnels, finding a proper method for stabilization of underground structures is a challenging task. The use of pre-reinforcement systems is an appropriate method to improve the status of the ground. In this study, the performance of umbrella system in Alborz tunnel in north of Iran has been investigated. Rock mechanics studies of tunnel running area have shown that parts of this tunnel have unstable capacity due to being located in weak zones. Therefore, the tunneling operation running is not possible in these areas. On this basis, umbrella pre-reinforcement system that can be used for loose and running ground are modeled numerically by Flac3D software. In this research, in addition to investigating the performance of umbrella system, the effect of geometrical parameters such as the angle of placement of pipes relative to the horizon and the distance between the umbrella system pipes was investigated. The criterion of investigating is the displacement occurred at the crown of the tunnel. The results of this study indicate that increasing the angle and decreasing the distance between pipes, cause an increase in stability and by using umbrella system, the displacement of crown of the tunnel has decreased by 60 %.

Keywords: *pre-reinforcement, Numerical modeling, Spiling Pre-reinforcement, Umbrella system, Tunnel.*

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Extended Abstract:

1. Introduction

Tunneling in poor environments leads tothe creation of alocal failure in thezoneof lack of support sy stem as well as creating unstable conditions in the tunnel face.

A safe and economical construction is always desired even though the conditions of the ground may not be optimal [7]. The use of an umbrella technique reduces the affected zone of tunnel drilling and tunnel effect on surface and beneath the surface. The umbrella tubes compensate the pressure exerted on the roof of the tunnel. Another important effect of tunnel excavation is that the Earth settlement occurs after the face movement [1]. The umbrella method is generally employed under the following conditions [2]:

- The existence of a shallow overburden above a tunnel
- The need to restrict ground surface settlement
- Poor ground conditions

As the design of the underground excavations becomes more and more complex, numerical analysis is required to investigate complex ground conditions that under this analysis, pre-support may be required [6]. 2D and 3D numerical analysis is used in the design of an umbrella arc systems and design parameters related to specific local considerations [3]. In the design of the tubes used in the umbrella arc method, length, hardness, cross - sectional area (thickness and diameter), the installation angle, spacing between the tubes, the length of the overlap and the injection pressure are determined [5].

In this study, three-dimensional numerical modeling has been carried out to find the optimal method of implementation of forepoling pre-support system, which is considered as a selective method for reinforcement of a very weak rock mass surrounding the tunnel. In addition, the overall performance of the advancement and implementation steps of project was compared with modeling under different operating conditions and finally tunnel stability was evaluated with respect to the proposed method. The structural performance of this method is studied and compared to different stages of excavation and also in pipes located at the crown of the tunnel and around it. since geometrical parameters of umbrella arch system such as pipe angle and distance between them as well as physical parameters such as ratio of water to cement in grout and injection radius have an effective role in providing stability of tunnel, by examining the available data and determination of grout parameters and reinforcement zone around pipes, numerical modeling has been studied to investigate of said factors.

2. Methods

In this study Forepoling pre-reinforcement method is investigated numerically in Alborz tunnel. Considering the material surrounding tunnel and the existing conditions, one of the most appropriate modeling methods for analyzing such a tunnel, considering the continuous environment, is using finite difference method and FLAC 3D software. The model considered for this analysis is The Mohr-Coulomb. The tunnel is simulated with a 13.6 m width and 10.3 m height and more than 600 m depth. Excavation method in this tunnel is top heading and bench. The aim of this study is to compare the different methods of pre-reinforcement in rock mass. The geometrical and strength parameters of pile element, synthetically (grout, tube and mixture of grout and rock mass) are calculated with Section Builder software.

Support system used in the tunnel is pre-reinforcement spiling method which is one of the umbrella systems, and primary support system includes of radial bolts, shotcrete and lattice grider. Radial rock bolts used in wall have a radius of 25 mm in diameter, with a length of 4.5 m, which are placed at a distance of 1.25 m from each other as soon as the drilling is completed and after the shotcrete is implemented. Shotcrete is sprayed to a thickness of 25 cm with the installation of lattice grider. The rock bolts are installed in the middle of each cycle, so that after excavation of 1.25 m, the rock bolts are installed radially at a distance of 0.625 meters from the face. Spiles are 6 m long and rock bolts 4.5 m. After installing the spiles and achieving the desired resistance, 1.25 meters of the upper section of the tunnel is excavated and the initial support system is installed immediately. After excavation of two cycles, spiling is performed again to create a 3 m long overlap.

3. Results and Discussion

The stability of the tunnels can be measured by comparing the strain that occurred in the rock mass around the tunnel with the allowable amount of this strain for the tunnels. If the strain is less than the allowable limit, the tunnel is stable. The strain is obtained by measuring the displacements. Considering the changes that have taken place and drawing the levels of risk of Sakurai [4], it is possible to examine the necessity of using the pre-reinforcement system and initial support.

The values of displacement in the state without pre-reinforcement system are above the second level of danger and close to the first line of danger, which is not within the allowable range for tunnels, while using the pre- reinforcement system and the use of radial rock bolts, it is below the second level and is within the allowable range of tunnels, which indicates that the use of an umbrella and pre-reinforcement system is appropriate (Figure 1).

To model the pre-reinforcement forepoling system, Mansion tubes with 90 mm diameter and 7.2 mm wall thickness with steel resistance parameters were used. To determine the overall parameters of the grout with a water-to-cement ratio of 0.5, which is often used in the injection of the umbrella method, it was prepared in the Rock Mechanics Laboratory and the necessary experiments were performed on it. The injection radius in this study is 400 mm.

The geometrical characteristics of the proposed forepoling system in the first stage include: pipe diameter: 90 mm, wall thickness: 7.2 mm, pipe length: 12 m, overlap length: 3 m, placement angle relative to Horizon: 7 degrees and the distance between the forepoles is 400 mm. In this study, the angle and distance between the forepoles have been changed and the effect of these changes has been studied. The affected radius is assumed to be the full filling of the space between the tubes, the distance between the center to center, i.e. 400 mm. With this arrangement, 27 tubes enter the studied area. After installing the 12-meter forepoles, the tunnel will be excavated and the primary support systems will be installed.

It is observed that using the pre-reinforcement system, the vertical displacements of the tunnel crown are controlled by 66% compared to the state without the use of the pre-reinforcement system, which is observed again by comparing these values with the Sakurai risk lines. This amount of displacement is permitted for tunnels. Also, by comparing the forepoling umbrella system with the spiling umbrella system, it is observed that the displacements decreased by 18% (Figure 2).

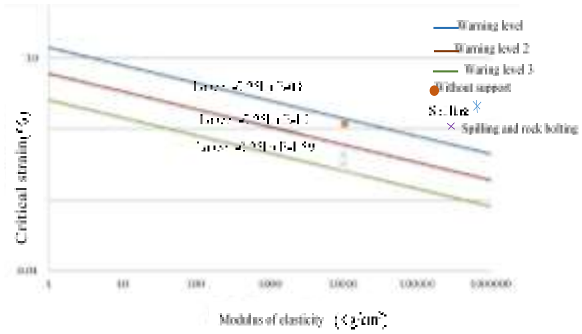
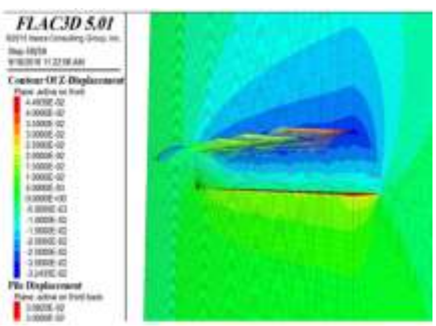
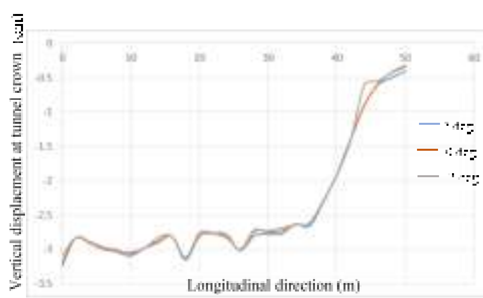


Figure 1. Comparison of different conditions based on risk criterion of Sakurai

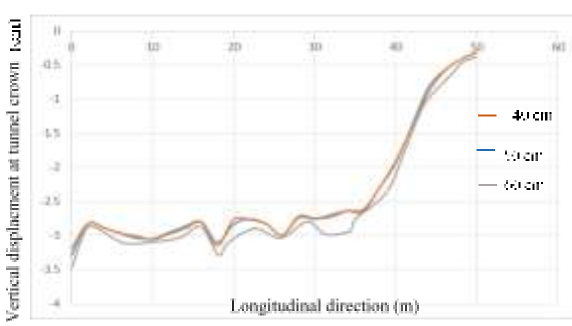
Also, by considering the rest of the factors constant, the effect of changing the angle in three modes of 7, 10 and 12 degrees is examined. Increasing the angle has led to a decrease in the amount of settlement and displacement in excavation of top of tunnel, but due to the large amount of overburden, this value is not significant. In addition, the distance changes of the forepoles have been investigated. For this purpose, the distance of the forepoles for the three distances of 40, 50 and 60 cm and its effect on the change of vertical displacements were examined. As expected, increasing the distance between the pipes from 40 to 60 cm will increase the vertical displacement of the tunnel crown. This increase is equal to 8.5% for the vertical displacement of the tunnel crown (Figure 2).



(A)



(B)



(C)

Figure 2. Results of Numerical Analysis A) Vertical displacement B) Vertical displacement of tunnel crown at 3 different angles of 7, 10 and 12 degree and C) Rectangular displacement of the tunnel crown at different distances of the forepoles at an angle of 10

4. Conclusion

According to the results obtained it can be concluded that:

- Considering the modeling done in the case study and reviewing the changes made in the tunnel crown and comparing them with the risk levels of Sakurai, it is appropriate to use a pre-reinforcement system to ensure the stability of the tunnel.
- Using the spiling system is the initial suggestion. The use of this system reduces the displacement of the crown by 60% compared to the state without the use of a pre-reinforcement system. Also, the use of radial rock bolts along with the pre-reinforcement system reduces the vertical displacement of the tunnel crown by 66% compared to the case where the pre- reinforcement system has not been used.
- Increasing the angle of the forepoles increases the stability. However, since in this method, the angular placement of the forepoles is only in order to create the necessary space for the installation of the next series of forepoles, it is necessary to consider this angle according to the project needs and the capability of the existing drilling rigs.
- Increasing the distance between the forepoles leads to a reduction in stability, however, due to the high cost of this method, the lower the number of forepoles entering the environment, the more cost-effective it is. Therefore, an optimal state must be considered.
- The use of the forepoling method in the proposed range has the desired efficiency and reduces the displacement of the tunnel crown by 66%.

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