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Construction Stability Analysis of the Portal Section of Georgia's E60 Highway Tunnel Based on Numerical Analysis

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Abstract. Combined with the construction of the No. 6 tunnel of the Khevi-Ubisa-Shorapani-Argveta section of Georgia's E60 highway, the Midas GTSNX software was used to simulate the stability of the tunnel portal section during full-face construction. This paper analyzes the characteristics of displacement and stress variation of the tunnel portal slope during the whole section construction, the deformation law of surrounding rock during the whole section excavation, the deformation law of the initial support and final lining structure of the tunnel. The results based on the numerical simulation analysis show that when the entrance section of Georgia Tunnel No. 6 adopts full-face construction, the displacement of the supporting structure and the rock mass at the 5 m in front of the tunnel entrance changes greatly. Therefore, it is recommended to complete the invert construction of the tunnel before construction to ensure the safety of the tunnel entrance section; As for the entrance section as a whole, during the full-section construction process, the side slope of the entrance, the surrounding rock of the tunnel, and the supporting structure are all in a relatively stable state. Therefore, the full-section excavation of the No. 6 tunnel entrance section is safe and feasible.

1. Introduction

The complexity, uncertainty and high risk of tunnel engineering under complex geological conditions make the construction of tunnel engineering face many challenges, especially the portal section of tunnel. In order to ensure the safety of construction, it is necessary to analyze and evaluate the tunnel construction scheme, and put forward a safe, economic and reasonable scheme [1-3].

The emergence of numerical analysis method provides a good way to help solve the analysis problem of tunnel construction stability. It can deal with complex boundary conditions, solve nonlinear problems, deal with the heterogeneity and anisotropy of materials, and consider the space and time variation of tunnel excavation. Song Zhanping [4] studied the deformation and stress characteristics of the supporting structure of the tunnel portal under the background of large section and shallow buried unsymmetrical pressure section at the exit of Xiaomanping tunnel of Baolan passenger dedicated line by using the numerical simulation test analysis method, and proposed the optimized construction scheme of the portal section to ensure the safety of tunnel construction. Xu Yizhong et al. [5] relying on the portal section of Shawan tunnel in Guangxi, based on the numerical analysis method, studied the safety and reliability of the construction of shallow buried tunnel portal section by adopting three-step seven step construction method on the basis of strengthening tunnel surrounding rock with advance small pipe grouting and circumferential grouting. Based on numerical simulation analysis, Zhuo gengshan et al. [6] simulated the whole construction process of Chongqing Zengjiayan unsymmetrical pressure small clear distance tunnel portal section, analyzed the stress evolution law of surrounding rock during the construction of tunnel portal section, and proposed the pre grouting reinforcement scheme for surrounding strata of the tunnel when the tunnel buried depth is less than 1 times tunnel diameter. The above research on tunnel portal section provides technical support for tunnel construction safety. However, for the feasibility of full-face construction in shallow buried section of large section tunnel portal and the stability of tunnel, it is necessary to carry out systematic numerical simulation analysis combined with specific engineering.

Taking the portal section of No.6 large cross section tunnel of E60 highway in Georgia as the background, the refined numerical analysis model of No.6 tunnel portal section is established by using Midas GTSNX software. This paper studies the deformation and stress characteristics of tunnel portal slope and tunnel support structure when the full section method is used in shallow tunnel portal section construction, analyzes the feasibility of full section construction at portal section and key construction parts, and provides technical support for tunnel site construction.

2. Material and Methods

2.1. Project Overview

No.6 tunnel of Georgia E60 highway is located in the middle of Georgia block, Transcaucasia block, between the north Caucasus region and the Southern small Caucasus region, as shown in figure 1. The starting and ending mileage of the tunnel is 82 + 11.00 ~ 84 + 54.40, the total length is 255.4 m, the maximum buried depth is 92.0 m, the minimum buried depth is 7.0 m; the maximum span of the tunnel is about 12.0 m, belonging to the large cross-section tunnel, the original design adopts full face excavation.

Figure 1. Topographic map of Georgia.

The stratum through which the tunnel passes is mainly the exhalative volcanic rock of crystalline basement of Middle Jurassic, which is represented by porphyry complex, including the following geological structures: porphyry, porphyry breccia and layered tuff. The class of surrounding rock is III ~ IV.

2.2. Building Tunnel Model

Taking the terrain and geological conditions of the entrance section of No. 6 tunnel as the research object, a three-dimensional numerical analysis model is established. According to the relevant principles of elastic mechanics and rock mechanics, the influence range of tunnel excavation on surrounding rock mass is 3 times of tunnel diameter width [7]. According to the actual situation of strata and mountains, the length of the model in X-axis direction is 124.0 m, that in Y-axis direction is 100.0 m, and that in vertical direction (Z-axis direction) is 32.0 m from the bottom of the tunnel to the lower boundary.

In the process of tunnel grading, excavation and backfilling, only the influence of self-weight on tunnel and slope is considered. The boundary conditions of the model are set to keep the whole model

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fixed in X, Y, Z directions. In order to ensure the calculation accuracy, fine elements are used around the tunnel. The model is divided into 129185 elements and 67340 nodes. The mesh division of the finite element model is shown in figure. 2:

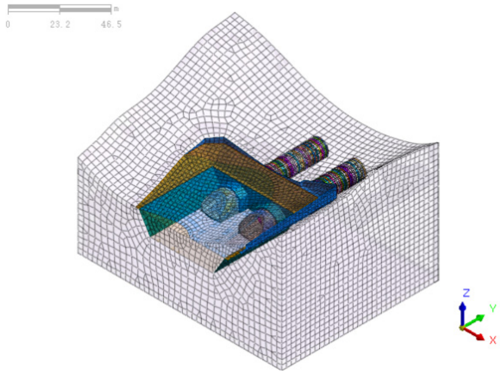

Figure 2. Finite element model grid.

In the process of establishing finite element model, isotropic Mohr Coulomb model is selected for rock mass, isotropic elastic model is selected for initial support and finial lining of tunnel. According to the experience of engineering practice, elastic plate element can be established by disjunction for initial support and finial lining of tunnel, and solid element is used for open cut tunnel and rock mass. The material parameters of the model are shown in table 1:

Table 1. Material parameter table.

	Material type	Poisson's ratio	Density kN/m3	Cohesion KPa	Internal friction angle
Rock Mass	1.5Gpa	0.25	25kN/m^3	80kN/m^2	45
Initial support	30Gpa	0.2	25kN/m^3		
Final lining	31.5Gpa	0.2	25kN/m^3		

3. Results

3.1. Simulation results and analysis of slope excavation

The side slope of tunnel No.6 is a three-stage slope, and the unit passivation function in Midas GTSNX is used to simulate the slope excavation. The process of simulating slope excavation is as follows: firstly, simulate the excavation of the third level slope, secondly, spary shotcrete reinforcement on the third level slope, at the same time, simulate the excavation of the second layer of slope, and repeat this until the end of slope excavation.

After the simulation of slope excavation and support is completed, the model displacement cloud chart is shown in figure 3. It can be seen from figure 3 that the maximum displacement is concentrated in the bottom plane of the slope, in which the minimum displacement of the bottom plane of the slope is 4.7mm and the maximum displacement is 8.4mm; the average displacement of the first, second and third grade slope is 4.0mm; and the displacement of the rock mass 20m or more away from the excavation slope is less than 2.2mm. The stress cloud chart is shown in figure 4. It can be seen from figure 4 that the plane tensile stress at the bottom of the slope is 72.3kpa, and both the mountain and the slope face are under compression. The results show that with the increase of the distance between the rock mass and the excavation face of the slope, the displacement decreases, and the farthest displacement does not occur. The maximum displacement occurs at the bottom plane of the slope, which indicates that the support treatment after slope excavation plays a role, and the average displacement of the side slope is kept at 4.0 mm. After excavation, tensile stress is produced at the bottom of slope due to stress release, which conforms to the actual situation. According to the experience of engineering practice, the displacement and stress produced by the excavation and support of the tunnel slope will not affect the stability of the tunnel, which can ensure the safety of the site construction.

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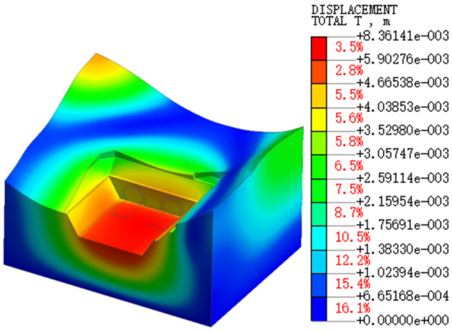

Figure 3. Cloud chart of displacement after slope excavation.

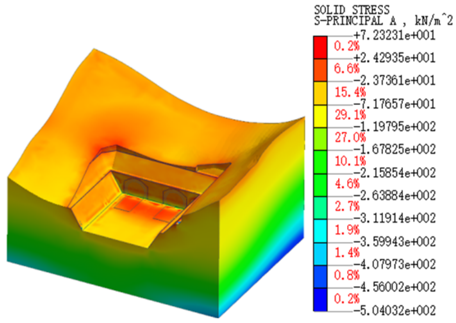

Figure 4. Cloud chart of maximum principal stress after slope excavation.

3.2. Simulation Results and Analysis of Tunnel Excavation

In the process of simulating tunnel excavation, the left and right tunnels are excavated at the same time, each excavation is 1m, and the initial support is carried out at the same time. After excavation, the cloud chart of tunnel displacement is shown in figure 5:

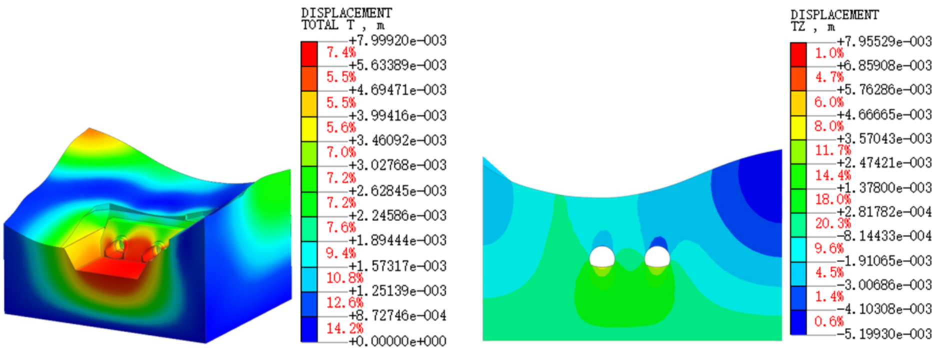

Figure 5. Cloud chart of tunnel displacement.

Extract the calculation results, and get the vertical displacement diagram of the left and right tunnel vault and tunnel bottom after excavation, as shown in figure 6:

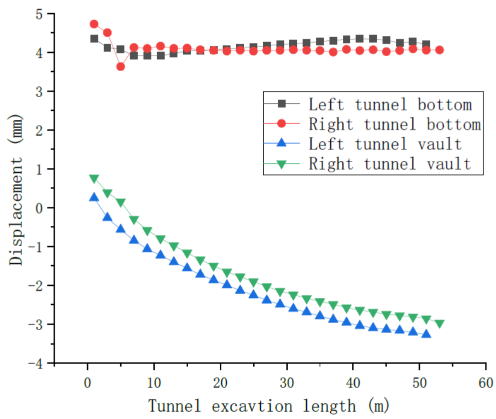

Figure 6. Displacement diagram of vault and bottom of left and right tunnels.

It can be seen from figure 6 that the displacement at the bottom of the left and right tunnels is small and stable at 4.1 mm. The maximum displacement occurs at the tunnel entrance, with the left tunnel being 4.4 mm and the right tunnel 4.7 mm. 5 meters away from the entrance of the tunnel, the bottom displacement of the right tunnel changes greatly from 4.5 mm to 3.6 mm, but the change value is relatively small, only 0.9 mm. The maximum displacement of the left and right tunnel vault is 3.3mm, which is located at 53m; the maximum displacement of the right tunnel is 3.0mm, located at 53m. The displacement of the vault of the left tunnel is 0.2mm larger than that of the right tunnel. According to the model analysis, the buried depth of the left tunnel is larger than that of the right tunnel, and the weight of the soil column above the left tunnel is greater than that of the right tunnel. When the portal section is shallow buried, the weight of the soil column is greater than the friction force and cohesion of both sides, so the stratum cannot play the role of arching [8]. Therefore, the vault displacement of the left tunnel is greater than that of the right tunnel. In conclusion, after the completion of tunnel excavation, the displacement of tunnel vault and bottom will not affect the stability of the tunnel. The displacement at the bottom of the right tunnel is 5m away from the portal, so it is necessary to strengthen the monitoring on this section to prevent sudden displacement mutation.

3.3. Simulation Results and Analysis of Tunnel Initial Support and Finial Lining

3.3.1. Displacement Analysis of Vault of Tunnel Initial Support. The longitudinal displacement data of the initial vault are extracted from the calculation results. figure 7 is shown below.

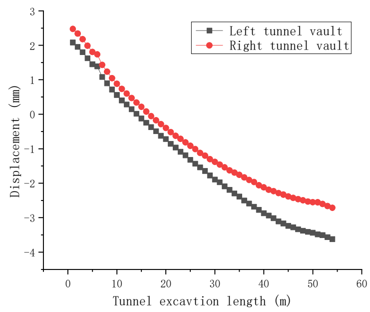

Figure 7. Displacement diagram of vault of left and right tunnels.

From figure 7, it can be seen that the variation law of the vault displacement of the initial support of the tunnel is similar to that of the surrounding rock mass. The maximum displacement of the first vault of the left tunnel is 3.6 mm, and that of the right tunnel is 2.7 mm, both located at 53m. It can be concluded that the displacement caused by the vault of the initial support of the tunnel will not affect the safety of the construction of the tunnel portal section and the stability of the tunnel.

3.3.2. Simulation Results and Analysis of Tunnel Finial Lining. In the model, the thickness of finial lining is defined as 80cm and the material is C35 concrete. The displacements of the second lining vault and invert of the left and right tunnels are shown in figure 8.

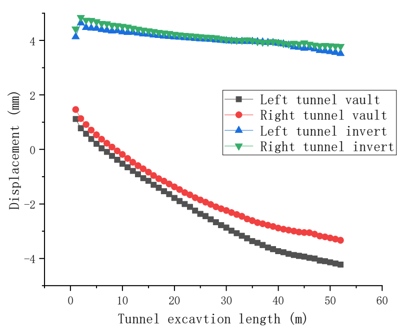

Figure 8. Displacement diagram of finial lining and invert of left and right tunnels.

From figure 8, it can be seen that the displacement of the inverted arch of the second lining is similar to that of the surrounding rock mass of the tunnel. The displacement of the left and right tunnel invert is small. The displacement of the second lining invert of the left tunnel is stable at 4.0 mm, and that of the right tunnel is 4.2 mm. The maximum displacement occurs at the section 2 m away from the tunnel. The left tunnel is 4.6 mm and the right tunnel is 4.8 mm. The maximum displacement of left and right tunnel is 4.2mm and 3.3mm respectively, which are located at 53.0m. To sum up, after the completion of tunnel excavation, the displacement of tunnel vault and bottom can ensure the safety of tunnel construction. The inverted arch displacement at 0 ~ 3.0m away from the tunnel portal varies greatly, so the monitoring of this section should also be strengthened during site construction.

4. Conclusion

Through the numerical analysis of full-face excavation of the portal section of Georgia No.6 large section tunnel in shallow buried condition, the following conclusions are drawn:

(1) The tunnel is in a stable state during the construction process, and the maximum displacement is at the bottom of the slope after excavation, which is 8.4mm.

(2) The displacement of rock mass and finial lining around the tunnel changes greatly within the first 5 meters of the tunnel, so it is necessary to strengthen the monitoring when the construction reaches here, and complete the invert immediately to prevent sudden displacement change.

(3) Through the numerical analysis of Midas GTSNX for slope excavation and tunnel portal construction, the changes of surrounding rock, initial support and finial lining during the construction can be known in advance before tunnel excavation, and the monitoring scheme can be designed specifically, so as to ensure the safety of construction and minimize the occurrence of engineering accidents.

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References

[1]. Zhang, Y.X. (2011) Analysis of reasonable excavation sequence and stress characteristics of portal section of shallow tunnel with unsymmetrical loadings. Chinese Journal of Rock Mechanics and Engineering., 2011(51): 3066-3073.
[2]. Han, X.W., Li, S. (2020) Tunnel construction technology under complex geological conditions. Transpoworld., 2020(19): 143-144.
[3]. Yang, D.L., Pan, H.K., Wang, Z.Y. (2006) The excavation and measurement of highway tunnel under complex geologic conditions. Highway Engineering.,2006(03): 1-5+37.
[4]. Song, Z.P., Wang, T., Zhou, J.Y., Yu, W.S. (2017) Analysis of construction optimization and mechanical characteristic of shallow large section tunnel. Chinese Journal of Underground Space and Engineering., 2017(02): 459-468.
[5]. Xu, Y.Z. (2020) Numerical simulation of tunnel portal construction in shallow siltstone stratum. Western China Communications Science & Technology., 2020(07): 113-117.
[6]. Zhuo, G.S., Sui, S.G., Pei, X.H. (2020) Application of whole process construction simulation in portal section of tunnel under unsymmetrical pressure and small clear distance soil layer. China Steel Focus., 2020(15): 121-122.
[7]. Xu, Z.L. (1982) Elasticity. Higher Education Press, Beijing.
[8]. Liu, Z.R. (2011) Underground structure design. China Architecture & Building Press, Beijing.