Stability analysis of full-section construction of staggered distance double-hole tunnel

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Abstract—In the staggered distance double-hole tunnel located on the slope of the mountain, the deformation of the surrounding rock and the supporting structure of the tunnel is complicated. The deformation stability of the tunnel entrance is one of the most difficult points of the tunnel. In order to clarify the deformation law of the full-section construction at the entrance of the staggered distance double-hole tunnel, the entrance section of the Georgia E60 Highway No. 3 tunnel under construction is used as the background, and the method of numerical simulation test is used to study the staggered distance double-hole tunnel, the influence of section construction on the deformation and stability of the side and front slopes of the tunnel entrance section and the support structure of the tunnel entrance section. The research results show that: For tunnels with full-section construction, excavation will cause certain deformations on the ground and the tunnel, and the stability of the left side support structure of the right line tunnel without rock column between the two tunnels is worse than that in other positions, on the whole, the construction plan is reasonable and feasible.

1. INTRODUCTION

In recent years, China has built highways, railways and other tunnels in many countries, and many of the tunnel caves have engineering problems such as shallow burying, biased pressure, and poor geological conditions [1]. Due to the complicated construction steps of the tunnel entrance section and the influence of shallow burying and bias pressure, this resulted in poor stability of the surrounding rock, supporting structure [2] and slope at the entrance of the cave [3], moreover, the surrounding rock pressure and deformation characteristics [4] of the entrance section are greatly affected by the construction and excavation methods. However, at present, many tunnel entrances are excavated using CRD method [5] and CD method [6] and other construction methods [7] for tunnel excavation, but there are few studies on the surrounding rock deformation and the force influence of the supporting structure using the full-section construction method. At the same time, although there are many studies on parallel tunnels [8], the study on a staggered distance double-hole tunnel formed by the influence of topography and existing buildings is still blank, therefore, the full-section method is used to simultaneously excavate the staggered distance double-hole tunnel portal section, the deformation and force characteristics of the supporting structure, the side and front slope, It has great research value and practical significance for ensuring the economic and reasonable construction of tunnels.
This article is based on the Georgia E60 Highway No. 3 Tunnel Entrance Section Project, the starting point is to ensure the stability of the side and front slope and the tunnel support structure during tunnel construction, and establishes a numerical model using Midas GTS finite element software, it also analyzed the deformation and force characteristics of the slope and uphill, and support during the construction of the tunnel, guided the construction of supporting projects, and provided a certain reference basis and solution ideas for the construction of similar tunnels.

2. MATERIALS AND METHODS

2.1. Research and Analysis of Engineering Geological Characteristics of Tunnel No. 3
The entrance section of the No. 3 tunnel in the study area is located on the slope of the mountain and close to the existing road. During the construction, in order to reduce the height of the side and front slope of the two tunnels entrances, therefore, this kind of staggered double-hole tunnel is formed. The stratigraphic-lithological framework in this area is complex, and its surface coverage is based on Quaternary volcanic rocks and sedimentary rocks as the main geology. Intrusive rocks and metamorphic rocks constitute the Proterozoic crystalline basement. The stratum that the No. 3 tunnel passes through is mainly gray quartz flakes. Gneiss stratum, the surrounding rock of this stratum has been weathered slightly to lightly, and the entrance section of the tunnel has the characteristics of large cross-section and poor surrounding rock properties.

2.2. Maintaining the Integrity of the Specifications
The finite element analysis software Midas GTS NX was used in the numerical analysis. It is determined that the left tunnel is 39 m from the left boundary, the right tunnel is 49 m from the right boundary, and the bottom of the tunnel is 25 m from the boundary. After considering the geology and lithology of the tunnel, the constitutive model of the rock mass was determined to be the Mohr-Coulomb constitutive model. Because the initial support of the tunnel includes steel arches, steel grids and shotcrete, the equivalent elastic modulus is used to convert the elastic modulus of the steel arch to shotcrete to obtain the elastic modulus of the initial tunnel support. The finite element models of the tunnel and the side and front slope before and after excavation are shown in Fig. 1 and Fig. 2.

The study area selected the right-line tunnel mileage from DK 5+000.000 to DK 5+064.000, and the left-line tunnel mileage from DK 5+016.000 to DK 5+064.000. The specific material support parameters during tunnel construction are shown in Tab. 1. The specific construction process for the study area is:

1. Determine the positions of the openings of the two tunnels and the positions of the side and front slope according to the design and site conditions, after determining the location, excavate the soil layer at the entrance of the cave from the top to the third layer, and the upside slope. The shotcrete support shall be carried out in time for each layer of excavation, and the excavation shall be carried out in this order. Protect to the side and front slope of the third floor.

2. The outer side of the mountain at the entrance of the main tunnel of the two tunnels to be excavated shall be supported with a length of 6 m and a thickness of 0.9 m.

3. Destroy the front slope concrete support at the two tunnel portals, the two tunnels were excavated and supported at the same time according to the footage of 2 m, which he distance between the front and back is 16 m, and the distance between the tunnels is 12 m.
Figure 1. Finite element model.

Figure 2. Model after tunnel excavation.

TABLE 1. Table of Tunnel Support Parameters

| Material name            | Unit weight (kN/m³) | Elastic Modulus (GPa) | Poisson’s ratio | Friction angle (°) | Cohesion (kPa) |
|--------------------------|---------------------|-----------------------|-----------------|--------------------|----------------|
| Quartz gneiss formation  | 25                  | 1                     | 0.25            | 54                 | 100            |
| Initial support          | 24                  | 30                    | 0.2             | /                  | /              |
| Final lining             | 26                  | 32                    | 0.2             | /                  | /              |

In order to better analyze the influence of the construction method on the stability of the side and front slope and tunnel, some points are selected in the model for detailed analysis.

3. RESULTS AND DISCUSSION

3.1. Displacement analysis of the side and front slopes
The vertical displacements of before and after tunnel excavation of the side and front slope tunnel are selected as the research object. As shown in Fig. 3.

From Fig. 3(a), before the tunnel excavation, the vertical displacements of the side and front slopes are generally evenly distributed and the main displacement changes are shown as Uplift of the side and front slope soil. At this time, the settlement range of the side and front slope is mainly manifested in the first layer of soil close to the surface, and the maximum vertical displacement settlement value is -0.046 cm.

From Fig. 3(b), after the excavation of the two tunnels is completed, under the coupled influence of the sliding force of the soil and its own gravity, the soil uplift reaches a maximum of 0.024 cm, and the largest range of uplift is mainly concentrated on the lowermost side and front slope; the maximum vertical displacement settlement value is -0.215 cm, and the settlement range is mainly manifested in the first layer of soil closer to the surface, and is more concentrated than the settlement range before the tunnel excavation.
3.2. Analysis of tunnel vertical and horizontal displacement
Select the right tunnel DK 5+020.000 and the left tunnel DK 5+046.000 as the characteristic sections. The vault settlement and horizontal convergence, as shown in Fig. 4 and Fig. 5.

It can be seen from Fig. 4 that when the right-line tunnel is excavated to the characteristic section, the two vaults will immediately produce large settlement deformation, and then as the tunnel excavation deformation rate gradually decreases, the deformation will continue to increase until it reach to stable, after the excavation and support of the two tunnels were completed, the settlements of the right-line tunnel and the left-line tunnel respectively reached 4.160 mm and 4.451 mm.

It can be seen from Fig. 5 that with the excavation of the right-line tunnel, the displacement value of the characteristic section DK 5+020.000 has reached the maximum value of 0.817 mm after the 38 m of the right-line tunnel excavation in the 27th step, and the deformation of the left-line tunnel that was excavated first was gradually reduced to stabilize under the influence of the right-line tunnel that was later excavated.
3.3. Vertical deformation analysis of the ground surface

The vertical displacement cloud map of the ground surface before and after the tunnel excavation is shown in Fig. 6(a) and Fig. 6(b).

It can be seen from Fig. 6(a) that the maximum vertical displacement is distributed on the ground surface in front of the two tunnel portal, and it is mainly manifested as the soil uplift, and the maximum value reach to 0.585 cm, while the unexcavated stratum surface is mainly manifested as downward settlement deformation.

It can be seen from Fig. 6(b) that after the tunnel excavation and support are completed, the settlement and deformation of the undisturbed ground surface soil have increased, and the uplift caused by the tunnel excavation is mainly manifested in the inverted position of the tunnel bottom, and The maximum value reach to 0.721 cm.
In order to further analyze the changes in surface settlement after the excavation and support of the two tunnels, the DK 5+058.000 section of the right-line tunnel is taken as the research object, and the centerline of the rock pillar between the two tunnels is used as the reference line, the surface settlement curve of the stratum surface at the DK 5+058.000 section is obtained, as shown in Fig. 7. The origin of the coordinates is the surface point above the center line between the two tunnels, and the positive direction of the X-axis is the distance between the surface points above the left-line tunnel and the center line, the negative direction of the X-axis is the distance between the surface points above the right-line tunnel and the center line.

From Fig. 7, the surface settlement curve is similar to the Peck curve, but the vertical direction of the left-line tunnel's surface settlement deformation is affected by its own weight and shallow buried bias, and the maximum displacement value of the left-line tunnel near the center-line of the rock column is 2.774 mm greater than the maximum displacement value of 2.645 mm above the right-line tunnel. However, the surface settlement value -0.052 mm above the left tunnel at the far end of the rock column center-line is less than the surface settlement value above the right tunnel -0.370 mm.
4. CONCLUSIONS
The method of numerical simulation test is used to study the deformation stability of the Georgian E60 highway No. 3 staggered distance double-hole tunnel with full-section excavation, the following research conclusions can be drawn through the research:

(1) When the staggered distance double-hole tunnel is simultaneously excavated by the full-section construction method. The displacement and deformation of the tunnel can be divided into three stages: the deformation slowly increases, the deformation increases sharply, and the deformation tends to stabilize. That is, the construction method is safe and feasible.

(2) In general, the uplift value of the side and front slope caused by tunnel excavation has decreased, and the settlement value has increased, and the increased settlement value mainly shows that the side and uphill slope of the first layer are close to the surface.

(3) Near the centerline between the two tunnels, the surface settlement value is larger above the tunnel on the buried depth shallower side; While at the far end away from the center line between the two tunnels, the surface settlement value is larger above the tunnel on the buried depth deeper side.

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