Numerical Simulation Analysis of the Stability of Heishan Tunnel's Surrounding Loess during Construction[1]

Song Yang[1 *],Sun Wen-jun[1], Guo Ke-xin[1], Lu Wei[1]

[1]Hebei Engineering and Technical College, Cangzhou 061001, Hebei, China

Keywords: Heishan tunnel; surrounding rocks; numerical simulation; loess

Abstract: Stability of tunnel's surrounding rocks is a big issue during construction. Based on the characteristics of crown settlement and convergence deformation of surrounding rocks, numerical simulation of Heishan tunnel has been carried out to investigate the interaction between right and left tunnels during construction. And then the effect of tunnel's primary lining was presented in this paper. The results of numerical analysis shows that the deformation of surrounding rocks was significantly influenced by the progradation of tunnel face. The redistribution of geostress induced by the firstly excavated tunnel is equivalent to the increase of right line depth. It is helpful to form arch effect. And it is indicated that the strength of tunnel's primary lining is good enough to meet the requirements of stability control with reliable safety redundancy.

Introduction

The stability of surrounding rocks is one of the key issues in the construction of tunnels and underground caverns. All of these analysis will provide theoretical support and technical guidance for on-site construction personnel. [1, 2]At present, mathematical analysis method and numerical simulation method are two important parts of the deformation and force analysis of tunnel's surrounding rocks.The theoretic elastic solution of oval cavern and the closed solution of circular cavity in sticky elastic and elastic-plasticity medium can be got with this method easily. And these results can be directly used in the design of tunnel engineering and stability analysis of surrounding rock during construction [3, 4]. However, when the cross section of tunnel or underground cavern is complex and the difference of surrounding rack medium's characters is obvious, the numerical analysis methods, such as finite element analysis and discrete element analysis are important methods to determine the deformation and stress of surrounding rocks [5, 6].

Overview of Heishan tunnel engineering

Heishan tunnel is an upper and lower separated tunnel with two-way six lanes in Zhang Zhuo expressway. The design speed is 100 km/h. The distance between tunnel's two sides is about 30~35m with the change of topography. The width, clear width, clear height, and building line's clear height of tunnel's every hole is 17.4m, 14.25m, 8.0m, and 5m respectively. And there are a bilateral maintenance road, a transverse traffic tube, and a pedestrian in every tunnel hole. The design size and construction method of tunnel are shown in Fig.1.

The number of initial pile in tunnel left hole is K22+964~K25+760, and right one is Y1K22+930~Y1K25+770. Bench mining method is used in the construction of tunnel. The surrounding rock of tunnel is consisted of Pleistocene loess on quaternary, mainly. Middle Proterozoic Jixian System Wumishan dolomite and mixture mass of loess and crushed rocks in transition period.

[1] This paper is supported by the Research Foundation of Education Bureau of He Bei Province（QN2015036）;Water resources research and extension project of Hebei Province（2015049）

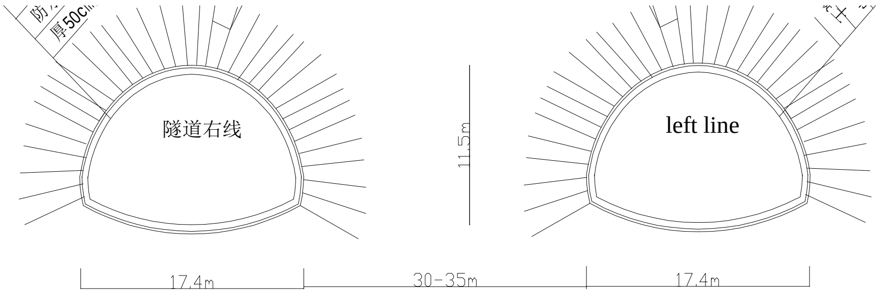


Fig.1 design and construction methods of tunnel cross section (the division of left and right line along with the marching direction from Zhangjiakou to Zhuozhou

Calculation and analysis of the stability of surrounding loess in Heishan tunnel during construction

Numerical model establishment of loess section in Heishan tunnel. Taking the influence range of tunnel excavation is often the twice of tunnel diameter before and after the tunnel face into consideration, a typical hole section is selected and located at the buried depth of about 50m (K25 + 375 section). As shown in Fig.2, the length, width, and height of simulation hole is 80m, 195m, and 90m respectively.

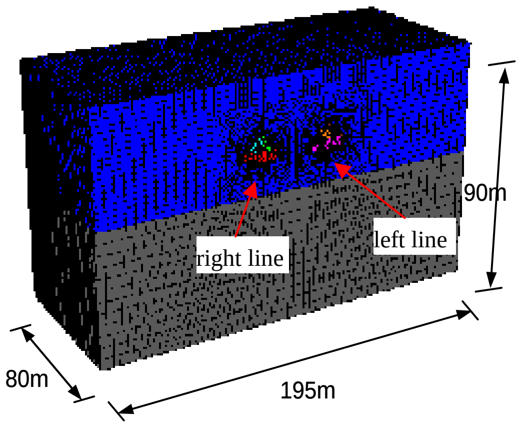


Fig.2 Numerical Model for Heishan tunnel

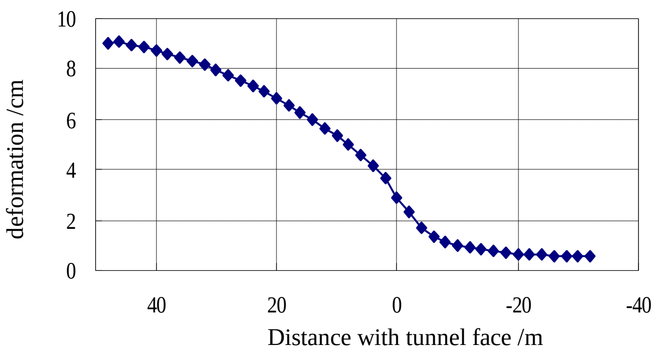


Fig.3 The effect of position of tunnel face on crown settlement

Selection of model parameters. Upper and lower bench method is used in the excavation of Heishan tunnel. C25 sprayed concrete and I22 joist steel were selected as support parameters. And the diameter of reinforcing mesh is Φ8. The I22 joist steel was regarded as support unit and simulated within the consideration of sprayed concrete. Bilinearsoften/ harden methods were used in loess model. And its main parameter are obtained from laboratory test. Its elasticity modulus, Poisson ratio, unit weight of soil, cohesion, and internal friction angle were 380MPa, 0.35, 18.1 kN/m^3, 75MPa, and was 24°respectively.

Excavation influence of left line on stability of surrounding rock in Heishan tunnel

Influence of tunnel face's progradation on crown settlement in left line. It can be seen from Fig.3 that the crown settlement tends to increase slowly with the left line progradation of tunnel face approaching to the predetermined cross section in left line. And the crown settlement here is small because of the supporting function. With the tunnel face passing through and away from the section, the support function becomes weak gradually. And the crown settlement is developing along the time. When the distance between tunnel face and cross section is more than 3 ~ 4 times of the tunnel span, the deformation tends to be gentle, which indicating that the primary lining structure plays an obvious role.

Analysis of tunnel surrounding rock's displacement and multi-point displacement in left line. Convergence deformation curve of monitored section is given in Fig.4. The measured convergence line of this section is installed within the range of 1m to 2m after tunnel face. From Fig.6, it can be known that the convergence deformation is about 4mm, which is nearly identical with the monitored result of 3.5mm. Convergence deformation of side wall is increasing during the bottom period. From the changing curve of convergence deformation's increment of side wall during the excavation process is shown in Fig.5, it can be seen that the law is similar to that of up section excavation as shown inFig.6. Because the convergent monitored section is embedded before thebottom excavation, so all of the change during this period can be monitored. The convergence deformation incremental of loess tunnel section's side wall in left line is 7.1 mm. And the calculating convergence deformation increment is 9.2 mm, which is bigger than the monitored result.

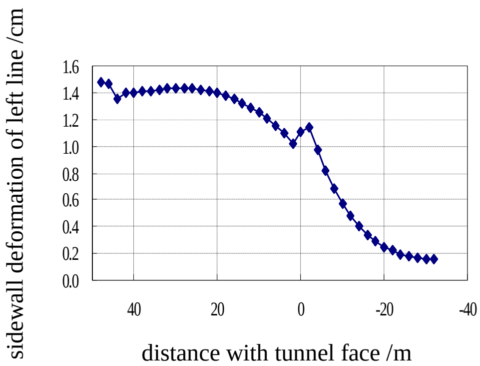


Fig.4The curve of convergence of side walls at K25+375

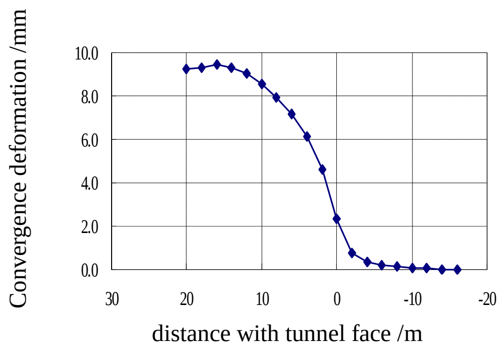
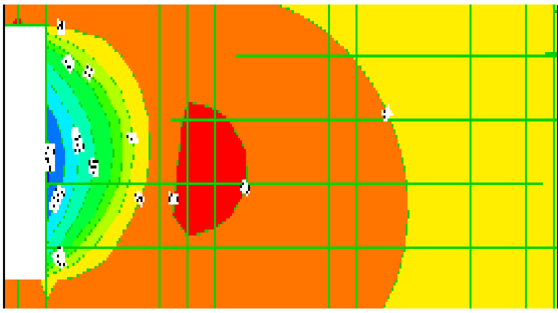


Fig.5 Incremental convergence of side walls when inverted arch formed

Deformation analysis of tunnel face in loess section. The deformation of tunnel face must be paid more attention in the soft rock tunnel. And there is a need to decide whether to support or reinforce the tunnel according to the deformation situation. The deformation of tunnel face along the tunnel axis in left line is shown in Fig.6. It can be seen from Fig.8 that compressional deformation of rocks is formed in the range of first 3m of tunnel face. The maximum deformation is 18mm, which indicated that the deformation is relatively small and the stability of tunnel face is well. All of these are corresponding with the site condition. Therefore, the advice for the implement of support or reinforcement for tunnel face is not necessary duringpractical construction based on the numerical calculation of tunnel face deformation stability in Heishan loess tunnel section.



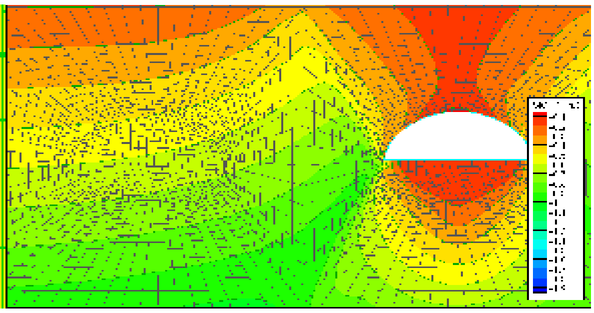
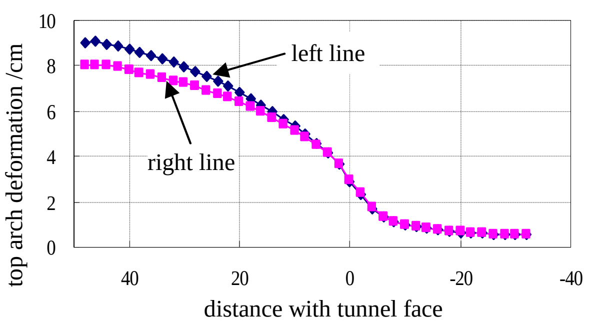


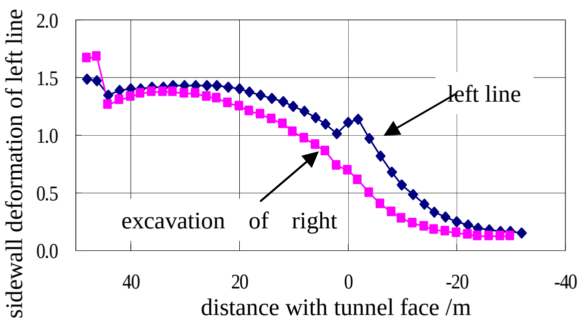
Fig.6 Deformation of tunnel face in axial direction Fig.9 Gravity field of right side tunnel after excavation of left side tunnel

Interaction between the left and right line of the tunnel excavation in Heishan tunnel.

The curve of crown subsidence and sidewall convergence deformation during the tunnel excavation in right line is shown in Fig.7. It can be seen from the curve that the deformation of right line tunnel is always smaller than left line no matter the crown subsidence or sidewall convergence. All of the evidence indicates that the influence of left line on right line belongs to the second kind of hole group effect.



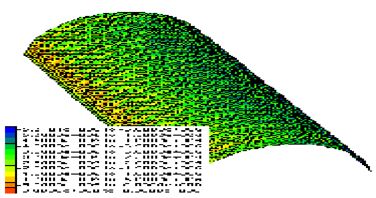
a) top arch deformation difference between left line and right line



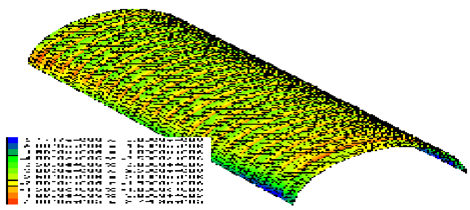
(b) sidewall convergence in the excavation of left and right cross

Fig.7 The curve of crown settlement and convergence of right and left side tunnels during construction for Heishan tunnel

Stability analysis of the supporting structure of surrounding rock surface in Heishan tunnel loess section. Most part of Heishan tunnel surface supporting structure is include steel arch and sprayed concrete layer. The steel arch here was regarded as sprayed concrete conservatively to carry out simulation analysis in this paper, because there is no technical steel arch imitate unit in Flac calculation software. The maximum pressure stress in surface support after excavation is shown in Fig.8. It can be known that stress level has increased compared with the maximum pressure stress after the excavation and support of left line alone as shown in Fig.8 (a).



(a) left line



(b) right line

Fig.8 The maximum pressure on primary lining

Conclusion

The deformation characteristics of surrounding rocks in the loess section of Heishan tunnel are analyzed with finite difference software named $Flac^{3D}$ with the consideration of interaction between left line and right line in the progradation of tunnel face. And the main conclusions are as following:

(1) The crown settlement tends to increase slowly with the left line progradation of tunnel face approaching to the predetermined cross section in left line. (2) The deformation of right line tunnel is always smaller than left line tunnel no matter the crown subsidence or sidewall convergence. (3) The calculated stability of supporting structure is well under the condition of lower strength of supporting structure in the numerical simulation.

References

[1] Hu Shimin, Analysis on pressure-arch effect of surrounding rock in loess tunnel, Journal of the China Railway Society. 36 (2014) 94-99.

[2] Wang Chengbing, Zhu Hehua, Tunnel collapse mechanism and numerical analysis of its influencing factors, Chinese Journal of Geotechnical Engineering. 30(2008) 450-456.

[3] Jiang Jiuchun, Monitoring measurement of loess tunnel and study on the function of rockbolt, Xi’an: Chang'an University, 2007.

[4] Hu Shimin, Analysis on spatial displacement of surrounding rock based on engineering properties of loess, China Civil Engineering Journal. 46(2013) 117-122.

[5] Jiang Kun, Xia Caichu, Analysis of monitoring and measurement of small clear spacing highway tunnel with eight lanes, Chinese Journal of Rock Mechanics and Engineering. 29(Supp.2) 3755-3761.

[6] Shao Shengjun, Yang Chunming, Jiao Yangyang, Lu Si, Engineering properties of collapsible loess tunnel, Chinese Journal of Geotechnical Engineering. 35(2013) 1580-1590.