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Analysis of Pouring Time of Invert Filling in Large Section Shallow Buried Tunnel

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Abstract

In order to solve the problem of invert and filling placement time of large-section shallow buried tunnel, this paper takes a highway tunnel in Georgia E60 F3 as the engineering background, and explores the effects of working conditions 1 and 2 on tunnel surrounding rock, invert roof and shotcrete. The results show that, compared with condition 1, condition 2 is more favorable to controlling the uplift deformation at the bottom of the tunnel, the tensile stress and stress concentration degree of invert and fill are reduced, and the negative bending moment of shotcrete is reduced. Therefore, it is more reasonable to use invert and fill separately for the large-section shallow buried tunnel.

Keywords

Large section shallow buried tunnel; Invert and fill; Bottom uplift deformation; Stress concentration.

1. INTRODUCTION

The invert of tunnel is one of the main components of the tunnel supporting structure. By closing the invert into a ring with the upper supporting structure, it can improve the bearing capacity of the surrounding rock and enhance the integrity of the tunnel surrounding rock[1-3]. Invert fill refers to the part above the initial support and under the pavement structure layer. The effect of one-time casting and separate casting on the surrounding rock at the bottom of the tunnel is different. In order to prevent stress concentration at the bottom of the tunnel, it is necessary to apply invert fill in time to improve the bearing capacity of the tunnel bottom and enhance the stability of the surrounding rock[4-5].

Xiong Xiaohui[6] studied the deformation of surrounding rock during integrated pouring of invert and fill, and concluded that invert fill is prone to cracking due to tensile stress. Du Mingqing[7] studied the dynamic response of invert fillings in tunnels and concluded that the strength of concrete increased but the dynamic stress of invert fillings decreased. Wang Zhiyong[8] compared the stress analysis of tunnels under different invert forms and concluded that setting inverts to be poured separately can improve the overall stress of tunnels. Wang Gengxin[9] simulated the influence of single invert placement and separate placement on the surrounding rock, and concluded that stress concentration was prone to occur at the bottom of the tunnel during single invert placement. By studying the application time of tunnel invert, Qiu Wenge[10] concluded that the invert had the best effect when applied before the initial support. Wu Min[11] studied the influence of invert concrete strength on the stability of surrounding rock and concluded that the water belt embedded by invert fill can reduce tunnel construction joints. Zhai Chunlin[12] analyzed the development trend of tunnel invert cracks and concluded

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that the reinforcement of invert filling can improve the strength of tunnel bottom. Ding Dongdong[13] simulated the displacement of surrounding rock before and after the tunnel invert encountered water, and concluded that the displacement of surrounding rock increased significantly and the range of plastic zone increased after water encounter.

Although the above studies have studied the invert and fill placement molding methods, the analysis object is mostly the deformation of tunnel surrounding rock, and the invert stress is not analyzed. There are few studies on determining the invert and fill placement methods of shallow buried tunnels excavated in full section. In this paper, based on a highway tunnel in E60 F3 section of Georgia, FLAC3D simulation is used to analyze the influence of single invert and separate invert placement on tunnel surrounding rock deformation, invert stress and shotcrete bending moment during full section excavation of a large section shallow buried tunnel, and to reveal the influence of single invert and separate placement of invert and fill on tunnel stability.

2. MODEL BUILDING AND ANALYSIS

2.1. Model building

The tunnel is located in central Georgia, on a mountainous terrain. The buried depth of the tunnel is 25m, and the geological unit through which the tunnel passes is comprehensively assessed as V level surrounding rock. FLAC3D was used to establish a three-dimensional calculation model, and the tunnel and model grid were shown in Figure 1. The dimensions of the x, y and z directions of the model are 120m, 60m and 76m, respectively. The upper boundary conditions of the model are free boundaries, and the other boundaries are subject to normal displacement constraints.

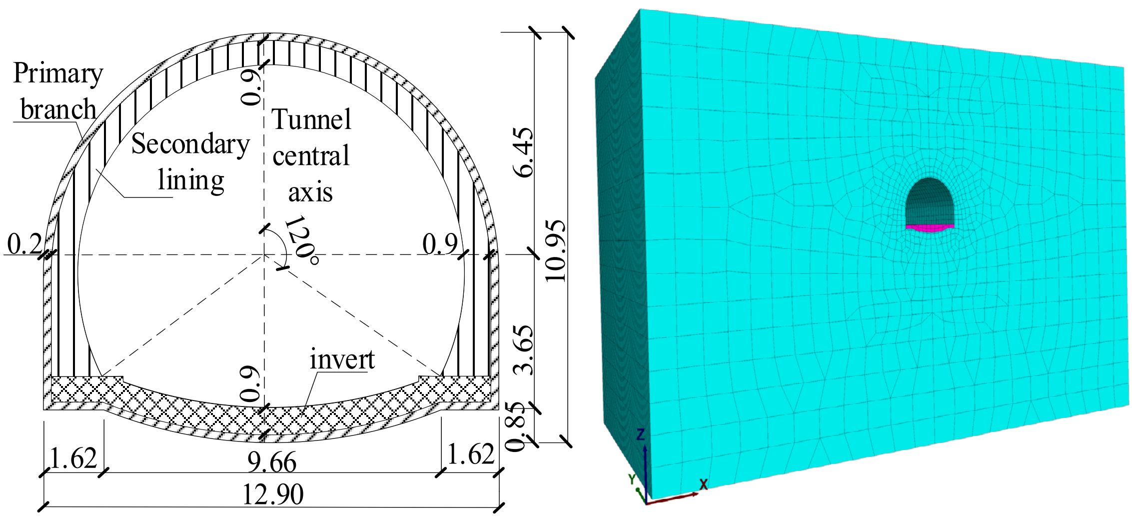

Figure 1. Tunnel and numerical model grid (unit: m)

2.2. Numerical simulation calculation parameters and working conditions

Mohr Coulomb model is adopted for tunnel surrounding rock. The tunnel was excavated in full section, and null model was used to simulate the excavation part. The invert adopts elastic model. The initial spray concrete thickness of 20cm was simulated by shell unit, and the ring distribution spacing of steel arch was 0.8m, and the simulation was carried out by beam unit. The length of the radial bolt is 3m, the longitudinal spacing is 0.8m, and the circumferential distribution spacing is 0.8m. The cable unit is used to simulate the bolt. The mechanical parameters of surrounding rock, shotcrete and invert are shown in Table 1. The mechanical parameters of anchor rod and steel arch are shown in Table 2 and Table 3 respectively.

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Table 1. Mechanical parameters of surrounding rock and primary support

name	Density (kg/m³)	Modulus of elasticity (GPa)	Cohesive force (MPa)	Poisson's ratio	Angle of internal friction (°)
V-class surrounding rock	2500	1	0.03	0.4	30
shotcrete	2500	30	--	0.2	--
invert	2500	28	--	0.25	--

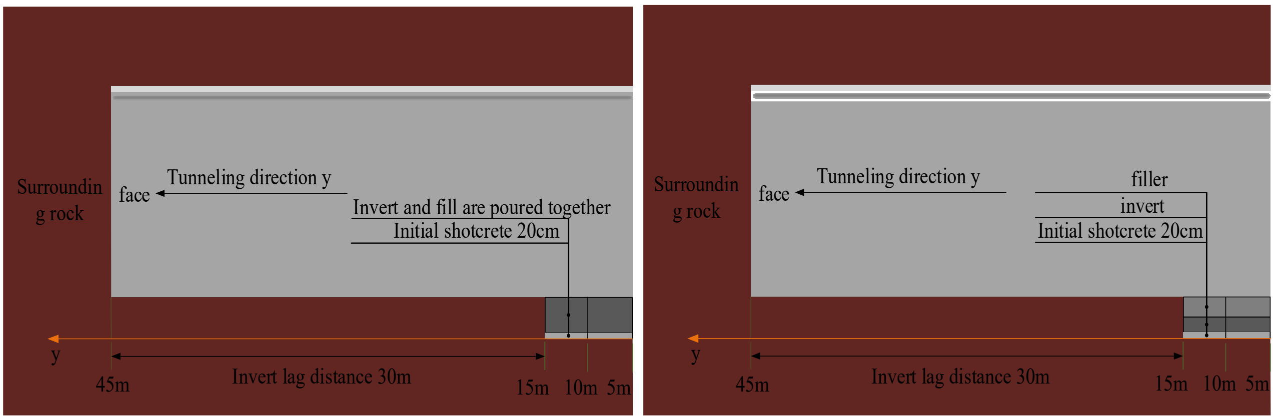
Table 2. Mechanical parameters of bolt element

name	traverse area (mm²)	elasticity modulusb (GPa)	Poisson's ratio	mud stiffness (MPa)	mud Viscous force (kPa)	tensile intensity (kN)	grouting perimeter (m)
Anchor bolt	1850	45	0.2	17.5	20	250	0.8

Table 3. Mechanical parameters of steel arch elements

name	traverse area (mm²)	elasticity modulus (GPa)	Poisson's ratio	Y-axis moment of inertia (m⁴)	Z-axis moment of inertia (m⁴)	hyperhabitus Sexual moment (m⁴)	density (kg/m³)
Steel arch	3530	210	0.3	4.72e-6	1.6e-6	4.24e-5	7850

In order to avoid model boundary effect, the tunnel was excavated for 0~5m and applied with initial support, invert and fill. The subsequent excavation for 5~45m section was the contrastive analysis section, where the invert lag distance was 30m and the excavation footage was 5m. The simulated working conditions were shown in Figure 2.



(a) working condition 1 (b) working condition 2

Figure 2. Numerical simulation conditions

2.3. Monitoring point arrangement

A total of 9 (1~9) characteristic sections are arranged on the comparative analysis section (5~45m), as shown in Figure 3. Invert and fill placement methods under two working conditions are shown in Figure 4.

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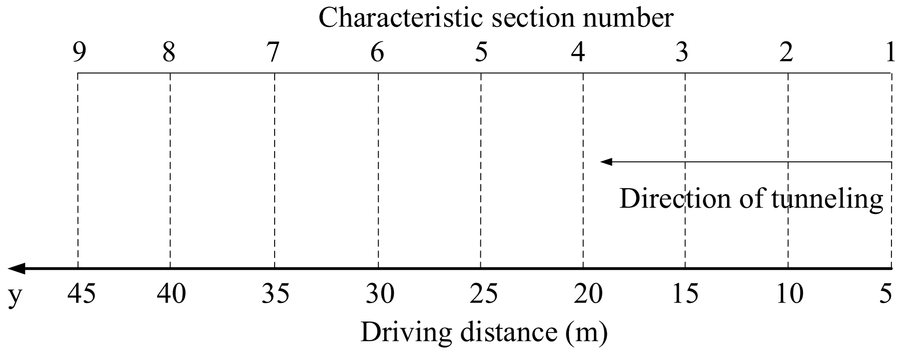
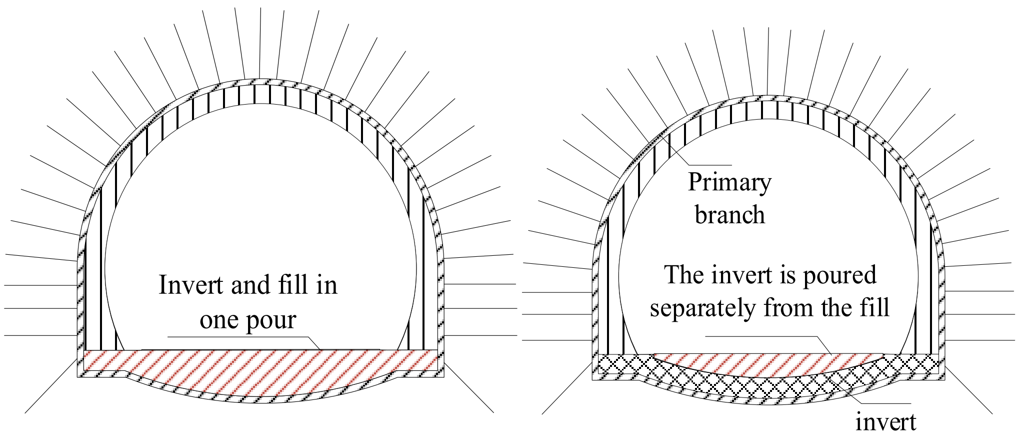


Figure 3. Feature section layout



(a) working condition 1 (b) working condition 2

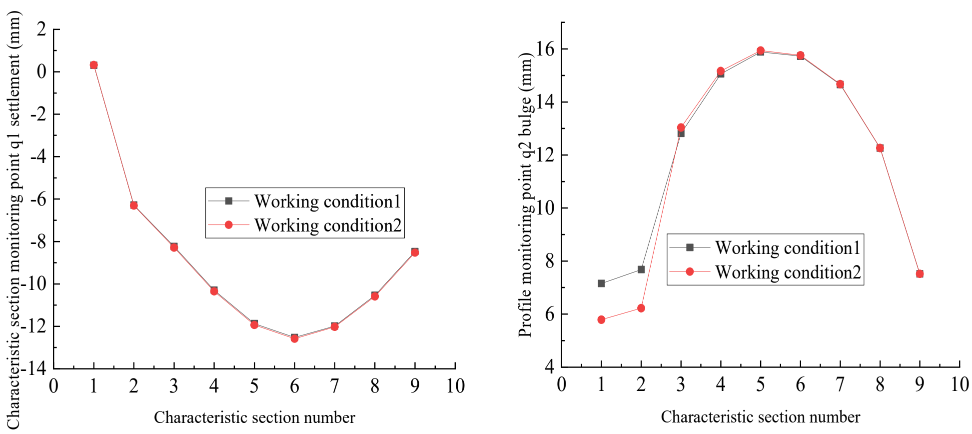
Figure 4. Invert and fill placement methods under different working conditions

3. STABILITY ANALYSIS OF TUNNEL SURROUNDING ROCK

When the tunnel is excavated to 45m and calculated to be stable, the deformation of surrounding rock, invert stress and shotcrete stress under two working conditions are obtained.

3.1. Deformation analysis of surrounding rock

The vertical displacement of vault top monitoring point q1 and tunnel bottom q2 at each characteristic section from 1 to 9 is shown in Figure 5.



(a) arch roof settlement of characteristic section 1 to 9 (b) arch bottom uplift of characteristic section 1 to 9

Figure 5. Deformation of tunnel surrounding rock under two working conditions

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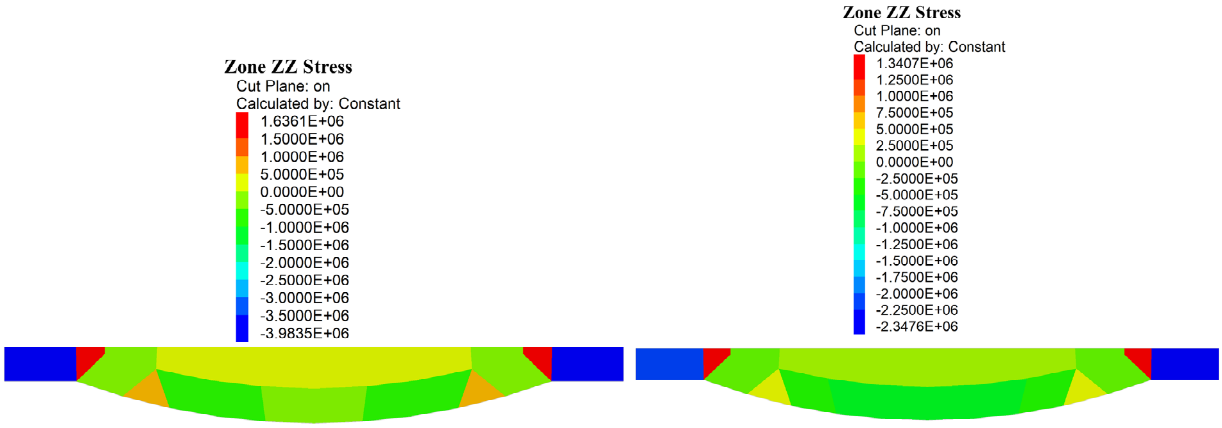
As can be seen from Figure 5, there is basically no difference in arch roof settlement between the two working conditions. The displacement of uplift in number 3 to 9 monitoring section is consistent with the change trend in the two working conditions. Invert and fill are applied between number 1 to 3 monitoring sections, which play a certain role in restricting the uplift displacement at the bottom of the tunnel. The uplift displacement at number 1 and number 2 sections is about 19.5% lower than that at number 1 and number 2 sections, indicating that the uplift displacement at the bottom of the tunnel can be well controlled under working condition 2.

3.2. Invert stress analysis

The invert stress value of feature section number 2 was taken as the stress analysis object. Figure 6-9 shows the stress analysis diagrams of invert horizontal stress, vertical stress, maximum principal stress and minimum principal stress under two working conditions respectively.

(a) working condition 1 (b) working condition

Figure 6. Horizontal stress of invert under different working conditions



(a) working condition 1 (b) working condition 2

Figure 6. Vertical stress of invert under different working conditions

As can be seen from Figure 6 and Figure 7, in the horizontal direction, the maximum horizontal compressive stress of the invert under working condition 2 increases by about 15.3% and the maximum horizontal tensile stress decreases by about 18.7% compared with that under working condition 1. In the vertical direction, the maximum vertical compressive stress and the maximum vertical tensile stress of invert under working condition 2 are reduced by about 18.3% and 41% respectively compared with that under working condition 1. It shows that the stress of invert and fill in condition 2 is more uniform, and it is more beneficial to exert the compressive property of concrete.

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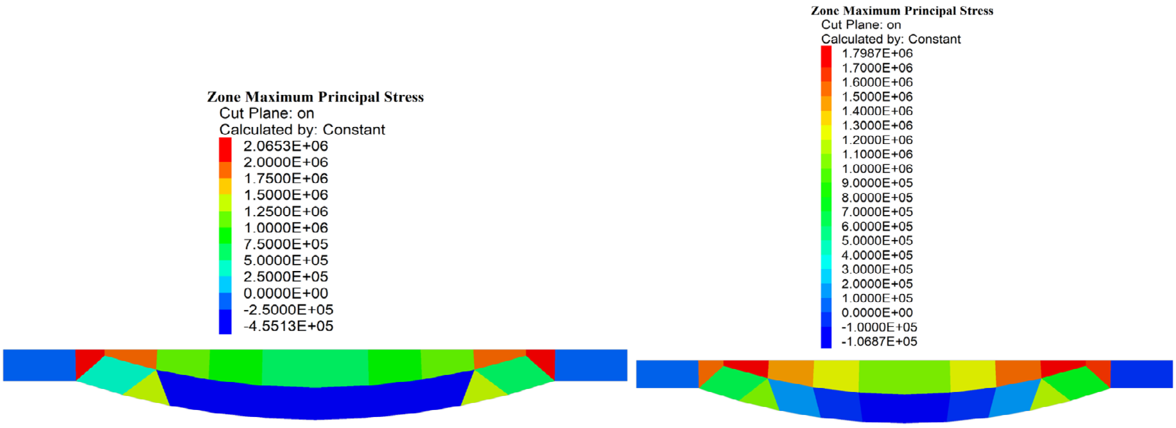


(a) working condition 1 (b) working condition 2

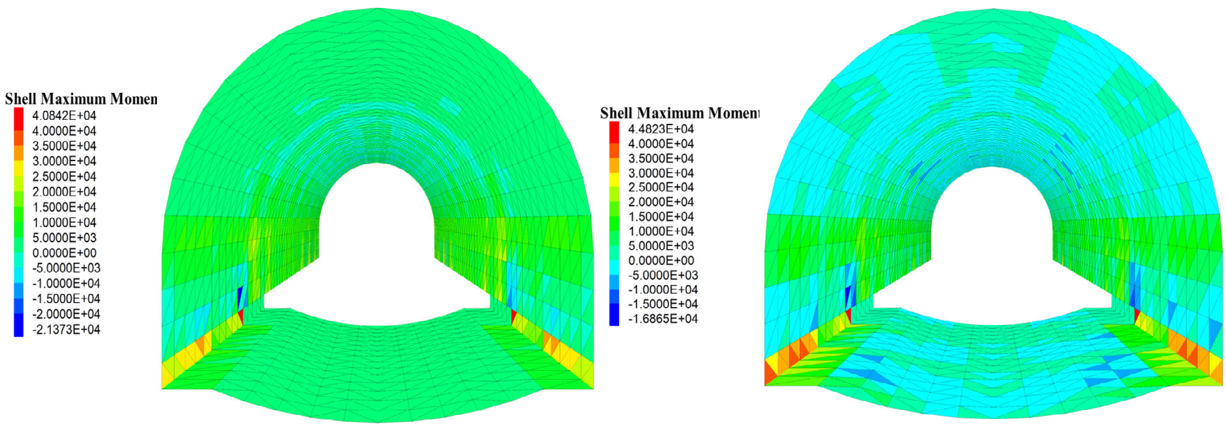
Figure 8. Maximum principal stress of invert under different working conditions

(a) working condition 1 (b) working condition 2

Figure 9. Minimum principal stress of invert under different working conditions

As can be seen from Figure 8 and Figure 9, in terms of maximum principal stress, the invert maximum principal stress of working condition 2 is about 12.6% less than that of working condition 1. In terms of minimum principal stress, the minimum principal stress of invert under condition 2 is about 37% lower than that under condition 1. According to the cloud image, the stress concentration of invert and fill in condition 2 is lower than that in condition 1.

3.3. Force analysis of shotcrete



(a) working condition 1 (b) working condition 2

Figure 10. Maximum bending moment of shotcrete under different working conditions

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It can be seen from Figure 10 that the maximum positive bending moment and negative bending moment of tunnel concrete under working condition 1 are 40.4kN·m and -21.4kN·m respectively. Compared with operating condition 1, the maximum positive bending moment increases by 9.8% and the maximum negative bending moment decreases by 21%. The results show that when the invert and the filler are poured at one time in working condition 1, the invert filler also bears the external surrounding rock stress, resulting in a large negative bending moment of the shotcrete.

4. CONCLUSION

By analyzing the influence of the two working conditions on the stability of the large section shallow buried tunnel, we can see that:

(1) the uplift displacement and change trend of the monitoring section number 3-9 under the two working conditions are basically the same; By comparing the uplift displacement at section 1 and section 2 of the two working conditions, it is concluded that the uplift displacement of the tunnel bottom can be better controlled under working condition 2.

(2) Comparing the stress of invert and fill in the two working conditions, the stress distribution in working condition 2 is more uniform, the stress concentration is low, and the tensile stress is correspondingly reduced, which is more conducive to the bearing capacity of invert and fill concrete.

(3) Compared with the two working conditions, the maximum negative bending moment of shotcrete in working condition 1 is larger, which has an adverse effect on the supporting structure. In conclusion, it is suggested that separate pouring of invert and fill can effectively utilize the bearing capacity of the tunnel invert, prevent the tensile fracture of the tunnel bottom, and better control the uplift deformation of the tunnel bottom.

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