Analysis of Influence of Invert Application on Stability of Large Section Shallow Buried Tunnel

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Abstract

The invert of a tunnel is a reverse arch structure set to improve the stress of the tunnel superstructure, and the invert at the bottom of the tunnel is enclosed with the upper lining to improve the stability of the surrounding rock of the tunnel. Taking the E60 (F3) Section 2 freeway tunnel in Georgia as the engineering background, this paper numerically simulates the invert construction of a large-section shallow buried tunnel. The influence of invert length and invert length on the stability of surrounding rock is investigated. The results show that under V-class surrounding rock, invert application can significantly reduce the deformation of surrounding rock and invert stress. Through simulation, the best conclusion is reached when the invert length is 3m at one time.

Keywords

Inverted arch; Closed into a ring; Length of one application; Surrounding rock stability.

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]. The length of an invert applied at one time is related to the stability of the surrounding rock of the tunnel. Due to the "void zone" at the bottom of the initial support caused by tunnel excavation, the invert should be applied in time to seal the ring with the upper support structure to enhance the stability of the surrounding rock[4-5].

Pan Jing hu[6] analyzed the stress characteristics of the tunnel invert, obtained the failure forms of the invert and proposed prevention measures. Zhang Tian tao[7] summarized the key points affecting the floor heave of the tunnel invert and proposed preventive measures for the key points through model experiments. Shi Jiyao[8] revealed the rule of influence of invert step distance and step length on initial support deformation. Li Jianhua[9] simulated the influence of a single excavation of an invert on the surrounding rock, and concluded that the invert has the greatest influence on the stability of the surrounding rock and the stress distribution pattern is "W". Ma Dong[10] controlled the distance between the initial support invert and the palm plane during rapid construction. 20m, can obviously play a role in inhibiting convergence. Wang Chuanwu[11]discussed the influence of invert parameters on the ultimate bearing capacity of inverts and their sensitivity. Baiyin[12] simulated the height and length of the upper and lower steps of the tunnel and concluded that it is most reasonable to control the height of the upper steps at 4~6m. Yang Jiasong[13] developed a "W-shaped" blasting network and a retractable lightweight belt slip device operating platform, forming a new micro-step belt invert blasting excavation technology.

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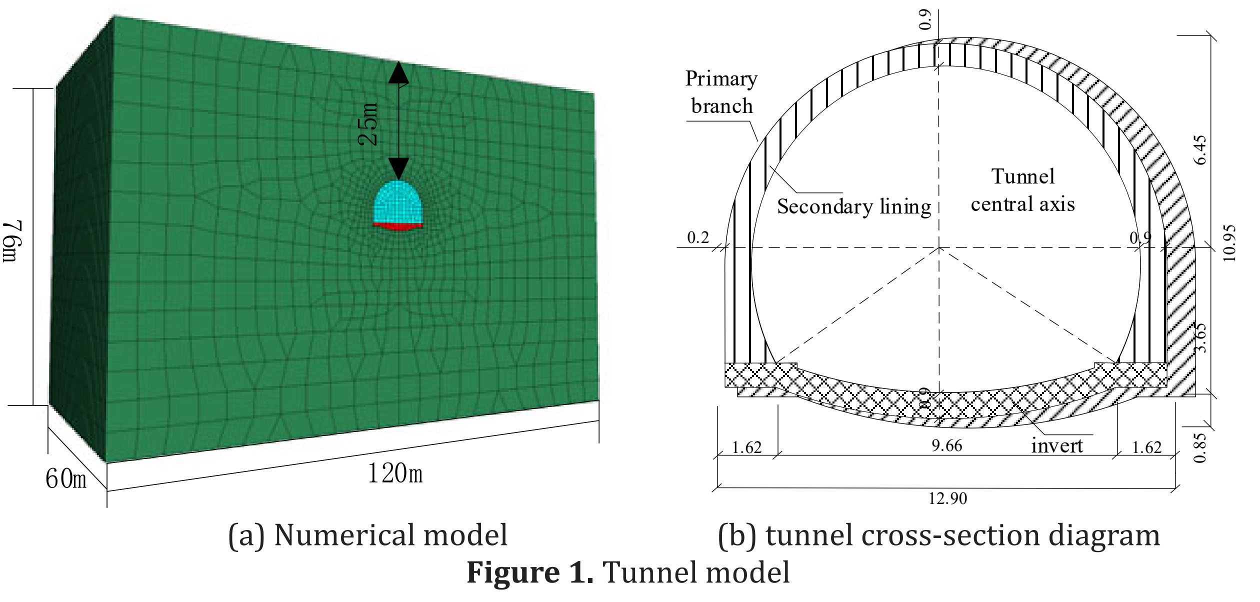
Although the above studies have studied the influence of invert on the deformation of surrounding rock, the geological conditions of surrounding rock are good, and the length of invert applied at one time has not been analyzed, and there are few studies on determining the length of invert applied at one time in shallow and weak surrounding rock tunnels excavated in full section. Based on a highway tunnel in the second section of E60 (F3) in Georgia, this paper uses FLAC3D to conduct numerical simulation. Under V-class surrounding rock, the results of arch settlement, arch bottom uplift, invert stress and radial anchor axial force on surrounding rock of a large section shallow buried tunnel with no invert and different invert length applied at one time during full section excavation are analyzed. The influence of invert length and invert length on tunnel stability is obtained.

2. MODEL ESTABLISHMENT AND ANALYSIS

2.1. Model Establishment

A highway 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.



(a) Numerical model (b) tunnel cross-section diagram

Figure 1. Tunnel model

2.2. Numerical simulation calculation parameters and simulation diagram

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 physical and mechanical parameters of surrounding rock are selected according to the results of on-site geological report and the parameters of supporting structure are shown in Table 1.

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Table 1. Parameters of surrounding rock and supporting materials

name	D (Kg/m3)	E (Gpa)	c (Mpa)	v	φ (°)
V-type surrounding rock	2500	1	0.03	0.4	30
shotcrete	2500	30	--	0.2	--
invert	2500	28	--	0.25	--
Anchor bolt	--	45	--	0.2	--
Steel arch	7850	210	--	0.3	--

In order to avoid the model boundary effect as much as possible, the tunnel was excavated for 0~5m to strengthen the support and apply invert. The subsequent excavation for 5~45m was the comparative analysis section. The simulation of the invert application was shown in Figure 2.

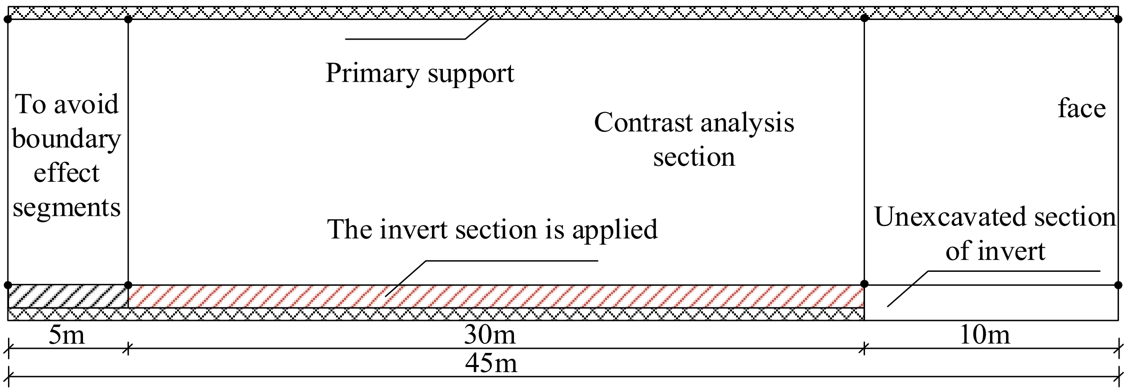

Figure 2. Schematic diagram of tunnel invert simulation (m)

2.3. Layout of monitoring points

A total of 9 characteristic sections are arranged on the comparative analysis section, as shown in Figure 3. The 9 characteristic sections correspond to sections at y=5m, y=10m, y=15m, y=20m, y=25m, y=30m, y=35m, y=40m and y=45m in turn. The displacement and stress monitoring points of each section are shown in Figure 4.

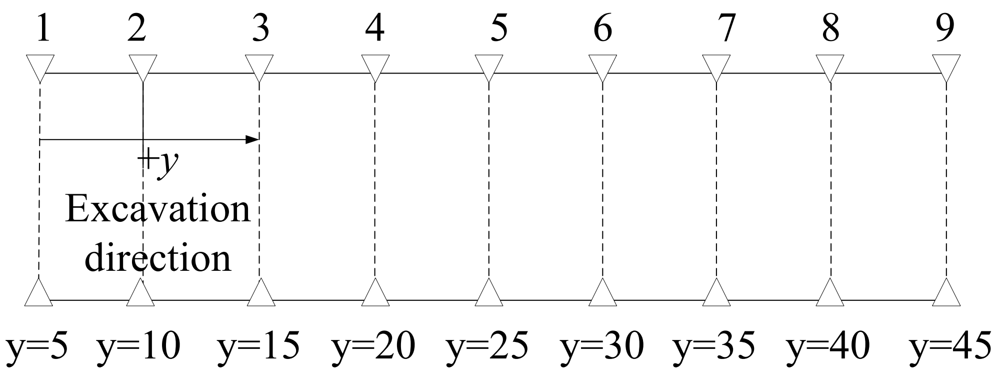

Figure 3. Feature section layout

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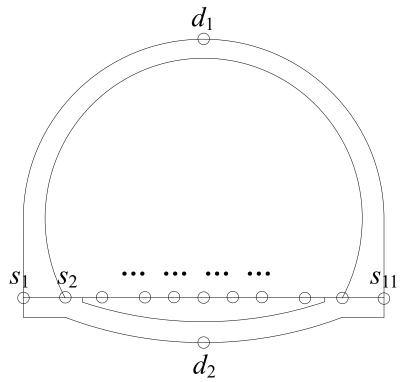


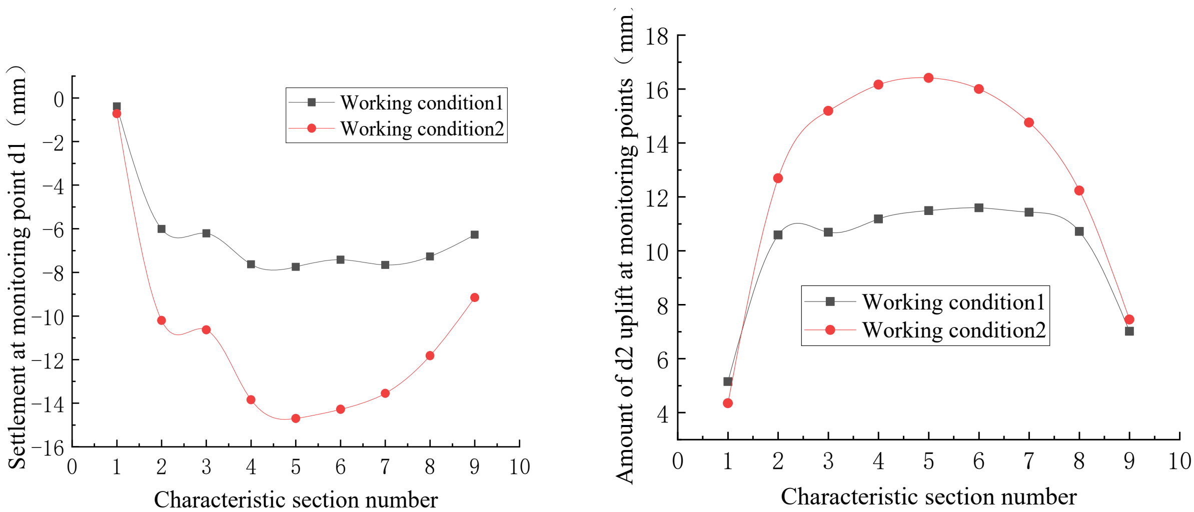
Figure 4. Layout of monitoring points for each characteristic section

3. ANALYSIS OF TUNNEL WITH OR WITHOUT INVERT

As shown in Figure 2, working conditions 1 (with invert) and 2 (without invert) were set in the comparative analysis section for comparison. When the tunnel was excavated to 45m and calculated to be stable, the calculation results of deformation field of surrounding rock, stress field of invert and axial force field of radial anchor were obtained under the two working conditions.

3.1. Deformation field analysis of surrounding rock

The vertical displacements of vault monitoring points d1 and tunnel bottom d2 at each characteristic section from 1 to 9 are shown in Figure 5.



(a) Dome settlement (b) Arch heave

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

It can be seen from Figure. 5 that the deformation of surrounding rock in the two working conditions increases first and then decreases, and the deformation of surrounding rock reaches the maximum value at characteristic section No. 5. In working condition 2, the maximum settlement of the arch roof is -14.4mm and the maximum uplift of the arch bottom is 16.3mm. It shows that the invert construction can improve the stability of surrounding rock.

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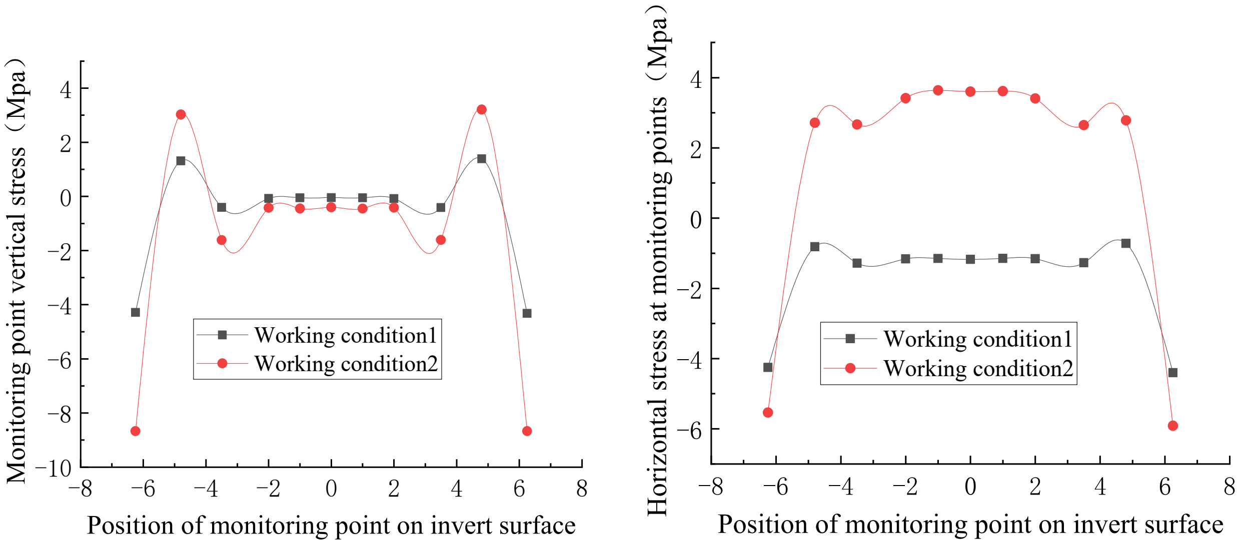
3.2. Stress field analysis of invert

The monitoring points s_1~s_{11} on the invert top surface of characteristic section No. 1 were taken as stress analysis objects, and the vertical and horizontal stresses of the invert under various working conditions were shown in Figure 6.



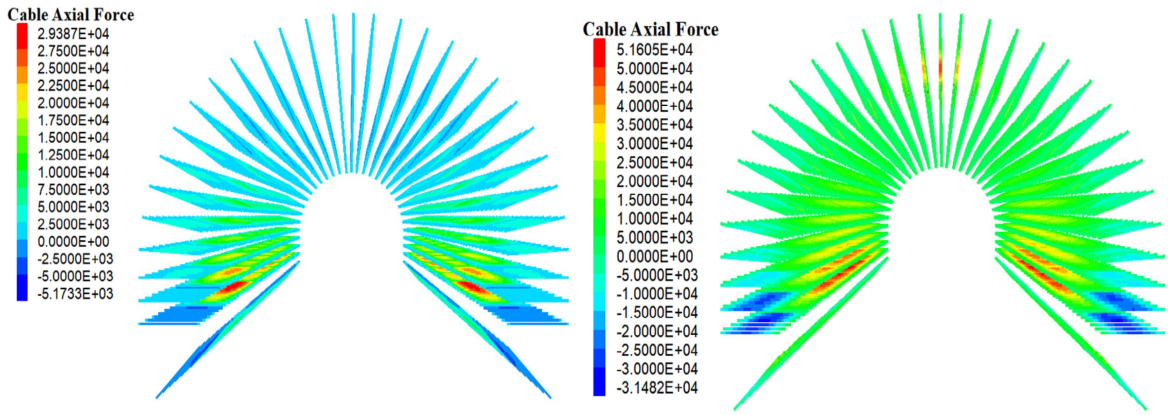
(a) Invert vertical stress (b) Invert horizontal stress

Figure 6. Invert stress of tunnel under different working conditions

As can be seen from Figure 6, the vertical stress and horizontal stress at the monitoring points on the invert surface of feature section No. 1 reach their maximum values at the tunnel side wall (monitoring points s_1 and s_{11}), and the maximum vertical stress of the invert in working condition 2 reaches -8.8MPa and the maximum horizontal stress reaches -5.8MPa. Compared with working condition 1, the maximum vertical stress of the invert increases by about 100%. The maximum horizontal stress of the invert increased by 38%, indicating that the invert construction can significantly reduce the stress on the tunnel invert and play a positive role in the safety of the tunnel invert.

3.3. Analysis of axial force field of radial bolt

3.4.



(a) Working condition 1 (b) Working condition 2

Figure 7. Axial diagram of radial bolt under different working conditions

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As can be seen from Figure 7, the maximum positive axial force of the bolt in working condition 2 is 51.6KN and the maximum negative axial force of the bolt is -31.5KN. Compared with working condition 1, the maximum positive axial force of the bolt increases by 75% and about 500%, indicating that the radial bolt is subject to greater axial force because the invert structure is not closed into a ring when the invert is not applied.

4. THE LENGTH OF THE TUNNEL INVERT IS ANALYZED AT ONE TIME

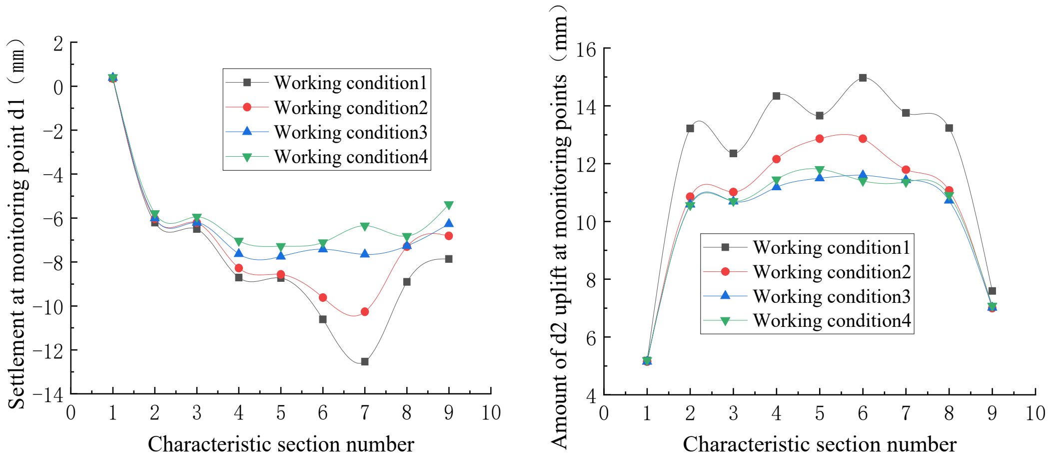
As shown in Figure 2, four calculation conditions with different invert length at one time were set in the comparative analysis section, as shown in Table 2. When the tunnel was excavated to 45m and calculated to be stable, the calculation results of deformation field of surrounding rock, stress field of invert and axial force field of radial anchor were obtained under four working conditions.

Table 2. Numerical simulation conditions

Simulated condition	condition 1	condition 2	condition 3	condition 4
Length of invert applied once /m	2	3	5	6

4.1. Deformation field analysis of surrounding rock

The vertical displacements of monitoring points d_1 and d_2 on each characteristic section of the tunnel are shown in Figure 8.



(a) The crown of the vault settles (b) Arch heave

Figure 8. Deformation of tunnel surrounding rock under different working conditions

As can be seen from Figure 8, from working condition 2 to working condition 1, the arch settlement and arch bottom uplift have great changes. In working condition 2, the maximum arch settlement is -10.1mm, and the maximum arch bottom uplift is 12.6mm. Compared with working condition 1, the maximum arch settlement and arch bottom uplift are reduced by 23% and 16% respectively, indicating that with the increase of the invert length once applied, Both the arch roof settlement and arch bottom uplift tend to decrease, and the displacement rate of surrounding rock is the largest when the invert length is 2~3m. Therefore, it is the most reasonable to control the invert length to 3m.

4.2. Stress field analysis of invert

The monitoring points s_1~s_{11} on the invert top surface of characteristic section No. 2 were taken as stress analysis objects, and the vertical and horizontal stresses of the invert under various working conditions were shown in Figure 9.

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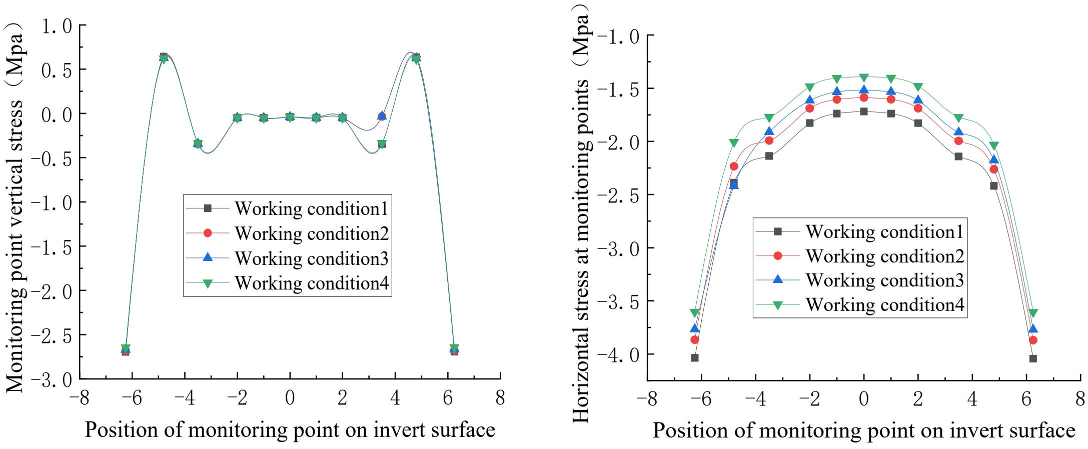
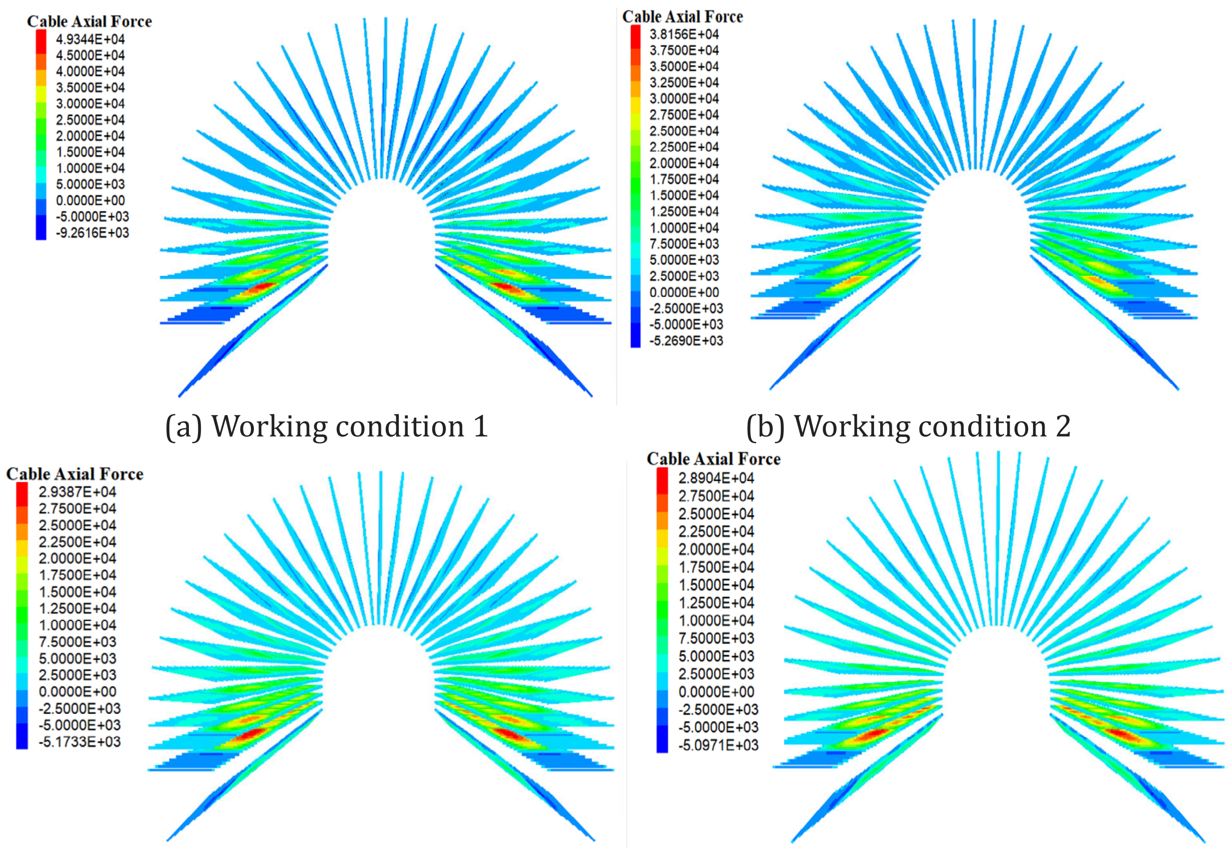


(a) Invert vertical stress (b) Invert horizontal stress

Figure 9. Invert stress of tunnel under different working conditions

As can be seen from Figure 9, the vertical stress and horizontal stress at the monitoring points on the invert surface of feature section No. 2 reach their maximum values at the tunnel side wall (monitoring points s_1 and s_{11}), and the invert vertical stress in each working condition has no significant change. The maximum horizontal stress of the invert in working condition 2 reaches -3.8MPa, which increases by 7% compared with that in working condition 1. It shows that the maximum horizontal stress of invert increases with the increase of the length of one application.

4.3. Analysis of axial force field of radial bolt



(a) Working condition 1 (b) Working condition 2

(c) Working condition 3 (d) Working condition 4

Figure 10. Axial diagram of radial bolt under different working conditions

It can be seen from Figure 10 that when the length of invert applied once increases, the axial force of radial bolt shows a decreasing trend. In working condition 2, the maximum positive axial force of anchor bolt is 38.1KN and the maximum negative axial force of anchor bolt is -5.26KN. Compared with working condition 1, the maximum positive axial force of anchor bolt is reduced by 22% and the maximum negative axial force of anchor bolt is reduced by 43%. The change of axial force on the anchor rod is obvious, and the support structure has greater force.

5. CONCLUSION

Based on the analysis of the influence of invert and invert length on the stability of large-section shallow buried tunnels, it can be seen that:

(1) Based on the deformation results of surrounding rock, invert application can significantly reduce the arch settlement and arch bottom uplift deformation, and the deformation of surrounding rock is the most obvious when the invert length is 2~3m.

(2) According to the results of surrounding rock stress, the stress state of surrounding rock can be greatly improved by invert construction, and the maximum horizontal stress of invert roof decreases gradually with the increase of invert length.

(3) Through the analysis of radial bolt axial force, the radial bolt axial force is greatly reduced when the inverted arch is closed with the initial support, and the radial bolt axial force decreases more when the invert length is 2~3m at one time.

It can be seen from above that under V-class surrounding rock, invert construction can obviously reduce the deformation of surrounding rock and invert force. At the same time, the optimal scheme is proposed when the length of invert is 3m.

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