Study on Bias Characteristics of Multi Arch Tunnel Under Different Side Overburden Thickness

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Abstract. The entrance and exit of the Qifengshan tunnel are shallow and the pressure has a certain offset, the overlying soil layer is thin, and the stability is poor. After the excavation disturbance, the upper soil layer tends to slide. The excavation of black holes often causes large deformation, collapse and instability of surrounding rock. In this paper, combined with the geological conditions of the multi arch tunnel and the mechanical characteristics of surrounding rock, the theoretical analysis and numerical simulation are used to study the deformation law of the buried depth, side cover soil thickness and the stress and displacement of the surrounding rock after excavation. The results show that the bias stress of the tunnel under the vertical direction increases with the depth of the buried tunnel. The bias stress of the tunnel in the vertical direction decreases with the increase of the buried depth. The shallower the buried depth is, the more obvious the bias effect is. When the depth of burial exceeds 20m, the increased amount of bias stress is gradually reduced after the bias is applied. The vertical deformation characteristics of the rock mass caused by tunnel excavation with different thickness of the side covering layer are analyzed. The vertical displacement is gradually reduced with the increase of the thickness of the side covering layer. When the thickness of the overlying soil is more than 21m, the vertical displacement is less affected by the thickness of the side cladding soil, basically only by the surrounding rock itself.

Keywords: multi arch tunnel; shallow buried bias; side overburden thickness; bias characteristic.

1. Introduction
At present, there are three main forms of tunnel construction: separate, small clearance and multi-arch tunnel [1]. Separate tunnels are a preferred form of highway and primary road construction under the principle that the topographical geological conditions permit and the minimum spacing between the left and right sides of the construction tunnel are not affected. In the actual road construction process, the construction of tunnels often encounters “chicken claws” such as steep terrain and spine. At this time, the arch tunnel will be widely used because of its small hole axis spacing, space saving, and easy connection between the inside and outside of the tunnel. According to the theoretical research and practical engineering of many scholars, the rock and soil are in a state of stress balance before tunnel excavation. Therefore, the use of the “natural hole method” [3] is advocated, that is, before the tunnel enters the hole, some surrounding rock reinforcement measures such as the large pipe shed, the retaining wall, and the grouting inside and outside the hole are taken, without destroying the original mountain. Under, to achieve a smooth hole. If the safety measures are not properly implemented, it is very likely that the collapse of the hole, the slope of the slope and other slopes will delay the construction period and cause unnecessary economic losses [4-7]. Zhang Zhiguo et al. [8] conducted a numerical simulation study on shallow-buried bias tunnels through FLAC3D software. When
excavating the tunnels with the core soil method using the circular guide pits, the first excavation shallow buried side and the first excavation deep buried side were analyzed. Two different construction procedures have obtained the optimal scheme; Tian Longgang et al. [9] combined with a highway biased arch tunnel to carry out model experiments, which shows that certain material ratio can better simulate the mechanical properties of surrounding rock; Zhang Chengliang et al. [10] used the Zhong hecun arch tunnel as the research object to analyze the deformation and stress characteristics of the surrounding rock and supporting structure. Liu Wenbin [11] combined with the inlet bias section of a double-arch tunnel The pipe shed pre-support is analyzed; Li Weijun et al. takes the head tunnel as the research object, analyzes and calculates the inlet bias section, and obtains the reinforcement scheme that can ensure the safe tunneling during tunnel construction; Guan Zhenchang et al adopts FLAC3D software, numerical simulation study on seismic response of the Yellow Lawn Tunnel; Jiang Xueliang et al. adopted the dynamic model similarity theory, designed the biased tunnel model as the research object, conducted a large shaking table test, and studied the bias tunnel in different Seismic dynamic response characteristics under vibration conditions; Wang Yaqiong by finite element analysis and site monitoring, problems of asymmetric bias force arch tunnel appeared were studied. The study on the deformation characteristics of the vertical surrounding rock during the excavation process of the buried depth and the thickness of the laterally covered soil layer is of great significance for ensuring the stability of the tunnel and reasonable disposal measures. Shallow buried arch tunnels have been less studied in this respect. In this paper, theoretical analysis and numerical simulation are used to study the deformation characteristics of the QiFengshan Bifurcated Arch Tunnel.

2. Project Overview

The starting and ending mileage of the Fengshan Tunnel is K4+915~K5+290, the length of the boundary is 375m, the maximum depth of the tunnel is about 48m, and the longitudinal section of the tunnel is -0.617%. The entrance and exit of the Qifengshan tunnel are located in the shallow-buried bias section. The overburden layer is severely weathered, the rock mass is broken, and the surrounding rock integrity is poor. The design of the surrounding rock in the tunnel site is mainly V-class. The tunnel is a two-lane road with an excavation span of 15.23m and a height of 7.65m. The tunnel adopts framing excavation, cancels the middle partition wall, and the left frame is excavated, supported, and lining completed, and then the tunnel is excavated. The geological profile of the tunnel is shown in Figure 1.

![Tunnel geological profile](image_url)

**Figure 1.** Tunnel geological profile.

For the boundary between shallow and deep buried tunnels, it can be combined with topographical geological conditions, construction methods, and load equivalent height values. The buried depth of the Qifengshan Tunnel was analyzed and the boundary depth was calculated to be 36m. Through the analysis of the longitudinal section design of the Qifengshan Tunnel, the on-site investigation, and the
critical value of the buried depth of the tunnel, it is worth to show the length of the shallow and deep buried tunnel. Table 1 shows the buried depth and cross slope of the shallow buried section. The relationship between the slopes is shown in Table 2.

Table 1. Division of section of shallow and deep buried section.

| Tunnel name     | Buried depth | position               | Length (m) |
|-----------------|--------------|------------------------|------------|
| Qifengshan Tunnel | Shallow buried section | Import section K4+915–K5+020 | 105        |
|                 |              | Exit section K5+165–K5+290 | 125        |
|                 | Deep buried section | Cave section K5+020–K5+165 | 145        |

Table 2. The relationship between the depth of the shallow buried section and the slope of the horizontal slope.

| Shallow buried section | Station number | Cross slope (°) | Buried depth (m) |
|------------------------|---------------|----------------|-----------------|
| Import section K4+915–K5+020 | K4+940 | 18 | 8 |
|                        | K4+960 | 23 | 18 |
|                        | K4+980 | 30 | 23 |
|                        | K5+000 | 26 | 25 |
|                        | K5+020 | 35 | 29 |
|                        | K5+045 | 38 | 35 |
|                        | K5+275 | 20 | 10 |
|                        | K5+255 | 24 | 12 |
|                        | K5+235 | 26 | 20 |
|                        | K5+215 | 31 | 22 |
|                        | K5+195 | 29 | 29 |
|                        | K5+175 | 35 | 32 |
|                        | K5+160 | 37 | 35 |

3. Analysis of Mechanical Properties of 3 Biased Tunnels

3.1. Definition of Critical Depth of Double-Arch Tunnel Bias

The definition of the critical depth of the biased tunnel is due to the severe weathering of the overburden on the tunnel, which is in the fracture zone and mostly V-class surrounding rock. Therefore, the natural arch of the tunnel is calculated by the Platts theory. The shape, height and span of the natural arch are related to the firmness factor of the rock. The parabolic equation of the natural arch is:

\[ y = -\frac{x^2}{bf} \]  

(1)

Where: \(b\)–half the span of the natural arch, \(b=B/2\); \(f\)–The firmness coefficient of the surrounding rock (Pry’s coefficient) is obtained from the look-up table, or \(f=\tan\Phi_0\), and \(\Phi_0\) is the calculated friction angle.

In the hard rock mass, because the tunnel rock itself has good self-stability, the span of the natural arch is consistent with the span of the tunnel. In the weakly weathered and fractured rock mass, the
stability of the tunnel rock mass is poor, and the tunnel arch wall is affected by the excavation disturbance, resulting in slippage, which leads to an increase in the span of the natural arch, as shown in Figure 2.

![Figure 2](image)

(a) Sturdy surrounding rock  
(b) Weak surrounding rock

Figure 2. A schematic diagram of a slump arch.

The span of the natural arch of the tunnel at this time $B$ for:

$$B = B_f + 2H \tan \beta = B_f + 2H_f \tan \left(45^\circ - \frac{\phi_0}{2}\right)$$  \hspace{1cm} (2)

Where: $B$—the span of the natural arch (m); $H_f$—the net height (m) of the tunnel; $B_f$—the net width (m) of the tunnel; $\beta$—the rupture angle (°).

According to the above theory, the critical depth is calculated in three steps:

In the first step, the half-span of the natural arch is calculated on the condition of the internal friction angle of the surrounding rock and the tunnel width, $b$ And surrounding rock solidity coefficient $f$.

In the second step, the result of the previous step is taken into the calculation of Equation (1), and the curve of the natural arch is drawn according to the curve equation;

In the third step, according to the different surface slopes and the natural arch, the distance between the intersection of the tangent line and the central axis of the tunnel to the tunnel vault is the critical depth.

The Qifengshan Tunnel is a two-lane road with an excavation span of 15.23m and a height of 7.65m. The parameters of different surrounding rock grades are shown in Table 3. The critical buried depth calculated according to the theoretical slope of the slope is shown in Table 4.

### Table 3. Calculation of the value of friction angle.

| Surrounding rock level | III | IV<sub>rock</sub> | IV<sub>soil</sub> | V |
|------------------------|-----|------------------|------------------|---|
| Calculate the friction angle $^\circ$ | 65  | 60   | 50   | 45 |


Table 4. The relationship between the critical depth of bias and the slope of the cross slope.

| Surounding rock level slope | Critical depth of class III surrounding rock | Critical depth of IV stone level grade surrounding rock | IV earth grade critical depth of surrounding rock | Critical depth of V-class surrounding rock |
|-----------------------------|---------------------------------------------|-------------------------------------------------------|---------------------------------------------|------------------------------------------|
| 1:0.75 (inclination angle 53°) | 12.2                                        | 13.9                                                  | 15.4                                       | 16.7                                     |
| 1:1.00 (inclination angle 45°) | 9.6                                         | 11.6                                                  | 13.5                                       | 15.8                                     |
| 1:1.25 (inclination angle 38.7°) | 7.9                                         | 9.9                                                   | 11.6                                       | 13.3                                     |
| 1:1.5 (inclination angle 33.7°) | 6.8                                         | 8.5                                                   | 10.3                                       | 12.4                                     |
| 1:2.00 (inclination angle 26.6°) | 5.4                                         | 6.9                                                   | 9.4                                        | 10.7                                     |
| 1:2.50 (inclination angle 21.8°) | 4.9                                         | 6.0                                                   | 8.5                                        | 9.7                                      |

3.2. Influence of Buried Depth in Boundary Tunnel on Surrounding Rock Pressure

The formula for calculating the surrounding rock pressure of a biased tunnel is:

\[
Q = \frac{\gamma}{2} \left[ (h + h')B - (\lambda h^2 + \lambda' h'^2) \tan \theta \right]
\]

among them: \( h, h' \) - the height of the inner and outer sides from the level of the vault to the ground (m);
\( B \) —the tunnel width (m);
\( \theta \) - the friction angle on both sides of the roof soil column (°);
\( \gamma \) - surrounding rock gravity (KN/m³);
\( \lambda, \lambda' \) - The lateral pressure coefficient of the inner and outer sides.

(2) Calculation of horizontal side pressure under load

Inside pressure: \( e_i = \gamma \cdot h \lambda \) \hspace{1cm} (4)

Lateral pressure: \( e_i = \gamma \cdot h' \lambda' \) \hspace{1cm} (5)

(3) Calculation of vertical pressure under load

\[
q_0 = \frac{Q}{B}
\]

Vertical pressure on the left side: \( q_1 = q_0 - \frac{B \gamma}{2} \tan \alpha \) \hspace{1cm} (7)

Vertical pressure on the right side: \( q_2 = q_0 + \frac{B \gamma}{2} \tan \alpha \) \hspace{1cm} (8)
It can be concluded from the analysis in Figure 3 that both the horizontal pressure and the vertical pressure increase with the increase of the buried depth. And with the increase of the buried depth, the horizontal pressure is faster than the vertical pressure increment. When the buried depth is greater than 20m, the vertical pressure increase is rapidly reduced. This shows that the biasing effect of the tunnel in the vertical direction is gradually reduced after the buried depth exceeds 20 m.

4. Numerical Simulation Analysis of Biasing Characteristics of Multi-Arch Tunnel under Different Soil Thickness

The QiFengshan tunnel belongs to a tunnel with a shallow depth. The analysis of the tunnel is close to the surface, and the structural stress has been fully released. The Mohr-Coulomb constitutive model was used and numerical simulation was performed using FLAC3D. Only self-weight stress is considered in the calculation, and the structural stress is not considered. In order to simplify the calculation and consider the influence of the boundary effect on the model calculation, the left boundary of the single tunnel model is not less than 76.15m from the centerline of the tunnel, and the right boundary is taken to the natural slope. The lower boundary of the model is far from the bottom of the tunnel. At 45.69m. The tunnel 3D model and excavation model are shown in Figure 4.

According to the bias angle of the field investigation, the deformation characteristics of the tunnel excavation of different lateral soil thickness are studied. The grade of the surrounding rock is selected as V grade. For the slope of the cross slope, the slope is selected as 25°, 35°, 45°, and the maximum depth is selected. Take 36m, the thickness of the side cover soil layer is 1m, 2m, 3m, 4m, 5m, 6m, 7m, 8m, 9m, 11m, 13m, 15m, 17m, 19m, 21m and other working conditions, the physical mechanics of the calculated materials. The parameter values are shown in Table 5.
Table 5. Material and material are physical and mechanical parameters.

| Material          | Elastic Modulus $E$ (MPa) | Poisson’s ratio $\mu$ | Volumetric weight $\gamma$ (KN/m$^3$) | Internal friction angle $\phi$ (°) | Cohesion $C$ (Mpa) |
|-------------------|---------------------------|-----------------------|---------------------------------------|-----------------------------------|--------------------|
| IV                | 300                       | 0.33                  | 22                                    | 40                                | 0.70               |
| V                 | 200                       | 0.35                  | 20                                    | 27                                | 0.30               |
| Initial support   | 25000                     | 0.30                  | 25                                    | —                                 | —                  |
| Secondary lining  | 30000                     | 0.20                  | 27                                    | —                                 | —                  |
| Anchor            | 250000                    | 0.25                  | 78.5                                  | —                                 | —                  |

4.1. Stress Analysis of Shallow Buried Section

According to the stress cloud map and the maximum shear increment cloud map analysis of the surrounding rock after tunnel excavation under different working conditions, it can be concluded that:

1) After tunnel excavation is completed, stress concentration occurs in both the left and right widths of the biased arch tunnel. It mainly occurs on the sides of the arch and the bottom of the arch and the position of the middle partition wall. It should be specially noticed during the construction process. Secondly, due to the special structure of the middle wall and the influence of the tunnel excavation, the middle partition wall of the tunnel is affected. The shear damage is serious, and the biased arch tunnel should be prevented from being damaged by shearing during the construction of the partition wall.

2) Under the same slope gradient, the maximum shear stress increases with the increase of the thickness of the side cover soil. As the thickness of the side cover soil increases, the stress concentration at the arch of the tunnel is improved.

4.2. Displacement Analysis of Key Points in Shallow Buried Section

The arch settlement and the horizontal displacement of the left shoulder are taken as the key points for analysis. The variation of the thickness of the overburden after tunnel excavation under different working conditions is plotted. The horizontal displacement of the shallow arch is shown in Figures 5 and 6.

**Figure 5.** The relationship between the overlying soil and the displacement of the vault conditions.
According to the analysis of Figures 5 and 6, it can be concluded that: (1) When the tunnel body is excavated, the vertical displacement value generally increases with the increase of the thickness $t$ of the side cover soil; when the thickness $t$ of the side cover soil is small, the excavation of the bias tunnel has a great influence on the vertical displacement. With the increase of the thickness of the lateral cover soil, the vertical displacement increase of the tunnel body gradually decreases. When the thickness of the lateral cover soil is $t=21m$, the vertical displacement is affected. The thickness of the side cover soil has a small influence on the $t$ value, which is only affected by the rock and soil properties of the surrounding rock itself. (2) Deep excavation of the main hole will cause a large increase in the settlement of the vault on the shallow buried side, because the submerged wall supporting the gravity of the two-hole vault soil is repeatedly disturbed with the excavation of the deep buried main hole, and The thickness of the middle partition wall itself is small, so that the bearing capacity is reduced, and the settlement of the dome is increased. (3) Under the same working condition, for the settlement of the vault, the main hole on the deep buried side is always larger than the settlement of the main hole on the shallow buried side, because the overburden side of the main hole on the deep buried side is thicker than the shallow buried side. Caused by it. (4) Under the same slope gradient, the horizontal displacement value of the left shoulder shoulder generally decreases with the increase of the thickness $t$ of the lateral cover soil, but with the increase of the thickness $t$ of the side cover soil, the level of the left shoulder shoulder. The displacement value decreases at a slower and slower speed.

5. Conclusion

Through theoretical and numerical analysis of the bias characteristics of the biased double-arch tunnel, the results are as follows:

(1) The horizontal pressure and vertical pressure of the surrounding rock increase with the increase of the buried depth, and the horizontal pressure increases faster than the vertical pressure with the increase of the buried depth. When the buried depth is greater than 20m, the vertical pressure The amount of increase gradually decreases.

(2) With the increase of the thickness of the side cover soil and the disturbance of the middle partition wall by the deep buried main hole excavation, the middle partition wall is subjected to a large shear stress. After being disturbed, special attention should be paid to the partition wall. The settlement of the rock mass, the rock and soil tunnel above the oblique wall of the middle partition wall disturbs and moves to the free surface, acting on the middle partition wall, and the middle partition wall is subjected to repeated pulling, pressing and shearing, and the partition wall The construction quality has become the key to control the movement deformation of the overlying rock. At the same time, when the shallow buried tunnel is excavated, a large stress concentration occurs in the arched foot. In the tunnel construction, care should be taken to avoid stress concentration on the arch.

(3) When the tunnel body is excavated, the vertical displacement value generally increases with the increase of the thickness $t$ of the lateral cover soil; when the thickness of the lateral cover soil is $t=21m$, the vertical displacement...
the vertical displacement has no relationship with the thickness t of the lateral cover soil. It is basically only affected by the geotechnical properties of the surrounding rock itself.

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