Study on Soft Foundation Load of Right Line of Double Truss Tunnel

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Abstract. According to the load line structure example, the vertical support force of the initial support structure of the tunnel construction section is analyzed based on the load structure method. The calculation results and analysis show that the arch foundation load is scientific and effective. The calculation is for the control of the bearing capacity of the shallow-buried tunnel excavation foundation, and it has important engineering guiding significance to effectively prevent the large deformation of the tunnel section and the surface subsidence.

1. Project Overview
The S25 Jingyuan-Huating (Ning-Ganjie) highway is part of the "Three Rings, Eight Shots and Nine Links", and the interconnection between Gansu Huating and Jingning is realized through the connection with G22. S25 Jingyuan to Huating (Ningganjie) Highway 2 Project, There are a total of 1 tunnel-Shuangxieliang Tunnel in the whole line of the project section. The left line of the tunnel is 325m long and the right line is 368m long, which belongs to a short tunnel.

The tunnel site is a low mountain in the eastern foothills of the Liupan Mountains. The geomorphic unit is an eroded hilly area with a ridge elevation of about 1800m and a relative height difference of about 57m. It is mainly overlying Quaternary Holocene residual slope silty clay and alluvial silty clay, and underlying Paleogene Eocene Sikouzi Formation mudstone and gravel.

2. Analysis of external force of initial supporting structure
The construction section of the reinforced second section (construction pile number: YK41 + 243.1-YK41 + 268) on the right line of the double line tunnel is taken as the engineering research background. The maximum burial depth of this section is 14.4m, and the surface lithology belongs to the Quaternary Holocene residual slope silty clay and alluvial silty clay, and underlying Paleogene Eocene Sikouzi Formation mudstone and gravel. Before the secondary lining of this line is completed, the initial supporting structure of the tunnel is stressed as shown in Figure 1.

As can be seen from Figure 1, the initial supporting structure is subject to the following forces. the vertical force of the loose surrounding rock on the initial supporting structure " q " ; the horizontal force of the loose surrounding rock on the initial supporting structure " e " ; Friction resistance of surrounding rock on initial support structure " T " ; Supporting force of foundation to arch foot " N " ; Elastic
resistance of surrounding rock to initial supporting structure " \( k \) " ; The axial restraint force " \( S_r \) " and transverse restraint force " \( S_t \) " of the anchor rod to the initial supporting structure.

![Figure 1. Stress analysis of the initial support structure of the second section of the right line of the double-knot beam tunnel](image)

In order to facilitate the load structure method to analyze the external force of the initial supporting structure of the tunnel, the elastic resistance of the surrounding rock and the acting force of the anchor rod are simplified [1]. Because the deformation of the support structure in the initial stage of the soft foundation tunnel is mostly toward the inner side of the tunnel, At the same time, the surrounding rock strength is too low, the elastic resistance coefficient is small, Therefore, the elastic resistance of surrounding rock " \( k \) " is negligible. The main function of the anchor is to strengthen the surrounding rock, without increasing the prestress. The axial binding force of the anchor rod to the initial supporting structure " \( S_r \) " is negligible; the pressure of the anchor rod on the initial supporting structure mainly comes from the surrounding rock, so the lateral binding force of the anchor rod on the initial supporting structure " \( S_t \) " is negligible.

In summary, the vertical mechanical equilibrium equation of the initial supporting structure of the tunnel is as shown in equation (1) [2].

\[
Q + G = S_v + S + N + N \]  

Among them, the value of \( G \) in formula (2) is shown in formula (3).

\[
G = \rho g DU 
\]
\( \rho \) is the initial supporting structure density; \( g \) is the acceleration of gravity; \( D \) is the initial supporting structure thickness; \( U \) is the initial supporting ring length. The vertical bearing capacity provided by the anchor rod to the initial support structure, The force analysis is shown in Figure 2.

![Figure 2. The vertical bearing capacity provided by the anchor rod to the initial supporting structure](image)

As can be seen from Figure 2, the maximum vertical force that the anchor can provide is shown in (4).

\[
S_V = 2 \int_0^\pi \tau \omega R \sin \omega \, d\omega = 2 \int_0^\pi n \frac{[S_T]}{\pi R} R \sin \omega \, d\omega \quad \text{………………. (4)}
\]

Simplify formula (4) so that the maximum vertical force that the anchor can provide is shown in formula (5).

\[
S_V = \frac{2n}{\pi} [S_T] \quad \text{………………. (5)}
\]

\( n \) is the number of anchor rods evenly distributed on the supporting structure per metre; \([S_T]\) is the maximum lateral force that a single anchor rod can bear; \( R \) is the excavation radius of the upper steps; \( \tau \omega \) is the tangential stress concentration.

For the vertical bearing capacity provided by the surrounding rock and the anchor rod due to friction, the force analysis of the first-stage unit body of the initial support structure is shown in Figure 2, and its size is shown in (6).

\[
d_T = C_r [q(\omega) R \cos \omega \, d\omega + e(\omega) R \sin \omega \, d\omega] \quad \text{………………. (6)}
\]

For the total vertical bearing capacity, see equation (7).

\[
T_V = \int C_r R[q(\omega) \cos \omega + e(\omega) \sin \omega] \sin \omega \, d\omega \quad \text{………………. (7)}
\]

Simplify formula (7) to get the total vertical bearing capacity as shown in formula (8).

\[
T_V = 2C_r R \left[ \frac{1}{2} q_{\text{shallow}} + \frac{1}{6} \gamma R + \frac{\pi}{4} e_1 + \left( \frac{\pi}{4} - \frac{1}{3} \right) \gamma R \right] \quad \text{………………. (8)}
\]

Among them, \( C_r \) is the friction coefficient; \( \lambda \) is the lateral pressure coefficient; \( \gamma \) is the surrounding rock bulk density; \( q(\omega) \) is the vertical pressure concentration; \( e(\omega) \) is the horizontal pressure concentration; \( q_{\text{shallow}} \) is the vertical surrounding rock pressure; \( e_1 \) is the horizontal surrounding rock pressure.

The vertical force of surrounding rock pressure on the initial supporting structure is shown in (9).

\[
Q = \int R q(\omega) \cos (\omega) \, d\omega \quad \text{………………. (9)}
\]

Simplify the formula (9) to get the expression of the vertical force of the surrounding rock pressure on the initial supporting structure as the formula (10).

\[
Q = 2q_{\text{shallow}} R + \left( 2 - \frac{\pi}{2} \right) \gamma R^2 \quad \text{………………. (10)}
\]

In summary, substituting equation (3), equation (5), equation (8), equation (10) into equation (2), you can get the pressure that the arch foot of the tunnel foundation should bear \( N_L + N_R \). Unbiased shallow buried tunnel \( N_L = N_R \).
3. Engineering example calculation and analysis
Take the field parameters of the second section of the shallow tunnel reinforced section of the right line of the double bump tunnel as an example. The specific parameters are shown in Table 1. The analysis of the foundation bearing capacity is as follows.

Table 1. Load calculation parameters of the second-phase reinforced arched foundation of the right-row of Shuangfeng Tunnel

| Geometric parameters | Material parameters | Surrounding rock parameters |
|----------------------|---------------------|----------------------------|
| Radius               | Density of concrete | 2400kg/m³ grade V          |
| Thickness            | Steel density       | 7800kg/m³ Test weight 16.5KN/m³ |
| Increase width       | Comprehensive density of initial support | 3038kg/m³ Friction angle 20° |
| Buried depth         | Coefficient of friction between surrounding rock and initial support | 0.4 Calculate friction angle 40° |
| Arch and anchor      | Anchor rod lateral bearing capacity | 10KN Lateral pressure coefficient 0.5 |
| Longitudinal spacing | Number of anchors per ring | Lateral bearing capacity of lock foot anchor pipe 15KN Bearing capacity of foundation 500KPa |

According to the calculation parameters in Table 1, the vertical pressure of the vault is $2.38 \times 10^5$Pa; the horizontal surrounding rock pressure is $1.47 \times 10^5$Pa according to the calculation formula.

Then each long meter tunnel has:

$$G = 3038 \times 9.8 \times 0.26 \times 3.14 \times 6.48 = 157504KN$$

$$S_V = \frac{2 \times 25 / 0.5}{\pi} \times 10 = 31830KN$$

$$T_V = 2 \times 0.4 \times 6.48$$

$$\times \left[\frac{1}{2} \times 238 + \frac{1}{6} \times 16.5 \times 6.48 + \frac{3.14}{4} \times 147 + \left(\frac{3.14}{4} - \frac{1}{3}\right) \times 16.5 \times 0.5 \times 6.48\right]$$

$$= 1432.66KN$$

$$Q = 2 \times 238 \times 6.48 + \left(2 - \frac{3.14}{2}\right) \times 16.5 \times 6.48^2 = 3382.40KN$$

Substitute the above values into equation (2).

$$N_L = N_R = \frac{1}{2} [\delta (Q - T_V) + G - S_V] = 975 \delta - 80.4$$

The load of arch foundation corresponding to different load release coefficients is shown in Table 2.

Table 2. Arch foundation loads corresponding to different load release factors

| Load release coefficient | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 | 1 |
|-------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|---|
| Arch footing load /KN   | 17.1| 114.6| 212.1| 309.6| 407.1| 504.6| 602.1| 699.6| 797.1| 894.6|

Figure 3 shows the relationship between the load release coefficient and the load on the arch footing. The horizontal axis represents the load release coefficient, and the vertical axis represents the load on the arch footing. When the load release coefficient is less than 0.34, the arch base load is less than 250KN, which meets the construction process and safety requirements. Therefore, when the load release coefficient is less than 0.34, the load given to the arch base by the initial supporting structure of the tunnel is safe and controllable; When the coefficient is between 0.34 and 1, with the increase of the load
release coefficient, the arch foot foundation load increases, and the two satisfy the positive correlation. Within the range of the load release coefficient, the arch foot foundation load increases sharply, causing large deformation of the upper part of the tunnel, indirectly making the arch foot foundation load too large, and the initial support safety fails.

![Figure 3. The relationship between the load release coefficient and the load on the arch footing](image)

4. Conclusion

Based on the background of the "Double Pimple Tunnel" right line strengthening the second section of the shallow buried soft foundation project, through the load structure method, the vertical support force of the initial supporting structure of the tunnel construction section is analyzed with examples. The analysis results are as follows:

(1) Based on the load structure method, the mechanical model of the initial supporting structure of the tunnel construction section is established, and the calculation method of arch foot foundation load is given.

(2) Taking the reinforced second section of the right line of the double lump tunnel as an example, the proposed arch foot load calculation method is used to obtain the relationship between the arch foot foundation load and the load release coefficient. The calculation results show that the load release coefficient and the arch foot foundation load are positively correlated; when the load release coefficient is less than 0.34, the arch foundation load meets the bearing capacity requirements; when the load release coefficient is between 0.34 and 1, the foundation bearing capacity is seriously insufficient.

(3) In the construction of shallow buried tunnels with soft foundations, there are many problems with insufficient bearing capacity of the arch foot foundation. Insufficient load on the arch foot foundation will cause a large area of settlement at the top of the tunnel. Therefore, a reasonable arch foot foundation load calculation is proposed and the construction process is actively adjusted, effectively controlling the problem of large deformation at the top of the tunnel.

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