Analysis of the Influence of New Parallel Tunnels on the Safety of Existing Highway Tunnels

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Abstract. With the increasing number of construction projects in China, the intersection or proximity between new tunnels and existing tunnels is increasing. How to evaluate the impact of existing tunnels and ensure the safe operation of existing tunnels are important issues to be considered in the design of new tunnels. Based on the actual conditions of the new tunnel and the existing Jianshi tunnel of Jinliwen Expressway in the north connection of S49 provincial highway in Zhejiang Province, this paper studied the influence of the new parallel tunnel on the existing highway tunnel by analyzing the net distance between the two tunnels, the change of the supporting structure during the construction of the new tunnel and the vibration caused by the blasting construction, etc., the influence of new parallel tunnels on the safety of existing highway tunnels was studied, which provides a reference for the design and construction of similar short distance parallel tunnels.

1. Introduction

With the increase of national basic investment, there are more and more construction projects, and there are more and more new tunnels crossing or adjacent to the original structure, the forms of encounter are also very complicated, some tunnels are parallel in the horizontal direction, and some tunnels cross and overlap in the vertical direction and the distance between adjacent caverns is smaller and smaller, while the cross section of tunnel is larger and larger. The construction of the new tunnel will inevitably affect the safe operation of the existing tunnel. Chi [1] used FLAC3D to analyze the influence of the new tunnel on the support performance of the existing tunnel under the vertical interaction condition. It was believed that during the construction of the new tunnel, the internal force of the existing tunnel lining structure will continue to increase, and the maximum positive and negative bending moments are mainly distributed at the arch crown, arch shoulder and side wall of the existing tunnel. Gui [2] studied the influence of different approach degree of new cross tunnel on the existing tunnel, the results show that the tensile stress of the existing tunnel will increase with the decrease of the clear distance between the two tunnels. Liu[3], Yang [4] and other carried out blasting construction of new tunnels and its influence on the vibration of existing highway tunnels, it was believed that strict vibration reduction measures should be taken in the construction, and the dynamic design and information construction can effectively guarantee the safety of the small clear distance tunnel by combining the monitoring measurement and the advanced geological prediction value.

In order to better guide the safety construction of the entity project, this paper combines the actual conditions of the new North Connection tunnel of S49 provincial highway and the existing Jianshi tunnel of Jinliwen Expressway in Zhejiang Province, established the numerical analysis model, and studies the influence of the tunnel construction on the existing tunnel under the parallel conditions.
2. Project Overview
The new North Connection tunnel of S49 provincial road is a curve multi arch tunnel, with the west exit stake number of K0 + 083 and the east exit stake number of K0 + 285, with a total length of 202m, it is adjacent to Jianshi tunnel of Jinliwen expressway. The longitudinal slope of Jianshi tunnel adopts one-way slope, with the left tunnel slope of 2.0% and the right tunnel slope of 1.9%. The plane position relationship between the newly-built North Connection tunnel and Jianshi tunnel is shown in Figure 1. The lines of the two tunnels are roughly parallel. The cross section position relationship between the North Connection tunnel and Jianshi tunnel is shown in Figure 2. The minimum horizontal clear distance between the two is about 26m, and the elevation difference of the road surface is about 8.6m. The geological survey shows that the thickness of the surface overburden in the tunnel area of the North Connection tunnel is 0.5-1.0m, and the lower part is moderately weathered slightly weathered granite. The rock mass is complete, the joint fissures are not developed, and the engineering physical and mechanical properties are good. The water quantity is poor and the hydrogeological conditions are simple.

![Figure 1. Parallel tunnels plane relationship diagram](image1)

![Figure 2. Relationship diagram between newly constructed tunnel and existing Jianshi tunnel.](image2)

The lining structure of the North Connection tunnel is a class IV surrounding rock connected arch tunnel lining structure. The anchor bolt is a φ25 first anchoring and then pouring hollow system anchor bolt (3.5m long). The initial support is φ8@25×25 welded steel mesh +12.6I-shaped steel arch support (0.8m spacing) +20cm thick shotcrete. The secondary lining is a 55cm thick formwork reinforced concrete secondary lining. The lining structure of Jianshi tunnel is S2B type lining structure. The anchor bolt is a φ25 first anchor and then grouting hollow system anchor (3.5m long). The initial support is φ6.5 @ 15×15 welded steel mesh +12.6I-shaped steel arch support (spacing 0.5 ~ 1.0m) +25cm thick shotcrete. The secondary lining is 45cm thick formwork reinforced concrete secondary lining.
3. Analysis of minimum distance requirements of adjacent tunnels

The distance between adjacent tunnels is the primary parameter that affects the safety of tunnels. The minimum distance between adjacent tunnels is required by the tunnel design codes at home and abroad.

The terrain of the newly-built North Connection tunnel is relatively simple, the representative grade of the main surrounding rock is class III, the excavation width of the single tunnel section is 12.7m, and the excavation width of the Jianshi tunnel section is 12.5m. According to the Code for design of Road Tunnel (JTG D70-2004), if calculated according to the excavation section width of the new North Connection tunnel, the minimum distance between the two tunnels is: \(2.0 \times B = 25.4m\); while calculated it according to the excavation section width of Jianshi tunnel, the minimum distance between the two tunnels is \(2.0 \times B = 25.0m\). Therefore, the minimum distance between the two should not be less than 25.4m. Due to the fuzzy classification of surrounding rock in tunnel, the surrounding rock in some sections can also be classified as sub-iv surrounding rock. In this case, the minimum distance between the two should not be less than 31.75m. The minimum design distance between the new North Connection tunnel and Jianshi tunnel is 26m. Therefore, only the minimum distance between excavation sections of class IV surrounding rock section of new North Connection tunnel is slightly less than the requirements of the specification, and the minimum distance of class III surrounding rock section meets the requirements of the specification.

![Figure 3. Schematic diagram of the influence range under normal circumstances.](image)

In order to analyze the influence of adjacent structures, Japan Railway Comprehensive Technology Research Institute proposed a method to determine the construction influence range of adjacent tunnels as shown in Figure 3: when the minimum distance between two tunnels \(l_0\) is less than 1.0\(\text{D}'\) (\(\text{D}'\) is the outer diameter of tunnel excavation), measures must be taken from the construction method, according to the displacement and deformation of the structure to study the influence degree and take measures, and carry out monitoring measurement; when 1.0\(\text{D}'< l_0< 2.5\text{D}'\), the measures to be taken shall be determined according to the allowable value of displacement and deformation of the structure, and the measurement management shall be carried out. When \(l_0 > 2.5\text{D}'\), the interaction may not be considered. The surrounding rock of the North Connection tunnel near the Jianshi tunnel is class III and class IV surrounding rock. The lithology is granite. The rock is hard and has good integrity. \((2.0 \sim 2.5)\times B\times (1\sim 20\%) = (20.32\sim 25.4)\) m. The minimum distance between the two tunnels is 26m. It can be seen that the minimum distance between the two tunnels meets the requirements.

4. Analysis of deformation and structural internal force of existing tunnel during construction of new tunnel

4.1. calculation model

Based on the section at the nearest distance between the right line of North Connection tunnel and Jianshi tunnel, Midas GTS NX was used to establish the analysis model as shown in Figure 4. Due to the shallow buried depth of the tunnel at the simulation site, the upper limit of the model was taken to the surface, and the stratum structure was established according to the geological report profile and plan. The right boundary of the model was 40 m to the right of the North Connection tunnel, the left
boundary was 30 m to the left of the Jianshi tunnel, the width of the model was 132 m, and the tunnel length method was 1 m. The rock and soil mass are simulated by the Drucker Planck criterion, and the parameters were selected according to the geological exploration data. See Table 1 for the parameters of each part.

![Finite element calculation model diagram.](image)

Table 1. Main physical and mechanical parameters

| Name                        | modulus of elasticity /MPa | Poisson's ratio | gravity /(kN/m$^3$) | cohesion /kPa | internal friction angle /° |
|-----------------------------|----------------------------|----------------|----------------------|---------------|---------------------------|
| Grouting                    | 1.00E+07                   | 0.26           | 26.2                 | 780           | 42                        |
| Completely weathered granite | 0.40E+07                   | 0.30           | 18.2                 | 80            | 30                        |
| Strongly weathered granite  | 6.00E+06                   | 0.30           | 22.8                 | 300           | 36                        |
| Moderately weathered granite| 1.00E+07                   | 0.26           | 26.2                 | 600           | 42                        |
| Slightly weathered granite  | 3.00E+07                   | 0.22           | 26.5                 | 900           | 48                        |
| C30 concrete                | 30.0E+07                   | 0.20           | 24.0                 | /             | /                         |
| C20 concrete                | 25.5E+07                   | 0.20           | 24.0                 | /             | /                         |

4.2. Calculating loads and construction steps
The calculated load mainly considers the self-heavy stress of the formation and concrete lining.

The excavation and lining of the rock mass in the construction step was realized by the unit “activation” and “passivation” functions provided by Midas GTS NX software, and the simulation of the whole construction process was completed.

The simulation steps in the calculation were as follows: Formation of initial geostress field → existing tunnel excavation and lining application → step-by-step excavation and lining of new tunnels.

4.3. Analysis of calculation results
Figure. 5 is the cloud chart of vertical displacement of surrounding rock after each excavation stage of North Connection tunnel. It can be seen that during the construction of the North Connection tunnel, slight uplift occurs at the bottom of the arch, and the maximum uplift is 1.04mm during the construction; and the maximum settlement occurs at the top of the arch, which is 1.34mm during the construction. Because the surrounding rock quality of the tunnel is good, during the whole construction process, the influence scope of the construction on the surrounding rock of the North Connection tunnel is mainly within 15m outside the North Connection tunnel, and the rock around the Jianshi tunnel is little affected.
Figure 5. Cloud chart of vertical deformation during construction of new North Connection Tunnel

Figure 6 and figure 7 show the stress change of the initial support of Jianshi tunnel before and after the excavation of North Connection tunnel. It can be seen from the analysis that the initial support of the Jianshi tunnel before and after excavation was in the state of compression, and the maximum stress appeared at the arch foot. The maximum compressive stress before and after excavation was 3.12 MPa and 3.30 MPa respectively, which increases by 0.18 MPa, and was also less than the compressive strength of C30 concrete.

Figure 6. Maximum stress change of initial support of Jianshi tunnel before and after excavation of new tunnel
Figure 7. Minimum bending stress change of initial support of Jianshi tunnel before and after excavation of new tunnel

Figure 8 and Figure 9 respectively show the maximum and minimum stress changes of the secondary lining of Jianshi tunnel before and after the excavation of North Connection tunnel. It can be seen that before and after the excavation of the new tunnel, the secondary lining of the Jianshi tunnel was in the state of compression; the maximum pressure stress occurs at the arch foot, the maximum pressure stress before the excavation was 3.59MPa, and the maximum pressure stress after the excavation was 3.82MPa, increasing by 0.23MPa. The second lining structure of Jianshi tunnel was cast with C30 concrete, and its compressive strength is 22.5MPa. Therefore, the secondary lining structure had enough safety reserves.

Figure 8. Maximum stress change of secondary lining of Jianshi tunnel before and after excavation of new tunnel

Figure 9. Minimum stress change of secondary lining of Jianshi tunnel before and after excavation of new tunnel

5. Blasting safety evaluation
The minimum distance between the newly built North Connection tunnel and Jianshi tunnel of Wenli expressway was only 26m, so the impact of blasting excavation on the lining, pavement and pipeline of expressway tunnel must be quantitatively analyzed.
In tunnel blasting construction, the total charge $Q$, vibration frequency and vibration speed of each cycle blasting can be calculated according to formula (1) - (3).

$$Q = kLS$$  

(1)

$$f = \left[ \frac{k\frac{C}{Q^\frac{1}{3}}}{Q^\frac{1}{3}} \right] \left[ \frac{Q^{\frac{1}{3}}}{R} \right]^{\frac{1}{2}}$$  

(2)

$$v = K \left( \frac{Q^m}{R} \right)^a$$  

(3)

Where, $K$ is the average explosive consumption per unit volume of rock; $L$ is the blasting driving footage; $s$ is the excavation cross-section area; $f$ is the frequency coefficient, taking 0.01; $C$ is the wave speed of rock; $q$ is the total explosive quantity initiated at the same distance at the same time; $R$ is the distance from the measuring point to the blasting source.

According to the actual conditions of the new tunnel in the north line, it can be calculated that when the footage was 1 m, the total charge quantity of each cycle of blasting was $q = 28.44$ kg, the vibration frequency is $f = 37.45$ Hz, and the particle velocity near the blasting area of the excavation face is $v = 3.56$ cm/s. According to the Safety Regulations for Blasting (GB 6722-2014), the allowable vibration speed of traffic tunnel is 10-20 cm/s. It can be seen that under the premise of strictly controlling the amount of blasting explosives, the blasting construction of the new tunnel will have little impact on the structure of the Jianshi tunnel.

6. Conclusions
(1) No matter from the specification of the minimum distance between adjacent tunnels or from the analysis of tunnel construction mechanics, the construction of the new North Connection tunnel has little impact on the Jianshi tunnel of Jinliwen expressway, and will not have a significant adverse impact on the safety and operation of the expressway.

(2) During the construction of the new North Connection tunnel, it is necessary to carefully construct, strictly control the amount of blasting explosives, and monitor the abnormal state of the blasting vibration speed and crack expansion of the highway tunnel at any time to ensure the safety of the highway tunnel.

References
[1] Chi, Z.Y., Fan, S.L. (2019) Study on the Influence of New Vertical Interactive Tunnel on the Supporting Performance of Existing Tunnel[J].Northern Architecture, 4(3): 69-73.
[2] Gui, Y.C. (2019) Research on Influence of Different Proximities of Cross Tunnels on Stability of Existing Tunnels[J]. Northern Traffic, (5):80-84.
[3] Liu, H.Z., Zhang, Z. (2019) Analysis of vibration effect of blasting excavation of metro tunnel on existing highway tunnels[J].Modern Urban Transit , (9):80-84.
[4] Yang, M.Y., Wang, X.Y., Gang, K. (2019) Research on Influence and Construction Technology of Newly-built Tunnel Blasting Excavation on Existing Tunnel[J], Northern Architecture, (1):77-80.
[5] Fang, Y.G., Zhou, H.S., Weng, H. (2011) The Design of Xiazhoudai highway tunnel across a hydropower diversion tunnel. Highway, (08): 317-320.
[6] Zhang, J. (2012) The safety assessment of new railway embankment on the cross-tunnel. Highway Engineering, 37(04): 37-39+143
[7] Architectural and Civil Engineering Design Institute Co., Ltd, Hangzhou. (2012) Qingtian County Urban Group Transportation Hub Construction Drawing Design Document.