Influence of Short Distance Super-large Diameter Shield Tunneling on Existing Tunnels in Sea Areas

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Abstract: In order to find out the influence of large diameter shield tunneling on the existing tunnel under the condition of compound strata in the sea area, taking the Maliuzhou traffic tunnel as the research background, numerical simulation and field test were combined to get the regulation of the additional internal force and deformation of the existing tunnel caused by the shield tunneling. Analysis of the data showed that: the shield construction caused the secondary additional internal force; The moment of the vault was most affected by the tunnel excavation; The axial force of the arch bottom was most affected by the excavation of the tunnel. The deformation of arch waist near excavation tunnel was more affected by tunnel excavation than that of the other side. Combined with the construction experience, the influence of the tunnel close-distance construction on the existing tunnel was within the control range, which could ensure the normal construction.

1. Introduction

With the rapid development of urban construction, the underground construction has also entered a period of rapid development. The construction of the shield has the advantages of fast construction speed, safety and little impact on the surrounding environment. Underground engineering is limited by the construction space. When the tunnel is constructed in short distance, the existing tunnel will be affected by construction. Therefore, it is of great significance to reaserch the influence law of shield short-distance construction on the normal operation of existing buildings.

At present, there are many achievements in domestic research on short-distance construction. For example, displacement rate of change guidelines was used by Wang et al. to partition the vertical section of the shield tunnel overlap[1]; Zhang Haibo et al. simulated the stress and deformation of the tunnel lining caused by the shield tunnel construction of the post-built tunnel[2]; He chuan et al. used model tests and finite element analysis to discuss the variation of the deformation and the additional internal force of the built parallel tunnel due to the clearance distance between the tunnel and the top thrust[3];Bahai et al. deduced the formula of ultim deformation of the existing tunnel under the condition of orthogonal under-penetration, and carried out safety evaluation[4].

Through the investigation of the above research results, it was found that the research contents of the stress in the aspect were less than the deformation research, and the stress was mainly focused on the overall stress condition of the aspect. For the actual construction process, the impact of the situation was not clear. Therefore, in this paper, the WK2+549–WK2+651 shield interval in Maliuzhou was taken as the research object. By using the combination of finite element numerical simulation and on-site monitoring, research on the deformation of the ground surface and the stress and deformation of the...
existing tunnel segments under the condition of the close construction. The research results can provide references for the construction safety and efficiency.

2. Engineering background

2.1 Project overview
Hengqin New District Maliuzhou Traffic Tunnel is located in Nanwan City and Hengqin New District, Zhuhai City. It is a total length of 3km, an outer diameter of 14.5m and the first composite large-diameter shield tunnel in South China. The tunnel is a two-way tunnel (west tunnel and east tunnel). The west tunnel has been excavated and the center distance of the tunnel is 29.7 ~ 31.5m. The shield construction plan is shown in Figure 1.

![Figure 1. Shield construction plan](image1)

![Figure 2. Geological section](image2)

2.2 Construction program
Both tunnels were constructed with mud-water shield, the diameter of the shield is 14.93m. The tunnel segment is made of C55 prefabricated reinforced concrete segment with the thickness of 0.6m. The outer diameter is 14.5m and the inner diameter is 13.3m. Three months after the western tunnel has been excavated, the eastern tunnel started construction.

2.3 Engineering Geology
Selected the mileage for the WK2+600 West line section of the tunnel as the target section and conducted the load test of the segment structure outside the load. The formation shown in Figure 2.

![Table 1 physical mechanics calculation parameter table](image3)

| Soil number and name | E/MPa | μ | γ/KN m³ | C/KPa | φ (°) | Thickness(m) |
|----------------------|-------|---|----------|-------|-------|--------------|
| ① silt               | 7.84  | 0.4 | 16.3     | 6.1   | 3.4   | 19.5         |
| ② clay               | 20.56 | 0.3 | 19       | 30    | 15    | 4.85         |
| ③ coarse sand        | 32    | 0.3 | 17.9     | 0     | 19.2  | 2.88         |
| ④ gravel cohesion soil | 46.7  | 0.3 | 18.8     | 35.3  | 26.1  | 2.78         |
| ⑤ fully weathered granite | 97.5  | 0.3 | 18.7     | 32.5  | 25.4  | 2.1          |
| ⑥ strong weathered granite | 183   | 0.2 | 18.9     | 35.7  | 24.7  | 2.32         |

2.4 Monitoring arrangement

2.4.1 Instrument layout. In order to find out the variation regularities of forces of the existing tunnel structure in the process of short distance construction, the concrete strain gauge was arranged on the target section to conduct the tracking test. The lining of each ring was composed of 10 blocks, assembled in the form of "7+2+1". The strain gauges were arranged on the inner and outer sides of each segments. The installation positions are shown in Figure 3 and Figure 4 below.
2.4.2 Deformation monitoring. TS09plus total station was used to monitor transverse convergence, laser distance measuring instrument was used to monitor vertical convergence. Seven convergent deformation points were arranged on each ring piece, and the layout of the measurement points is shown in the figure 5.

3. Numerical analysis of the impact of newly built tunnels on existing tunnels

3.1 Calculation model
The finite element analysis software FLAC3D was used to calculate the WK2+600 section during excavating. Calculation model length, width and height were 144m, 102m and 76m, as shown in Figure 3. Considering the influence of the lining joints on the lining structural rigidity, the stiffness of the lining was reduced to 0.75, the Poisson's ratio was 0.2 and the width of the segments was 2m. Solid unit was used to simulate grouting-layer material made by C15 concrete. Mohr-Coulomb model was used to calculate and the structural elements adopted the linear elastic constitutive relation.

3.2 Calculation of conditions
In actual construction, each excavation was 2m. Each step of excavation was completed by four processes, the simulation conditions as shown in the table 2.

| Construction stage | construction conditions |
|--------------------|-------------------------|
| 1 excavation process | In the process of excavation, there were jacking force F1, side frictional resistance F2 and torque F3; The shield shell was simulated with a temporary shell before segment was assembled. |
2 segments assembly process

(1) Removed the temporary support shell elements and replaced with the same stiffness support shell elements;
(2) Deleted the role in kind of load around the tunnel face and shield shell

3 grouting and solidification process

(1) Applied grouting pressure on the soil layer around the segments to simulate the synchronous grouting;
(2) The material properties of the shield were gradually increased and the process of grouting hardening was simulated.

4 consolidation settling process

Stoped grouting and removed grouting pressures until calculated to balance.

3.3 Calculation results analysis

3.3.1 Additional internal force analysis. As it shown in the Figure 7, the change trend of the additional bending moment of the existing tunnel segment was related to the position of the segment. The bending moment of the vault and the left arch was gradually increasing, and the arch top bending moment was most affected by the tunnel excavation, and the maximum additional bending moment was 27.5 KN·m. After decreasing first and then increasing, the bending moment increased to the maximum when the tunnel was excavated to the target section. The bending moment at the arch base was not affected by tunnel excavation. the bending moment of the vault, left and right sides were affected by the excavation of tunnels in the range of 68m, 64m and 62m.

Figure 7. Time travel curve of additional bending moment

As it shown in the Figure 7, in the process of tunnel excavation, the right arch waist axial force was most affected by tunnel excavation. When the tunnel excavation exceeded the target section 12m, the axial force increased to the maximum, and its value was 95KN. After tunnel excavation has been completed, the additional axial force of the arch reached to the maximum. The sphere of influence about axial force of the vault, arch bottom and the left and right sides of the arch were 30m, 40m, 40m and 80m, respectively.

3.3.2 Deformation Analysis. As it shown in the Fig 9, when the tunnel was not exacted to the target section, horizontal displacement on both sides of the tunnel was approximately equal to each other; When the tunnel was exacted to the target section, horizontal displacement stared to weaken or disappear sharply; when the excavation to the 48th step, the arch waist on both sides began to weaken or disappear and the deformation on the right was larger than that on the left side, and its value was 1.05mm.
Figure 9. Time range curve of horizontal displacement

As it shown in the Fig.10, With the excavation of the tunnel, the arch bottom gradually apophysed, and Vault displacement stared to weaken or disappear outward. When the tunnel was not exacted to target section, amount and growth rate of deformation of both sides were the same approximately. When the tunnel was excavated to target section, the deformation trend of the vault increases sharply, and the deformation of the arch bottom began to weaken or disappear outward.

Figure 10. Time range curve of Vertical displacement

Figure 11. Surface subsidence curve

As it shown in the Fig.11, after the tunnel has been excavated, the surface subsidence value of the tunnel vault at the top of the tunnel was maximum, with a value of about 130mm, and the surface subsidence was about 3.5 times the hole diameter.

3.4 additional internal force monitoring and analysis

As it shown in the Fig.12, the change regulation of additional bending moment monitored by field experiment was similar to that obtained by numerical calculation. With the shield tunneling, the bending moment of the vault gr adually increased and tended to be stable, and the bending moment of the bottom, the left and right sides of the arch decreased and tends to be stable; The change of arch bottom bending moment is the largest and the increment of vault moment is minimum. In the numerical calculation, the bending moment changes of the vault, the arch bottom, the left arch waist and the right arch waist were 28, 0, 13 and 6KN·m respectively, and the actual monitoring results of bending moment were 63, 7, 28, 18 KN·m. The vault bending moment is most affected by the excavation of the tunnel.

Figure 12. Measurement of time travel curve of additional bending moment

Figure 13 showed the actual monitoring of the additional axial force of the pipe when the curve. From Figure 13, it can be seen that the construction of new tunnel will increase the axial force in the pipe and gradually stabilize with the gradual excavation of the tunnel. The numerical results showed that the change of axial force when the arch, arch, left arch waist and right arch were in steady state were 45, 73, 15 and 65KN, respectively. The actual monitoring results showed that the change of axial force is 70, 90, 6,80KN. Arch bottom axial force by the tunnel excavation of the greatest extent, the second right arch waist.
4. Conclusion

(1) For shallow-buried large-diameter tunnels, under the conditions of close-distance construction, the thrust force and grouting pressure of the new tunnel shield and the friction force exerted by the shield on the surrounding soil during the excavation of the shield machine, the axial force of the existing tunnel segment tended to increase. As the shield machine moved away from the target monitoring section, the axial force tended to be stable gradually. With the excavation of the tunnel, the vault and arch waist force of the right side reached the stability before the arch bottom, and the axial force of the arch bottom was greatly affected by the tunnel excavation.

(2) Under the condition of close distance construction with a clear distance of about 1 times the hole diameter, the bending moment at the arch and the arch waist at the left and right sides were respectively 64, 64 and 70m, and the bending moment Affected by the greatest extent of tunnel excavation.

(3) For the shallow buried-large diameter tunnel, the new ground settlement value after tunnel excavation was large, and the maximum settlement value appeared just above the tunnel dome. The range of about 50m (3.5 times of the diameter) of the earth's surface will be excavated by tunneling impact.

(4) Shield in the process of close-distance construction, part of the arch tunnel of the existing tunnel is restored. The arched side of the tunnel adjacent to the new tunnel will gradually inwardly converge and deformation due to the tunneling. According to the measured data, its deformation was more affected by the tunnel excavation than the vault.

Acknowledgments

Foundation items: The National Natural Science Foundation Project (51578458); Project supported by the Shanghai Tunnel Engineering Co. Ltd. and Zhuhai Dahengqin Co. Ltd. (2015-sk-4): Application development of key projects in Chongqing(cstc2014yykfB30003).

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