Study on the influence of tunnel construction on existing tunnel below by above-crossing tunnel

Chun LIU, Qing ZHANG, Heng LIU
Chongqing University of Science and Technology, Chongqing 401331, China
Correspondence should be addressed to Qing ZHANG; 2018207027@stu.cqust.edu.cn

Abstract. During the construction of the above-crossing tunnel, the surrounding rock of the existing tunnel will be disturbed in different degrees due to the different spacing between the upper tunnel and the existing tunnel. In order to study the regular pattern between the surface deformation of the existing tunnel surrounding rock and the tunnel spacing, the surrounding rock deformation of 10 groups of existing tunnels with different spacing is studied by numerical simulation based on the project of the upper loop section of Chongqing rail transit line 9. The results show that the uplift deformation of the vault of the existing tunnel will be caused by the construction of the upper double-track tunnel, and the final deformation of the existing tunnel is in the shape of "M". The maximum displacement of the existing tunnel decreases first and then increases with the increase of the transverse distance of the upper crossing tunnel, but the maximum displacement of the existing tunnel does not change much; As the vertical distance between the new tunnel and the existing tunnel increases, the maximum displacement of the existing tunnel decreases linearly within the 3L vertical distance. It gradually stabilized after 3L, indicating that the existing tunnels beyond 3L are almost unaffected by new tunnels.

1. Introduction
With the continuous expansion of urban scale and the rapid growth of urban population, noise pollution, traffic congestion and other problems have become increasingly prominent, seriously restricting the healthy development of cities. With large volume and fast speed, subway can effectively solve the above problems, which is an important direction of urban construction and development in China. However, in the process of subway construction, there will inevitably be many special conditions, among which the three-dimensional "well" crossover tunnel is one of the rare special conditions.

Using 2Dand 3D models, Soliman et al. [1] discussed and studied the mutual influence of construction near parallel tunnels. Jinxing Lai [2] the tunnel vehicle load and metro train load to the structure of shield tunnel was analyzed by applying the three-dimensional (3D) dynamic finite element model. Shi et al. [3] investigated the settlement behaviours of a metro tunnel during metro operation based on a nonlinear vibration model of vehicle track. Lai et al. [4] established a wireless sensor network (WSN) to monitor the effect of the blast-induced vibration on the structure of an existing tunnel. W Chen et al. [5] the construction method was numerically simulated for safety and construction sequences have been suggested according to vibrate speed control criterion for DWSS tunnel.

Therefore, it is necessary to study the influence of the construction of the new overlying double-hole tunnel on the existing tunnel and explore its rules, so as to ensure the structural safety of the existing tunnel and maintain the normal operation of the existing underground tunnel. Taking a tunnel under construction in Chongqing Metro Line 9 as the research object, a numerical calculation model of the up-
crossing tunnel is constructed. Considering different tunnel spacing, a comparative study of numerical simulation is conducted.

2. Project overview
There are many underpass structures near the geotechnical engineering of a tunnel project under construction in Chongqing. The tunnel soil is mainly weathered sandstone and weathered sandy mudstone, which are all constructed by underground excavation method. The tunnel in this section spans the TBM section. The minimum vertical distance from the interval is about 3.5m, which belongs to the second-level hazard source. The proposed section adopts the tunnel type with single hole and single line, 8.00m in width, 7.63m in height, 15.17~22.30m in shaft spacing, and is constructed by drilling and blasting method. This is shown in Figure 1.

![Tunnel engineering geological profile](image1)

3. Numerical simulation analysis of different spacing
A 120m×60m×60m model was established, and the origin of coordinates was located at the center of the front of the model. In the model, three layers of soil were built from top to bottom in order of filling soil (5m thick), sandstone (10m thick), and sandy mudstone (35m thick). All four tunnels are located in a sandy mudstone formation. The net distance between the two newly built overlying tunnels is 12.5m, and the net distance between the two existing underlying shield tunnels is 12m. Model element division: solid element is adopted for soil, and Mohr-Coulomb criterion is adopted for constitutive relation. This is shown in Figure 2.

![3D model](image2)

The stress and displacement responses of the ground surface of the new double-hole tunnel under the condition of adjacent to the existing tunnel are discussed, which can provide some reference for the similar construction cases of three-dimensional well-shaped cross-adjacent tunnel. In the research process, it is necessary to take into account the different vertical and transverse spacing between the new tunnel and the existing tunnel, and consider that there is a large gap between the designed sections of the two tunnels as the research background. For example, the shield tunnel excavation diameter of 6.6 m, and the mining method of tunnel section of span is 7.1 m, the new line around the tunnel rock pillars between the minimum horizontal distance as a tunnel, the horizontal spacing of 12.8 m as standard
unit of double hole diameter, $D = 12.8 \, \text{m}$, namely construction of tunnel and existing tunnel span $3.5 \, \text{m}$ as standard unit of double vertical spacing, namely $L = 3.5 \, \text{m}$. In the design and construction process of urban subway tunnel, if the buried depth is too small, it is necessary to add the active load on the surface, the road surface and subgrade to take comprehensive consideration. There are many influencing factors that are not conducive to the control variables. The maximum vertical spacing between the new tunnel and the existing tunnel is set as $4L$. The minimum horizontal net distance is set as $0.5D$, namely $6.4 \, \text{m}$, considering the limit cases that may be encountered in actual engineering and the complexity and construction difficulty of the two tunnels. Finally, five different horizontal spacing ($0.5D$, $1D$, $2D$, $3D$, $4D$) and five different vertical spacing ($0.5L$, $1L$, $2L$, $3L$, $4L$) were selected as the simulation conditions. Schematic diagram of working conditions is shown in Figure 3.

In order to describe the displacement changes of the lining cross-section at different positions of the existing tunnel and the different positions of the lining cross-section itself, the position of the lining cross-section in the existing tunnel and the placement of the displacement monitoring points in the lining cross-section are agreed: the gravity direction is vertical; The quadrilateral center point generated by the horizontal projection of four tunnel axes is the intersection center point and takes the intersection center point as the origin. The two directions of the tunnel axis are the coordinate directions of the cross-section positions of the tunnel. For the existing 0-60m section of the tunnel coordinates, the interval of the cross-section positions is monitored by 10m (a total of 26). This is shown in Figure 4 for details.

3.1. Influence analysis of different transverse spacing on existing tunnel and surface
The newly built tunnel passes through the existing tunnel lying underneath at the upper part of the tunnel with horizontal spacing of $0.5D$, $1D$, $2D$, $3D$ and $4D$. The vertical displacement curves of each monitoring point on the vault of the existing tunnel and the ground monitoring point are shown in Fig.5 and Fig. 6.
According to Fig. 5, with the excavation of the upper tunnel, the soil above the existing shield tunnel was unloaded, and the upper pressure gradually decreased, resulting in the uplift deformation of the vault of the existing tunnel within a certain range. When the new tunnel is completed, the monitoring points of the existing tunnel vault have different degrees of displacement. The monitoring point near the intersection of the tunnel has a large displacement, and the displacement curve has a double peak, so that the existing tunnel vault presents an overall "M" shape. It can be seen that the magnitude of monitoring point movement is related to the distance from the intersection of the tunnel. The closer the distance to the intersection of the tunnel, the greater the deformation will be, and the uplift will become smaller as the distance from the intersection becomes larger.

With the increase of the lateral spacing of the newly built tunnel, the maximum displacement of the existing tunnel vault firstly decreases and then increases. When the horizontal spacing is 0.5D, 1D, 2D, 3D and 4D, the maximum displacement of the monitoring point is 5mm, 4.35mm, 1.34mm, 3.62mm and 4.13mm, respectively, as shown in Fig. 6. It can be seen that the double-hole effect has a certain influence on the deformation of the existing tunnel.

### 3.2. Influence analysis of different vertical spacing on existing tunnel and surface

The newly built tunnel passes through the existing tunnel lying below at the upper part with vertical spacing of 0.5L, 1L, 2L, 3L and 4L. The vertical displacement curves of the vault of the existing tunnel and each monitoring point on the surface are shown in Fig. 8 and Fig. 9.
According to the analysis of Fig. 7 and Fig. 8, with the increase of vertical spacing, the maximum displacement of monitoring points on the arch of the existing tunnel gradually decreases and reaches the minimum when the vertical spacing is 3L. When the spacing is 4L, the deformation of the existing tunnel is basically the same as that when the spacing is 3L. When the vertical spacing is 3L and 4L, the monitoring points of the arch maximum displacement approach from both sides to the intersection center of the tunnel, and the displacement curves of each monitoring point change from two peaks to one peak. The influence of new tunnel on existing tunnel gradually develops from double tunnel to single tunnel.

According to the regression formula in Fig. 9, the statistical relationship between the added value of the existing tunnel displacement and the vertical spacing L within the range of 0.5L-3L can be obtained:

\[ y = -1.608x + 5.8467 \]  

4. Conclusion

By analyzing the deformation of the surrounding rock of the existing tunnel under different spacing, it can be found that different spacing has different influence on the existing tunnel. The excavation of new tunnel will cause unloading above the existing tunnel, which will lead to uplift deformation of the
existing tunnel. The closer the tunnel intersection is, the greater the deformation will be, and the overall deformation of the vault of the existing tunnel is in the shape of "M".

(1) With the increase of transverse spacing D, the maximum displacement of the existing tunnel decreases first and then increases. The displacement is maximum at 0.5D and minimum at 2D.

(2) With the increase of longitudinal spacing L, the maximum displacement of the existing tunnel decreases linearly within 0.5L -- 3L and then tends to be stable, indicating that the existing tunnel is basically not affected by the new tunnel outside the range of 3L.

References:
[1] E. Soliman, H. Duddeck, and H. Ahrens, “Two- and threedimensional analysis of closely spaced double-tube tunnels,” Tunnelling and Underground Space Technology incorporating Trenchless, vol. 8, no. 1, pp. 13–18, 1993.
[2] Lai, Jinxing , et al. "Vibration Response Characteristics of the Cross Tunnel Structure." Shock and Vibration, 2016, (2016-6-29) 2016. pt. 5(2016):1-16.
[3] W.B. Shi, L.C. Miao, Z.X. Wang, and J.H. Luo, “Settlement behaviors of metro tunnels during the metro operation,” Shock and Vibration, vol. 2015, Article ID 863961, 11 pages, 2015.
[4] J.X. Lai, H.B. Fan, J.X. Chen, J.L. Qiu, and K. Wang, “Blasting vibration monitoring of undercrossing railway tunnel using wireless sensor network,” International Journal of Distributed Sensor Networks, vol. 2015, Article ID 703980, 7 pages, 2015.
[5] W. Z. Chen, D. Zhang, and J. X. Yu, “Study on stability of closecross tunnel on existing tunnel,” Chinese Journal of Rock Mechanics and Engineering, vol. 34, no. 1, pp. 3097–3105, 2015.