Analysis of Mutual Influence on Blasting Construction of Urban Shallow-buried Small Spacing Tunnels

Yong Wu¹, Yichang Dai¹*, Shuaishuai Wang¹, Bo Wu², Shixiang Xu² & Han Wei²
¹CCCC-SHEC First Highway Engineering Co. Ltd., Wuhan, Hubei, 430056, China
²College of Civil Engineering and Architecture, Guangxi University, Nanning, Guangxi, 530004, China
*Corresponding author’s e-mail: 22758854@qq.com

Abstract. Relying on the ten-mark project of Fuzhou Rail Transit Line 2, after the right-line tunnel was excavated for 25m, the left-line tunnel was excavated, and the three-dimensional tunnel calculation model was established by the finite element analysis software Ls-dyna. The stress of the right-line tunnel lining, the ground vibration velocity and the vibration velocity of the right-line tunnel were analyzed to evaluate the influence of the left-line blasting excavation on the right-line tunnel, and verified with the on-site monitoring data. The results showed that when the maximum dose of single hole was 2kg, the left tunnel blasting excavation analysis was carried out when the minimum spacing of the two tunnels was 1.6m, the maximum stress generated on the right tunnel was 2.762MPa, which had exceeded the tensile strength of the concrete; the maximum vibration velocity generated on the ground at the top of the left-hand tunnel was 13cm/s, which exceeded the relevant control requirements; the maximum vibration velocity generated by the right arch waist was 32cm/s, which had a great influence on the right-line tunnel.

1. Introduction
The small spacing tunnel is one of the ideal choices for constructing tunnels under certain terrain conditions. Its advantages are obvious and play an active role in tunnel construction. At present, most of the construction of small spacing tunnels in China are based on drilling and blasting. When the spacing is too small, blasting will cause certain disturbance to the existing tunnel and affect the safety of the existing tunnel structure[1]. Therefore, it is particularly important to study the interaction between the tunnels built by the small clear distance tunnel and the existing tunnel. In view of the unique advantages of numerical simulation analysis, domestic and foreign scholars have used numerical simulation and on-site measurement methods to conduct a lot of research on reasonable clearance of small clear distance tunnel, response analysis of tunnel blasting vibration, optimization of construction method and safety blasting control method[2-14]. But currently there is still a lack of systematic structural design and construction experience.

In this paper, the ANSYS/LS-DYNA dynamic finite element software is used to analyze the influence of the subsequent tunnel blasting excavation on the existing tunnel. The conclusions obtained have certain guiding significance for the site construction.

2. Engineering background
The left line of the tunnel by mine method section of Fuzhou Rail Transit Line 2 project is 71.934m long and the right line is 73.251m long. The distance between the two tunnels is only 1.6~3.5m, which
is a small spacing tunnel with shallow depth and complex strata. The surrounding rock grade is VI~V, and there is a soft soil-rock interface. The tunnels underneath and sideways pass through Fuma Road, culvert, and ancient temple. There are many buildings beside the Fuma Road Embankment, and the distance is within 20m. The tunnel construction risk is extremely great.

The tunnel mine method section of Fuzhou Rail Transit Line 2 project mainly adopts the drilling and blasting method. The excavation method is constructed by full-section excavation method and up-and-down step method according to the surrounding rock level and the buried depth of the tunnel. The length of the footage of each cycle excavation should be strictly controlled during construction, and the general footage should not exceed 3m. The proposed plan is to start excavating the left-line tunnel when the right line of the tunnel is excavated to 25m. The upper and lower step are used to excavate the construction. Maximum dose of single hole of the upper step is 2kg (1 section of the cutting, 13 sections and 15 surrounding). Maximum dose of single hole of the lower step is also 2kg.

3. Establishment of finite element model

3.1. Establishment of finite element model

The right line of the tunnel was first constructed. When the right line tunnel was excavated to 25m and then the left line tunnel was excavated, the relative positions of the two tunnels were shown in Figure 1.

![Figure 1. Two holes’relative position plane schematic view.](image1)

The arrangement of the upper stepped blasthole of the tunnel was shown in Figure 2 and Table 1. The analysis showed that the first section of the cutting was the largest, and the maximum dose of the single section was 2.0Kg. Therefore, the numerical model focused on the cutting 1 segment affects on the right-line tunnel.

![Figure 2. Arrangement of blast hole.](image2)

| Blasthole name | Slot 1 | Slot 2 | Auxiliary eye | Peripheral eye |
|---------------|-------|-------|---------------|----------------|
| Number of blast hole | 4.0 | 6.0 | 5.0 | 5.0 | 6.0 | 6.0 | 10.0 | 10.0 |
| Blast hole depth(m) | 0.7 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Dose per hole (kg) | 0.5 | 0.3 | 0.3 | 0.3 | 0.3 | 0.2 | 0.2 |
3.2. Model size and boundary condition
The tunnel had a width of 7.1 m and a height of 8.4 m. The analysis model was selected to have an axial length of 60 m, a boundary of 22 m for each of the left and right boundaries, and a depth of 8.3 m for the tunnel. The upper surface took the free boundary and the other surfaces were set to have no reflective boundaries. The model were shown in Figure 3 and Figure 4.

![Figure 3. Solid model.](image1)

![Figure 4. Grid of model.](image2)

3.3. Selection of material parameters
In this model, the Langrange unit and the joint node algorithm were used for explosive, concrete lining and rock. The explosive was selected from the *MAT_HIGH_EXPLOSIVE_BURN and *EOS_JWL equations of state, and the lining and rock were modeled using *MAT_PLASTIC_KINEMATIC. The explosive material parameters were shown in Table 2, and the lining and rock parameters were shown in Table 3.

| Detonation segment order | 1.0 | 3.0 | 5.0 | 7.0 | 9.0 | 11.0 | 13.0 | 15.0 |
|--------------------------|-----|-----|-----|-----|-----|------|------|------|
| Single-stage dose (kg)   | 2.0 | 1.8 | 1.5 | 1.5 | 1.8 | 1.8  | 2.0  | 2.0  |
| Total dose (kg)          |     |     |     |     |     | 14.4kg |     |      |
| Total number of blast hole |    |     |     |     |     |      | 52.0 |      |

4. Results and analysis

4.1. Lining stress analysis

---

Table 2. Explosive material parameters

| density (kg·m⁻³) | Detonation speed (m·s⁻¹) | Explosive pressure (MPa) | JWL equation of state | A/MPa | B/MPa | R₁ | R₂ | ω | E₀/GPa |
|------------------|--------------------------|--------------------------|-----------------------|-------|-------|----|----|----|--------|
| 1200             | 3200                     | 9700                     | 2.14400E5             | 182   | 4.2   | 0.9| 0.15| 4.192|

Table 3. Surrounding rock and the lining parameters

| model            | Elastic Modulus (GPa) | density (kg/m³) | Poisson's ratio (μ) |
|------------------|-----------------------|-----------------|---------------------|
| Surrounding rock | 60                    | 2300            | 0.23                |
| Lining           | 30                    | 2500            | 0.20                |
The stress cloud diagram of 1MS, 3MS, 5MS, and 8MS of lining after the start of the explosion was analyzed. It can be seen from Fig. 5 that the stress reached the maximum at 1 MS was 2.762 MPa, and the maximum stress occurred near the arch of the right-line tunnel.

4.2. Ground point vibration velocity analysis

Three measuring points were selected on the ground as shown in Fig. 6, the ground vibration velocity Z direction was selected for analysis. The vibration velocity diagram was shown in Fig. 7. It can be seen from the graph analysis that the maximum vibration velocity of the ground at the top of the left-line tunnel reaches 13cm/s, and the other two measurement points do not exceed 10cm/s.
4.3. The vibration velocity analysis of the right-line tunnel.

Figure 8. Vibration measuring points of the right-line tunnel.

Figure 9. Right-line tunnel vibration velocity measurement.

Four measurement points were selected in the longitudinal direction near the explosion source of the right-line tunnel, the relative positional relationship of the measurement points was shown in Fig. 8. The vibration velocity diagram of the Y-direction of each measurement point was shown in Fig. 9. The analysis showed that the vibration velocity was the highest near the explosion source, and the maximum vibration velocity was 32 cm/s.

5. On-site monitoring and analysis

5.1. Monitoring plan

In order to truly reflect the degree of influence of the tunnel blasting construction on the existing tunnel, and verify the reliability of the numerical simulation, vibration velocity and the concrete initial lining strain was monitored of the existing tunnel. The vibration test points were arranged on the arch of the bursting side tunnel at intervals of 5 m. The vibration measuring point arrangement was shown in Figure 10, and the measuring point site layout was shown in Figure 11.
The lining stress measuring points were arranged next to the vibration test points. The measurement point number was consistent with the vibration measurement point number. The stress test data acquisition system used the high performance dynamic signal analysis system DH8302 of Jiangsu Donghua Testing Technology Co., Ltd., as shown in Figure 12 and Figure 13.

5.2. Vibration field monitoring analysis
When the right line tunnel was excavated to 25m and then the left line tunnel was excavated, and the vibration monitoring data of on the arch of the bursting side of the right-line tunnel was obtained. The vibration monitoring results were shown in Table 4.

Table 4. Blasting vibration monitoring result

| Measuring point | Tangential vibration velocity (cm/s) | Radial vibration velocity (cm/s) | Vertical vibration velocity (cm/s) |
|-----------------|-------------------------------------|----------------------------------|----------------------------------|
| JZ1             | 20.4                                | 31.6                             | 22.6                             |
| JZ2             | 8.1                                 | 18.4                             | 10.2                             |
| JZ3             | 4.5                                 | 15.6                             | 9.8                              |
| JZ4             | 5.4                                 | 12.1                             | 9.5                              |

The monitoring results showed that the vibration monitoring point closest to the explosion source had the highest vibration velocity, and the vibration velocity of the four monitoring points gradually decreases. The radial velocity was the largest at each vibration monitoring point, the vertical velocity was second, and the tangential velocity was the smallest. The blasting vibration monitoring results were very close to the simulation results.

5.3. Lining stress analysis
The peak stress of the lining of the right-line tunnel were obtained when the the left-line tunnel was blasting construction. The peak stress results were shown in Table 5.

Table 5. Measuring point stress peak

| Measuring point | Tensile stress peak/MPa | Stress stress peak/MPa |
|-----------------|-------------------------|------------------------|
| JZ1             | 0.84                    | 2.42                   |
| JZ2             | 0.75                    | 1.53                   |
| JZ3             | 0.31                    | 0.56                   |
| JZ4             | 0.27                    | 0.32                   |

The results showed that the stress test were close to the simulation results. The stress at the test point closest to the source was the largest, and the maximum stress decreases with the distance of the working face.
6. Conclusions
In this paper, the stress of the right-line tunnel lining, the ground vibration velocity and the vibration velocity of the right-line tunnel were analyzed respectively, and the influence of the left-line blasting excavation on the right-line tunnel was evaluated.

(1) At the 1MS time after the start of blasting, the stress generated on the right-line tunnel was the largest, and the maximum stress was 2.762 MPa, which exceeded the tensile strength of the concrete. This range may cause tensile damage to the tunnel structure, and the lining structure will exhibit tensile cracking.

(2) The maximum vibration velocity generated on the top of the left-hand tunnel is 13 cm/s. The tunnels underneath and sideways pass through buildings exceed the relevant vibration speed control requirements.

(3) The maximum vibration velocity generated by the right-line arch portion during the left-line blasting was 32 cm/s, which had a great influence on the right-line tunnel.

(4) Comprehensive measures such as millisecond delay initiation technology, strict control of the maximum dose of single hole and total dose of primary explosive, strengthening vibration monitoring and further optimizing blasting parameters should be taken to reduce the impact of Left-Line blasting excavation on Right-Line tunnel.

References
[1] Ding X, Yang S Q, Lin P, et al. (2015) Analysis of the blasting vibration characteristics during light rail tunneling. Journal of Railway Science and Engineering, 12(3): 590−595.
[2] Chen P. (2018) Research on the Rationality of the Excavation Method of Small-distance Tunnel. Journal of Railway Engineering Society, 35(04):65-69.
[3] Zhao Y L, Ren G, Kong J, et al. (2019) Determination of Reasonable Delay Distance of Small Spacing Tunnel. Journal of Water Resources and Architectural Engineering, 17(01):215-220.
[4] Zhu Z G, Sun M L, Zhu Y Q, et al. (2012) Field monitoring on blasting vibration and dynamic response of ultra-small spacing tunnels. Rock and Soil Mechanics, 33(12): 3747−3759.
[5] Wang C M. (2013) Analysis of vibration influences of small spacing tunnel blasting on existing tunnel. Blasting, 30(2): 84−89.
[6] Song K I, Oh T M, Cho G C. (2014) Precutting of tunnel perimeter for reducing blasting-induced vibration and damaged zone-numerical analysis. Ksce Journal of Civil Engineering, 18(4): 1165−1175.
[7] Ahmed L, Ansell A. (2014) Vibration vulnerability of shotcrete on tunnel walls during construction blasting. Tunnelling & Underground Space Technology, 42(42): 105-111.
[8] Li Y P, Ai C Z, Han C L, et al. (2007) Numerical simulation of blasting dynamical response of small spacing tunnel. Explosion and Shock Waves, 27(1): 75−81.
[9] Wang J H, Liu H, Yan D H. (2012) Blasting vibration impact analysis of small spacing tunnels. Chinese and Foreign Highway, 32(3): 268−271.
[10] Feng Z R, Wen X. (2008) Numerical simulation of blasting vibration from excavation of a new tunnel on existed tunnel. Blasting, 25(4): 20−23.
[11] Shi H C, Zhang J C. (2019) Blasting Vibration Effect of Wedge Cut Blasting in Parallel Small-distance Tunnel. Chinese Journal of Underground Space and Engineering, 15(02):607-613+621.
[12] Yue X G. (2018) Numerical Simulation Study on Blasting Vibration Influence While Excavating a New Tunnel Close to Existing Tunnel. Railway Construction Technology, (04):9-12+22.
[13] Guo L J. (2017) Deformation Features and Construction Method Optimization for Surrounding Rock of Tunnels with Small Net Spacing. Railway Engineering, (03):50-52+57.
[14] Sun Z Y, Zhang D L, Fang Q, Su W. (2018) Distribution of Surrounding Rock Pressure of Shallow Highway Tunnels with Small Spacing. China Journal of Highway and Transport, 31(09):84-94.