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Research on Influence Law of Explosion Load on New Subway Cross-structure

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Abstract: In order to reveal the influence law of explosion load when new subway under-crossing existing subway, the research with the method of combining theoretical calculation and numerical simulation was developed. With theoretical calculation method, the reasonable structural parameters and material parameters were chose, then the equivalent static load of under-crossing structure was obtained at the condition of explosion wave. By using the ANASYS/LS-DYNA software, the propagation law of explosion wave and the load change law of structure were simulated in four different models. Through comparison analysis, it showed the theoretical calculation method and numerical simulation method were rational, and the influence that existing subway on new under-crossing subway was only about the explosion wave propagation velocity except the explosion wave form and amplitude value, and the influence that new under-crossing subway on existing subway about explosion wave was very small. It provided a theoretical basis for design and construction for new under-crossing subway.

1 Introduction

Due to the needs of underground space planning and development, there are more and more crossovers in underground civil air defence projects[1]. The new subway could pass through the existing subway, thus changing the basic status of the existing subway. Improper handling would reduce the resistance level of the existing subway and destroy the stability of the existing subway. The existing subway would also have an impact on the resistance of the new subway [2,3].

Liu Jie[4] et al. relied on the Nanjing Ninglang Railway to penetrate the deep foundation pit of the Nanjing South Railway Station. The combination of theoretical analysis and on-site monitoring was used to analyse the deformation of the deep foundation pit of the subway tunnel. The internal force, displacement and axial force of the steel support in the retaining pile were numerically simulated. The influence of shield tunnel construction on the settlement of surrounding buildings, and the stresses and strains of the shields in different directions in the shield tunnelling process were studied by Xu Zemin of Tianjin University[5]. Yan Guodong[6] took a subway construction tunnel in a city as an example. The finite numerical software FLAC3D was used to carry out three-dimensional numerical simulation of construction and mining, and analyze the deformation of surrounding rock. It provided a theoretical basis for similar construction in China for great promotion value.The static and dynamic characteristics of the three-dimensional cross railway tunnel and its engineering application were researched by Yu Heran[7]. The dynamics research mainly focused on the response analysis of different structural forms to the dynamic load of high-speed trains. However, there were relatively few

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studies on the load variation law of subway tunnels under the blast loading. Especially for subway tunnels belonging to civil air defense engineering, it is especially important to analyze the response of subway tunnels under blast loading. .

In this paper, for the subway station of intersection of subway lines, the combination of numerical simulation and theoretical calculation were used to study the variation law of the explosion loading when the new subway underpassed the existing subway. It would ensure that the cross structure meets the specified resistance requirements and provide a theoretical basis for solving the design and construction problems for structural crossover.

The new A-line section line is from west to east. After passing through the existing subway station of B-Line, the tunnel depth was 17~21m. The section was constructed by shield method. The A-line crossed the existing subway stations and other underground pipelines. The resistance level of the two subway lines should be not reduced by the crossover structure. In this section of the project, the plane relationship of the A subway line crossing the B subway line is shown in Figure 1. The relationship between the section of the tunnel of Line A below the line B is shown in Figure 2.

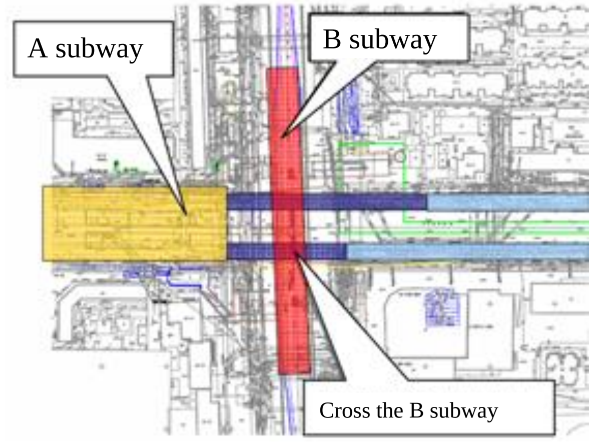

Fig.1 The plane relation between running tunnel of A subway and the subway station of B subway

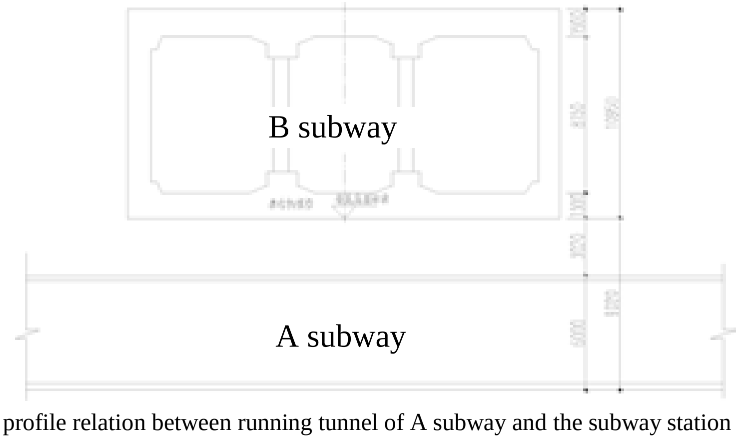

Fig.2 The profile relation between running tunnel of A subway and the subway station of B subway

2 Theoretical calculation

Assumed that the explosion shock wave overpressure of the B-line was *p*, and the equal-pressure action time was *t*.

2. 1 Structure self-vibration frequency

The natural frequency of the circular structure is calculated as follows:

- $$\omega = \frac{2.68}{R^2}\sqrt{\frac{\psi EJ}{\overline{m}}} \tag{1}$$

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in which,

R——calculated radius of the ring (*cm*);

ψ ——the stiffness reduction factor generally taken as 0.85;

E——material elastic modulus (*kg/cm*^{2});

J——section moment of inertia (*cm*^{4}); $J = \frac{bd^3}{12}$

$\overline{m}$ ——mass per unit length (*kg sec*^{2}/*cm*^{2}); $\overline{m} = \frac{\gamma F}{g}$

γ ——material bulk density (*kg / cm*^{3});

g——gravity acceleration g=981*cm/sec*^{2};

b——longitudinal unit length (*cm*);

d——section thickness (*cm*).

2. 2 Calculation of compression wave in soil

The compression waveform in the soil (rock) is simplified into a triangle. The maximum pressure and boosting time is calculated according to the following formula:

- $$P_h = \left[1 - \frac{h}{c_1 t_2}(1-\delta)\right]\Delta P_m \tag{2}$$
- $$t_{0h} = (\gamma_c - 1)\frac{h}{c_0} \tag{3}$$
- $$\gamma_c = \frac{c_0}{c_1} \tag{4}$$

in which,

P_h ——the peak pressure of the compression wave (*MPa*);

ΔP_m —— ground air shock wave overpressure peak (*MPa*);

h —— the calculated depth of the soil (rock) (*m*); when calculating the roof, the thickness of the roof should be took; when calculating the outer wall, the depth from the midpoint of each layer to the surface;

c_0 —— the initial pressure wave velocity of the soil (*m/s*);

c_1 —— the peak pressure wave velocity of the soil (*m/s*);

γ_c —— wave speed ratio;

δ —— the strain recovery ratio of soil;

t_{0h} —— compression wave boost time (*s*);

t_2 ——buck time (*s*), the equivalent positive pressure action time can be simplified according to the equal impulse.

2. 3 Structural dynamic coefficient

When the waveform of explosion loading was reduced to a triangle, the power factor should be calculated according to the following formula:

- $$K_d = \frac{[\beta] + \sqrt{[\beta]^2 - (2[\beta]-1)(1-\varepsilon^2)}}{2[\beta]-1} \tag{5}$$

2. 4 Structurally unfavorable soil thickness

Unfavorable soil thickness was calculated by the following formula:

- $$h_m = \frac{2\pi}{\omega_1} \cdot \frac{\alpha c_0}{\gamma_c - 1}$$

2. 5 Structural integrated reflection coefficient

The integrated reflection coefficient of structural top cover was related to the unfavorable soil thickness. When the thickness of the top cover soil is equal to or greater than the structural unfavorable soil thickness, the comprehensive reflection coefficient of the arch structure can be calculated according to the following formula:

- $$k_r = 2 - 0.4\left(1 - \frac{1}{\gamma_c^2}\right) \tag{6}$$
- $$\alpha_w = 1 - \frac{\rho c_1}{m\bar{c}}(1 - n\alpha_k)\left[1 - \frac{1}{\bar{c}t_{oh}}\left(1 - e^{-\bar{c}t_{oh}}\right)\right] \tag{7}$$
- $$K = 0.5(1 + k_r\alpha_w) \tag{8}$$

k_r ——fixed rigid body reflection coefficient;

α_w —— structural displacement influence coefficient, when the value of k_r α_w is less than 1.0, it is 1.0;

2. 6 Equivalent Static Load Calculation

When the underground engineering structure is designed by equivalent static load, the load should be designed according to the simultaneous action. The standard value could be calculated according to the following formula:

- $$q_1 = K_{d1}KP_h \tag{9}$$
- $$q_2 = K_{d2}\xi P_{\bar{h}} \tag{10}$$
- $$q_3 = K_{d3}\eta\frac{q_1}{K_{d1}} \tag{11}$$

in which,

q_1、q_2、q_3 —— the equivalent static load standard values of the structural top cover, outer wall and bottom plate respectively (*N/mm²*);

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K_{d1}、K_{d2}、K_{d3}——the dynamic coefficients of the structural roof, outer wall and floor;

P_h——the peak pressure of the compression wave at the depth of the overburden soil (*MPa*);

$P_{\bar{h}}$——the peak pressure of the compression wave at the midpoint of each layer of the outer wall (*MPa*);

K——the comprehensive reflection coefficient of the top cover;

ξ——the lateral pressure coefficient of the soil;

η——the base pressure coefficient.

Taking the relevant structural parameters, material parameters [8-10] into above formulas, the equivalent static loads q_1, q_2, q_3 of the structural dynamic load are calculated.

3 Numerical simulation

The numerical simulation calculation software ANSYS/LS-DYNA is a general-purpose nonlinear dynamic analysis finite element software with explicit and implicit supplements. It is especially suitable for solving high-speed collisions of various 2D and 3D nonlinear structures. Nonlinear dynamic shock problems such as explosion, metal forming, heat transfer, fluid and fluid solid coupling problems also would be solved[11,12].

This paper intended to use the combination method of numerical simulation and comparative to carry out related research. It was proposed to carry out numerical simulations of the following modes.

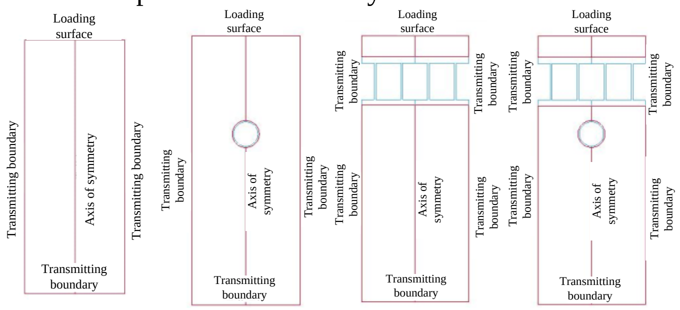
A. The propagation of an explosion shock wave in a soil-covered medium;

B. Regardless of the existing subway structure, the propagation of the explosion shock wave in the overburden and underlying structures;

C. Regardless of the new undercut structure, the propagation of the explosion shock wave in the overburden medium and the existing subway structure;

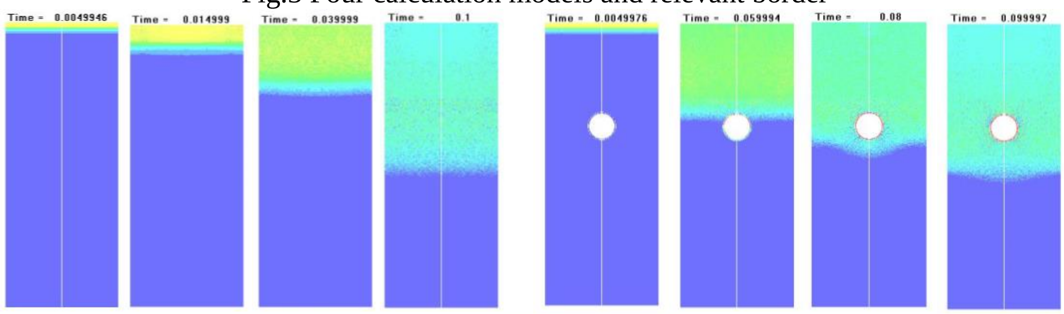
D. Propagation of blast shock waves in earth-covering media and intersecting structures.

The four calculation models and boundary definitions of numerical simulation are shown in Figure 3. The explosion shock wave propagation process are shown in Figure 4. Figure 5 shows the key measurement points and their pressure time history curves selected in Model A.



Model A Model B Model C Model D

Fig.3 Four calculation models and relevant border



Model A Model B

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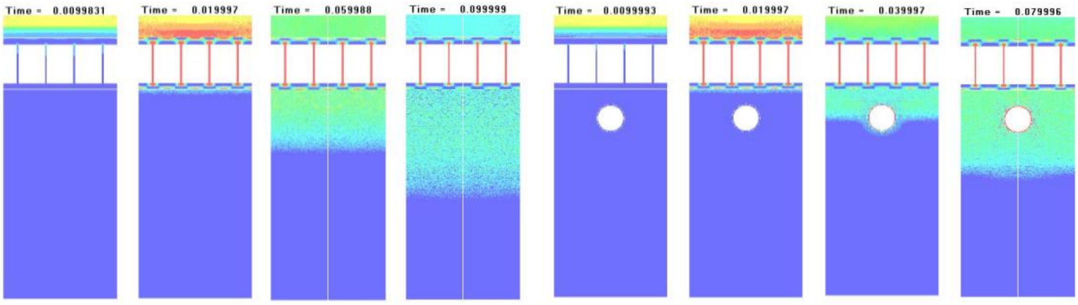

Model C Model D

Fig.4 The explosion shock wave propagation process

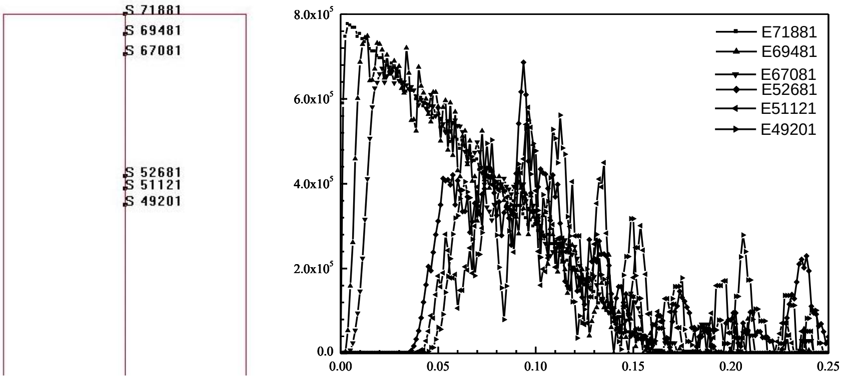

Fig.5 The place and the pressure curve of measuring point in model A

4 Results and analysis

4. 1 Comparison of theoretical calculation results and numerical simulation results

The peak value of the explosion shock wave after the attenuation of 18.9m was 0.47MPa, which was very close to the theoretical calculation result of 0.45MPa. The correctness of the numerical simulation and theoretical calculation method was verified, and the relevant parameters could be reasonable.

4. 2 Influence of station structure on pressure wave propagation

The new subway A-line passed through the existing subway station of B-line. The compression wave of explosion load propagated downward as a plane wave. When the wave met the station, the reflection waves would be occurred. Under different model conditions of different ground depths, the pressure curves of different measuring points were shown in Fig. 6. It could be seen from the figure that the peak value of the overburden pressure in the upper part and the lower part of the station was larger than that in the no station. It was mainly caused by the superposition of incident waves and reflected waves. Compared with the overburden, the station structure could be regarded as a rigid body, and the pressure acting on the top of the station would be transmitted directly to the bottom of the station through the column. Therefore, the compression wave at the bottom of the station would arrive firstly, when there were no station. It could be seen from Fig. 6 that there were little effect that the impact of the new A-line on the peak of the compression of the top and bottom of the station.

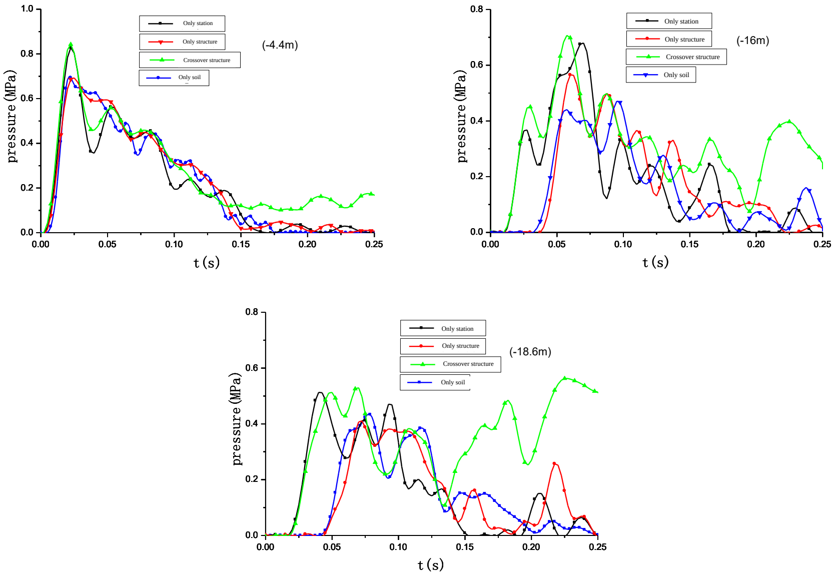

Fig.6 The earth pressure curve in different models

4. 3 Influence of the existing station built on the force of the new underpass subway line structure

E1 to E6 in Fig. 7 were the key stress measurement points of the structure. The pressure and effective stress curves were shown in Fig. 8 and Fig. 9 about the six measurement points in the structure with and without the station. From the pressure and stress distribution of the new subway line structure, it was easy to see that the pressure and effective stress curves were very close in the case of station and no station under the explosion load. It indicated that there was little effect that the existing station on the dynamic response of the structure. It could be ignored. Therefore, in the calculation of the structural dynamics of the newly built subway under the built subway, the influence of the station could be disregarded, and the upper part of the structure could be considered as pure covering soil.

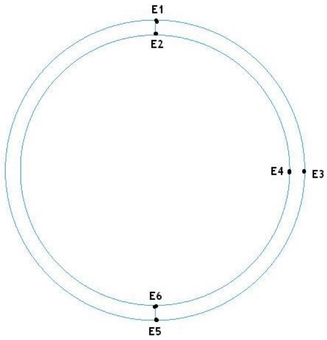

Fig.7 The key structural measuring point

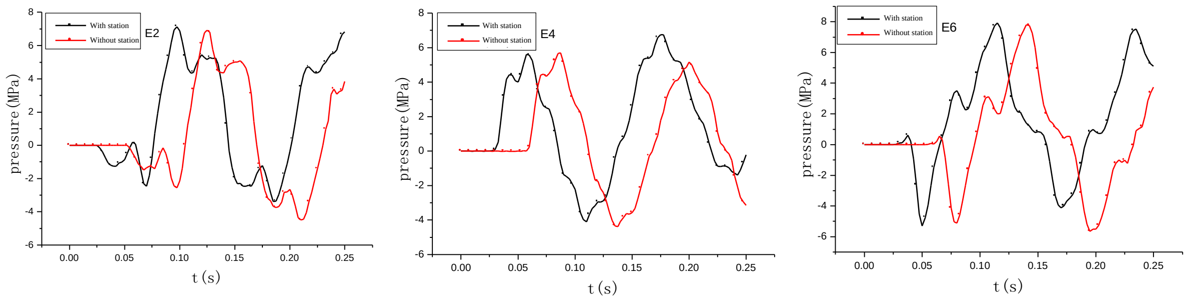

Fig.8 The pressure curve of key structural measuring points

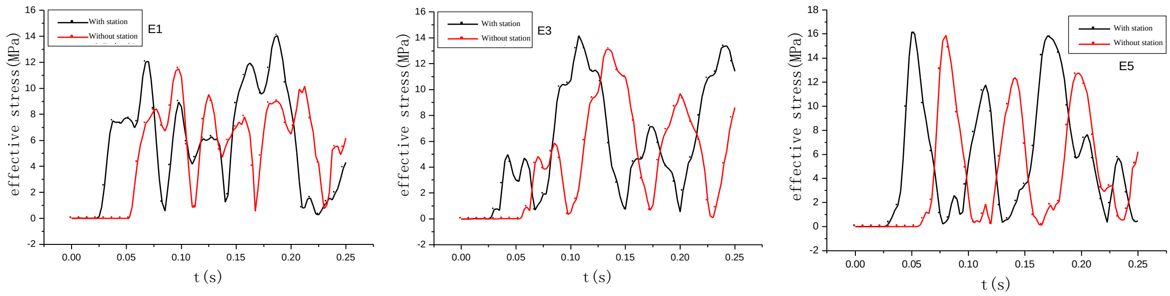

Fig.9 The effective stress curve of key structural measuring points

5 Conclusion

In this paper, the reasonableness and correctness of theoretical calculation methods and numerical simulation methods were verified by the combination of theoretical calculation and numerical simulation. By analysing and comparing the propagation modes of four different explosion shock waves, it was revealed that the propagation law of the built-up station structure on the explosion shock wave and showed the influence law of the built station structure on the new underpass subway structure. The conclusions of this paper could be used to solve the problems of new underpass subway structures. The theoretical basis was also benefit for future design and construction practices.

Acknowledgements

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