Simulation and analysis of seismic response of parallel double-hole tunnel

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Abstract: In order to realize the seismic response analysis of the parallel double-hole tunnel, this paper takes the double-hole tunnel of an underground section of shenyang subway as the research object, USES midas-gts to establish a three-dimensional finite element numerical calculation model, and analyzes and discusses its seismic response. The results show that: Under the action of seismic wave, the maximum position of relative displacement of soil is usually at the soil boundary, and the maximum position of relative displacement of tunnel lining is usually at the tunnel entrance. Along the input direction of seismic wave, the maximum relative displacement of the tunnel is greater than the corresponding value of the other two directions.

1. The introduction

In recent years, with the rapid development of China's economy, the quality of life is increasingly improved, the limited surface space has been unable to meet the needs of people, in order to truly achieve sustainable development strategy, we must make full use of underground resources, for the benefit of mankind, to achieve people-oriented. China is a country with frequent earthquakes. Compared with the above-ground structure, the investment of the underground structure is relatively large. If it is damaged, the loss is immeasurable. The underground structure is very important, and once it is damaged, it is difficult to repair it again. Current research on tunnel seismic response, Jiang jianqun and lu cirong etc[1-2], adopted the dynamic finite element method of soil-junction interaction and introduced a 3-dof spring element without length to simulate the longitudinal bolt joint, and analyzed the effects of traveling wave length, foundation stiffness and damping on the longitudinal seismic response of shield tunnel. Gaofeng etc[3-4], studied the damping effect, the applicable conditions and the mechanism of the two methods of setting damping layer in tunnel and grouting reinforcement of surrounding rock within a certain range, and analyzed the damping effect of the method of grouting reinforcement of surrounding rock. Using dynamic finite element method, yu-shu li etc[5-6], studied the dynamic response law of the transverse slope of the biased tunnel entrance under the simultaneous action of horizontal and vertical earthquakes and horizontal and vertical earthquakes. Zhou jian etc[7-8], combined the dynamic finite element method with a beam and a spring to analyze the seismic response of the cross section of the shield tunnel, and studied the influence of different joint forms and parameters on the structural stress and deformation, as well as the reinforcement and damping effect of the foundation.
2. Project overview

The research object of this paper is a parallel double-hole tunnel in a lower section of Shenyang metro. The line is a v-slope longitudinally. The maximum burial depth at the bottom of the tunnel structure is 24.6m (covering thickness is 18.6m) and the minimum burial depth is 15.5m (covering thickness is 9.5m). The starting and ending mileage is: right line K0+547.025 ~ K1+837.452, 1290.427m long, left line K0+547.025 ~ K1+836.699, 1282.618m long (including short chain 7.056m).

According to the urban rail transit structure seismic design code (GB50909-2014) of the provisions of article 3.2.1, the analysis of subway station, the requirements for seismic resistance according to the key fortification class (b) into consideration, namely the requirements under the effect of E1 and E2 earthquake, the seismic performance requirements for I of subway station structure. At E3 under earthquake action, the subway station structure seismic performance requirements for II[9].

| Peak acceleration region of ground motion (g) | 0.05 | 0.10 | 0.15 | 0.20 | 0.30 | 0.40 |
|------------------|------|------|------|------|------|------|
| Earthquake action of E1 (g) | 0.03 | 0.05 | 0.00 | 0.10 | 0.15 | 0.20 |
| E2 earthquake action (g) | 0.05 | 0.10 | 0.15 | 0.00 | 0.30 | 0.40 |
| E3 seismic action (g) | 0.12 | 0.22 | 0.31 | 0.40 | 0.51 | 0.62 |

According to the urban rail transit structure seismic design code (GB50909-2014) of table 1, II class partition field ground motion peak acceleration of 0.1 g, E1, E2 and E3 design ground motion under the action of the peak acceleration of 0.05 g and 0.1 g and 0.22 g.

3. Finite element numerical simulation

3.1. Selection and input of seismic waves

The time history of acceleration is recorded by the ground motion of strong earthquakes: The el-centro wave[10] in 1940, as an initial time history synthesis of the ground motion time history suitable for the project site, introduced the real ground motion phase information to reflect the real ground motion spectrum characteristics, especially the phase characteristics, and realized the reasonable calculation and analysis of the seismic response.

The loading time of seismic wave is 30s, the loading step is 0.04s, and the output is 750 steps. According to "seismic safety evaluation of engineering site of Shenyang metro line 10", the peak value of ground motion in the m-n interval of Shenyang metro line 10 with the probability of exceeding 2% in 50 years is 0.38g.

![FIG. 1 Waveform of el-centro wave in the X direction](image1)

![FIG. 2 Fourier amplitude of el-centro wave in the X direction](image2)

3.2. Dynamic boundary selection

Using finite element analysis, can only from the selection of semi-infinite space limited soil, truncation boundaries cannot reflect the effects of soil borders, in order to reduce the error, this paper USES the viscoelastic artificial boundary, the dynamic boundary can not only simulate the scattering
wave propagation from the finite field to the infinite domain, at the same time also can simulate elastic recovery properties of soil medium boundary.

The viscoelastic artificial boundary can be equivalent to a parallel spring shunner system with continuous distribution at the truncated boundary. The physical element parameters are as follows:

\[ K_b = \frac{G}{2R} c_b = \rho c_s \]  
\[ K_b = \frac{G}{2R} c_b = \rho c_p \]

Where, is the mass density of the medium; G is the shear modulus; R is the distance from the scattered wave source to the artificial boundary; Is shear wave velocity; Is the velocity of the compressed wave.

In the bottom of the model input seismic wave, the horizontal vibration at the top of the model using free surface (figure 3), using the above mentioned at the bottom of the viscoelastic artificial boundary (figure 4), at the same time model peripheral application of free field in the GTS NX unit to simulate the free field boundary, to produce the same effect as the infinite free space, in order to achieve the purpose of the absorption of incident wave.

3.3. 3d finite element model of tunnel

According to the shenyang metro line 10 M - N range of geotechnical engineering investigation report in detail, in the concrete finite element modeling, little change along the depth of the soil or soil layer thickness is to simplify the small double layer or multilayer soil, the parameters take its average, in the end could be divided into miscellaneous fill soil, coarse sand and gravel sand, gravel, mud gravel, soil constitutive model using common yield criterion, the soil parameters shown in the following table.

| Table 2 Main physical and mechanical parameters of soil layer |
|------------------------|----------------|----------------|----------------|-----------------|----------------|----------------|----------------|
| Layer No. | Name of the soil | The thickness of H/m | Friction Angle / ° | Cohesion of c/kPa | Poisson's ratioμ | Move mouldE/MPa | severeγ/ (kNꞏm⁻³) |
| 1       | Miscellaneous fill | 7.5 | 11.5 | 18.5 | 0.28 | 42.7 | 19.2 |
| 2       | Coarse sand       | 11.6 | 29.5 | 0    | 0.26 | 66.6 | 18.5 |
| 3       | Gravel sand       | 6.4 | 33   | 0    | 0.25 | 98.9 | 20  |
| 4       | Round gravel      | 11.5 | 34   | 0    | 0.21 | 134.5 | 20.4 |
| 5       | Boulder           | 14.6 | 37.5 | 7    | 0.23 | 317 | 20  |

The dynamic time - history analysis is carried out for the metro area. The upper boundary of the model is taken to the surface, the lower boundary is taken to the equivalent bedrock surface, and the bottom of the model is fixed. The calculation model is 1215.85m long, 416m wide and 51.6m high. The model has 1349297 cells and 273773 nodes. The soil layer adopts solid element and the constitutive model of lining structure is elastic model. The 3d model is shown in figure 5-7.
3.4. Analysis of numerical simulation results

In the following figure, the positive direction of coordinate system X axis is the transverse direction of seismic wave, the positive direction of Y axis is the longitudinal direction of seismic wave, and the positive direction of Z axis is the vertical direction of seismic wave. FIG. 8 and 9 are the cloud images of total relative displacement of transverse seismic waves.

According to figures 8 and 9, the maximum total relative displacement of the soil mass in the transverse seismic wave is 0.293996m, and the total relative displacement of the tunnel lining in the transverse seismic wave is 0.107431m. The maximum value of the total relative displacement of the soil occurs at the boundary of the soil, and the total relative displacement of the soil surface is relatively large. It can be seen from the total relative cloud image of transverse seismic wave tunnel lining that the upper part of tunnel lining has a large deformation. The maximum relative displacement occurs in the left tunnel, and the total relative displacement in the upper part of the left tunnel is greater than that in the upper part of the right tunnel, which is consistent with the direction of seismic wave propagation. FIG. 10 and 11 are the cloud images of total displacement of longitudinal seismic waves.
FIG. 10 and 11 show that the maximum total relative displacement of the longitudinal seismic wave soil is 0.252177m, and the total relative displacement of the longitudinal seismic wave lining is 0.0624105m. The total relative displacement of soil in longitudinal seismic wave is distributed symmetrically on the whole, and the total relative displacement of soil tends to decrease with the increase of soil depth. The maximum total relative displacement of longitudinal seismic wave tunnel lining occurs at the tunnel entrance. FIG. 12 and 13 are the cloud maps of total displacement of vertical seismic waves.

FIG. 12 Cloud map of total relative displacement of soil in vertical seismic waves
FIG. 13 Cloud image of total relative displacement of vertical seismic wave tunnel lining

It can be concluded from FIG. 12 and 13 that under the action of seismic waves, the maximum position of relative displacement of soil is mostly at the soil boundary, and the maximum position of relative displacement of tunnel lining is mostly at the tunnel entrance. Along the input direction of seismic wave, the maximum relative displacement of the tunnel is greater than the corresponding value of the other two directions. Therefore, when studying the seismic dynamic response of tunnel, the response value along the input direction of seismic wave should be mainly detected.

3.5. Analysis of key nodes
From the previous analysis, it can be seen that under the action of earthquake load, the maximum position of relative displacement of tunnel lining is mostly at the tunnel entrance. Therefore, we set a key detection point at the key part of the tunnel lining hole, so as to detect the change of displacement and acceleration of the detection point with time, that is, the earthquake response. In this paper, the key nodes of the left and right holes of the tunnel are selected to reflect the dynamic response of the double-hole tunnel of the shield, so as to facilitate the effective analysis of the characteristics of the double-hole tunnel of the shield under the seismic load. The location of key points is shown in the following figure:
From the previous analysis, it can be concluded that under the action of seismic waves, the openings of parallel double-tunnel are mostly the places where the displacement peak of the whole tunnel occurs. Therefore, the seismic response of tunnel openings under the action of transverse seismic waves is analyzed by taking the parallel double-hole openings as an example. FIG. 15 is the time history curve of relative displacement response of each key position under the action of transverse seismic wave. FIG. 16 shows the peak relative displacement of key nodes under the action of transverse seismic waves.
Figure 15 The relative displacement response time history curve of each key position under the action of transverse seismic wave

As can be seen from FIG.16, the negative and positive maximum relative displacement values of relative displacement in the X direction of each key node reached respectively at 2.04s and 4.52s, and the maximum value of relative displacement in the whole 20s range was reached at 2.04s. The relative displacement peak of each key node is reached at the same time.
4. Conclusion
In this paper, the key problems of establishing 3d numerical model of parallel double-hole tunnel and the seismic response are studied, and the following conclusions are drawn:

Under the action of seismic wave, the maximum position of relative displacement of soil is usually at the soil boundary, and the maximum position of relative displacement of tunnel lining is usually at the tunnel entrance.

Along the input direction of seismic wave, the maximum relative displacement of the tunnel is greater than the corresponding value of the other two directions.

Under the action of transverse seismic wave, the vertical displacement peak value of left and right tunnel is not different, and it shows good symmetry under the same buried depth. The relative displacement of tunnel structure decreases with the increase of buried depth. This shows that the safety performance of underground structure increases with the increase of burial depth.

Under the action of transverse seismic wave, the time history curves of the left and right tunnel have the same trend with time. The peak relative displacement response of the key nodes in the left tunnel is larger than that of the right tunnel, but the difference is not significant. This shows that the seismic response of double-hole tunnel is related to the propagation direction of seismic wave and the interaction between the double-hole tunnel.

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