Study on the Influence of Buried Depth on Seismic Performance of Underground Structure

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Abstract. With the large-scale construction of urban rail transit in China, subways often cross the bottom of surface buildings or are located near them. In order to study the complex catastrophic correlation effects of the underground structure of the subway, the soil and the adjacent existing structures under earthquakes, we performed numerical simulation calculations based on ANSYS to conduct research on the effects of underground structures and adjacent existing structures under earthquakes. The interaction law of nearby existing buildings, the influence mechanism of the neighboring building's depth factors on the seismic response of the complex system, and the system's seismic response law were determined.

1. Introduction
With the social and economic development and the acceleration of urbanization, high-rise buildings are too dense, and urban underground space has become a new development area. Tunnels often cross the bottom of high-rise buildings or are located nearby. Under the action of earthquakes, underground structures, soil and adjacent buildings may produce complex correlation effects. This correlation effect will change the wave field of the seismic wave propagation and make the input ground motion different from the free field, thereby greatly change the underground structure and adjacent buildings. Based on the above-mentioned deficiencies, it is necessary to carry out calculation theoretical research on the characteristics of the interaction between the underground structure, soil and adjacent existing buildings based on the existing work of previous people. The research of the project is of profound significance both to the development of the discipline itself and to the application of engineering.

2. Domestic and foreign research status and development trends
The development of underground structures will change the original foundation conditions of the ground structure, thus affect nearby existing buildings. Masoud[1] et al. carried out a shaking table model test to study the influence of underground structures on the surface acceleration of the site. The test results showed that factors such as the size and depth of the underground structure have significant effects on the surface acceleration; Professor Chen Guoxing[2] studied the variation law of the site soil seismic effect caused by the excavation of shallow tunnels in soft soil foundation with numerical simulation; Liang Jianwen[3] studied the series solution of the ground motion of the underground tunnel group when the seismic waves were incident. Chen Jianyun[4] studied the effect of the underground structure in the layered soil on the seismic response of the site soil and surface buildings. A preliminary study was conducted by Wang Guobo[5] on the effect of the group-cavity effect on the soil dynamic characteristics of the surrounding site; Yan Shuwaing[6] established an overall dynamic analysis model of the subway tunnel and adjacent buildings in the layered site, and systematically studied the influence law of the distance between buildings and other factors on the seismic response.
of adjacent existing buildings. The research results show that the existence of the subway tunnel will significantly amplify the dynamic response of the surface [7].

In addition to the impact of the presence of subway tunnels on the dynamic response of the site soil, the study of the impact of the existence of adjacent existing buildings on the seismic response of underground structures is equally important. As early as the 1980s, Wang Kaishun pointed out through research [8]: The influence of the superstructure on the dynamic characteristics of the surrounding site soil is transmitted through the structural foundation, and the depth of the surface building foundation's impact on the surrounding site soil during earthquake is 30 meters. However, research work in this area did not start to attract attention until the large-scale construction of urban underground space in recent years, and there are few relevant literatures, mostly domestic scholars. Chen Fangjie [9] studied the influence of adjacent surface structures on the seismic dynamic response of underground structures; Professor Wang Guobo [10] established an overall two-dimensional model to study the seismic response of the system underneath the tunnel-soil-surface adjacent frame structure interaction system. Professor Most research results indicate that the existence of adjacent existing buildings will increase the seismic dynamic response of underground structures.

Due to the complexity of the interaction system between the underground structure and the neighboring building structure, the existing research is still far from enough, and there is a lack of systematic understanding of the earthquake catastrophe of this complex system. The research of this paper will provide a scientific basis for urban earthquake disaster control.

3. Model establishment and experimental methods

3.1. Model basic data

The three-dimensional frame model was selected for research. Among them, the first floor is located underground, the third floor is located above, and the height above ground is 3.3m. The overall dimensions are 14.4m in x direction and 10.8m in y direction. A square column is adopted. The dimensions are 250mm × 500mm and 250mm × 600mm. The board thickness is 120mm. A raft-type foundation with good integrity is adopted, with a size of 14.8m × 11.2m × 2m.

Drucker-Prager (D-P) model is used to simulate the constitutive model of soil. The size of the foundation is 135m × 130m × 35m, and the influence of the structure spacing on the structure is studied. Artificial boundaries are used around the soil, and spring comb in 14 is used for simulation. A one-way spring damper is used to connect the foundation and the surrounding soil. The mechanical parameters of the structure and foundation soil are shown in Table 1.

| Mechanical parameters     | Elastic Modulus(MPa) | Poisson's ratio | Density(kg/m³) | Elastic foundation stiffness(N/mm³) |
|---------------------------|----------------------|----------------|----------------|------------------------------------|
| Structure                 | 3.0×10⁸              | 0.2            | 2600           | -                                  |
| Foundation soil           | 2.5×10⁷              | 0.45           | 260            | 2.0×10⁷                            |

3.2. Model unit selection

![Fig.1 Global finite element model](image1) ![Fig.2 Distribution of contact elements](image2)
The large-scale finite element analysis software is used in this research, considering the requirements of the dynamic model. The beam simulated with BEAM189 element and column based on Timoshenko beam theory including the shear deformation effect is selected, and the SHELL181 element is used for the floor (ground) slab. The 8-node solid element SOLID65 is used for the retaining plate and foundation, and the SOLID45 element is used for the foundation. Connection between the foundation and the surrounding soil is focused on with a one-dimensional tensile or compression unit COMBIN14 to simulate the axial spring-damper, and the auxiliary surface effect unit SURF154 is used to simulate various changing loads and surface effects. In addition, with the contact guide, the friction coefficient is 0.8, and point-to-surface contact is used. The rigidity such as the retaining plate and foundation is selected as the target, and the flexible foundation is selected as the contact object. The overall model is shown in Figure 1, and the distribution of contact elements are shown in Figure 2.

3.3. Load input and solution

The load of each layer is $5 \times 10^{-3}$N/mm$^2$. Rayleigh damping is used.

$$[C]=a[M]+b[K]$$  

where $[C]$ is the damping matrix, $[M]$ is the mass matrix, and $[K]$ is the stiffness matrix. Damping matrix is determined according to equation (2).

$$\begin{bmatrix} a \\ b \end{bmatrix} = \frac{2\xi}{\omega_i + \omega_j} \begin{bmatrix} \omega_i \omega_j \\ 1 \end{bmatrix}$$

where $\xi$ is the damping ratio, and $\omega_i$ and $\omega_j$ are the natural frequencies of the $i$-th and $j$-th order structures. The Elcentro wave $x$ direction data are used to calculate and summarize the law. Seismic wave data within 3.4s are adopted.

4. Research content and results

4.1. The effect of burial depth.

(a) Interlayer displacement of the underground layer  (b) Interlayer displacement of the first layer
The seismic response of the structure in three directions of x, y, and z when the burial depth is 6.8m, 7.3m, 7.8m is studied.

The variation of the interlayer displacement (m) of each layer in the x direction with time is shown in Figure 3. The changes of the interlayer displacement (m) in the y and z directions with time in the underground layer and the ground layer are shown in Figures 4 and 5, respectively.

It can be seen from Figure 3 that under the action of the seismic wave in the x direction, the law of the interlayer displacement of each layer in the x direction varies basically with time. The change of burial depth has the most obvious change on the interlayer displacement of the underground layer, indicating that with the increase of the burial depth, the internal force caused by the earthquake action has a certain increase in the impact on the underground structure. Since the underground structure was first affected by the earthquake, the energy dissipation mechanism did not fully play its role, and it was most likely to be destroyed during the earthquake. Therefore, to minimize the effect of seismic action on the interlayer displacement of underground structures, a smaller burial depth should be selected.
It can be seen from Figures 4 and 5 that the displacement of the structure in the $y$ and $z$ directions changes with time. The change of the buried depth of the structure is not obvious to the displacement of the underground structure in the $y$ direction, but it still reflects the characteristics of the most obvious effect of the buried depth on the vertical displacement of the underground layer. As the burial depth increases, the displacement of the underground layer in the $z$ direction shows a gradually decreasing trend.

4.2. Conclusions

In this paper, through the numerical simulation, based on the dynamic finite element method, the change rule of the underground structure with the buried depth is studied, and the following conclusions are obtained:

1. Under the earthquake, there are certain correlation effects on the underground structure and soil, and the displacement response of the structure in three directions of space shows obvious regularity with the change of buried depth.

2. The depth of the structure has a significant effect on the horizontal displacement of the underground structure. As the burial depth increases, the interlayer displacement of the underground structure increases significantly in both horizontal directions and decreases in the $z$ direction.

3. Under the action of the $x$ direction ground motion, the interlayer displacement along the $x$-direction gradually increases with the increase of the burial depth, indicating that the internal force generated by the underground structure under the earthquake action will increase to a certain extent as the burial depth increases.

4. In this paper, the displacement law of single-layer underground structure under earthquake is studied. The displacement characteristics under the influence of multi-layer underground structure and different foundation types have not been taken into consideration. It is reasonable under the influence of soil characteristics and other factors. The value of the structure's buried depth has not been quantified specifically, which is also the research work that should be continued in the future.

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