The earthquake under the action of underground structure and the influence of the distance between adjacent buildings

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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 carried out numerical simulation calculations to study 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

The problem of resources and population is becoming more and more serious in the process of urban development. The number of underground structures is increasing, but the relevant seismic design theory and methods, especially the seismic performance index of underground structures is still insufficient. Various structural forms can well solve various construction problems. In the future underground construction, taking into account the rapid urbanization process in recent years, the underground become a major development direction to alleviate the insufficient underground space in the city and the underground construction of the traffic lines around the city. Although the building height and design difficulty are higher than those of the aboveground structure, it can provide a more independent and stable environment, so the research on underground structure is particularly important.

2. Domestic and foreign research status and development trends

Seismic deformation of underground structures is mainly controlled by relative displacement of surrounding strata. Active absorption of seismic displacement by setting isolation layer is an effective seismic measure. Liu Peng[1] analyzed and compared the isolation effect of isolation layer setting position and thickness on subway station by response acceleration method. Jiang Zhiwei[2] et al. studied the influence of buried depth on shaking table test results of underground structure, and proposed a method combining numerical simulation of integral response displacement method with free experiment to predict the seismic response of underground model structure in shaking table test. Yang Yusheng[3] et al. proposed a practical seismic model of underground structures which can consider the restoring force of underlying elastic bedrock and the dissipation effect of reflected seismic wave to the depth of earthquake. Sheng Anxiang[4] studied the influence of buried depth on the seismic action of underground structure. Qiu Yanjia[5] et al. proposed a seismic experimental method
for building basement considering soil-structure interaction. Yu Haitao\cite{6} et al. aimed at the wave method and vibration method which are widely used in the seismic analysis of underground structures, the difference and connection between the two methods were clarified from the physical equation and finite element scheme.

Referring to the classification method of ground building performance level, Du\cite{7} et al. divided the seismic performance level of underground structure into four levels, and briefly described the function of the structure under each level. Through Pushover analysis analysis method, Lan Xinghuan\cite{8} deeply analyzed the seismic performance of the above-ground and underground structures, discussed the similarities and differences of the seismic performance of the above-ground and underground frame structures, and proposed a pseudo-static loading test method for underground structures realized on the ground. Xu Kunpeng\cite{9} compares and analyzes the applicability of various simplified seismic analysis methods for underground structures through numerical simulation and quasi-static experiments. Wang Yang\cite{10} et al. proposed to apply the analysis column to the underground structure, and improve the horizontal deformation capacity of the key support of the underground station through structural measures, so as to improve the seismic performance of the whole station.

Due to the complexity of the interaction system between underground structure and adjacent building structure, the current research lacks systematic understanding of the earthquake disaster of this complex system. The research in this paper will provide a scientific basis for the seismic disaster control of urban underground structures.

3. Model establishment and experimental methods

3.1. Model basic data
Select three-dimensional frame model for research. Among them, the third floor is above the ground, and the first floor is below the ground, with the height of 3.3 m. The overall size of each layer is selected as 14.4 m in x direction and 10.8 m in y direction. Size of 250mm × 500mm and 250mm × 600mm column load, floor thickness 120mm. The raft foundation with good integrity is 14.8 m × 11.2 m × 2 m in size. The sizes of the two three-dimensional frame models were the same.

The Drucker-Prager (D-P) model is used to simulate the constitutive model of soil, and the foundation size is 135m × 130m × 35m. The influence of structural spacing on the structure is studied by changing the spacing between the two buildings. Artificial boundary is used around the soil, and spring combination14 is used to simulate the constraint effect of surrounding soil on the foundation. A unidirectional spring damper is used to simulate the connection between foundation and surrounding soil. The mechanical parameters of structure and foundation soil are shown in Table 1.

| Mechanical parameters | Elastic Modulus (MPa) | Poisson's ratio | Density (kg/m³) | Elasti foundation stiffness(N/mm³) |
|-----------------------|-----------------------|-----------------|-----------------|-----------------------------------|
| Structure             | 3.0×10⁴               | 0.2             | 2600            | -                                 |
| Foundation soil       | 2.5×10⁵               | 0.45            | 260             | 2.0×10⁷                           |

3.2. Model unit selection
In this study, considering the requirements of the dynamic model, large-scale finite element analysis software was used for analysis and simulation. Among them, the beam and column are simulated by BEAM189 element, and the floor (ground) is simulated by SHELL181 element. Retaining plate and foundation adopt 8 node solid element SOLID65 element, foundation adopt SOLID45 element, SURF154 is used to simulate various load and surface effect. The constraint between foundation and surrounding soil is simulated by one-dimensional tension or compression element COMBIN14 to simulate axial spring-damper. The contact effects between foundation, retaining plate and foundation are set by using the contact guide, where the friction coefficient is 0.8 and the point-to-face contact is adopted. The stiffness of 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 Fig. 1, and the distribution of contact elements is shown in Fig. 2.

![Figure 1. Global finite element model](image1)

![Figure 2. Distribution of contact elements](image2)

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

$$[C] = a[M] + b[K]$$  \hspace{1cm} (1)

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).

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

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 influence of the distance between adjacent structure.

![Displacement changes in the x direction of each layer](image3)

When the distance between 10 m and 15 m and 20 m respectively, Figure 3 shows the layers of the
interlayer displacement in the x direction with the change of time, Figure 4, Figure 5, the underground layer and a layer of the earth are given respectively in y and z direction of the displacement between the layers with the change of time.

The figure 3 shows that in the x direction under the action of seismic wave, the structure of each layer in the x direction interlayer displacement variation law with time are basically identical. Underground layer of interlayer displacement relative to the ground each layer is small, but the change of the spacing between layers of the underground displacement change the most obvious. With the increase of the layer number, seismic displacement caused by volatility decreases, shows the structure of energy consumption increase.

Underground structures due to the earthquake, the first to receive energy mechanism not give full play to the role, so in the most prone to damage during the earthquake. When the spacing is too large, seismic wave energy absorption will be hard to adjacent buildings, resulting in greater damage. For the three layer structure, when the spacing of 20 m, clear displacement between layers in the space below 10 m. Therefore, to make the displacement between layers of the underground structure seismic action minimal impact, should choose the appropriate spacing structure.

From the displacement of structure in y and z direction, the change of the structure of spacing of underground structure of the y direction displacement change is not obvious, but still reflects the gap on. With the increase of spacing, a layer of the vertical displacement between floors of the underground decreases gradually. Therefore, the greater the distance between structure, the impact on the vertical displacement is smaller.
5. Conclusions
(1) Under the action of earthquake, the displacement response of the structure in three spatial directions shows obvious regularity with the change of the spacing of adjacent buildings.
(2) The underground structure under the effect of x to the earthquake, Along the x to the displacement increase gradually with the increase of the distance, shows that nearby building seismic responses of structure has obvious energy absorption and energy dissipation effect. But considering the structural subsidence and lighting effects, such as structure spacing should be in a reasonable range.
(3) Under the effect of x to the earthquake, the structure of the distance between the change of underground structure of y, z direction of the displacement change is not obvious, but still reflect spacing to the ground as the structure of spacing, the greater the effect on vertical displacement is smaller.
(4) In this paper, the displacement law of single-story underground structure under earthquake is studied under the condition of adjacent building spacing change. The displacement characteristics under the influence of multi-storey underground structures and different soil characteristics were not considered. The buried depth of the structure has not been specifically quantified, which is also the research work that should be continued in the future.

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