Establishment of an analysis model for the influence of seismic liquefaction site position change on seismic performance of metro stations

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Abstract. In recent years, the construction of subway projects has flourished, and the flow of personnel in underground structures such as subway stations has also increased. Once earthquakes occur, they will bring a series of unpredictable and malignant effects to the country. Therefore, it is necessary to strengthen the subway stations, etc. Research on earthquake resistance of underground structures. According to the research on the earthquake damage that has occurred, it is found that the underground structure damage such as the subway station is caused by the liquefaction caused by the earthquake. Based on the powerful functions of ABAQUS in solving nonlinear problems, this project establishes a two-dimensional liquefiable field-metro station finite element analysis model. The subway station form mainly adopts the commonly used two-story double-span island metro station structure. Based on the open secondary development port of ABAQUS embeds a sand constitutive subroutine that can describe the nonlinear characteristics of sand liquefaction dynamics, which provides a reference for a certain degree of reference for the difference of seismic response of metro stations in the future.

1. Introduction
In this paper, the most commonly used numerical simulation method is used to study the seismic response of the subway station caused by the liquefaction caused by the earthquake. The subject first establishes a two-dimensional finite element analysis model based on ABAQUS, and then sets the relevant parameters, condition parameters and ground motion [1-3], according to the engineering site conditions designed by the subject. Finally, ABAQUS powerful nonlinear solution ability is used to carry out numerical simulation calculation of the model considering the influence of soil-structure interaction on static-dynamic coupling numerical analysis. The sand liquefaction power established by the author’s tutor is used in the calculation. The characteristic constitutive model[31] simulates the dynamic nonlinear characteristics of sand, and the dynamic characteristics of concrete adopts the viscoplastic dynamic damage model.

2. Liquefaction site - establishment of two-dimensional finite element analysis model for metro station
2.1. soil-mechanical interaction finite element calculation model of metro station structure
This paper mainly selects two-story double-span island subway station as the research object. The width of the subway station is 20 m. The height of the subway station is 12 m. The depth of the subway station is 4 m. And the thickness of the roof of the metro station structure is 0.9 m. The
thickness is 0.9 m. The thickness of the middle plate is 0.4 m. The thickness of the side wall of the bottom layer is 0.9 m. The thickness of the side wall of the top layer is 0.9 m. The center column of the station structure is a cylinder with a diameter of 0.8 m. And the axis of the middle column is from the bottom of the metro station. The distance between the axes of the side walls on both sides is 9.6 m, and the distance between the centers of the adjacent middle columns is 9 m. The longitudinal beams of different sizes along the axial direction of the station are designed at the joint between the center column and the top plate, the middle plate and the bottom plate. The twisting treatment is performed at the intersection of the panel and the side wall and its longitudinal beam.

The four-node plane strain full-integration unit is used to simulate the liquefiable site and the underground structure of the metro station. Only the pressure can be generated between the soil and the structure during the modeling, and the tensile force cannot be generated. Therefore, the action form of the soil and the structure is the contact surface method. To the hard contact, the tangential direction of the contact surface is frictional contact, and the vertical direction of the bottom most boundary of the model is set as the constraint. The horizontal direction of the left and right sides of the model is set as the constraint, and the vertical direction is not set. The upper boundary horizontal and vertical boundary conditions at the surface are not constrained. The dynamic constitutive model of the soil uses the nonlinear dynamic constitutive model\[4\] of sand liquefaction dynamics established by the instructor of the author. The four-node plane strain full-integration unit is used to simulate the sand liquefaction site, and the Byrne simplified Martin-Finn is adopted. The vibration pore pressure increment model describes the liquefaction characteristics of the soil. The Davidenkov viscoelastic constitutive model is used to describe the nonlinear characteristics of the soil. This model has been developed in ABAQUS software\[5\].

According to the research of Lou Menglin et al.\[6\] and Chen Yueqing et al.\[7\], when the width of the finite element model of the whole site is greater than 5 times the width of the structure, the influence of the boundary on both sides of the foundation on the structural dynamic response basically disappears due to the subway. The maximum size of the station structure is 20 m. Therefore, the calculated width of the foundation is 130 m. It is basically necessary to consider the influence of the boundary on both sides of the foundation on the dynamic response of the structure. The dynamic constitutive model of the concrete adopts Jeeho Lee et al.\[8\]. The proposed viscoplastic dynamic damage model, the meshing of the dynamic interaction system of soil-metro station structure is shown in Figure. 1. The grid size of the metro station is about 0.25 m × 0.25 m. The core area of the soil layer (the dense area of the grid in Fig. 6) has a grid size of 1 m × 1 m and a maximum grid size of 2 m×2 m.

![Figure 1. Mesh division of dynamic interaction model of soil-metro station structure](image)

### 2.2. Engineering site conditions

| Soil layer | Soil description            | Thickness / m | Severe Y (kN/m³) | Shear wave velocity vs / (m/s) | Davidenkov model parameters | Byrne model parameters |
|------------|------------------------------|---------------|------------------|-------------------------------|-----------------------------|------------------------|
|            |                              |               |                  |                               | YW (×10⁻⁴) | A    | B    | C1 | C2 |
| 1-2        | Soft-plastic silty clay      | 2.0           | 19.8             | 192                           | 4.0          | 1.00 | 0.36 |
| 3-6        | Silt sand, fine, saturated   | 4.0           | 19.6             | 138                           | 3.8          | 1.03 | 0.40 | 0.82 | 0.49 |
According to the engineering site conditions of the metro station in Nanjing, the typical liquefiable site in Nanjing is selected as the soil condition, and the typical liquefiable site in Nanjing is selected as the soil condition. The material parameter is set to 33 m and the bottom is the bedrock surface. The soil width is set to 130 m. This paper divides five sand sites with different locations of seismic liquefied soil layers as the construction site of the two-story double-span island subway station structure. As shown in Table 3, the groundwater depth of the site conditions is 2 m. The buried depth is 2 m, and the groundwater level is above the clay layer. The physical and mechanical properties and constitutive model parameters of each soil layer are shown in Table 1[9], where $V_S$ is the shear wave velocity, $\gamma_0$ is the reference shear strain, $A, B, C_1, C_2$ are test parameters. There are 7 soil layers. In the calculation, the soil layer is divided into 33 sub-soil layers as shown in Figure 2. The setting method of the liquefied soil layer is shown in Table 4. Because of the short time of the earthquake, the pore water is too late to discharge. So the Poisson's ratio of the soil in the calculation of the total power stress method is usually 0.49[10].

| Liquefied soil layer name | Soil layer thickness | Relative position to the subway station |
|--------------------------|---------------------|---------------------------------------|
| Liquefied soil layer 1   | 3-6 4.0             | 4m thick soil layer on the roof of the subway station |
| Liquefied soil layer 2   | 7-10 4.0            | 4m to 8m thick soil layer at the top of the side wall of the subway station |
| Liquefied soil layer 3   | 11-14 4.0           | 4m to 8m thick soil layer at the bottom of the side wall of the subway station |
| Liquefied soil layer 4   | 15-18 4.0           | 4m thick soil layer at the bottom of the subway station |
| Liquefied soil layer 5   | 3-22 16.0           | Metro station roof 4m down to bottom 4m thick soil layer |

Figure 2. Schematic diagram of sub-soil division of engineering site.

3. Conclusion

Based on the ABAQUS finite element analysis software, this paper selects the coupling boundary conditions of the finite element physics analysis model for the static-dynamic coupling nonlinear simulation of the underground structure of the two-story double-span island subway station. Considering the actual deformation characteristics of the geological conditions of underground structures such as subway stations under the surface, a static numerical simulation analysis model for
the static-dynamic coupling of the underground structure of the two-story double-span island subway station was established.

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