Study on simulation method of excavation of metro transfer station

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Abstract. In order to study the numerical simulation method of metro transfer station, a three-dimensional finite element model with and without considering fluid-solid coupling effect is established based on a metro transfer station of Jinan. The difference between the displacement of diaphragm wall, as well as the ground surface settlement, under the two conditions is compared. And a conversion equation of the retaining structure is deduced to convert the discontinuous pile wall into a continuous wall for numerical simulation modelling. The conclusions of this paper could serve as a reference for the numerical simulation of other metro transfer station projects.

Keywords: fluid-solid coupling; numerical simulation; conversion equation; retaining structure.

1. Introduction
For the excavation engineering with dewatering, the influence of seepage can not be ignored [1, 2]. At present, the two-dimensional (2D) finite element model tends to be used in the numerical simulation of excavation considering the seepage effect [3, 4], while the fluid-solid coupling effect is rarely considered in the existing 3D numerical simulation of excavation of metro transfer station [5, 6]. Therefore, in order to study the numerical simulation method of metro transfer station, a three-dimensional finite element model with and without considering fluid-solid coupling effect is established based on a metro transfer station of Jinan. The difference between the displacement of diaphragm wall and the ground surface settlement under the two conditions is compared. In addition, a conversion equation of the retaining structure considering elastic modulus reduction is deduced to convert the discontinuous pile wall into a continuous wall for numerical simulation modeling. The results of this paper can provide a reference for the numerical simulation of other metro transfer station projects.
2. Conversion equation of retaining structure

Compared with the general foundation pit, the foundation pit of the metro transfer station could be divided into two parts: transfer zone and non-transfer zone. Taking a Jinan metro transfer station as an example, the maximum excavation depth of non-transfer zone is 16.7m, and that of transfer zone is 25.9m. When the excavation of the public soil layers of the transfer and non-transfer zone is completed, a certain depth will continue to be excavated in the transfer zone, and therefore an additional internal retaining structure should be added at the interface between transfer and non-transfer area, as shown in Fig. 1.

\[ \frac{\pi D^4}{64} = \frac{LH^3}{12} \]  

Where \( E_1 \) and \( I_1 \) are the elasticity modulus and inertia moment of the pile wall, and \( E_2 \) and \( I_2 \) are those of the converted wall.

Assuming that the elasticity modulus is constant before and after conversion, the wall thickness calculation equation is shown in Eq. (3):

\[ \frac{\pi D^4}{64} = \frac{LH^3}{12} \]  

Where \( D \) is the pile diameter, \( L \) is the wall length, and \( H \) is the wall thickness.

Although this conversion method only considers the continuity of the pile wall in the vertical direction, it does not consider the discontinuity of bored piles in the plane along X-axis direction which is different from secant piles, as shown in Fig. 2. If \( H \neq D \) is obtained, the cross-section characteristic of pile wall in Y-axis direction will be changed. Therefore, in order to make the conversion result more reasonable, it is necessary to change the elastic modulus of the converted wall as a result of its thickness should be equal to the pile diameter after conversion.
When $D=H$, Eq. (3) could be obtained according to Eq. (1) and Eq. (2):

$$E_2 = \frac{3\pi D}{16L} E_1$$

(3)

3. Numerical model

3.1. Model of soil and retaining structure

In the model, the plane length of the foundation pit is 90m and the width is 50m. The soil, diaphragm wall and converted wall are modeled by half using a symmetry plane which is the XZ plane passing through the midpoint of the short side of the foundation pit, as shown in Fig. 3. The soil element type is C3D8RP with considering fluid solid coupling effect, which is C3D8R without considering the effect. The thickness of the g diaphragm wall is 0.8m, and the element type is C3D8R. Models of the internal retaining structure are converted into continuous wall with a thickness of 1m and 0.8m according to Eq. (2) and Eq. (3) respectively, and C3D8I is selected as element type. The parameters of the two converted walls are shown in Table 1.

![Figure 3. Three-dimensional model](image)

| Converted wall parameter |
|--------------------------|
| Thickness /m | Equation | Bulk density/(kN·m⁻³) | Elastic modulus/MPa | Poisson's ratio |
| Converted wall 1 | 1 | (3) | 25 | 31500 | 0.3 |
| Converted wall 2 | 0.8 | (2) | 25 | 15500 | 0.3 |

3.2. Boundary conditions and Construction sequence

When fluid-solid coupling effect is considered, the boundary conditions of the soil model are as follows: symmetrical and impervious boundary conditions are applied on the symmetry plane; the other side surfaces are restricted horizontal displacement and imposed constant pore pressure
boundary; the bottom surface is fixed and impervious, and the upper surface is free. When fluid-solid coupling effect is not considered, except all the pore pressure boundary conditions not imposed, the other boundary conditions are the same.

The foundation pit is excavated in layers shown in Fig. 1 specifically, and the initial groundwater level is located on the ground surface, which would be dewatered to the bottom of the excavation layer before each excavation step. When the fluid solid coupling effect is not considered, the saturated gravity of soil is used, and the other construction steps are the same except dewatering in excavation.

3.3. Analysis of calculation results

![Displacement contour graph of the diaphragm wall](image)

(a) With fluid-solid coupling effect

(b) Without fluid-solid coupling effect

Figure 4. Displacement contour graph of the diaphragm wall
Fig. 4 and Fig. 5 show that after the excavation, the simulation results of horizontal displacement of diaphragm wall and the ground surface settlement behind the wall with the fluid-solid coupling effect are greater than those without the effect where the former is about twice and four times as much as the latter respectively. The results indicate that the effect of seepage on the horizontal displacement and the settlement is obvious due to the increase of the effective stress in the soil, and therefore, the fluid-solid coupling effect must be considered in the simulation.

Fig. 6 is the comparison of horizontal displacement of two converted wall. Although the horizontal displacement of the two walls increases with the increase of excavation depth, the deformation law of
wall 1 is the same as that of general diaphragm wall [7, 8], while the maximum displacement of converted wall 2 is always at the top, and the wall deformation decreases downward along the depth, which is the same as that of pile support structure [9, 10], which indicates that the conversion method of Eq. (3) is more reasonable.

4. Conclusion
The following conclusions can be drawn through research:
(1) Seepage has an obvious effect on the lateral deformation of the supporting structure and the settlement of the soil around the foundation pit. The simulation results of horizontal displacement of diaphragm wall and the ground surface settlement behind the wall with the fluid-solid coupling effect are 2 times and 4 times of those without the effect respectively. In areas with significant groundwater seepage effects, the fluid-solid coupling effect must be fully considered for the numerical simulation of metro transfer station projects.
(2) According to the equivalent principle of bending stiffness, a conversion equation of the retaining structure is deduced to convert the discontinuous pile wall into a continuous wall for numerical simulation modelling, which is more reasonable to describe the deformation law of pile support structure. The maximum displacement of the structure is always at the top, and the displacement decreases along the depth.

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