Study on the influence of deep foundation pit excavation on adjacent metro structure

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Abstract. The excavation of deep foundation pit will have an adverse impact on the existing adjacent subway structure, which is affected by a series of factors such as subway structure, foundation pit depth and excavation construction process. Based on the excavation of a deep foundation pit adjacent to a subway station in Tianjin, through three-dimensional numerical calculation and analysis, it is concluded that after the excavation of the foundation pit, the structure of the subway station has local settlement, local floating and small horizontal displacement. According to the numerical results, the corresponding hazard sources are put forward, and the monitoring and early warning pre-values of hazard sources are given, in which the reference value of floating wind pavilion is about 1.3cm, the reference value of settlement value at the entrance and exit of subway station is about 6mm, the maximum horizontal displacement of diaphragm wall is about 7cm, and the maximum settlement outside pit is about 5cm. The results of this paper provide a basis for engineering risk points, and provide operational guidelines for monitoring risk points.

1. Introduction
The research on the influence of foundation pit excavation on the surrounding environment has a history of nearly one hundred years, which mainly includes the following stages: The first stage, from the perspective of soil mechanics, studies the causes of foundation pit deformation. Meinzer[1] defined the concept of floor subsidence in 1923, Fokkensa and Weijenberga[2] measured the groundwater level in 1960s, and Lohman[3] further discussed the causes of ground subsidence. The principle of effective stress is basically used to explain the mechanism of land subsidence, and it is considered that the increase of effective stress caused by the decrease of groundwater pressure is the cause of aquifer compaction. Goldberg[4] made statistics on more than 60 foundation pit data, and found that wall types and supporting methods have little influence on foundation pit deformation in gravel or hard clay. On soft clay foundation, diaphragm wall has better supporting effect than flexible structure. Clough and Schmidt[5], by counting the data of eleven hard clay foundation pits with flexible retaining structures, think that there is a certain relationship between the lateral displacement of foundation pit retaining
structure and the uplift resistance coefficient of the pit bottom, and put forward a method to estimate the maximum ground settlement according to the uplift resistance stability coefficient of the pit bottom. In the third stage, aiming at the complex foundation pit, further improve the relevant theories and sum up experience. Xue Yuqun [6, 7] and many other scholars have studied the problem of land subsidence from the mechanism of aquifer compaction caused by pumping. Zhou Zhiyang et al. [8] combined with the south anchor foundation pit project of Runyang Yangtze River Highway Bridge, considering the nonlinear change of parameters in soil layer, deduced a new calculation method of fluid-solid disaster, which provided a new calculation method for the stability and deformation control of foundation pit. Ye Weimin et al. [9] analyzed the influence of confined water dewatering on the surrounding land subsidence in a deep foundation pit project in Shanghai, and considered the influencing factors, scope and degree of the dewatering process on the land subsidence. Although there are many successful experiences of foundation pit, with the continuous increase of excavation area and depth, the foundation pit project presents strong complexity and uniqueness [10]. First of all, different foundation pits have different engineering geological conditions and hydrogeological conditions, and their supporting schemes and excavation schemes need to be adapted to local conditions, so the existing engineering experience cannot be simply copied and applied. Especially in some areas with special geological conditions, such as Shanghai, Haikou and other cities, the geological conditions are poor and the foundation deformation is serious, which makes the deformation control of deep foundation pit a major difficulty. Secondly, the higher the urbanization, the more complex the adjacent buildings in cities, such as adjacent high-rise buildings, viaducts, subway stations, underground pipe networks, and the groundwater level and stress field will be redistributed during the construction of foundation pits [11, 12]. Therefore, when excavating foundation pits, it is necessary not only to comprehensively consider the impact of adjacent facilities on the safety of foundation pits, but also to measure the impact of foundation pit construction on the safe use of surrounding sites [13]. In this paper, the excavation of a deep foundation pit adjacent to the subway in Tianjin is taken as the research object, and numerical simulation is used to provide the basis for raising risks of the project, and provide operational guidelines for monitoring risk points.

2. Engineering survey

Tianhe City Shopping Center is a large commercial building with eight floors above ground and three floors underground. The total area of the foundation pit is about 13,000 m^2, which is about 185m along Harbin Long Road and 85m wide along Dagu North Road. The circumference of the foundation pit is about 540m, and the excavation depth is 17.7m. The deepest drop area of local elevator shaft and collecting well is 2m deeper than the bottom of the foundation pit. Part of the foundation pit and Heping Road Station of Metro Line 3 share the ground wall, that is, the ground wall of Heping Road Station serves as part of the retaining structure of Tianhe City foundation pit.

The diaphragm wall of foundation pit is about 31m deep, and the main body of Heping Road Station is east-west. The total length of the station is 149m, and the clear width and full width of the standard section structure are 22.3m and 47.10m respectively. It is an island platform, and the main (underground) structure of the station adopts a rectangular frame structure with three floors and three spans and two columns. The buried depth of foundation pit and shield well of Heping Road Station is about 21.46m and 22.61m respectively. The retaining structure adopts 1m thick diaphragm wall with a length of about 40 m.

3. Finite element model

A three-dimensional solid model is established by using finite element software, which covers the main structure of the station and its pile foundation, some shield sections, the station wind pavilion, some entrances and exits and the foundation pit enclosure system. In order to reduce the influence of boundary conditions on the calculation results, the vertical subway station line extension direction is taken as 500 m (including the whole foundation pit area), the parallel subway station (the direction of shield tunnel)
is taken as 688 m, and the depth is taken as 80 m. The overall finite element model is shown in Figure 1, and the foundation pit supporting structure and subway structure are shown in Figure 2.

![Figure 1 Overall finite element model](image1)

![Figure 2 Foundation pit supporting structure and subway structure](image2)

Elastic solid elements are adopted for the side walls, roof, middle plate, bottom plate and retaining structure of Heping Road Station. Solid elements are also adopted for the foundation pit supporting structure. The structure is simulated by linear elastic constitutive model, and the soil adopts modified Cambridge constitutive model. The soil parameters are shown in Table 1. C40 reinforced concrete is used for beams, slabs and side walls of Heping Road Station. Pile foundation C35; Concrete column C50; Segment C50; of shield tunnel; Underground continuous C30. C35 reinforced concrete is used for diaphragm wall of foundation pit of Tianhe City Shopping Center. C30 foundation pit support. The elastic model of each structure shall be selected according to Code for Design of Concrete Structures (GB 50010—2010).

| Name          | Density (kg/m³) | Young's Modulus (Pa) | Poisson's Ratio | Cohesive Strength (Pa) | Internal Friction Angle(°) |
|---------------|-----------------|----------------------|-----------------|-------------------------|---------------------------|
| Soil          | 1800            | 9e6                  | 0.36            | 17600                   | 17.6                      |
| Diaphragm Wall Support | 2300            | 31.5e9               | 0.2             | /                       | /                         |
| Support       | 2350            | 41.5e9               | 0.2             | /                       | /                         |
Fixed constraints are adopted at the bottom of the model, and normal constraints are adopted at four sides. All grids adopt C3D8 hexahedron grid stress element. The number of grids is 76672.

The construction steps are as follows: first, far away from the subway, then close to the subway, and divide the adjacent foundation pits according to the principle of different excavation at the same time. After the underground structure is completely constructed, excavated in four layers.

4. Simulation results

The finite element calculation and analysis steps are the same as the construction process. With the deepening of foundation pit excavation, the soil at the bottom of the pit bulges due to unloading rebound, and the settlement of soil around the foundation pit gradually increases. As shown in Figure 4, the vertical displacement of soil around the foundation pit at the end of foundation pit excavation.

![Figure 3](image1.png)

**Figure 3** Cloud picture of soil strip settlement after foundation pit excavation

It can be seen from fig. 3 that after the foundation pit excavation, the soil in the pit will rebound and the soil outside the pit will settle. The maximum settlement value outside the pit is about 5cm, which is about 10m outside the foundation pit opposite the subway station.

![Figure 4](image2.png)

**Figure 4** Displacement nephogram of retaining structure of foundation pit after excavation

Figure 4 shows the deformation of foundation pit retaining structure, which mainly reflects the deformation of support, and the maximum deformation of support is about 6.5cm.

![Figure 5](image3.png)

**Figure 5** Cloud picture of horizontal displacement of diaphragm wall after foundation pit excavation

It can be seen from fig. 5 that after foundation pit excavation, the maximum deformation of diaphragm wall is about 7.9cm, and it is close to the ground surface.
Figure 6 shows the location of subway station and its ancillary structures after foundation pit excavation. The wind pavilion and the subway tunnel structure near the wind pavilion float upwards due to the foundation pit excavation, and the floating value is about 1.3cm. While the structure near the entrance and exit produces settlement, and the settlement value is about 6mm.

From the above results, it can be seen that the main risk points in the excavation process of this foundation pit mainly include the following: Fengting and its nearby subway tunnel structure, subway station entrance and exit, the diaphragm wall opposite the subway station and the surface outside the diaphragm wall. The main contents of monitoring the above risk points during construction are as follows: whether the wind pavilion and its nearby subway tunnel structure float up; Settlement value of subway station entrance and exit; Horizontal displacement of diaphragm wall opposite subway station; And the settlement value of the ground opposite the subway station.

5. Conclusion

In this paper, taking the excavation of a deep foundation pit adjacent to a subway station in Tianjin as an example, a three-dimensional numerical model is established, and it is analyzed that the risk point in the excavation process lies in structural deformation, which is mainly as follows: the wind pavilion and the subway tunnel at the junction of the wind pavilion are affected by the uplift of the foundation pit, where the structure floats, with a floating reference value of about 1.3cm, but the entrance and exit of the subway station are mainly settlement with a settlement value of about 6mm. In foundation pit excavation, the deformation of diaphragm wall is mainly horizontal deformation, and its risk point is at the top of diaphragm wall opposite the subway station, with the maximum horizontal displacement of about 7.9cm. Settlement deformation mainly occurs outside the pit. The maximum settlement point is displaced from the outer surface of the foundation pit opposite the subway station, about 10m away from the edge of the foundation pit, and the maximum settlement is about 5cm. The results of this paper provide effective reference and guidance for safe construction, monitoring and early warning of complex foundation pits.

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