Deformation of the Deep Foundation Pit under the Excavation on the Island of a River

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ABSTRACT
In order to investigate the deformation regularity of deep foundation pits in the process of excavation on the island of a river, Juzizhou subway station is taken as the research object, that is the first subway station built in island of a river in China. According to the geographical location and special geological and hydrological conditions which have the features of upper-soft and lower-hard and groundwater level effected largely by Xiang river water level, based on the FLAC and combined with field monitoring data, the numerical simulation of the Juzizhou subway station foundation pit excavation was carried out. Then, analyze to get the change law in term of the ground settlement, the horizontal displacement and bending moment of diaphragm wall during the excavation construction. This article research results have important reference and guidance significance for the similar foundation pit engineering in soil reinforcement surrounding the foundation pit, diaphragm wall insertion depth and internal support design, etc.

KEYWORDS: deep foundation pit, excavation, numerical simulation, deformation
INTRODUCTION

With the large-scale subway construction in the major cities, more and more deep foundation pit engineering will appear in engineering, but there have been some major engineering accidents\[^{1}\]. Because of the strong regional features, foundation pit under construction are large different in the size or law of the force and deformation in different regions. And in the construction process, the interaction between foundation pit support structure and soil makes the supporting structure is always under the complex process of force translation, so in the construction process of foundation pit, the study of the force and deformation of the foundation pit become more important. Scholars at domestic and foreign have done a lot of researches about force deformation of foundation pit. Such as OU et al\[^{2}\], WONG et al\[^{3}\], LEUNG et al\[^{4}\], XU et al\[^{5}\], LI et al\[^{6}\] and JIANG et al\[^{7}\] analyzed and studied the features and influence factors of local foundation pit deformation, which aim at foundation pit practice of Taipei, Singapore, Hong Kong, ShangHai, BeiJing and TianJin. Based on centrifuge model test, XU et al\[^{8}\] simulated the excavation of ultra-deep foundation pit in soft ground, get retaining wall deformation, bending moment, brace axial force, earth pressure around the retaining wall, ground surface settlement, etc. He et al\[^{9}\] analyzed the force and deformation relationship of foundation under diaphragm wall and bored pile support form by finite element method. LU et al\[^{10}\] verified the reliability of the soil nailing support in deep foundation pit by the comparative analysis between the numerical simulation results and the deformation monitoring data. Based on summarizing type of wall, water related problems and water pressures, lateral earth pressures, type of support, solution to earth retaining walls, types of failure, internal and external stability problems, displacements of walls and adjacent ground, instrumentation of deep excavation projects, M. Ufuk Ergun\[^{11}\] gave sequence of the subjects in order of design steps. LIU et al\[^{12}\] studied deep foundation pit construction near the history style construction through simulation, and predict the biggest horizontal displacement of soil and the history style construction. JI et al\[^{13}\] predicted dynamic lateral deformation of retaining structure and ground surface settlement in deep foundation pit engineering by LSSVR-based time series method (LTSM). WANG et al\[^{14}\] studied the importance of dynamic monitoring and control in deep foundation pit engineering for construction safety.

As the first subway station built on the Juzizhou island, Juzizhou station’s geological and hydrological environment have the features of upper-soft and lower-hard; besides the groundwater level change has large effect by Xiangjiang river water level. This paper take the Juzizhou subway station foundation pit in Changsha as the research background, use the numerical simulation method, and base on the special hydro-geological conditions and geographical location, analysis the deformation of Juzizhou subway station foundation pit in construction process, what we do has very important guiding significance to the construction process, and also can reference for future similar projects.

ENGINEERING SITUATION

Juzizhou station is located in the Juzizhou island of Xiangjiang river, it was arranged along the Juzizhou bridge from east to west as ‘one’ shape. There is a parking lot around the station, in the north side is Juzizhou bridge, distance of 41.52 m, in the south side is a need to protect ancient tree, distance about 16m from foundation pit edge, east and west ends of the station are close to the Xiangjiang river, the minimum distance from the Xiangjiang river is respectively 13.5m and 15m. The Station is an underground four layers and three cross island type station,
the effective length of the platform is 118m, width is 12m, the station total length is 138m, the standard width is 22.2m. The open surface method is used for the station construction, foundation pit’s depth is about 30.8~31.6 m, width is about 22.2~25m. The station main body internal structure use the integral cast-in-place reinforced concrete rectangular frame structure, each layer board use plate structure: the standard base plate thickness is 1200mm; the middle plate thickness is 400mm; the top plate thickness is 900mm. The station overbite soil thickness on top plate is about 3.4m.

Geological condition

The Juzizhou station engineering site belong to the Xiangjiang river terrace, according to the geological survey and geological drilling, the calculation parameters of major soil are shown in table 1.

The underground water in exploration area mainly divided into pore ground water of Quaternary loose layer and completely weathered zone, fissure water in completely weathered or intermediary weathered bed rock. The pore water in soil and fissure water in rock develop very well, at the same time supplied by the Xiangjiang river, the water level is influenced by precipitation significantly, the difference reach 10m due to the connection between groundwater and surface water of Xiangjiang river.

<table>
<thead>
<tr>
<th>Geotechnical names</th>
<th>Thickness (m)</th>
<th>ρ(kg/m³)</th>
<th>C (kPa)</th>
<th>φ (°)</th>
<th>E (MPa)</th>
<th>μ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Filled earth</td>
<td>10</td>
<td>1940</td>
<td>15</td>
<td>20</td>
<td>9</td>
<td>0.3</td>
</tr>
<tr>
<td>Fine sand</td>
<td>3</td>
<td>2000</td>
<td>5.1</td>
<td>24</td>
<td>25</td>
<td>0.3</td>
</tr>
<tr>
<td>Gravel</td>
<td>6</td>
<td>2030</td>
<td>0</td>
<td>35</td>
<td>30</td>
<td>0.28</td>
</tr>
<tr>
<td>Completely weathered slate</td>
<td>11</td>
<td>2700</td>
<td>800</td>
<td>43</td>
<td>100</td>
<td>0.28</td>
</tr>
<tr>
<td>Intermediary weathered slate</td>
<td>9</td>
<td>2720</td>
<td>1000</td>
<td>55</td>
<td>300</td>
<td>0.22</td>
</tr>
<tr>
<td>Slightly weathered slate</td>
<td>11</td>
<td>2760</td>
<td>2500</td>
<td>65</td>
<td>800</td>
<td>0.22</td>
</tr>
</tbody>
</table>

Foundation pit support reinforcement program

The station’s enclosure structure consists of diaphragm wall which thickness is 1000mm and height is 37m. The inner support is reinforced concrete brace system. There are five supports. The first reinforced concrete support’s shape like a pipa, and its horizontal spacing is 8m and section is 600mm×1000mm; From the second to the fourth reinforced concrete support, their horizontal spacing is 4m, and section is 700mm×1200mm. The fifth support is steel tube which the diameter is 609mm and the thickness is 16 mm. The steel tube support set on the waist of steel beam which support spacing is 3m.

In order to reduce influence to foundation pit excavation by the Xiangjiang river water, we should reinforce the begin side and end side of the shield tunnel combined with the station two side, the grouting reinforcement scope include the south and north outsides wall which distance
is 6m, depth is 21m, and the east and west outside wall which distance is 9m, depth is 31.5m. Grouting hole spacing is 1000mm which has the plum flower form.

**SIMULATION CALCULATION**

Model foundation

As a result of the foundation pit excavation length is greater than the width of the foundation pit, and the maximum lateral deformation of the retaining wall on the longer sides of the pit was larger than the deformation on shorter sides of the pit\cite{19}, the forced deformation of foundation pit problem is simplified to plane problem. We carry out numerical simulation method to analysis the stress deformation law of Juzizhou station foundation pit under construction process with FLAC$^{2D}$ software.

The geotechnical uses solid element to simulate. The diaphragm wall and support use the beam element to simulate. The soil stress-strain relationship uses Mohr-Coulomb model. According to the geological section, it is divided into 6 layers. The model is meshed with 50200 grids, the geometry model of Juzizhou station foundation pit numerical simulation is shown in Figure1.

![Figure 1: Juzizhou station numerical simulation geometric model](image)

Simulation on the excavation process

The excavation process is simplified and extracted the main construction process to analysis its construction process. The simulation steps of the excavation process are as follows:

1. Mesh research object and set the boundary conditions;
2. Balance the soil initial stress, then regulate the displacement of the formation and movement rate of soil to zero.
3. Set up diaphragm wall which the thickness is 1m and height is 37m use the C30 concrete;
4. Excavate the first layer to 3m below the soil surface, iterate to balance, and set the first cross-brace which the horizontal distance is 8m at -3m depth;
5. Excavate the second layer to 8m below the soil surface, iterate to balance, and set the second cross-brace which the horizontal distance is 4m at -8m depth;
6. Excavate the third layer to 14m below the soil surface, iterate to balance, and set the
third cross-brace which the horizontal distance is 4m at -14m depth;
7. Excavate the fourth layer to 19m below the soil surface, iterate to balance, and set the fourth cross-brace which the horizontal distance is 4m at -19m depth;
8. Excavate the fifth layer to 25m below the soil surface, iterate to balance, and set the fifth cross-brace which the horizontal spacing is 4m at -25m depth;
9. Excavate the sixth layer to 31m below the soil surface, and iterate to balance.

ANALYSIS OF THE RESULTS

Ground Settlement

![Diagram of ground settlement](image)

Figure 2: The ground settlement

Figure 2 can show the results as follows:
1. The soil around the pit within a certain range is grouted reinforcement under the high water level, the final ground surface settlement form of soil around the pit is "fluted" in the excavation process, and settling tank appear at a distance of 6-38m off the pit. The emergence of "fluted" settling tank show the envelope structure have inserted a better formation and it is enough for the envelope structure, and set a good support.

2. The rate of surface deformation around the pit increased rapidly when excavated the upper soft soil, the rate of surface deformation around the pit increased slowly when excavated the lower hard slate, at final both the excavation subsidence value become accordance. The maximum surface subsidence in a location away from the pit 10m-12m and the maximum subsidence value is -15.98mm. According to the results of the field measurement, the maximum cumulative surface subsidence value between 14 mm to 17mm, the numerical simulation results is very close to field measurement results.

3. In the beginning of the pit excavation, there are less than 5mm uplifts in the grouting reinforcement area away from the pit 6m, the maximum of uplift is in the location distance pit 6m, the closer away from pit, the smaller value of uplift linearly, the vertical displacement become zero at diaphragm wall position, the uplift value of the first excavation layer is 2.45mm, with the increasing depth of excavation, the uplift value decreases continuously, the soil in the grouting reinforcement area come up tiny subsidence when excavate the second layer to the sixth layer. The mainly reason of uplift is that the soil in the grouting reinforcement area is harder than
the excavating and around soil, and the diaphragm wall have inserted the better slate, due to the unload effect at the beginning of foundation pit excavation, the diaphragm wall was raised because soil at pit bottom was uplifted elastically, and due to the bonding force effect between the grouting reinforcement area and the diaphragm wall, the soil in the grouting reinforcement area become uplift, besides, bonding force between the grouting reinforcement area and the diaphragm wall is greater than between the grouting reinforcement area and the common soil, therefore, the position deformation of the grouting reinforcement area and the diaphragm wall is very small, which mainly come up in the grouting reinforcement area away from the pit side.

**Horizontal displacement of the diaphragm wall**

![Graph showing lateral displacement of the diaphragm wall](image)

**Figure 3:** The lateral displacement of the diaphragm wall
Figure 3 shows that the diaphragm wall horizontal displacement deformation rate increased rapidly due to the weak soil adaptive capacity after excavating the first to the third upper soft soil. When excavate the forth to the sixth upper hard slate, due to the high strength of the slate, the diaphragm wall horizontal displacement increases rate is relatively slow. The maximum increase value is also smaller. The maximum horizontal displacement appear at the top of the wall when excavate the first layer and the value is 11.7mm. With the increasing excavation depth, the value of the maximum horizontal displacement of the wall is also increasing, and the position is moving down. When excavate the sixth layer, the maximum horizontal displacement appears at the position of the diaphragm wall 25m height and the value is 18.9mm. However, the deformation of the wall below the basement become is decreasing due to the passive earth pressure effect and the horizontal displacement is also decreasing even the value is zero at the base of the wall. According to the results of the field measurement, the majority point of the measured values is in the range of 15-20mm.

**Bending Moment of the Diaphragm Wall**

![Graph showing bending moment distribution of the diaphragm wall](image)

**Figure 4:** The bending moment distribution of the diaphragm wall

Figure 4 shows that the maximum bending moment value increases gradually with the continuous excavation, and the value is 276KN•m at the first excavation layer to 1050KN•m at the last excavation layer. When excavate the fourth layer at the position of the diaphragm wall 18m height and previous layers, the maximum bending moment value appear below position of
the continuous wall 17m height. When excavate the fifth and the sixth layer, the maximum bending moment value appears at the fourth support position. The transverse brace position is generally the location of the inflection point of the bending moment or the maximum bending moment value, this is because that set up a support is equivalent to add a great concentration of force for the continuous wall and the bending moment will be changed at that position, at the same time horizontal brace limit the deformation of the continuous wall so that the position is equivalent to the wall node.

**CONCLUSION**

1. The soil around the pit which is under the high water level is grouted reinforcement in a certain range, the final ground surface settlement form of soil around the pit is "fluted". The range of "fluted" settling tank is expanding with the increasing excavation depths. At the beginning of excavation, the grouting reinforcement area around the pit appear the surface uplift, the surface uplift change to be tiny surface subsidence for the increasing excavation depths . Therefore, we can get the conclusion that taking grouting reinforcement measures within a certain range around the foundation pit is very useful to control surface subsidence.

2. When the upper soft soil excavation, the rate of surface subsidence and the diaphragm wall horizontal displacement increased rapidly due to the low strength of the soft soil. However, with the depth of excavation into the relatively hard slate, the rate of deformation increases slow, so we should take reinforce measures in a range of soft soil around the pit or control the construction progress of the excavation to control the deformation before excavation soft soil.

3. With the increasing depth of excavation and the decreasing depth which the wall insert the stratum, the bending moment of the diaphragm wall is increase, and the location of each support appear comparatively large bending moment or inflection. We can get the conclusion that the reasonable continuous wall insertion depth and support design have large effect on decreasing bending moment the wall suffered.

**REFERENCES**


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