Application of Secant Piles for Excavation Pit in Complicated Environment

Meng Cui\textsuperscript{1,2}, Xiao Fu\textsuperscript{*}, Linna Hu\textsuperscript{1} and Hailin Liu\textsuperscript{3}

\textsuperscript{1}College of Civil and Structure Engineering, Nanchang Institute of Technology, Nanchang, 330099, China
\textsuperscript{2}Key Laboratory of Hydraulic and Waterway Engineering of the Ministry of Education, Chongqing Jiaotong University, Chongqing 400074, China
\textsuperscript{3}China Nerin Engineering Company Limited, Nanchang, 330031, China

Email: 524308755@qq.com

Abstract. In order to study the application of secant pile in deep foundation pits in complex environments, this paper takes an actual foundation pit project as the research background, and combines the characteristics of the deep excavation of the foundation pit and the large influence of the groundwater level. Propose the design scheme of partition and segment and use finite element analysis method for numerical calculation. By calculation it is known that the overall displacement of the foundation pit support system is 13.11 mm, the maximum horizontal displacement is 11.8 mm, and the ground settlement is 5.7 mm. All indexes meet the requirements of foundation pit specifications. The research results show that the secant pile has its unique advantages and applicability, which can effectively stabilize the overall performance of the foundation pit and the surrounding environment. The design philosophy in this article can provide references for similar foundation pit projects.

Keywords. Secant pile, deep foundation pit, numerical simulation.

1. Introduction
With the further development of urban construction, the land space is becoming more and more tight, and the deep foundation pit adjacent to the complex environment is faced with strict requirements such as deformation control. As a form of deep foundation pit enclosure, the secant pile has the advantages of strong anti-seepage ability, and low engineering cost. The secant pile has been used in China [1] late. In recent years, many scholars have used the advantages of this method and applied it to the design of deep foundation pit such as subway and high-rise building [2-5]. At the same time, a lot of scholars use the advantages of secant pile to apply to special soil, offshore bridge and foundation pit, and study its construction technology [6-10]. The experience of using secant pile in foundation pit design in Nanchang area is less. According to specific foundation pit engineering cases, this paper puts forward the supporting scheme of secant pile as enclosure structure, and uses finite element software to calculate the key section numerically.

2. Project Overview
The project is located at the intersection of Xiangshan South Road and Sanyanjing Street, with two underground floors. The pile foundation is adopted, the supporting circumference is about 270 m, the excavation depth is 9.60 m to 10.80 m, and the safety grade of foundation pit support structure is grade one. The distance between the west side of the pit basement side line and the nearest building is 3.15
m, the basement side line on the north side is from the red line and the nearest 5.0 m, and there are no adjacent roads and pipelines on the west and north sides of the building; the distance between the east basement side line and Xiangshan South Road is about 11.48 m, and the distance between the power line and the power line is about 13.45 m, and the distance between the subway line and the subway line is about 15.82 m. The distance between the south basement and the edge line is about 7.35 m, and there is no road or pipeline adjacent to it; the distance between foundation pit and Ganjiang River is about 1.9 km, the distance between foundation pit and river is about 400 m simultaneously.

3. Engineering Geology and Hydrogeology Condition

3.1 Engineering Geology

Through the analysis of geological survey data, the landform of this site is Ganjiang alluvial plain. According to the genetic types of rock and soil layers, the lithologic structure and engineering geological characteristics can be divided into 7 layers, and the main physical and mechanical properties of each soil layer are shown in table 1.

| Name of soil layer | State         | Natural unit weight (kN/m³) | Cohesion (kPa) | Internal friction angle (°) |
|--------------------|---------------|-----------------------------|----------------|----------------------------|
| Miscellaneous Fill | Loose         | 18.0                        | 5              | 10                         |
| Silty              | Compacting    | 19.0                        | 16.51          | 22.08                      |
| Medium Sand        | Slightly dense| 18.0                        | 0              | 28                         |
| Silty Clay         | Waxiness      | 19.38 (Saturation)          | 17.32          | 20.95                      |
| Round Gravel       | Middle dense  | 19.0                        | 0              | 40                         |
| Gravel Sand        | Middle dense  | 19.0                        | 0              | 35                         |
| Argillaceous siltstone | Crushing | 21.5                        | 40             | 30                         |

* is empirical value

3.2. Hydrogeology Condition

During the investigation period, there was no distribution of stagnant water in the upper layer fissure water was poor. Pore phreatic water is revealed in the sand layer of 3 medium sand and below. The stable water level ranges from 8.80 to 9.60m, the site is about 2.0 kilometers from the Ganjiang River, and the distance from the Fuhe River, a tributary of the Ganjiang River, is about 1.0 kilometers.

4. Foundation Pit Support Project Design

Combined with the characteristics of general soil conditions, deep excavation depth, high water table, the surrounding environment is complex and the working space on the site is narrow, the calculation and design are divided into the following points, and the surrounding environment map is shown in figure 1.

Figure 1. Surrounding environment map
4.1. Design Scheme

The foundation pit support design is divided into six sections. The upper part of each section of supporting pile is supported by soil retaining wall, and the lower part is constructed by reverse construction method with secant pile. Piles with a diameter of 0.8 m with a distance of 1.1 m between piles. Among them, the section size of crown beam is 900×800, concrete grade is C30. The column should have a cross section size of φ600 concrete filled steel tube with wall thickness of 10. Table 2 shows the calculation results of pile length and excavation depth.

| Segmentation | Excavation depth | Pile length |
|--------------|------------------|-------------|
| AB           | 10.80 m          | 20.50 m     |
| BC\DE        | 10.10 m          | 19.86 m     |
| CD           | 9.60 m           | 20.80 m     |
| EF           | 10.80 m          | 20.00 m     |
| FA           | 10.80 m          | 20.20 m     |

In the meantime, the horizontal support system uses the underground garage roof as the first concrete support to connect with the crown beam; the second concrete support is provided by the underground garage intermediate plate. When the foundation pit is excavated downward, the basement floors are used as the level of the foundation pit supporting structure. The vertical supporting structure adopts φ600 concrete-filled steel pipe piles as the vertical supporting member for horizontal support.

Significantly, according to the overall situation of the foundation pit, secant piles are used in each section of the foundation pit. Secant pile Construction (1) leveling up construction site (2) rig arrangement (3) determination of drilling depth (4) making steel cages, mixing concrete (5) hole perfusion (6) reinforcement cages (7) post-pile inspection (8) construction quality control. From B1, strictly follow the construction sequence of figure 2.

![Figure 2. Construction sequence](image)

4.2. Overall 3D Calculation

Create 3D model to analyze the whole structure system of foundation pit support, the model is shown in figure 3. The results show that the maximum displacement of the support system is calculated as 13.11 mm, the position is in the middle of the west side of the foundation pit, and the displacement on one side of the subway is controlled within 10 mm. The overall displacement meets the design and specification requirements. At the same time, the maximum axial force of the supporting beam is 1859 kN, the maximum axial force is obtained in the middle of the foundation pit near the north. The maximum bending moment of supporting pile is 364.3 kN·m, it is located in the middle of the north side of foundation pit. See figure 4 to figure 6 for details. After accounting, the reinforcement of supporting pile and the resistance of supporting beam material meet the design and specification requirements.
4.3. Finite Element Analysis
In order to analyze the stability of the design, the finite element analysis of the west section of the complex foundation pit environment is carried out, and the joint action of enclosure structure, adjacent foundation, pile and tunnel and soil is analyzed. The joint is established in the corresponding position of the pipeline to reflect the influence of foundation pit excavation on the underground pipeline, and the contact surface unit is arranged between the retaining structure and the soil. The calculation model diagram and cloud graph are shown in figures 7 to 9.

4.4. Comparative Analysis of Results
Through the finite element analysis of the segmental section closer to the surrounding environment and the overall structure displacement, the results are shown in table 3. Based on the above analysis, it can be seen that the overall displacement of the foundation pit is 13.11 mm, the maximum horizontal displacement of the enclosure structure is 11.8 mm, the maximum vertical displacement of the ground is 5.7 mm, and the settlement of adjacent foundation is 1.6 mm, all of which meet the requirements of
the design code of the foundation pit, indicating that this design can effectively control the deformation of the support structure and surrounding buildings.

Table 3. Summary of calculation results

|                                | Calculated value | Allowable value | Unit |
|--------------------------------|------------------|-----------------|------|
| Maximum horizontal displacement | 11.8             | 30              | mm   |
| Ground surface settlement      | 5.7              | 30              | mm   |
| Settlement of adjacent foundation | 1.6              | 10              | mm   |

5. Conclusion
The successful application of secant pile in this project can be seen that the secant pile has achieved good results in the construction of the project, and no large area leakage phenomenon has been found. Through analysis validation, the overall displacement, maximum lateral displacement and vertical settlement of the foundation pit support structure are lower than the allowable value of the design code, which indicates that the deformation of the foundation pit is stable, that is, the secant pile can effectively stabilize the overall performance of the foundation pit and protect the surrounding environment. The supporting scheme proposed in this paper can be used for foundation pit with similar engineering conditions, which provides reference and reference for support design.

Acknowledgements
This work was supported by the Science and Technology Research Program of Jiangxi Provincial Education Department [GJJ180929], Open Fund of Key Laboratory of Hydraulic and Waterway Engineering of the Ministry of Education, Chongqing Jiaotong University [SLK2017B02], the National Natural Science Foundation of China [51609114, 51769016].

References
[1] Zhu B H and Lei C H 2001 Construction technology of secant pile enclosure for foundation pit in Shenzhen Metro *Railway Engineering* **12** 2-4.
[2] Hu Q, Chen J, Ke H, Chen R P and Yang H 2008 Analysis on the stress deformation of secant pile in deep foundation pit *Rock and Soil Mechanics* **08** 2144-2148+2176.
[3] Gao X N, Wang Z S, Tong L Y and Fang L 2010 Application of Secant piles in Nanshi Street Station of Suzhou Metro *Chinese Journal of Geotechnical Engineering* **32**(S2) 463-466.
[4] Chen B, Shi B and Lin M A 2005 Technical study on the enclosure structure of inner closing pile in soft soil layer of Nanjing Metro *Chinese Journal of Geotechnical Engineering* **03** 354-357.
[5] Richard J F, Sebastian B and Michele C 2002 Performance of a stiff support system in soft clay *Journal Geotechnical and Geoenvironmental Engineering* **128** (8) 660-671.
[6] Lei B, Chen Y, Li C, et al. 2019 Combined pile-forming technology of the secant piles in deep and loose rock-fill layer *Construction Technology* **48**(23) 108-112.
[7] Yang J X, Hou W S, Zheng C M, et al. 2010 Engineering application of punching secant pile in the enclosure of a near-sea deep foundation pit *Chinese Journal of Geotechnical Engineering* **32**(S1) 207-209.
[8] Zhao Y 2007 Application of impact bored secant pile in the protection of deep foundation pit of bridge *Railway Engineering* **11** 9-11.
[9] Shen X P, Lei B, LI S Q, et al. 2020 Comprehensive construction technology of secant piles long auger and barrel type rotary drill for foundation pit support *Construction Technology* **49**(19) 19-22.
[10] Yan W F, Yu Z, Yang T, et al. 2020 Study on the mechanism of force and deformation of the supporting structure with Secant piles *Chinese Journal of Ground Improvement* **31**(04) 285-289.