Research on Construction Method of Soft Soil Foundation Pit with L-Shaped Small Steps

Yanhui Cao, Jinhua Ye, and Gang Hao

Abstract A layered, segmented, and block building technique was created during the construction of the cut-and-cover foundation pit. Traditional foundation pit excavation often necessitates both support erection and mechanical excavation at the same time, however owing to the intersection of support and excavation mechanical operation, which may decrease building efficiency, and the construction requirements are higher due to the low mechanical characteristics of the soil in the silty soil layer. Therefore, the construction method of an L-shaped short step with small steps soft soil foundation pit is proposed, based on the mechanical characteristics of the silty soil layer and the construction operation characteristics of the foundation pit. After excavation, the support is erected using a numerical calculation of the stability of the foundation pit. According to engineering practice, the L-shaped short step with small steps soft soil foundation pit building technique can significantly facilitate basement pit deformation, improve construction efficiency, and be popularized.

Keywords Silty soil layer · Foundation pit · L-shaped short steps with small steps

1   Introduction

The excavation process of the foundation pit will inevitably cause the deformation of the surrounding strata. There has been a lot of practical work done to control the deformation of the foundation excavation. The excavation of large-area deep foundation pits in soft soil is currently possible using segmental and layered excavation methods [1]. The construction process for excavating a silt-deep foundation pit with prestressed pipe piles was thoroughly explained by Jiang Hui [2]. Currently, there are two types of foundation pit excavation: unsupported excavation and supported

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excavation [3]. According to Wang Wei [4], mechanical excavation is designed for large-scale foundation pit excavation work, and it is preferable to excavate in layers or open excavations with a depth of 5 m or more. A grab excavator is used to excavate the bottom layer of soil from the cantilever bridge, and a small bulldozer is used to pile the earth in the foundation pit. Wu Minhong [5] demonstrated that the space–time impact should be considered while determining the foundation pit excavation design. The size of the foundation pit area, the design of the enclosing structure, the excavation depth, and the engineering environmental conditions should all be evaluated. Based on the Shanghai Metro foundation pit project, Sun Jiuchun [6] analyzed the small-scale pot excavation method for soft soil deep foundation pits and developed a finite element analysis model utilizing the soft-soil creep model taking time effect into account. Wang Jiangtao et al. [7] analyzed soil deformation in the x and y directions during foundation pit excavation. They were able to establish the multi-dimensional deformation law of the foundation pit soil that was retrieved during excavation. Numerical simulation of various foundation pit excavation depths was done by Zhang Hui et al. [8]. Additionally, researchers compared the on-site monitoring data with the changes in the pile body's surface settlement, supporting axial force, and lateral displacement.

Cai Dongming et al. [9] presented a "double-layer gantry reinforcement system" targeted anti-uplift plan for the excavation of the subway tunnel's foundation pit, as well as the associated sectional, layered, and troughed progressive foundation pit excavation scheme. Liu Yi and colleagues [10] used a two-dimensional finite element numerical simulation method and the soil elastoplastic model (ST model) to analyze the support process of the foundation pit. They compared the calculation results with the practical engineering monitoring data and the design values calculated by the beam-spring model. Using the finite element software Plaxis 3D, Yang Zhonghong et al. [11] simulated the process of building deep foundation pits on silty soft soil in coastal areas. The impact of supporting structures on the deformation of foundation pits was then investigated. According to Lin Zhibin et al. [12], soft soil creep would significantly affect when foundation pits are excavated and deformed. Du Jiazhi [13] fully takes into consideration that many variables, such as the physical and mechanical properties of the soil, the geometrical requirements of the foundation pits, and the excavation methods, affect the numerical model. Xiong Yuanlin [14] studied the supporting effect of the foundation pit engineering envelope in soft soil area, and optimized the detailed parameters of the supporting structure. At present, the research on the excavation of cut-and-cover foundation pits is mostly an introduction to the formal segmentation and blocking, and rare reports on how to excavate and support each piece of earth in the detailed foundation pit, how to solve the cross problem between mechanical excavation and support erection, and the timing of support excavation. Moreover, the existing results show that the numerical analysis method can better reflect the excavation process of foundation pit.

In this paper, based on a tunnel project in Nanjing, the finite element analysis model is established by using the soft soil creep model. Taking into account the time effect, the influence of support erection timing, and refining the specific construction technology for earthwork excavation and support erection have been discussed.

2   Engineering Background

Nanjing Hengjiang Avenue SG-2 is located in Pukou District, Nanjing. It belongs to the floodplain landform unit of the Yangtze River. Inadequate geological conditions coexist with distributions. The main construction consists of a pipe gallery and an open tunnel.

The excavated partial foundation pit, for example, has a total length of 240 m, a width of approximately 60 m, and an overall excavation depth of approximately 10 m. The foundation pit enclosure construction uses the SMW engineering approach, piles + internal support system, and is reinforced in the strips and edges. The SMW engineering technique piles are φ850@600SMW three-axis mixing piles with a steel insert of H7003001324 mm. Two internal supports are positioned vertically: the first is an 800-by-800-mm concrete support placed on top of the foundation pit, and the latter is a Φ609 double steel pipe support located at a depth of approximately 5 m.

3   L-Shaped Short Step with Small Steps. Construction Technology

3.1   Process Overview

The standard stepped excavation method takes a long time to excavate muddy foundation pits. The machine's back and forth movement increases the number of interruptions to the enclosure structure and soil, which has a significant impact on the creep of the muddy foundation pit topsoil. At the same time, the support system in the foundation pit has a significant effect on the operational space in the pit as well as the mud transportation parameters. To address the aforementioned issues, the building method of L-shaped short and small stairs is proposed. Figure 2. depicts the technical principle. The soil is modified with precipitation and soil hardening subsequent to the excavation of the earthwork in the pit. A 3 m-wide platform is prepared for excavator operation at a depth of approximately 5 m (in the center of the foundation pit) at a slope of about 1:1. Whereas, B-B sections employ a slope with a minor slope for grading excavation, and the slope is typically not greater than 1:3. Section A-A is being excavated by bulldozer type at the same time as section B-B, and steel supports will be constructed when the bottom slope foot of the pit is excavated to the location of the steel support projection line. The bottom covering construction is completed once the steel support has been built. Engineering practice has confirmed that this method is adequate for the construction of muddy long-span and long-distance foundation pits with excavation depths ranging from 7 to 12 m (Fig. 1).
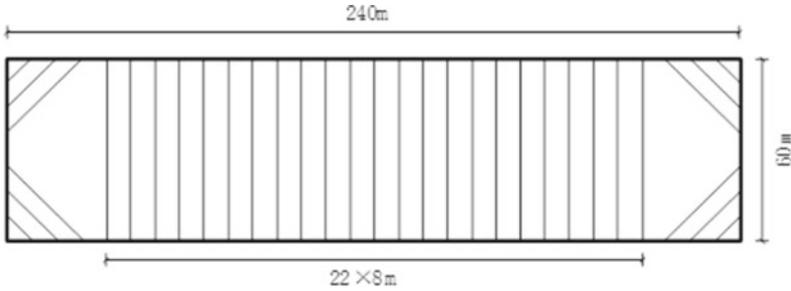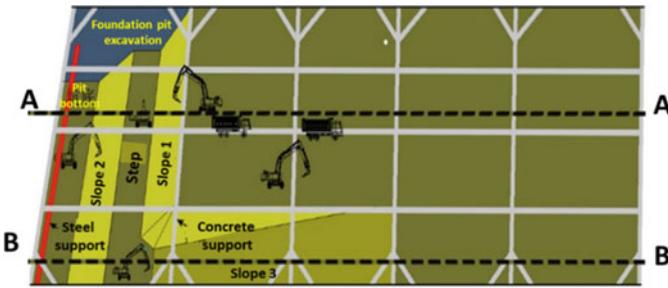
Fig. 1 Plane diagram of foundation pit

Fig. 2 Plan of foundation pit excavation

3.2 A-A Cross-Section Excavation Method

Figure 3. depicts the earthwork excavation process for the A-A section, as well as the construction stages:

(1) In Fig. 3(a), the A-A profile of the foundation pit adopts a 1:1 slope excavation, and the PC320 excavator excavates vertically downward at the excavation surface as the PC320 excavator enters the foundation pit. The PC320 excavator will excavate the dirt to a depth of 3 m, and the PC400 excavator will then pour the soil into the mud truck..

(2) Fig. 3(b) illustrates how to construct a 3 m wide step at 5 m after the foundation pit has been excavated out to a depth of 5 m.

(3) The foundation pit is excavated to its bottom using a PC320 excavator, as shown in Fig. 3(c). The excavator at the bottom of the pit transports the soil to the excavator on the 5 m step, where it is relocated to the excavator in the upper part of the foundation pit. The upper excavator is then immersed into the muck truck, and the excavation is functional.
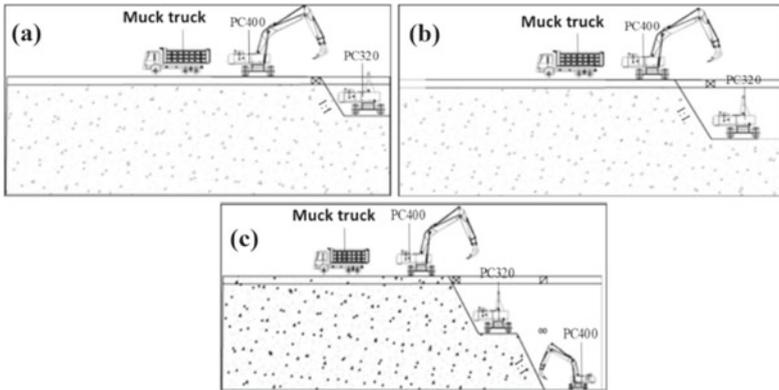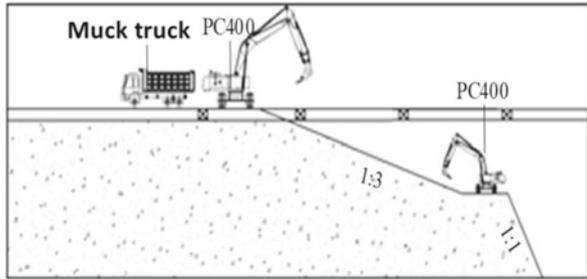
Fig. 3 Schematic diagram of earthwork excavation at section A-A: (a) Preliminary excavation, PC320 excavator into the foundation pit, (b) when excavating to 5 m, (c) continue to slope excavation below 5 m

Fig. 4 Excavation sequence of section B-B

3.3 B-B Cross-Section Excavation Method

Figure 4. depicts the schematic diagram of the excavation of the B-B section, which is analogous to the excavation method of the A-A section but is carried out with a slope of approximately 1:3 on the side of the excavation direction.

3.4 Excavation Angle

Finally, the excavation is completed to the pit's corner, and to achieve the capping angle, the B-B profile is excavated simultaneously along the foundation pit's long-distance direction and span direction. Figure 5. illustrates the accurate construction steps. The mud truck is excavated at the pit's edge.
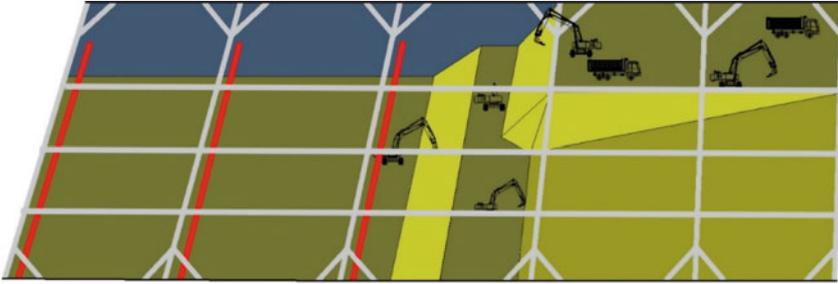
Fig. 5 Schematic diagram of foundation pit retracting

4 Numerical Model Building and Analysis

4.1 Model Building

In this study, a three-dimensional model is created using the finite element MIDAS GTS software. The internal support utilizes the beam element for simulation, while the soil simulation method adopts the HS (modified Mohr–Coulomb parametric) model. The equivalent stiffness approach is used in the SMW building method pile [15]. The pile length is 23 m, the excavation depth of the foundation pit is 10 m, and it is an underground diaphragm wall. Create a model with the dimensions $340 \times 160 \times 50$ m (length x width x height). Displacement and angle impose a complete constraint on the model boundaries. The concrete support is made of C30 concrete, which has a Poisson's ratio of 0.2 and an elastic modulus of 30GPa. Figure 6. depicts the model of a foundation pit. Table 1. displays the physical characteristics of the soil layer.
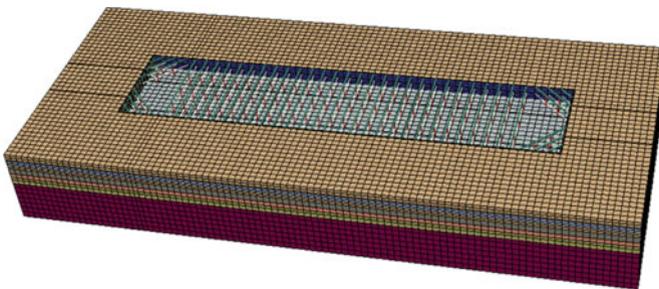

Fig. 6 Model of foundation pit

Table 1 Physical and mechanical parameters of soil layers

Layer No	Soil	Soil thickness /m	γ/kN/m³	c/kPa	φ/°	μ	E_s/MPa
1	Muddy silty clay	4.5	17.5	10.3	11.8	0.42	3.46
2	Powdered sand and soil	3.0	18.9	2.5	30.5	0.39	11.61
3	Muddy silty clay	4.0	17.5	10.3	11.8	0.42	3.46
4	Powdered sand and soil	3.0	18.8	2.2	32.6	0.30	11.76
5	Muddy silty clay	3.0	17.4	5.1	11.8	0.42	3.71
6	Fine sand	8.0	18.7	2.1	32.4	0.28	12.44

4.2 Numerical Analysis Results

Due to the large excavation range of the foundation pit after the final closing angle, the deformation of the support structure is the largest. Figures 7, 8 and 9. shows the closing angle state model and calculation and analysis results of the excavation process of the foundation pit. It is evident that the side of the supporting structure with the larger excavation surface (B-B section) has a significant deformation and supporting axial loads. The axial force and maximum displacement of the supporting structure, in both, are 766.5 kN and 34.69 mm, respectively. The early warning value of the horizontal displacement of the foundation pit is determined to be 55 mm in accordance with the DGJ32/J189-2015 "Technical Regulations for Building Foundation Pit Engineering Monitoring in Nanjing Area". The specific circumstance and analogous engineering experience suggest that the early warning value of the concrete support axial force is 800 kN. When the foundation pit is excavated using the construction method of L-shaped short and small steps, the overall foundation pit is stable.
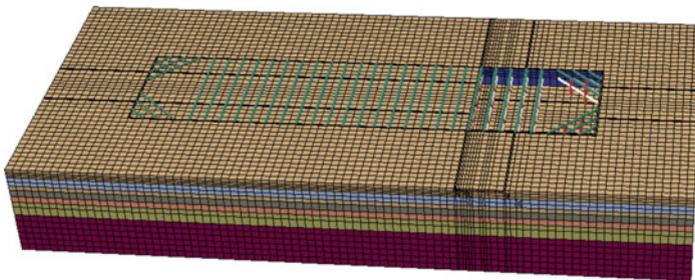

Fig. 7 Numerical model of L-shaped short step and small pace construction after foot retraction state
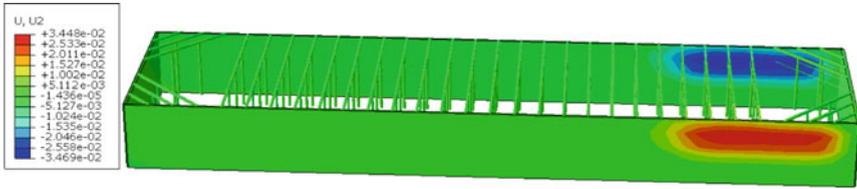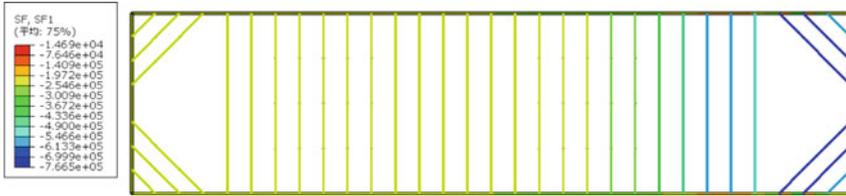
Fig. 8 Deformation of envelope structure

Fig. 9 Axial force of concrete bracing piece

5 Influence of Steel Support Erection Timing on Supporting Structure

During excavation, the foundation reinforcement, SMW engineering method piles, and concrete supports are all performed throughout the construction phase. The steel support is excavated during the L-shaped short steps and small step distance technology construction process from the slope foot of the pit bottom to the extrapolation of the steel support on the base.

The deformation and stability of the foundation pit are significantly impacted by the time of the construction of the line and the steel support. The efficiency of the construction process may be increased by optimizing the time of the erection of steel supports, which will also increase the foundation pit's overall safety. The steel support is simulated and calculated based on the L-shaped short step small step building method immediately following the steel support's erection at intervals of 2, 4, 6, 8, 10, and 12 h. When the erection time of the steel support is not taken into account, as shown by the calculation results in Table 2. and Fig. 10. The displacement of the foundation pit and the axial force of the concrete support are both less than the value based on the erection time. It reveals that the erection time of the steel support has a significant impact on the displacement and deformation of the foundation pit.

With increasing erection time, the axial force of the concrete support for the foundation pit and the displacement of the enclosed structure gradually rise, and the increase rate decreases gradually. The creep deformation is mostly concentrated in the initial stages after the excavation is completed. Therefore, early construction of the steel support can effectively reduce creep. with the effect of deformation on foundation pit deformation. When the steel support was constructed within 12 h from

Table 2 Calculation results

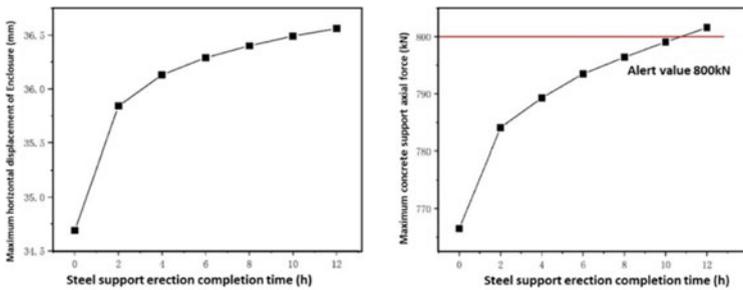| S. No	Support erection timing	Maximum horizontal displacement (mm)	Maximum concrete support axial force (kN)
1	Erected slope-bottom excavation	34.69	766.5
2	Erected slope-bottom excavation 2 h	35.84	784.1
3	Erected slope-bottom excavation 4 h	36.13	789.3
4	Erected slope-bottom excavation 6 h	36.29	793.5
5	Erected slope-bottom excavation 8 h	36.40	796.4
6	Erected slope-bottom excavation 10 h	36.49	799.1
7	Erected slope-bottom excavation 12 h	36.56	801.6

Fig. 10 Influence of brace erection time on stress and deformation of supporting structure: (a) Maximum horizontal displacement of enclosure structure-erection time relationship, (b) Concrete support axial force maximum - erection time relationship

the excavation of the foundation pit to the bottom of the slope. The axial force of the concrete support exceeded 800kN, but it was still within a safe range when it was erected within 10 h. Therefore, the L-shaped short steps and small steps construction method is used. The steel support erection completion time in this project should be controlled within 10 h.

6 Conclusions

Due to the limitations of the traditional excavation method, interior support construction cannot be finished while foundation pit excavation is being done. The construction efficiency is poor, which is detrimental to silty soil creep management. The construction method of an L-shaped short step and small step foundation pit was designed to resolve the problem of delayed construction efficiency during the excavation of long-span and long-distance foundation pits in silty soil layers. The finite element method was used to study the deformation of the supporting structure during excavation, and the impact of steel support erection time was investigated. According to practical application and calculated values, the L-shaped short step and tiny step construction method may increase excavation construction and excavation efficiency under foundation pit safety parameters. The displacement and supporting axial force of the foundation pit can meet the specification requirements. Furthermore, it is suggested that the steel support structure in the foundation pit be constructed earlier taking into account all of the creep characteristics of the silty soil foundation pit and the connection of the building process. To avoid the excavation surface being unsupported for an extended period of time, resulting in severe deformation of the foundation pit.

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