Postprint: Monitoring and Analysis of a Hotel Foundation Pit Engineering Project in Shanghai

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Abstract

Based on actual engineering case studies, deformation patterns of deep horizontal soil displacement, support axial forces, and ground settlement during foundation pit construction were derived through analysis of extensive field monitoring data: During actual construction, deep horizontal soil displacement increases continuously with excavation depth, with the location of maximum displacement migrating progressively downward, resulting in a 'bulging belly' curve profile; support axial forces also increase continuously throughout construction, where the installation of a second support effectively relieves the axial force on the first support, however, axial forces on both supports increase at a relatively rapid rate until the completion of excavation; ground settlement and displacement of adjacent pipelines also increase continuously with excavation. The findings of this project can serve as a reference for similar engineering projects.

Full Text

Preamble

Foundation Pit Monitoring Analysis of a Hotel Project in Shanghai

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Abstract

Based on an actual engineering case, this paper analyzes extensive field monitoring data to investigate the deformation patterns of deep soil horizontal displacement, support axial forces, and ground settlement during foundation pit construction. The results show that deep soil horizontal displacement increases progressively with excavation depth, with the location of maximum displacement gradually moving downward, producing a characteristic "bulging" curve profile. Support axial forces also increase continuously throughout construction;

while the installation of a second support level effectively reduces the load on the first support, both supports experience rapid axial force growth until excavation completion. Ground settlement and displacement of adjacent pipelines likewise increase continuously with excavation. These findings can provide valuable reference for similar projects.

Keywords: foundation pit engineering; foundation pit monitoring; deformation; settlement

1. Introduction

Over recent decades, Shanghai’ s rapid economic development has created new urban challenges, including population saturation, reduced green space, limited building interior space, traffic congestion, and scarce land resources. Sustainable development within environmental carrying capacity, guided by scientific development principles, necessitates expansion underground as the inevitable path for future urban growth. Effective utilization of underground space–such as underground structures in large-scale urban complexes, high-rise building parking facilities, metro stations, major drainage systems, and underground substations –all involve deep foundation pit engineering.

Deep foundation pit projects have become increasingly common, with growing pit areas and excavation depths. Consequently, foundation pit engineering in the Shanghai region is characterized by the “three major features” : large scale, great depth, and tight spacing. Given these characteristics, urban foundation pit construction often occurs adjacent to major buildings, utility pipelines, metro tunnels, and arterial roads, with limited site space. This requires not only satisfying bearing capacity and stability requirements but also implementing strict displacement control measures. Excavation involves unpredictable factors related to external forces, deformation, and soil properties, while urban deep foundation pits operate in complex surrounding environments where adjacent structures such as underground pipelines, passages, metro tunnels, and nearby buildings exhibit varying resistance to differential deformation. Therefore, construction of foundation pits in complex environments demands higher standards for theoretical research, design, and construction, representing a pressing issue in the construction industry.

Monitoring foundation pits to obtain timely information and conduct construction research represents a viable approach. Scholars worldwide have performed extensive research on monitoring foundation pit excavation effects on retaining structures and surrounding environments. Regarding surrounding soil, Peck presented a comprehensive report at the 7th International Conference on Soil Mechanics and Foundation Engineering, analyzing measured data to study heaving at pit bottom, lateral displacement, and surface settlement, with particular focus on deformation influencing factors including soil conditions, construction quality, and excavation depth. Lambe investigated soil displacement effects and measured data from multiple metro tunnel foundation pits, analyzing retaining and support systems to derive relevant conclusions. Guo Yin et al. studied the internal forces and deformation characteristics of retaining piles under various working conditions through measured data from a deep foundation pit, conducting experimental analysis of bending moment and pile top displacement, with results indicating that retaining piles move downward with increasing excavation depth and maximum bending moment increases linearly.

Regarding adjacent buildings, Wang Weidong and Xu Zhonghua proposed a method for estimating surface settlement behind retaining walls based on measured data from Shanghai' s slurry wall-supported foundation pits, providing a practical assessment approach for predicting excavation impacts on surrounding buildings. For adjacent underground passages, Kuang Longchuan studied factors affecting tunnel deformation using metro tunnel monitoring data and excavation conditions, with measured data showing significant displacement on the pit side and elliptical deformation patterns in tunnel cross-sections. Jiang Hongsheng and Hou Xueyuan investigated the effects of deep foundation pit excavation on adjacent metro tunnels under various influencing factors (horizontal movement, vertical settlement, and transverse deformation of tunnels) based on monitoring data and theoretical analysis of soil disturbance.

This paper analyzes the deformation patterns of retaining structures and surrounding pipelines during construction based on field monitoring data from a hotel foundation pit project in Shanghai, aiming to provide reference for similar projects.

2. Project Overview

2.1 General Information

The proposed site is located in Changning District, Shanghai, bounded by Hongxu Road (Middle Ring Road) to the west, Yan' an Elevated Road to the south, and Hongqiao Road to the north. The foundation employs a pile-raft system. The basement floor elevation is -8.250 m in general areas and -11.250 m in the sunken courtyard area, with an 800 mm thick base slab in both zones and a 150 mm thick cushion layer. The foundation pit covers approximately 23,240 m^2 with a total perimeter of about 706 m. Excavation depth is 8.60 m in general areas and 11.60 m in the sunken courtyard area, corresponding to base elevations of -9.200 m and -12.200 m, respectively.

2.2 Surrounding Environment

The site layout and surrounding environment are shown in [Figure 1: see original paper]. To the east of the red line lies the New Hongqiao Villa area, with three 2-story villas along the pit boundary. To the south is Yan' an West Road, featuring a 3-story concrete office building of the Changning District Municipal Engineering Management Authority at the southwest corner, and gas, water supply, and information pipelines beneath the road. To the west is Hongxu Road, with five 2-story concrete office buildings between the road and site boundary, the Middle Ring Beihong Road underpass (burial depth approximately 17.80 m) beneath Hongxu Road, and various municipal pipelines including gas, water supply, information, power, stormwater, sewage, and electrical supply lines. To the north, the western section adjoins the Shanghai School for the Blind teaching building, while the eastern section borders Hongguan Villas (government office buildings requiring special protection during construction), with stormwater and sewage pipelines running along the eastern northern boundary.

2.3 Hydrogeological Conditions

The site is located in Changning District, Shanghai, within the coastal plain physiographic unit of Shanghai' s four major geomorphic divisions. The area formerly contained the Shanghai Xinyuan Hotel and New Hongqiao Villas, with existing buildings now demolished. A wall previously separated the villa and hotel areas, with cement roads and pavements throughout, trees being relocated, and a small lake present on-site. Except for the lake area, the site is generally level, with ground surface elevations at exploration points ranging from 4.21 m to 3.48 m (difference of 0.73 m).

Borehole data indicate that deposits within 45.38 m below ground surface consist of Quaternary estuarine, coastal, shallow marine, and swamp facies, primarily comprising saturated cohesive soil, silty soil, and sand with stratified distribution. Based on deposition age, genetic type, and physical-mechanical property differences, six main layers are identified from top to bottom: miscellaneous fill; silty clay and clayey silt; muddy silty clay; muddy clay; silty clay; medium-coarse sand and fine sand. presents the physical-mechanical parameters of soil layers within the foundation pit influence zone.

2.4 Support Structure Selection

Deep foundation pits generally employ a slurry wall support system. For this excavation depth, bored cast-in-place piles of appropriate diameter serve as retaining piles, with a row of cement-soil mixing piles as a waterproof curtain outside the piles [Figure 2: see original paper]. Capping beams are installed atop the piles, with two levels of horizontal concrete struts inside the pit. Passive zone reinforcement uses double-axis cement-soil mixing pile hidden 墩 reinforcement. The combination of bored piles and waterproof curtain represents a mature construction method offering relatively high structural stiffness, flexible selection of pile length and diameter, and continuously increasing pile strength over time.

3. Monitoring Scheme

The monitoring program covers both the retaining structure and surrounding environment, including: deep soil horizontal displacement; groundwater level outside the pit; support axial forces; retaining pile settlement; surface and road settlement outside the pit; pipeline horizontal displacement; and adjacent building settlement.

Key monitoring points (partial) are shown in [Figure 3: see original paper]. Construction is divided into the following stages: (1) Stage 1: First-level excavation removing 1 m of surface soil, installing first horizontal support; (2) Stage 2: Second-level excavation removing 4.2 m of soil, installing second horizontal support; (3) Stage 3: Third-level excavation removing 3.4 m of soil, installing base slab; (4) Stage 4: Fourth-level excavation removing 3 m of soil from sunken courtyard, installing base slab.

4. Analysis of Measured Results

Given the extensive monitoring data, this analysis focuses on representative measurement points for several monitoring categories to examine variation patterns during construction.

4.1 Deep Soil Horizontal Displacement

Deep soil horizontal displacement was measured at points designated CX. Representative points CX2, CX8, and CX11 were selected to analyze displacement patterns during construction, as shown in [Figure 4: see original paper] through [Figure 6: see original paper].

[Figure 4: see original paper] illustrates deep soil horizontal displacement at point CX2 during different construction stages. During Stage 1, maximum horizontal displacement of approximately 6.89 mm occurred at 6.5 m depth. In Stage 2, continued excavation increased soil disturbance significantly, with maximum displacement reaching 11.8 mm at approximately 7 m depth—a difference of nearly 5 mm from Stage 1. During Stage 3, displacement continued increasing to 14.42 mm at 7.5 m depth. In the final Stage 4, ongoing excavation further increased disturbance, with maximum displacement reaching 22.49 mm at approximately 9 m depth. Overall, maximum deep soil horizontal displacement increased progressively with construction stages, with the depth of maximum displacement continuously moving downward.

[Figure 5: see original paper] shows displacement patterns at point CX8. During Stage 1, maximum displacement was 3.93 mm at 6.5 m depth. Stage 2 excavation increased displacement significantly to 11.32 mm at 7 m depth—approximately double the Stage 1 value. In Stage 3, displacement further increased to 13.99 mm at 7.5 m depth. During Stage 4, maximum displacement reached 19.54 mm at 8 m depth. In summary, deep soil horizontal displacement continuously increased, with the depth of maximum displacement deepening progressively. Points CX8 and CX2 exhibited similar patterns and curve shapes.

[Figure 6: see original paper] presents displacement at point CX11, showing substantially similar patterns. Maximum displacements were 7.69 mm at 7 m depth (Stage 1), 12.8 mm at 7 m depth (Stage 2), 15.6 mm at 7.5 m depth (Stage

3), and 20.26 mm at 8 m depth (Stage 4). Overall, maximum displacement increased continuously while its depth descended.

These three typical points reflect variation patterns of deep soil horizontal displacement at different pit locations. Synthesizing [Figure 4: see original paper] through [Figure 6: see original paper], maximum horizontal displacement locations progressively moved downward with construction, generally occurring at 7-10 m depth. Displacement values were substantial during soil excavation stages, with significant differences between stages. All displacement-depth curves exhibit a characteristic "bulging" shape.

4.2 Support Axial Force Variation

[Figure 7: see original paper] and [Figure 8: see original paper] illustrate axial force variation patterns for the first and second support levels, respectively, with typical measurement points selected for analysis.

First-level support axial forces generally increased with construction progress. As soil was removed and the pit relied on supports for retention, axial forces grew rapidly. During second-level support installation, the first-level support shared load, resulting in more gradual growth. In subsequent construction, axial forces continued increasing until excavation completion.

When excavation reached the second level, the second-level support was installed. This support shared load from the first-level support, with its axial force increasing rapidly to substantial levels. With subsequent excavation and base slab installation, support axial force growth rate slowed but continued steady increase.

4.3 Ground Settlement

Representative ground settlement monitoring points were selected for analysis. [Figure 9: see original paper] shows that as construction progressed and excavation deepened, soil around the pit subsided, with surface settlement values increasing continuously. Point D3, being closer to the pit, exhibited relatively smaller settlement values. Settlement at all points stabilized after final excavation completion.

4.4 Pipeline Settlement

Given the numerous and complex distribution of pipelines around the pit, information pipeline monitoring data were selected to examine displacement patterns. Positive values represent heaving, negative values represent settlement.

[Figure 10: see original paper] shows that pipeline displacement increased continuously during construction, ultimately manifesting as settlement. All measurement points exhibited similar variation patterns and final settlement values, stabilizing at approximately 9 mm. During excavation, pipeline settlement decreased rapidly as surrounding soil moved toward the pit.

5. Conclusions

Based on field monitoring data from a hotel foundation pit project in Shanghai, this paper analyzed variation patterns of retaining structures and surrounding environment under complex construction conditions, yielding the following conclusions:

(1) Deep soil horizontal displacement curves exhibit a "bulging" pattern. With construction stage progression, deep soil horizontal displacement increases continuously, with the location of maximum depth descending progressively, demonstrating clear time-space effects.

(2) Support axial forces increase continuously at a relatively rapid rate throughout construction. The installed second-level support effectively shares load from the first-level support. Subsequent base slab construction slows the growth rate of support axial forces until construction completion.

(3) Ground settlement around the pit and pipeline displacement both increase continuously with excavation, manifesting as subsidence. This occurs because soil collapse adjacent to the pit after excavation causes nearby ground and pipelines to subside.

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Note: Figure translations are in progress. See original paper for figures.