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Implementation of Settlement Monitoring for Foundation Pit Constructionat Qingliangsi Station of Changzhou Rail Transit

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Abstract

Settlement monitoring is essential in foundation pit construction for ensuring excavation safety, structural stability, and protection of the surrounding environment. Taking the foundation pit construction of Qingliangsi Station of Changzhou Rail Transit as a case study, this paper presents the implementation and application of settlement monitoring in deep excavation engineering. Based on the project characteristics, hydrogeological conditions, and monitoring requirements, a monitoring scheme was established, covering retaining structure top settlement, column settlement, and surrounding ground settlement. Precision leveling and standardized observation procedures were adopted to ensure data reliability. The monitoring results show that most settlement data remained within the control range and the overall deformation of the foundation pit was stable. However, abnormal column settlement was detected at certain monitoring points. By combining monitoring feedback with on-site construction conditions, timely reinforcement measures were taken, which effectively controlled further deformation and ensured construction safety. The study indicates that scientific monitoring layout, standardized data acquisition, and timely information feedback are of great importance for deformation control and risk prevention in foundation pit construction.

Keywords

Settlement Monitoring; Foundation Pit; Construction; Data Analysis.

1. Engineering Overview

Changzhou Rail Transit Qingliangsi Station is situated east of the intersection of Heping Middle Road and Qingliang East Road, positioned along the central median of Heping Middle Road running north-south. The station features an 11-meter island platform and is a two-level underground facility, with its starting mileage at SK19+744.677 and terminating mileage at SK19+939.777. The proposed site features relatively flat terrain within the southern Jiangsu plain of the lower Yangtze River delta, characterized primarily as an alluvial-lacustrine uplifted plain. The main foundation pit bottom lies predominantly within silt and clay layers, with excavation depths primarily composed of silty soil and silt layers. The toe of the retaining wall is situated within silty clay and clay layers.

The foundation pit support scheme design is as follows: The station main foundation pit retaining structure employs 800mm-thick diaphragm walls with a wall depth of approximately 40m. The standard section diaphragm walls have an embedment depth of about 23.59m, while the end shaft diaphragm walls have an embedment depth of approximately 21m to 22m. This excavation employs the cut-and-cover sequential construction method, with four vertical support layers installed: the first layer utilizes 800×800 concrete supports, while the remaining layers employ φ600mm steel pipe supports with a wall thickness of 16mm.

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Based on groundwater burial conditions, groundwater types primarily consist of phreatic and confined water. At Qingliangsi Station, phreatic water exists as upper perched water buried within fill material. During investigation, the stable water level of this upper perched water was measured at a burial depth of 1.80 to 3.70 meters. For groundwater management, vacuum deep well dewatering is employed within the excavation pit. Since the diaphragm wall completely isolates the confined aquifer, pumping of confined water is unnecessary provided its water-stopping effectiveness is assured. However, a limited number of standby wells must be installed.

2. Implementation of Settlement Monitoring Technical Plan

Settlement monitoring during the excavation of the Qingliangsi Station foundation pit is a critical step in ensuring the safety of the project and the stability of the surrounding environment[1]. By monitoring the settlement and displacement of the foundation pit retaining structures, the ground surface, buildings, and underground utilities, we can dynamically assess the impact of construction on the soil and surrounding facilities. The implementation of the settlement monitoring technical plan is based on established monitoring criteria and objectives, as well as a thorough understanding of the key challenges and difficulties involved. It is carried out in accordance with on-site conditions, the construction environment, and detailed monitoring procedures, and includes the establishment of a monitoring information feedback mechanism, emergency response plans, and quality and safety assurance measures [2]

2.1 Settlement Monitoring Scope and Technical Requirements

The layout of monitoring reference points shall strive to avoid potential impacts on their stability from this project and other surrounding factors. Existing elevation control points near stations and shield tunnel sections were selected as monitoring benchmarks for this project. Three working control points were established approximately 100 meters outside the excavation perimeter. A closed leveling route was formed between the reference and working points, with monthly re-measurements conducted[3].

Settlement monitoring content is divided into the following sections:

(1) Top Settlement of Retaining Structure: Establish one monitoring point every 20m along the long sides of the excavation pit. Points must be set at the midpoint and external corners of the short sides, observing at the same points as the horizontal displacement at the top of the retaining structure. Monitoring point layout method: Install settlement benchmarks.

(2) Column settlement: Settlement monitoring points for columns shall be evenly distributed throughout the entire excavation pit, with one point installed approximately every 40 meters. Monitoring point layout method: Install settlement benchmarks.

(3) Surface Settlement Around Excavation Perimeter: Settlement monitoring points for surface settlement around the excavation perimeter shall be established within 56m of the excavation perimeter along the soil mass. Settlement monitoring sections shall be established every 15 to 20 meters along the excavation's longitudinal axis, with 6 settlement points per section. Monitoring point installation method: Embed monitoring points at corresponding locations on surrounding roads and ground surfaces one week prior to excavation. To accurately reflect surrounding surface settlement, monitoring points must be installed above soft soil layers. Drive φ18 steel reinforcement bars with a minimum length of 800mm into the ground, then encase them with C20 concrete[4]..

(4) Building Settlement: Settlement monitoring points for the building shall be installed at intervals of 15 to 20 meters, with priority given to the four corner points, locations of floor level changes, and points of structural stiffness variation. Simultaneously, the building's inclination shall be calculated. Monitoring point installation method: L-shaped settlement observation points are used. Holes are drilled into the structure using an impact drill, and the monitoring points are securely embedded in the holes using anchor adhesive.

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(5) Pipeline Settlement: Pipeline monitoring points are installed on pipelines within the excavation influence zone, with one settlement observation point placed every 15 meters. Monitoring Point Layout Method: Direct monitoring points should be installed on pressure pipelines such as water supply, gas, and heating lines. These points should be placed directly on the pipeline or utilize pipeline equipment like valve switches, vent holes, and inspection chambers. Indirect monitoring points may be installed where direct points cannot be embedded. Monitoring points should be positioned at pipeline junctions, corners, and areas with significant deformation curvature.

In accordance with the "Code for Surveying of Urban Rail Transit Engineering" (GB 50308-2017), deformation and settlement monitoring points shall be established in compliance with the technical requirements for Class II vertical displacement monitoring networks and arranged as continuous leveling routes. The settlement monitoring benchmark network shall be established in accordance with the technical requirements for Class II vertical displacement monitoring control networks and arranged as closed leveling routes. Tables 1 to 3 present the relevant technical indicators and requirements[5]..

Table 1. Main Technical Requirements for the Vertical Settlement Monitoring Control Network

Monitoring Grade	Mean square error in Adjacent Point Elevation Differences (mm)	Mean error in elevation difference at each station (mm)	Closing error of round-trip or loop leveling(mm)	Calculate the error in the measured elevation difference (mm)
II	±0.5	±0.15	$\pm 0.3\sqrt{n}$	$\pm 0.4\sqrt{n}$

Table 2. Main Technical Requirements for Vertical Settlement Monitoring

Monitoring Grade	Elevation mean square error (mm)	Mean square error in elevation difference between adjacent points (mm)	Closing error of closed or connected leveling lines (mm)
II	≤ ±0.5	≤ ±0.3	$\pm 0.3\sqrt{n}$

Note: n represents the number of stations.

Table 3. Requirements for Settlement Monitoring Sightlines and Monitoring Stations

Monitoring Grade	Instrument Model	Leveling rod	Sight Length(m)	Difference between foresight and backsight distances(m)	Cumulative sight distance difference(m)	Sight Height(m)
II	Leica DNA03	Indium Steel Ruler	≤30	≤0.5	≤1.5	0.5～2.8

2.2 Settlement Monitoring Implementation

Settlement monitoring follows the principle of establishing control points before densifying the network, strictly adhering to national second-order leveling survey requirements. The same observation routes and methods are employed throughout the process. Precision leveling instruments and their suitable indium steel rods are used, with monitoring points between adjacent working benchmarks observed via continuous leveling routes. The leveling instrument observation method follows the aBFFB format. Prior to each internal data processing calculation, field observation records are first inspected according to the aforementioned technical requirements. Control indicators such as round-trip height differences and closure errors are strictly monitored. Only after all parameters meet specifications can internal adjustment be performed[6].

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The benchmark network initially conducts two independent observations, with the mean of these two observations serving as the initial elevation for each benchmark point. Following each observation cycle, a stability analysis is performed by comparing the observed elevation values of each benchmark point against their initial elevation values. If the detected deviation exceeds twice the mean elevation error, the point is deemed unstable. Subsequent monitoring will apply elevation corrections to unstable points; otherwise, the original values are retained.

Vertical displacement observation results are adjusted using station-weighted least squares to calculate the elevation of each monitoring point. The settlement for each observation is calculated by comparing the current elevation with the previous one, while cumulative settlement is calculated by comparing with the initial elevation. Vertical settlement is expressed as negative values for subsidence and positive values for uplift. Calculations are performed according to Equations 1 and 2.

$$dh_i = h_{i-1} - h_i \tag{1}$$

$$\mathrm{Dh} = \sum_{n=1}^{i} \mathrm{dh}_n \tag{2}$$

In the formulas,dh_i represents the settlement value for this measurement; h_i represents the elevation value for this measurement; h_{i-1} represents the elevation value from the previous measurement; DH represents the cumulative settlement value for this measurement.

When the absolute value of daily settlement exceeds 1 mm (including 1 mm), the settlement monitoring point is deemed to have undergone deformation or exhibit a deformation trend. When the absolute value of cumulative settlement exceeds 2 mm (including 2 mm), the settlement monitoring point is deemed to have undergone settlement deformation. After data collection, complete the settlement deformation form, plot the time-settlement deformation curve, and conduct deformation analysis[7].

3. Analysis of Monitoring Results

Construction monitoring at the Qingliangsi Station excavation pit strictly adhered to the requirements of the established monitoring plan. Monitoring results were reported to relevant units on schedule. Based on monitoring data, analyses were conducted to address issues identified at the construction site, and timely construction recommendations were proposed to ensure smooth progress. This process accumulated valuable experience for information-driven construction practices[8].

3.1 Monitoring Control Parameters

Monitoring control values are determined based on design drawing requirements. For aspects not explicitly specified in the design drawings, the provisions for monitoring control values of Grade II excavation pits in the relevant standards shall be referenced. The control values for each monitoring parameter are shown in Table 4.

Table 4. Monitoring Control Values for Qingliangsi Station Excavation Pit

Monitoring Items	Alarm threshold	
	Cumulative value	Rate of change
Ground settlement around the foundation pit foundation pit	13mm	2mm/d
Groundwater level	500mm	0.5m/d
Pillar settlement	10mm	2mm/d

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3.2 Analysis of Monitoring Data

Monitoring of various parameters at the Qingliangsi Station—including ground surface settlement, column settlement, and retaining wall crown settlement—was conducted to promptly track changes in conditions both inside and outside the excavation pit. This provided a reference basis for ensuring the safety of excavation pit construction.

(1) Ground Surface Settlement Monitoring. Figure 1 shows surface settlement monitoring data measured at a specific cross-section during the initial stage of excavation construction. The monitoring data indicates that despite the dynamic loads from excavation activities and surrounding mechanical construction, surface settlement changes remained minimal and tended toward stability. The cumulative variation fluctuated within the range (-5, 5) (Note: unit in mm), demonstrating that the impact on surrounding roads and the surface was negligible[9].

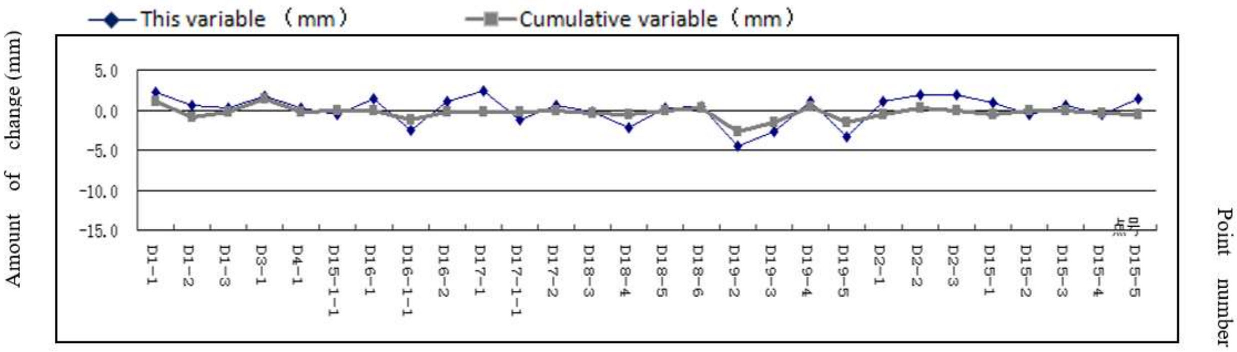

Figure 1. Surface Subsidence Change Curve Chart

(2) Pile Settlement Monitoring. Table 5 shows the actual settlement data from three monitoring points over the past half-month. Monitoring indicates that both LZ2 and LZ3 meet requirements for both daily and cumulative settlement changes, remaining in a safe state. However, at LZ1, the daily changes on October 21, 23, and 25 all exceeded the alarm rate, and the cumulative changes also surpassed the alarm value. At this point, LZ1 was in a hazardous state, necessitating immediate measures to control the continued increase in excavation pit deformation. The construction team effectively resolved this issue by promptly reinforcing the steel supports and ensuring sufficient stability of the excavation pit support system[10].

Table 5. Partial Monitoring Data for Pillar Settlement (Unit: mm)

Pot number	Oct.1	Oct. 15	Oct. 17	Oct. 19	Oct. 21	Oct. 23	Oct. 25	Cumulative change
LZ1	0.7	1.4	1.2	1.9	2.3	2.5	2	12
LZ2	0.3	-0.6	-0.5	-0.7	-1.7	-1.2	-0.9	-5.3
LZ3	0.3	-0.9	-0.9	-0.3	0.7	1.5	1.6	2

4. Conclusion

Through preparatory work, monitoring point layout, installation and protection of testing instruments, and data collection and analysis, a systematic on-site monitoring program was implemented for the excavation pit construction at Qingliangsi Station of the Changzhou Rail Transit. Monitoring revealed that surface settlement and other parameters remained safe and stable. However, abnormal data emerged in column settlement measurements. By integrating construction conditions with on-site analysis, a deformation control plan was swiftly formulated, ultimately resolving the issue and fully demonstrating the value of on-site monitoring. It is also crucial to note that the integrity and accuracy of monitoring point layout in the preparatory phase are essential prerequisites for ensuring data reliability and accurately reflecting construction deformation information.

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