Postprint: Study on the Impact of Dewatering for Foundation Pit Excavation at a Wuhan Metro Station

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Abstract

Deep foundation pit excavation and dewatering for subway stations constitute an important component of subway construction projects. Since subway station construction sites are generally located in areas with high pedestrian traffic, and foundation pit dewatering often exerts adverse impacts on the surrounding environment, research and analysis on foundation pit dewatering are necessary. This paper takes a station on Wuhan Metro Line 6 as a case study, utilizing actual monitoring data to illustrate the variation patterns of settlement of surrounding buildings and deformation of retaining structures during the foundation pit dewatering process. The main conclusions drawn are: 1) The effect of external dewatering on surrounding buildings is far greater than that of internal dewatering; 2) External dewatering can reduce the active earth pressure outside the foundation pit to a certain extent, thereby decreasing the deformation of the surrounding retaining structures; 3) Soil conditions and foundation pit dewatering status exert significant influence on the deformation of retaining structures.

Full Text

Study on the Influence of Foundation Pit Dewatering during Excavation of a Wuhan Metro Station

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Abstract: Foundation pit dewatering during deep excavation of metro stations constitutes a critical component of subway construction. Since metro stations are typically located in high-traffic urban areas, foundation pit dewatering often exerts adverse impacts on the surrounding environment, necessitating thorough research and analysis. This paper examines a station on Wuhan Metro Line 6, utilizing actual monitoring data to characterize the patterns of settlement in surrounding buildings and deformation of retaining structures during dewatering. The main conclusions are: (1) the impact of external dewatering on surrounding buildings far exceeds that of internal dewatering; (2) external dewatering can reduce active earth pressure outside the pit, thereby decreasing deformation of adjacent retaining structures; and (3) soil conditions and dewatering status significantly influence retaining structure deformation.

Keywords: Metro station; Foundation pit dewatering; Construction monitoring; Retaining structure deformation; Surrounding building settlement

1 Project Overview

1.1 Project Description The station is a two-story underground island-platform station on Wuhan Metro Line 6, with the concourse level on the first underground floor and the platform level on the second. The station features a 13-meter-wide island platform with an effective length of 140 meters, an effective screen door length of 135.74 meters, and a line center spacing of 16.2 meters. The total station length is 531.54 meters, with a standard section width of 22.3 meters, burial depth of 17.59 meters, and overburden thickness of 3.8–4.0 meters. The absolute elevation of $±$0.000 at the station’ s effective platform center is 5.53 meters, and the rail surface elevation is 4.45 meters. The public area of the station structure adopts a 13-meter-wide two-column three-span island platform, while the equipment area employs a two-column three-span structure.

With continuous development in engineering construction, large-scale metro construction has become commonplace. Deep foundation pit dewatering for metro projects represents a crucial construction component that directly affects construction quality and safety. Wuhan’ s groundwater is extremely abundant, requiring dewatering operations in most foundation pit projects. Metro stations are typically built in bustling urban areas with limited construction space and numerous surrounding buildings, and foundation pit dewatering inevitably causes surface settlement and building settlement, creating adverse environmental impacts.

This paper uses a station on Wuhan Metro Line 6 as a case study to illustrate the impacts of foundation pit dewatering on surrounding buildings and retaining structures during excavation, with particular emphasis on analyzing the effects of external dewatering. This research provides valuable empirical data for similar future projects and holds practical application significance.

1.2 Geological Conditions The overlying soil layers along the proposed project site primarily consist of recent artificial fill, Quaternary alluvial-pluvial soil layers, and sand layers, underlain by Cretaceous-Paleogene sandy conglomerate. Based on field drilling descriptions, in-situ test results, and laboratory geotechnical test data, the strata within the exploration depth are divided into 6 major layers and 16 sublayers: (1) Quaternary fill layer (Q^{ml}), including Q^{ml}-1-1 miscellaneous fill, Q^{ml}-1-2 plain fill, and Q^{ml}-1-3 muddy clay; (2) Quaternary Holocene alluvial layer (Q^{al}), including Q^{al}-3-1 clay, Q^{al}-3-2 clay, Q^{al}-3-2a clay, Q^{al}-3-3 mucky silty clay, Q^{al}-3-5 silty clay interbedded with silt and fine sand, Q^{al}-4-1 fine sand interbedded with silt, Q^{al}-4-2 fine sand, and Q^{al}-5 medium-coarse sand interbedded with gravel; (3) Second terrace accumulation plain area (Q^{pal}), including Q^{pal}-12-2 medium-fine sand interbedded with gravel and Q^{pal}-12-3 gravelly sand containing cohesive soil; (4) Underlying bedrock, including K-E-15b-1 weakly cemented sandy conglomerate, K-E-15b-2 moderately cemented sandy conglomerate, and K-E-15b-3 strongly cemented sandy conglomerate. The station base slab is mainly located in the 3-5 silty clay interbedded with silt and fine sand layer and the 4-1 fine sand interbedded with silt layer.

1.3 Hydrogeological Characteristics No surface water is distributed within the proposed station site. Groundwater primarily consists of perched water, pore confined water, and bedrock fissure water. Perched water occurs mainly in the upper artificial fill, recharged by atmospheric precipitation, domestic water, and seepage from drainage pipelines. Its water level and quantity are closely related to topography and seasons, and significantly affected by human activities. During the investigation, the static water level of perched water was measured at 0.90–5.20 meters below ground surface, corresponding to an elevation of 15.85–19.95 meters above the Yellow Sea datum. Perched water has minimal impact on foundation pit excavation.

Confined water is mainly stored in the 3-5 mixed layer, 4th layer, 5th layer, and 12th layer sandy soils. The 3-5 layer is a weakly confined, weakly permeable aquifer, while the 4th, 5th, and 12th layers are medium-to-highly permeable layers, primarily receiving lateral groundwater recharge and discharge. The 4th and 5th layers constitute the first terrace confined aquifer, which has hydraulic connections with the Yangtze and Han Rivers, exhibiting a complementary relationship. The 12th layer is a medium-permeability aquifer at the bottom of the second terrace. Since the site is relatively far from the Yangtze and Han Rivers, seasonal groundwater level variations are small (2–3 meters), though water quantity is substantial. According to the geotechnical investigation report, the confined water level is approximately 4.8 meters below ground surface (elevation 15.70 meters). The confined water level must be verified before construction and monitored during construction.

Bedrock fissure water occurs mainly in the lower bedrock, recharged by downward seepage and lateral flow from overlying aquifers. Bedrock fissure water is hydraulically connected with confined water and has minimal impact on foundation pit construction.

2 Site Dewatering Construction Conditions

The excavation depth for the Wuhan Metro Line 6 station ranges from 17.78 to 20.4 meters (classified as an ultra-deep foundation pit with a safety grade of Level I). The pit bottom is located in the 3-5 silty clay, silt, and fine sand interbedded layer. Without effective control of site confined water after excavation, high-pressure water at the pit bottom would cause heave. The control method involves installing dewatering wells both inside and outside the pit for dewatering and drainage. During construction, dewatering should be comprehensively considered based on confined water level, excavation depth, and soil geological conditions at the excavation face, minimizing water extraction while preventing heave. During dewatering maintenance, the number of operating extraction wells should be reasonably adjusted according to different excavation depths and excavation procedures in various sections: partial dewatering wells can be centrally activated in specific construction zones while appropriately closing some wells in other areas, with specific operating quantities controlled and adjusted based on field-measured water level drawdown.

On August 3, 2015, excavation of the station foundation pit commenced. The area south of Houhu Avenue is designated as Work Zone I, and the north as Work Zone II, with both zones excavating simultaneously. Work Zone I excavated twenty sections at the southern end, while Work Zone II excavated twelve sections at the northern end. As excavation progressed, dewatering was synchronized. The inclinometer rate changes for the 12th and 19th sections of the foundation pit increased significantly, with cumulative deformation gradually increasing. A row of residential buildings near the 20th section was located close to the pit edge, and as excavation and dewatering proceeded, the settlement rate continued to increase, with cumulative settlement far exceeding the warning value. Special analysis was therefore conducted on these surrounding buildings and the pit retaining structures.

3 Monitoring Data Analysis

3.1 Settlement Analysis of Residential Buildings Settlement monitoring data for the residential buildings began on August 18, 2015. The spatial relationship between the buildings and the foundation pit and the monitoring point layout are shown in Figure 1 [Figure 1: see original paper].

During construction, personnel observed that measured groundwater levels remained at a constant elevation, making it difficult to further lower the water level through internal dewatering. Therefore, on August 22, 2015, an additional external dewatering well was installed on the left side of the 20th section end, and two external wells were installed on the right side. Subsequent construction revealed that installing these external dewatering wells did not lower the groundwater level but instead caused increasing settlement in the residential buildings, with settlement rates further accelerating. Specific monitoring data for a certain extraction period are shown in Figure 2 [Figure 2: see original paper].

The settlement rates of the residential buildings differed significantly before and after external dewatering. After installation of the external dewatering wells, the settlement rate surged far beyond the warning value, and settlement magnitude also substantially exceeded the warning threshold. Figure 2 shows the settlement conditions before external dewatering installation; based on August 18 monitoring data, the maximum settlement rate at various building measurement points was -5.0 mm/day, with a maximum settlement of -21.9 mm.

After completion and commissioning of the three external dewatering wells on August 22, the data in Figure 3 [Figure 3: see original paper] show that daily settlement rates at each measurement point increased rapidly. On August 27, the maximum building settlement reached 43.5 mm, with a maximum settlement rate of -8.4 mm/day, demonstrating that external dewatering exerts substantial influence on surrounding buildings. The buildings continued to settle rapidly for dozens of days thereafter. Since both external and internal dewatering proceeded simultaneously during subsequent construction, and the cumulative settlement and settlement rates of the residential buildings far exceeded warning values and posed significant risks, the monitoring frequency was increased on September 12 from once daily to twice daily.

On September 5, as the 20th section excavation reached the pit bottom and the base slab was constructed, building settlement decreased significantly. External dewatering ceased on September 14, at which point the maximum settlement reached -166.4 mm and the maximum settlement rate was -2.1 mm/day. After stopping external dewatering, the buildings continued to settle for a period before the deformation rate gradually stabilized, with the final stable maximum value reaching -213.4 mm.

3.1.1 Analysis of Settlement Causes Ground settlement occurs due to reduced buoyancy in overlying layers from confined water level reduction, causing self-weight drainage consolidation and compaction. In upper weakly permeable layers, groundwater level decline or dewatering also causes soil self-weight drainage consolidation and compaction. Additionally, after confined water level reduction, the additional effective stress generated in the soil mass, after deducting pressure relief from water pressure reduction in the aquifer, causes consolidation compression in underlying layers.

The 3-5 silty clay interbedded with silt and fine sand is a weakly permeable layer. When the groundwater level is lowered, soil self-weight drainage consolidation occurs, triggering settlement. When field personnel measured groundwater levels, the water level remained above the excavation face; in reality, no water existed above the excavation face. This was likely due to the weak permeability of the 3-5 silty clay interbedded with silt and fine sand, which blocked the groundwater level beneath this layer. The actual water level had indeed dropped below the excavation face, but field measurements only captured the water level in the dewatering wells. Therefore, due to insufficient experience of field measurement personnel, installing external dewatering wells caused significant building settlement.

Another direct cause was that the residential buildings were old structures slated for demolition, with poor stability due to their age. Their foundations were shallow, making them much more susceptible to foundation pit dewatering than pile-founded buildings. Combined with the geological conditions at the station location, total settlement far exceeded warning values by the time the 20th section roof slab construction was completed.

3.2 Deformation Analysis of Retaining Structures The station employs diaphragm walls as the foundation pit retaining structure. Significant deformation of the retaining structures occurred due to dewatering. This analysis focuses on the inclinometer point variations at the 20th section end, specifically points CX01 and CX40. CX01 is located at the right end of the 20th section, while CX40 is on the right side of the 20th section. Monitoring data from time points before and after dewatering well installation are shown in Figure 5 [Figure 5: see original paper].

Comparison of CX01 inclinometer data (Figure 6 [Figure 6: see original paper]) reveals minimal change in inclinometer distance. After initiating external dewatering, the inclinometer rate initially changed significantly before gradually stabilizing. Even after stopping external dewatering, values remained below warning thresholds with minimal variation. The reasons are: CX01’ s location relative to the external dewatering wells at the 20th section end, where steel corner braces are typically installed and generally erected more promptly than horizontal struts; external dewatering along the pit longitudinal direction means the diaphragm wall at CX01 is perpendicular to the pit direction, resulting in smaller direct impact from external dewatering compared to walls nearest the wells, thus exhibiting more stable deformation.

Comparison of CX40 data (Figure 7 [Figure 7: see original paper]) shows that after installing external dewatering wells, the deformation rate of inclinometer point CX40 actually decreased. On August 31, the pit was still excavating the fourth soil layer without base slab construction. Qualitative analysis leads to the conclusion that simultaneous external and internal dewatering causes concurrent changes in active and passive earth pressure, thereby reducing the diaphragm wall’ s inward offset compared to pits without external dewatering wells. Additionally, CX40 is also located at the end section, where steel corner braces and supports are denser than in standard sections, which can also restrain diaphragm wall deformation to some extent.

Since the geological conditions at the station’ s 12th section are generally similar to those at the 20th section, inclinometer points near the 12th section were selected for comparative qualitative analysis. Specifically, points CX42 and CX32 were chosen. As CX32 was damaged during construction, CX32 (modified) was used after August 20. The monitoring point layout is shown in Figure 8 [Figure 8: see original paper].

The 12th section did not employ external dewatering, using only internal dewatering wells. Monitoring data variations over a selected period illustrate the issue, with data from before and after August 22 compared. The time-series plots for selected monitoring points are shown in Figure 9 [Figure 9: see original paper].

The 20th and 12th sections were excavated almost simultaneously with basically the same progress. The CX42 inclinometer point position is similar to CX01. Figure 9 shows that CX42' s deformation rate is much greater than CX01' s, with the final maximum diaphragm wall offset exceeding 30 mm. Under similar geological conditions between the 12th and 20th sections, this demonstrates that internal dewatering significantly affects diaphragm wall inclinometer variations. Lowering the internal water level below the excavation face changes the soil structure to some extent, altering passive earth pressure and causing inward displacement that increases as excavation proceeds. For point CX01 at the 20th section with external dewatering, the variation is significantly smaller and more stable than at CX42.

For the CX32 inclinometer point (Figure 10 [Figure 10: see original paper]), the variation rate was small during shallow excavation depths, gradually increasing as excavation deepened. Since CX32 is located in a standard section, deformation rate slowed after timely installation of steel supports. Dewatering proceeded almost continuously throughout the day. Theoretically, internal dewatering affects retaining structures to some degree, with the magnitude of impact related to excavation depth, soil conditions, groundwater level, and timeliness of steel support installation. This represents only a qualitative analysis, but monitoring data variations demonstrate that internal dewatering significantly influences retaining structure deformation.

4 Treatment Measures

4.1 Residential Building Settlement Issues After installing external dewatering wells, large-scale settlement occurred in the residential buildings, far exceeding warning values. The construction party promptly identified the problem, optimized the excavation plan, and rationally implemented dewatering operations while strengthening monitoring and inspection to avoid collapse risks from excessive differential settlement. Through close coordination among multiple parties, external dewatering was stopped on September 15. After September 25, the 20th section' s intermediate slab was constructed, and the building settlement rate basically decreased with smaller differential settlement, though overall settlement remained substantial. Local building walls developed cracks, but settlement had essentially stabilized after completion of the 20th section roof slab.

4.2 Retaining Structure Deformation Issues As excavation progressed, localized large-scale settlement of the diaphragm wall occurred, exceeding warning values. The construction party promptly installed steel supports after soil excavation, strengthened observation of diaphragm wall joints and surface cracks, timely treated leakage points, rationally implemented dewatering, and intensified internal and external pit inspections. Emergency materials were prepared on-site and contingency plans were established. The monitoring frequency was increased from once to twice daily starting September 12. With construction of the intermediate slabs in the 20th and 12th sections, the diaphragm wall deformation rate gradually stabilized.

Conclusions

The Wuhan Metro Line 6 station is located in the transition zone from the first to second terrace of the Yangtze River. Combined with actual excavation conditions, this case provides clearer understanding of how soil conditions and foundation pit dewatering affect the surrounding environment and retaining structures. Lessons learned from this project provide valuable reference materials for similar future projects and hold important guiding significance.

The analysis yields the following conclusions:

(1) The station’ s retaining structures do not penetrate the bedrock, and groundwater inside and outside the pit is interconnected. Simultaneous internal and external dewatering significantly impacts surrounding buildings, with external dewatering effects far exceeding those of internal dewatering.

(2) External dewatering can reduce active earth pressure outside the pit to some extent, thereby decreasing deformation of adjacent retaining structures.

(3) The soil within the excavation depth is dominated by fine sand layers, whose properties differ from typical clay soils. During excavation and dewatering, retaining structure deformation magnitude and rate far exceed warning values, indicating that soil conditions and dewatering status significantly influence retaining structure deformation.

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Abstract: The foundation pit dewatering of subway station during excavation is an important part of the work progress. However, the job location of the subway station is generally located in the region of high population flow, and the foundation pit dewatering always brings some bad influence on the surroundings. So the foundation pit dewatering should be studied and analyzed. Based on a metro station of Line No.6 of Wuhan Metro, this paper explains the change law of surrounding building settlement and deformation of retaining structures by using the practical monitoring data during the process of foundation pit dewatering. Main conclusions are as below: 1) in terms of the influence of surrounding buildings, the effect of external foundation pit dewatering is much bigger than that of internal foundation pit dewatering; 2) the effect of external foundation pit dewatering can reduce the active earth pressure of the foundation pit lateral in some degree, and then reduce deformation of retaining structures;

3) the soil property and condition of foundation pit dewatering would have a great impact on the deformation of retaining structures.

Key Words: Subway Station; Foundation Pit Dewatering; Construction Monitoring; Deformation of Retaining Structures; Surrounding Buildings Settlement