A Study on Dewatering Impacts During Foundation Pit Excavation at a Wuhan Metro Station (Postprint)

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Abstract

Deep foundation pit excavation and dewatering for subway stations constitutes a crucial component of subway construction projects. Since subway stations are typically located in areas with high pedestrian traffic, and pit dewatering often exerts adverse impacts on the surrounding environment, research and analysis of foundation pit dewatering are therefore necessary. This paper, based on a station of Wuhan Metro Line 6, utilizes actual monitoring data to illustrate the variation patterns of building settlement around the foundation pit and deformation of the retaining structure during the dewatering process. The main conclusions drawn are as follows: 1) The effect of external pit dewatering on surrounding buildings far exceeds that of internal pit dewatering; 2) External pit dewatering can, to a certain extent, reduce the active earth pressure outside the foundation pit, thereby decreasing the deformation of the surrounding retaining structure; 3) Soil conditions and foundation pit dewatering status exert significant influence on the deformation of the retaining structure.

Full Text

Preamble

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Research on the Influence of Foundation Pit Dewatering During Excavation of a Subway Station in Wuhan

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Abstract: Foundation pit dewatering during deep excavation of subway stations constitutes a critical component of metro construction. Since subway stations are typically located in high-traffic urban areas, dewatering operations often adversely impact the surrounding environment, necessitating thorough research and analysis. This paper examines a station on Wuhan Metro Line 6, utilizing field monitoring data to characterize the patterns of settlement in adjacent 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: Subway station; Foundation pit dewatering; Construction monitoring; Retaining structure deformation; Surrounding building settlement
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1. Project Overview

1.1 Project Description

With the continuous development of construction, large-scale metro construction has arrived. Deep foundation pit dewatering for metro projects is an integral part of construction that directly affects quality and safety. Wuhan' s groundwater is extremely abundant, requiring dewatering in most foundation pit projects. Metro stations are typically built in bustling urban areas with limited construction space and numerous surrounding buildings, making dewatering-induced ground settlement and building settlement inevitable and potentially harmful.

This paper uses a station on Wuhan Metro Line 6 as a case study to illustrate the impacts of dewatering on surrounding buildings and retaining structures during excavation, with particular focus on the effects of external dewatering. The findings provide valuable experience for similar future projects.

The station is an underground two-level island-platform station. The underground first level houses the concourse, and the second level contains the platform. The station employs a 13 m wide island platform with an effective length of 140 m, a screen door effective length of 135.74 m, and a line center spacing of 16.2 m. The total station length is 531.54 m, with a standard section width of 22.3 m. The burial depth is 17.59 m, with overburden thickness of 3.8–4.0 m. The absolute elevation of $±$0.000 at the effective platform center is 5.53 m, and the rail surface elevation is 4.45 m. The public area of the station structure uses a 13 m wide two-column three-span island platform, while the equipment area employs a two-column three-span structure.

1.2 Engineering Geology

The overlying soil layers along the proposed project site primarily consist of recent artificial fill, Quaternary alluvial-pluvial strata, and sand layers, underlain by Cretaceous-Paleogene sandy conglomerate. Based on field drilling descriptions, in-situ test results, and laboratory geotechnical tests, the strata within the exploration depth are divided into 6 major layers and 16 sublayers:

1. **Quaternary fill layer (Q_4^{ml})**: Includes Q_4^{ml}-1-1 miscellaneous fill, Q_4^{ml}-1-2 plain fill, and Q_4^{ml}-1-3 muddy clay.
2. **Quaternary Holocene alluvial layer (Q_4^2)**: Includes Q_4^2-1 clay, Q_4^2-3-2 clay, Q_4^2-3-2a clay, Q_4^2-3-3 muddy silty clay, Q_4^2-3-5 silty clay interbedded with silt and fine sand, Q_4^2-4-1 fine sand interbedded with silt, Q_4^2-4-2 fine sand, and Q_4^2-5 medium-coarse sand with gravel.
3. **Second terrace accumulation plain (Q ^{al})**: Includes Q ^{al}-12-2 medium-fine sand with gravel and Q ^{al}-12-3 cohesive soil with gravel.
4. **Underlying bedrock**: Includes 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 primarily located in layer 3-5 (silty clay interbedded with silt and fine sand) and layer 4-1 (fine sand interbedded with silt).

1.3 Hydrogeological Characteristics

No surface water is present within the station site. Groundwater primarily consists of perched water, confined pore water, and bedrock fissure water. Perched water occurs in the upper artificial fill, recharged by atmospheric precipitation and leakage from water supply/drainage pipelines. Its level and quantity are closely related to topography and season, and significantly affected by human activities. During investigation, the static water level of perched water was measured at 0.90–5.20 m depth (elevation 15.85–19.95 m above Yellow Sea datum). Perched water has minimal impact on excavation.

Confined water occurs in sand layers 3-5, 4, 5, and 12. Layer 3-5 is a weakly confined, low-permeability aquifer, while layers 4, 5, and 12 are medium-high permeability layers receiving lateral groundwater recharge and discharge. Layers 4 and 5 are first-terrace confined aquifers hydraulically connected to the Yangtze and Han Rivers, while layer 12 is a second-terrace medium-permeability aquifer. Due to the site’ s distance from these rivers, seasonal water level variations are small (2–3 m), but water quantity is abundant. Geotechnical investigation reports indicate confined water at approximately 4.8 m depth (elevation 15.70 m). The confined water level must be verified before construction and monitored during work.

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

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2. Field Dewatering Conditions

For Wuhan Metro Line 6 station, the excavation depth of 17.78–20.4 m qualifies as an ultra-deep foundation pit (safety level I). The pit bottom lies in layer 3-5 (silty clay, silt, and fine sand interbeds). Without effective control of confined water after excavation, high-pressure water would cause heave failure. The control method involves installing dewatering wells both inside and outside the pit for dewatering and drainage.

During dewatering, water extraction should be minimized while ensuring no heave failure occurs, considering confined water level, excavation depth, and soil conditions. The dewatering process should be adjusted according to excavation progress in different sections: partial dewatering wells can be activated in concentrated construction zones while appropriately closing wells in other areas, with specific quantities controlled by field-measured water level drawdown.

Excavation began on August 3, 2015. The area south of Houhu Avenue is the first construction zone, and the north is the second zone, both excavating simultaneously. The first zone excavated twenty sections at the southern end, while the second zone excavated twelve sections. As excavation progressed, dewatering was synchronized. The inclinometer readings for sections 12 and 19 showed significant deformation rates, with cumulative deformation gradually increasing.

A row of residential buildings near section 20 was close to the pit edge. As excavation and dewatering proceeded, settlement rates continued increasing, with cumulative settlement far exceeding warning values. This prompted analysis of the surrounding buildings and retaining structures.

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3. Monitoring Data Analysis

3.1 Residential Building Settlement Analysis

Settlement monitoring of the residential buildings began on August 18, 2015. The spatial relationship between buildings and the pit and monitoring point layout is shown in Figure 1 [Figure 1: see original paper].

During construction, field measurements showed groundwater levels remained at a constant elevation, making further drawdown difficult with internal dewatering alone. Therefore, on August 22, 2015, one external dewatering well was installed on the left side of section 20’ s end, and two wells on the right side. Subsequent monitoring revealed that external wells did not lower the water level but instead caused building settlement to increase continuously, with settlement rates rising further. Detailed monitoring data for a specific period are shown in Figure 2 [Figure 2: see original paper].

Settlement rates differed significantly before and after external dewatering. After external well installation, building settlement rates surged far beyond warning values, as did total settlement. Figure 2 shows pre-dewatering settlement: on August 18, maximum settlement rate was -5.0 mm/d with maximum settlement of -21.9 mm.

After three external wells became operational on August 22, daily settlement rates increased rapidly. By August 27, maximum settlement reached 43.5 mm with a rate of -8.4 mm/d, demonstrating substantial external dewatering impacts. Buildings remained in rapid settlement for dozens of days. Since both internal and external dewatering operated simultaneously and building settlement far exceeded warning values, monitoring frequency was increased from daily to twice-daily on September 12.

On September 5, as section 20 excavation reached the base and the base slab was constructed, building settlement decreased significantly. External dewatering ceased on September 14, when maximum settlement reached -166.4 mm with a maximum rate of -2.1 mm/d. Settlement continued briefly after stopping external dewatering before stabilizing gradually, with a final stable maximum of -213.4 mm.

3.1.1 Settlement Mechanism Analysis Settlement occurs through several mechanisms: lowering confined water levels reduces uplift pressure on overlying strata, causing self-weight consolidation; in low-permeability layers above, groundwater drawdown causes soil consolidation; and reduced water pressure creates additional effective stress on underlying strata.

Layer 3-5 (silty clay interbedded with silt and fine sand) is a low-permeability stratum. Water level reduction causes self-weight consolidation and settlement. Field personnel measured water levels above the excavation face, but in reality, no water existed above this level. This discrepancy likely occurred because the low permeability of layer 3-5 blocked the water table beneath it. The measured water level only reflected conditions in the dewatering wells, not the actual lowered water table below the excavation face. This measurement error led to unnecessary external dewatering wells and consequent excessive building settlement.

Another direct cause: the buildings were old structures slated for demolition, with poor stability and shallow foundations. Dewatering impacts shallow foundations far more than pile foundations. Combined with the site’ s geological conditions, total settlement far exceeded normal values by the time section 20’ s roof slab was completed.

3.2 Retaining Structure Deformation Analysis

The station uses diaphragm walls for retaining structures. Significant deformation occurred due to dewatering. Analysis focuses on inclinometer points at section 20' s end: CX01 (right end of section 20) and CX40 (right side of section 20). Monitoring data before and after external well installation are shown in Figure 5 [Figure 5: see original paper].

CX01 Analysis:
Comparison shows minimal change in CX01' s displacement (Figure 6 [Figure 6: see original paper]). After external dewatering began, the deformation rate initially increased then stabilized, remaining below warning values even after dewatering stopped. This stability results from: (1) CX01' s location at the section end where steel corner supports are typically installed more promptly than horizontal supports; and (2) the end diaphragm wall being perpendicular to the pit's longitudinal axis, making it less directly affected by external dewatering along the pit' s length.

CX40 Analysis:
After external well installation, CX40' s deformation rate actually decreased (Figure 7 [Figure 7: see original paper]). On August 31, the pit was still excavating the fourth soil layer without a base slab. Qualitative analysis reveals that simultaneous internal and external dewatering changes both active and passive earth pressures, reducing the wall' s inward displacement compared to pits without external dewatering. Additionally, CX40' s end location has denser steel supports than standard sections, further restraining deformation.

Since section 12 has similar geological conditions to section 20, inclinometer points near section 12 (CX42, CX32) were compared for qualitative analysis. CX32 was damaged during construction, so CX32 (modified) was used after August 20. Monitoring point layouts are shown in Figure 8 [Figure 8: see original paper].

Section 12 used only internal dewatering. Monitoring data before and after August 22 were compared (Figure 9 [Figure 9: see original paper]). Sections 12 and 20 were excavated simultaneously with similar progress. CX42' s location mirrors CX01' s, yet Figure 9 shows CX42' s deformation rate was much greater than CX01' s, eventually exceeding 30 mm maximum displacement. Under similar geological conditions, this demonstrates that internal dewatering significantly affects diaphragm wall deformation. Lowering the internal water table below the excavation face alters soil structure and passive earth pressure, causing increasing inward displacement. CX01 (with external dewatering) showed significantly smaller, more stable deformation than CX42.

Figure 10 [Figure 10: see original paper] shows CX32' s behavior: small deformation rates during shallow excavation, increasing with depth. As a standard section point, deformation rates slowed after timely steel support installation. Continuous dewatering theoretically affects retaining structures, with impacts depending on excavation depth, soil conditions, water level, and support installation timing. This qualitative analysis demonstrates that internal dewatering substantially influences retaining structure deformation.

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4. Mitigation Measures

4.1 Building Settlement Control

After external dewatering caused large-scale building settlement exceeding warning values, the contractor promptly identified the problem, optimized the excavation plan, and implemented rational dewatering operations. Monitoring and inspection were intensified to avoid collapse risks from excessive differential settlement. Through close coordination among all parties, external dewatering ceased on September 15. After section 20’ s intermediate slab construction on September 25, building settlement rates decreased substantially with minimal differential settlement, though overall settlement remained large and local wall cracks appeared. Settlement essentially stabilized after section 20’ s roof slab completion.

4.2 Retaining Structure Deformation Control

As excavation progressed, local diaphragm wall deformation exceeded warning values. The contractor promptly installed steel supports after excavation, intensified observation of wall joints and cracks, repaired leaks immediately, and implemented rational dewatering. Internal and external patrols were strengthened, emergency materials were stockpiled, and contingency plans were prepared. Monitoring frequency was increased from daily to twice-daily on September 12. After intermediate slab construction in sections 20 and 12, deformation rates gradually stabilized.

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5. Conclusions

The Wuhan Metro Line 6 station is located in the transition zone between the first and second terraces of the Yangtze River. Analysis of actual construction conditions clarifies how soil conditions and dewatering affect the surrounding environment and retaining structures, providing valuable experience for future projects.

Key conclusions:

1. **The station’ s retaining structures do not extend into bedrock**, allowing groundwater communication between inside and outside the pit. Simultaneous internal and external dewatering significantly impacts surrounding buildings, with external dewatering effects far exceeding internal dewatering effects.

2. **External dewatering reduces active earth pressure** outside the pit, thereby decreasing deformation of adjacent retaining structures.
3. **Soils in the excavation zone are primarily sandy**, with properties differing from typical clay. During excavation and dewatering, retaining structure deformation magnitudes and rates far exceed warning values, demonstrating that soil conditions and dewatering status substantially influence deformation.

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English Abstract (Original):

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

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

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