Influence of groundwater level change on deep foundation pit and its control technology

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Abstract: During the construction of deep foundation pits with rich water straight grooves, instability of deep foundation pits due to groundwater frequently occurs, posing a huge challenge to construction safety and economy. Based on the deep foundation pit of the intercity connecting line of Beijing New Airport, the technical method of combining theoretical analysis and on-site monitoring is adopted to analyze the influencing factors of groundwater on the retaining structure of deep foundation pit, and control and analyze the influencing factors. The deformation control technology for deep foundation pit is proposed. The following conclusions are obtained: (1) Based on the on-site geological conditions and the mechanism of groundwater level change, the deformation and failure forms and precipitation forms of deep foundation pits are obtained through theoretical analysis. (2) Based on the Deformation monitoring technology of deep foundation pit, the change of groundwater level and Deformation monitoring of retaining structure are carried out. (3) Combining on-site monitoring with theoretical calculation, conducting comparative analysis of data, summarizing the influencing factors of deep foundation pit damage, obtaining targeted deformation control technology for deep foundation pit, guiding the construction of practical projects, and providing reference for similar projects.

Key words: deep foundation pit; Field monitoring; Pipe surge; A surge; Control technique.

1. Preface

With the large-scale investment in infrastructure construction in China, the construction of deep foundation pits has become a trend. However, due to the complex excavation conditions of deep foundation pits and the ever-changing environment, groundwater poses challenges and hazards to deep foundation pit excavation. Therefore, it is necessary to systematically study the impact of groundwater level changes on deep foundation pit construction, and develop detailed and targeted control techniques to reduce the impact of groundwater on deep foundation pit construction.

Many scholars at home and abroad have conducted a series of discussions on the impact of groundwater level changes on deep foundation pits and control technologies. Zhou Chuanshui [1] obtained the deformation law of the foundation pit diaphragm wall by studying the groundwater level, and optimized the method of groundwater level control and the supporting structure of the diaphragm wall; Xu Zhongtao [2] analyzed the deformation laws of deep foundation pits and supporting structures caused by dewatering excavation and the impact of different supporting structure design parameters on foundation pit deformation through combining theory with on-site monitoring and using numerical simulation methods; Li Yuzi [3] has conducted research on the dynamic change law of groundwater level, prediction and early warning of water level drawdown, and optimization of monitoring well network through dynamic monitoring and numerical simulation methods; Based on on-site monitoring and finite element numerical simulation, Wang Hao [4] analyzed and studied the deformation of deep foundation pit, surrounding surface settlement, and the impact on building foundation settlement caused by dewatering and excavation process; Long Zhang [5] optimized the monitoring method of groundwater level in deep foundation pits through theoretical research on existing projects; Xia Wen, Li Pan, Qiu Wei, Li Xudong[6] analyzed the impact of underground water level in deep

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foundation pit excavation on surrounding building settlement under existing support methods through on-site real-time monitoring and numerical simulation; Wu Peng [7] analyzed the deformation law of the retaining structure of the deep foundation pit during the process of groundwater precipitation, as well as the surrounding structure settlement and groundwater level changes, and conducted a conditional analysis of the foundation pit construction method; Tao Hongliang [8] preliminarily deduced the theory of computation of the water gate through theoretical calculation and numerical calculation analysis based on the analysis of the factors affecting the embedding depth of the water stop curtain; Gao Dong [9] conducted finite element simulation on the excavation, support, and precipitation methods of deep foundation pits, and the obtained data was compared and analyzed using the software Origin; Zhang Dongdong [10] used a combination of indoor tests and on-site experiments to conduct numerical simulation of experimental data, and conducted research on vacuum drainage and precipitation methods, precipitation optimization, and intelligent methods for deep foundation pit engineering precipitation; Wang Chuanlin [11] systematically studied the influence of precipitation depth on the stability of foundation pits; Zhao Min et al. [12] studied the variation of groundwater level and optimized the dewatering method of deep foundation pit based on the example of deep foundation pit engineering in the loess area of Xi'an City; Li Lin [13] used finite Meta computing and FLAC program to study the influence of dewatering mode on the retaining structure of deep foundation pit and surrounding ground settlement.

According to the current research status of the impact of groundwater on deep foundation pit excavation, most scholars use theoretical analysis to analyze the impact of groundwater on deep foundation pit excavation, while few use the deformation law of deep foundation pit to find accurate control methods, which are closer to engineering practice. Some use numerical analysis and simulation for simulation experiments, but the on-site conditions are complex, there are many uncertainties in on-site construction, and there are certain deviations in the control technology used.

On the basis of theoretical calculation, combined with on-site monitoring data, this paper compares and analyzes the change of underground water level of deep foundation pit with the Deformation monitoring data of retaining structure, discusses the relationship between the deformation law of retaining structure and the change law of underground water level in detail, and adopts stage analysis, by comparing the monitoring data with theoretical calculations, the deformation control technology for deep foundation pits is obtained to verify the feasibility of the excavation and monitoring plans, which can guide actual construction, avoid engineering hazards caused by improper construction, and reduce engineering risks and economic losses.

2. Project Overview

2.1 Overview of tunnel route

The line is located in Da Xing District, Beijing, and Lang Fang City, Hebei Province. The intercity railway connecting line runs from north to south, with a starting and ending mileage of DK42+038~DK46+115, all tunnels are constructed by open excavation method.

2.2 Overview of geological conditions

The sources of natural groundwater include shallow groundwater, runoff water, drainage water, atmospheric precipitation, etc. The tunnel passes through the Yong Ding River and the Tian Tang River, where the water resources are affected by seasonal changes and the water level significantly increases during the rainy season.

The groundwater level in the site is Quaternary pore phreatic water, and the groundwater in local silt or silt layers is slightly pressurized. The sand layer has abundant water content, and the groundwater depth along the line varies greatly. It is mainly supplied by atmospheric precipitation and underground runoff, and the discharge is mainly runoff and manual mining. The sand layer in the tunnel body is distributed intermittently due to its thin layer, and the water content is not large.

3. Analysis of groundwater level change mechanism

3.1 Impact forms of groundwater changes on foundation pits

Taking the pile anchor retaining structure in the retaining structure of straight open cut deep foundation pit as the research object, the deformation and damage forms of deep foundation pit caused by changes in groundwater level include the following aspects:

(1) When the water pressure is too high, seepage phenomenon will inevitably occur. When the seepage force of groundwater flows in the gap, it will exert a force on the retaining structure, causing deformation of the retaining pile and instability of the foundation pit.

(2) Groundwater will reduce the integrity of the soil behind the pile, resulting in uneven overall stress on the retaining structure. The water and soil move, causing piping.

(3) When the water level in the foundation pit is high, with the continuous excavation of the soil mass, the overlying soil mass is jacked up by the groundwater level, causing cracks at the bottom of the pit, causing sediment to surge from the cracks, resulting in a surge phenomenon.

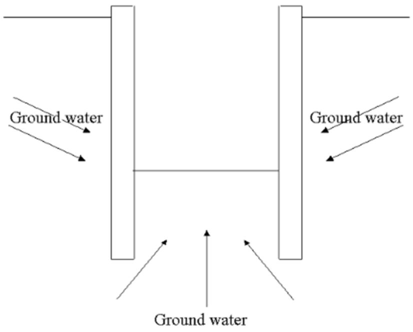


Figure 1. groundwater sketch effect on deep foundation pit

3.2 Dewatering mechanism of deep foundation pit

During excavation of the foundation pit, the unloading of the soil in the pit will increase the water level difference inside and outside the retaining structure, and the groundwater from the outside of the foundation pit will flow into the inside of the foundation pit, inevitably causing a decrease in the water level and pore water pressure outside the foundation pit, resulting in a large uplift of the foundation base.

After excavation of the foundation pit, various parameters also change, with significant changes in pore water pressure. According to the Skempton formula:

$$\Delta u = B[\Delta\sigma_3 + A(\Delta\sigma_1 - \Delta\sigma_3)] \quad (1)$$

Where, A and B are pore pressure coefficient.

To facilitate observation, formula (1) can be simplified as follows:

$$\Delta u = B[A\Delta\sigma_1 + \Delta\sigma_3(1-A)] \quad (2)$$

The magnitude of water content changes the soil structure and causes consolidation of the foundation pit soil. Generally, measures to reduce the impact of precipitation on the foundation pit are taken to reduce the water level.

According to the Terzaghi effective stress principle, After the groundwater level drops, the seepage pressure of water increases. In the construction of foundation pits, it is often used to install water stop curtains to control water seepage, but the effect is not ideal. Seepage phenomena often occur in foundation pits. Under normal circumstances, groundwater moves in the soil, and formula (3) is as follows:

$$J = \gamma_w \cdot i \quad (3)$$

Where: J ——Osmotic pressure; γ_w ——Water density; i ——Hydraulic gradient.

When the groundwater drops too fast, it can be seen from the formula that the seepage pressure will increase rapidly, and the seepage pressure will act on the soil particles, causing "flowing soil" phenomenon and deformation of the soil behind the structure.

In the well point dewatering foundation pit, a water stop curtain is used to form a vacuum near the well point pipe, causing the foundation pit to become in a negative pressure state, and the soil mass moves towards the negative pressure direction. This is due to the compression effect caused by the accumulation of soil particles, causing partial soil mass to settle.

4. Research on Deformation monitoring of deep foundation pit

4.1 Groundwater level monitoring

(1) Monitoring instruments

The deep foundation pit project uses a steel ruler water level gauge to measure the underground water level, and the water level pipe is made of PVC engineering plastic. As shown in Figure 2.

Figure 2. ruler gauge

Figure 3. PVC water level tube

(2) Embedded measurement points

Underground water level observation holes shall be respectively arranged within the precipitation range and the precipitation impact range. Water level pipes are buried separately according to different water layer depths. When monitoring the lower water level, the upper water level is sealed around the water level pipe, and perforated filter pipes are used at the monitoring water level position.

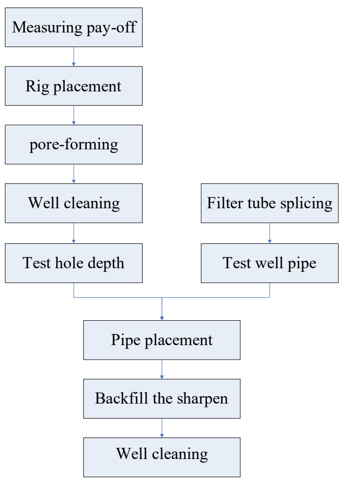


Figure 4. Water level pipe embedding flow chart

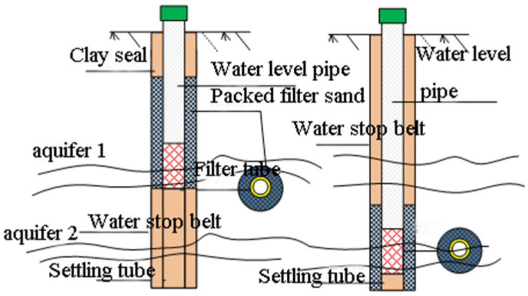


Figure 5. Schematic diagram of water level pipe installation

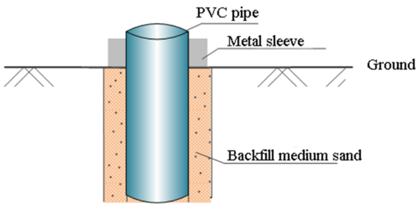


Figure 6. Schematic diagram of protection measures for water level holes

(3) Water level monitoring method

Place the probe of the water level gauge into the water level pipe. When the probe touches the groundwater, the water level gauge sends an alarm signal. At this time, the depth of the groundwater level can be obtained by waiting for the instrument to stably read the readings.

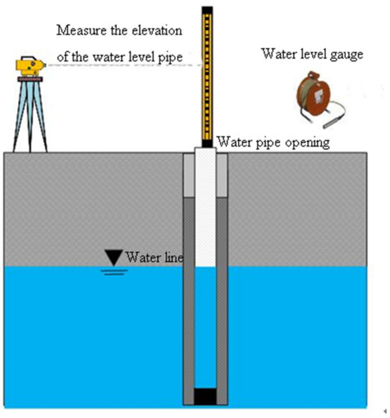


Figure 7. Schematic diagram of water level measurement

According to the pipe top elevation and elevation difference, the elevation and buried depth of the groundwater level can be calculated. During observation, conduct independent observation for each observation hole for 3 consecutive times, and take the average value. The formula is as follows:

$$H_{\text{stage}} = H_{\text{Pipe top}} - h_{\text{Pipe top}-\text{surface of water}} \quad (4)$$

(4) Site water level monitoring

There are 21 monitoring points for groundwater level, numbered DSW1~DSW21.

4.2 Deformation monitoring of enclosure structure

(1) Monitoring instruments

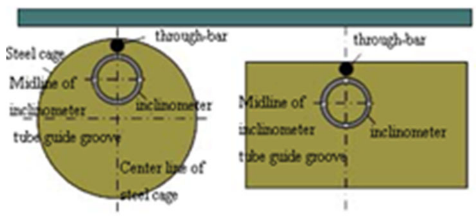
The monitoring instrument is a CX806D inclinometer, and the inclinometer tube is made of PVC material, as shown in Figure 8 and Figure 9.

Figure 8. CX806D type foundation pit slopemeasuring instrument

Figure 9. PVC inclinometer

(2) Installation method

Before the excavation of the foundation pit, the deep horizontal displacement monitoring points shall conduct initial data collection on the inclinometer pipe position monitoring points for three consecutive times, and take the average value of the three data as the initial value. At the interface of each section of the inclinometer pipe, slurry is prevented from entering the inclinometer pipe. Tape is used to seal the pipe, and an anchor hoop is set every 1m to tightly bind the inclinometer pipe to the steel mesh to ensure the perpendicularity of the inclinometer pipe.



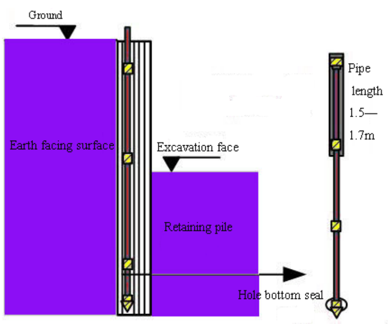


Figure 10. Installation of the inclinometer

Figure 11. Protection measures for the inclined tube

(3) Monitoring methods

During observation, it is necessary to correct the change in the coordinate port. place the inclinometer vertically into the inclinometer tube until it reaches the bottom of the tube. After the instrument data is stable, read and store it, and measure it every 0.5 meters. After the front side is completed, perform a reverse measurement, and rotate the inclinometer head for 180º to insert it again.

After the measurement is completed, turn the probe over for 90º, and perform the measurement again according to the above procedure. The inclination measurement principle is shown in Figure 12.

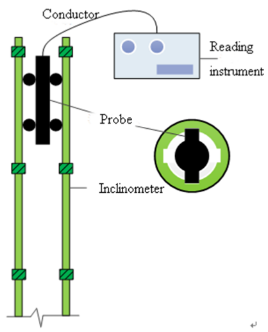


Figure 12. Schematic diagram of the tilting operation

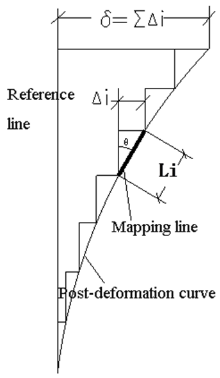


Figure 13. Principle of inclination

(4) On-site monitoring

The data of the civil engineering reserve project CJLLXTJYL DK48+300~DK48+700 section of the Beijing New Airport section of the new intercity railway connecting line was selected for research. The total length of the foundation pit in this section is 400m, the width of the foundation pit is 14m, the excavation depth of the foundation pit is 16m, the length of the retaining pile is 26m, and the deep horizontal displacement monitoring points are arranged at a spacing of 30m. There are a total of 34 monitoring points, numbered ZQT1~ZQT34.

5. Monitoring numerical analysis and research

5.1 Research on deformation laws of enclosure structures

(1) Analysis of monitoring results of deep horizontal displacement

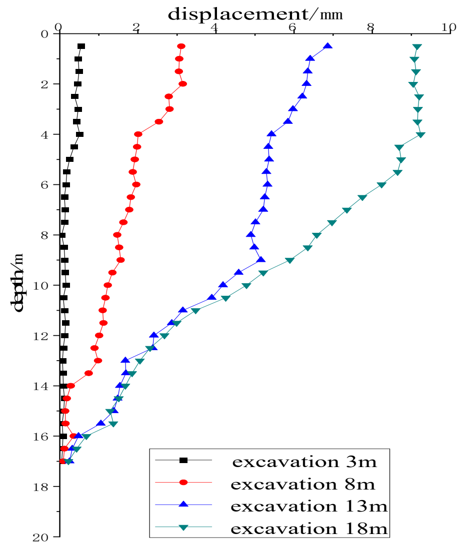


Figure 14. Deep horizontal displacement of ZQT1 hole

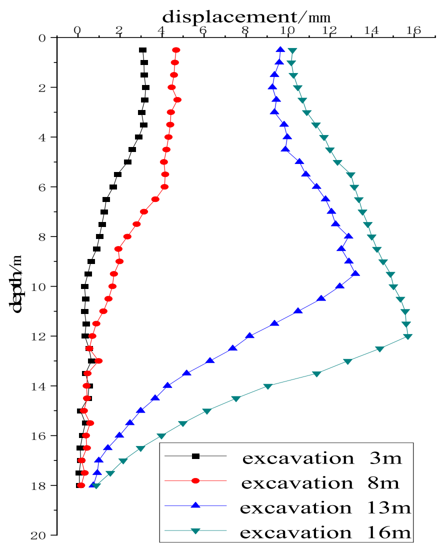


Figure 15. Deep horizontal displacement of ZQT8 hole

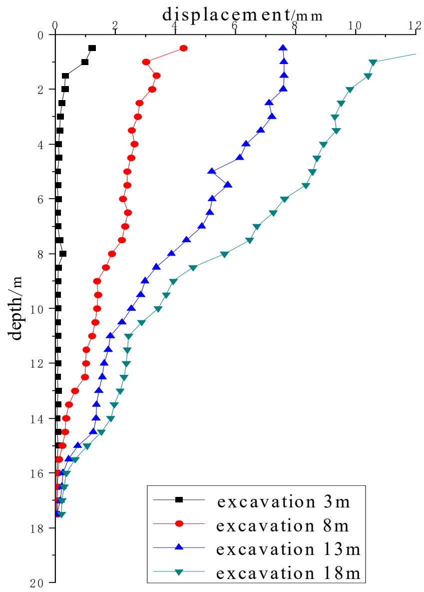


Figure 16. Deep horizontal displacement of ZQT16 hole

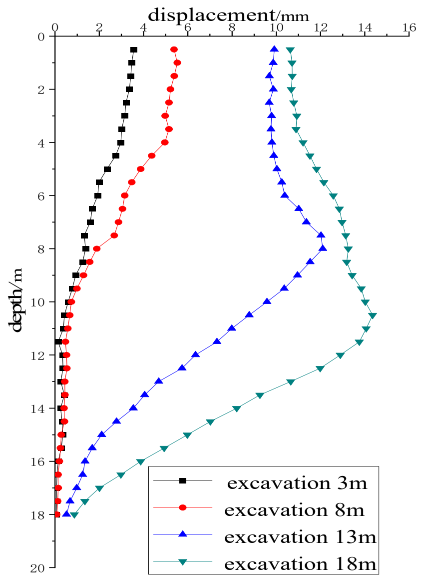


Figure 17. Deep horizontal displacement of ZQT24hole

The monitoring data of deep horizontal displacement inclinometer holes ZQT1, ZQT8, ZQT16, and ZQT24 were selected for study. The ZQT1, ZQT16 points are located at both ends of the foundation pit, and ZQT8 and ZQT24 are on the same monitoring section. The groundwater level in this section is high. The monitoring work has collected initial data values before excavation. The pouring of the retaining structure and the embedding of the inclinometer pipe were completed in June 2017, and the soil in the foundation pit was excavated in September 2017. The strength of the retaining structure meets the excavation construction conditions. During the excavation process, the monitoring of the deep horizontal displacement of the retaining structure shall always be maintained.

(2) Analysis of deformation law of deep horizontal displacement

According to the data and rules in the figure, when the soil excavation within the retaining structure is within 4 meters, the deep horizontal displacement of the retaining pile has little change, with the maximum displacement of 3.61 mm and the displacement controlled within 4 mm. Moreover, the bottom displacement of the retaining structure has basically not changed, and the retaining pile is in a stable state as a whole.

When the excavation reaches 8m, the deformation of the retaining pile is obvious, and the horizontal displacement of the pile top increases. When the excavation reaches 13m, the maximum displacement of the retaining pile transitions from the pile top to the middle of the pile, with the maximum deformation reaching 12.51mm, when the excavation reaches the bottom of the 16m foundation pit, the deformation of the retaining piles at points ZQT8 and ZQT24 reaches 16.11mm. At this time, the foundation pit is in the excavation exposure period. If the bottom plate and side wall are not poured in a timely manner, the deformation of the retaining piles will continue to increase. Point ZQT8 and point ZQT24 are on the same section, which clearly shows that the deformation amount and deformation law of the retaining piles on both sides of the foundation pit are very similar.

(3) Comparative Analysis of Deformation Laws of Enclosure Structures

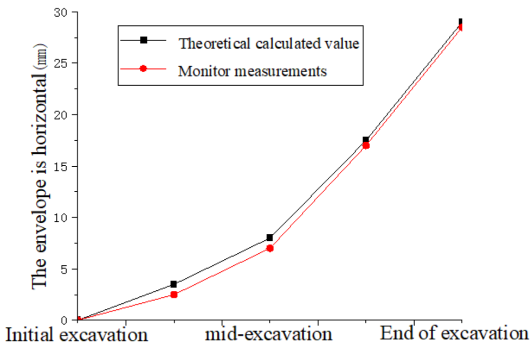


Figure 18. Comparison of calculated values of deformation of retaining structure

The deformation of the retaining structure can better reflect its changes based on the changes in the deep horizontal displacement of the retaining structure. Therefore, the deep horizontal displacement deformation of the retaining structure is selected to replace the deformation of the retaining structure for comparative analysis of the calculated deformation values of the retaining structure. It can be seen that the deformation of the retaining structure gradually increases with the excavation of the deep foundation pit. There is a certain difference between the actual monitoring measurement value and the theoretical calculation value, but the difference between the two values is not significant, indicating that the theoretical calculation is correct and the monitoring data is accurate.

5.2 Research on the variation law of groundwater level in deep foundation pit

(1) Groundwater level monitoring results

Select the water level observation holes DSW5, DSW6, DSW15, DSW16 in the foundation pit, and the JSJ10, JSJ11 of the dewatering wells outside the foundation pit to analyze the changes of groundwater level during the dewatering of the foundation pit inside the retaining structure and the dewatering of the outside of the retaining structure. The water level changes are shown in Figure 19 and Figure 20.

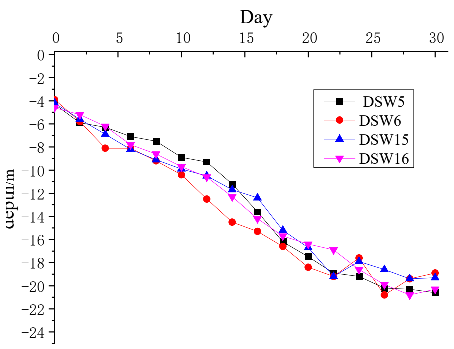


Figure 19. Water level change of the precipitation well inside the foundation pit

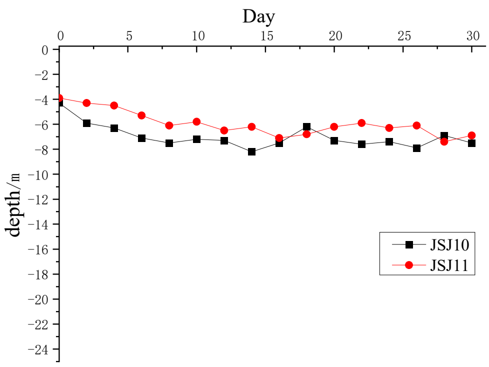


Figure 20. The water level change of the observation well outside the foundation pit

(2) Analysis on deformation law of groundwater level monitoring

Due to the preliminary dewatering of the inner side of the foundation pit before construction, it can be seen from the data and rules in the figure that the groundwater level in the foundation pit is continuously decreasing, and the water level changes tend to stabilize within 25 days. The water level outside the foundation pit decreased somewhat during the initial precipitation, but after 10 days, the water level remained stable. But at the beginning of precipitation, the water level on the outer side of the foundation pit is affected by the precipitation on the inner side of the foundation pit. However, based on subsequent analysis of the precipitation effect, its impact is limited.

(3) Comparative analysis of groundwater level changes in deep foundation pits

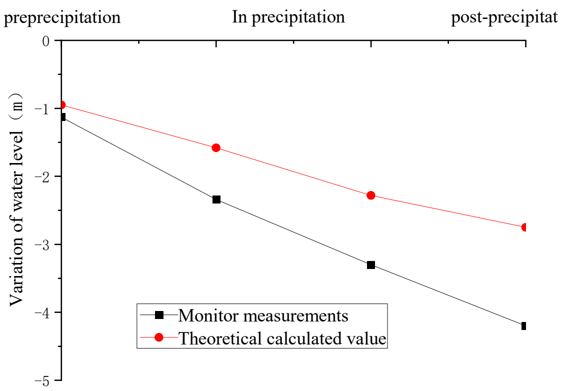


Figure 21. Comparison of calculated groundwater level

The monitoring measurement value in the figure is the variation of the groundwater level outside the foundation pit, and the actual monitoring water level variation is significantly higher than the theoretical calculation value by up to 4m. In combination with the civil engineering reserved line project of the Beijing New Airport Section, due to construction reasons such as untimely anchoring and shot creting of the anchor network, and untimely drainage and blocking of the groundwater level, some groundwater outside the foundation pit flows into the inside of the foundation pit, causing the groundwater level outside the foundation pit to exceed the theoretical calculation value. However, the overall numerical variation trend is not significantly different from theoretical calculations.

6. Deformation control technology for deep foundation pit

(1) When the groundwater level seeps into the pit due to improper construction reasons, grouting fluid should be used to seal the formation, stop excavation or adjust the one-time excavation depth to reduce the exposure time of the excavation surface.

(2) When the water level around the foundation pit is high, first ensure that there are no new leakage points on the retaining wall; Subsequently, clean up the debris at the leakage point, use a drill bit to chisel out a surface with a width of 15 cm to 20 cm around the leakage point of the diaphragm wall, and use quick-drying cement or fast-setting concrete to seal the leakage point until there is no leakage.

(3) When there is a large amount of water leakage, high water flow pressure, and the phenomenon of mud and sand seepage at the leakage point, using quick drying cement or instant setting concrete is insufficient to seal it. The method of inner sealing can be considered, including water glass cement double liquid grouting to seal the inner pores of the soil, and the treatment method of setting a diversion pipe to guide water and reduce pressure; The periphery of the leaking water site shall be sealed with quick-drying cement or concrete with good instantaneous setting effect. When the strength of the surrounding cement is sufficient, a diversion device shall be installed at the leaking point and the leaking point shall be completely sealed, forming a method of combining a

diversion and drainage system with sealing outside the pit. This method can use cotton to plug the leaking point to prevent the mud and sand from seeping out with the water flow.

Figure 22. Anti-leakage measures on the inside of the foundation pit

7. Conclusion

Based on the geological conditions of the open cut straight trench deep foundation pit and the deep foundation pit of the intercity connecting line of Beijing New Airport as the engineering support, the technical method of combining theoretical analysis and on-site monitoring is adopted to analyze the influencing factors of groundwater on the deep foundation pit retaining structure, and control and analyze the influencing factors. The deformation control technology for the deep foundation pit is proposed. The main conclusions are as follows:
(1) Based on the on-site geological conditions and the mechanism of groundwater level change, the deformation and failure forms and precipitation forms of deep foundation pits are obtained through theoretical analysis.
(2) Based on the Deformation monitoring technology of deep foundation pit, the change of groundwater level and Deformation monitoring of retaining structure are carried out.
(3) Combining on-site monitoring with theoretical calculation, conducting comparative analysis of data, summarizing the influencing factors of deep foundation pit damage, obtaining targeted deformation control technology for deep foundation pit, guiding the construction of practical projects, and providing reference for similar projects.

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