Analysis of deformation monitoring results of a deep and large foundation pit

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Abstract: Taking a deep and large foundation pit project as an example, the paper analyzed some developmental characteristics of its deformation during construction. The deformation included vertical displacements of the ground surface and horizontal displacements of deep soil surrounding the foundation pit. At the same time, the trends of the ground settlement were predicted based on the monitoring data. The analysis and predictions showed that: (1) The soil around the foundation pit was influenced by the excavation and supporting construction; (2) The vertical and horizontal displacements appeared some regular patterns of gradual development over time. In addition, there were certain differences in the trends of measuring points at different locations; (3) By fitting the monitoring data, the deformation of the foundation pit could be effectively predicted and offer a guidance to the engineering practice.

1. Introduction
In-situ monitoring plays a very important role in the construction of foundation pits. Through monitoring, technicians discover environmental changes during the construction process and give effective feedback in time [1]. The goal of effectively controlling the impact of foundation pit construction on the surrounding environment is achieved ultimately.

At present, the corresponding researches on the monitoring and prediction of foundation pits are gradually mature [2-5]. Basing on a deep and large foundation pit project, this paper analyzed the development law of soil deformation around the foundation pit during the construction of the foundation pit. At the same time, the curve fitting model was built to predict the development trends of the foundation pit and achieve early warning.

2. Project Overview
The project of the Dazhi River sluice-pump station is located about 530 meters downstream of the Xiasha Bridge. As one of the most important drainage channel of inland rivers, the rebuilt project is a comprehensive hub that includes water retention and drainage functions. The total designed drainage flow of the pumping station is 100m³/s with 5 pumps. The flood control standards for the sluice and pumping station are designed once in 100 years and checked once in 300 years.

The average elevation of this project site was about 0.3~9.5 meters, the design elevation of the foundation pit was about -4.7~0.4 meters. There were two foundation pits on both sides of the project. The foundation pit on the outer river side was about 115 meters long and 145 meters wide and the
excavation depth was about 1.6~14.2 meters. The foundation pit applied a multi-level grading excavation program and used soil nailing walls for reinforcement. Figure 1 presents a typical profile of excavation support in the foundation pit.

![Figure 1. Typical profile of excavation support](image)

In the light of the needs of the project and the requirements of relevant codes, Monitoring of the foundation pit should be carried out in construction period. Combining the layout of the foundation pit and characteristics of the excavation, 10 groundwater level monitoring holes were set inside the foundation pit, 11 deep horizontal displacement monitoring pipes and 21 surface vertical displacement monitoring points were arranged around the foundation pit.

Deformation controlling indexes of the foundation pit are shown in table 1.

| Monitoring items               | Control indexes(mm) |
|-------------------------------|---------------------|
| Surface vertical displacement | 40                  |
| Deep horizontal displacement  | 50                  |

The layout of the monitoring points of the foundation pit is shown in figure 2.

![Figure 2. Monitoring layout of the foundation pit](image)
3. Analysis of monitoring results

3.1. Analysis of groundwater level
There were 10 groundwater level monitoring holes inside the foundation pit, numbered from SW-01 to SW-10. Cement mixed piles were used as the waterproof curtain outside the pit in this project. The bottom elevation of the cutoff wall is -14.6 meters and the depth is about 10 meters. Figure 3 shows a typical diagram of groundwater level process.

![Figure 3. Typical diagram of groundwater level process](image)

(1) In the first 100 days, the foundation pit was excavated to the design height, and then the floor was poured. The groundwater level inside the foundation pit was maintained below the floor elevation.
(2) After the completion of pouring, the concrete strength gradually increased with time and the groundwater level increased somewhat in the later 100 days.
(3) During the monitoring period, the groundwater level inside the foundation pit was slightly affected by the water level of rivers on both sides of the foundation pit, and significantly influenced by well-point dewatering and the progress of the project.

3.2. Analysis of surface vertical displacement
Surface vertical displacement monitoring points were mainly arranged along the south seawall and the east side of the foundation pit. The points along the south seawall were numbered from CJ-01 to CJ-16. The points along the east side of the foundation pit were numbered from CJ-36 to CJ-40. According to the characteristics of locations and settlement curves, four of the points were selected for analysis. Their corresponding settlement curves are shown in figure 4.

![Figure 4. Settlement curves of typical monitoring points](image)
(1) Monitoring point CJ-8 was located in the old floodgate and less vulnerable to construction. There was a certain settlement rate at beginning. The 180-day settlement was 10 mm. Monitoring point CJ-16 was located on the southwest side of the foundation pit, adjacent to the construction access road and greatly affected by construction. The settlement continued to increase during the monitoring period and the 180-day settlement was 26 mm.

(2) Monitoring points CJ-8 and CJ-37 were located on the east side of the foundation pit, which were greatly affected by excavation construction. The settlement rates of these two points were relatively large and gradually slowed down in the later period. The 180-day settlements were 22~30 mm.

3.3. Analysis of deep horizontal displacement
Deep horizontal displacement monitoring pipes were arranged on the east, south and west sides of the foundation pit, numbered from CX-1 to CX-11. The starting point of the displacement was selected as the bottom of the pipe. According to the differences of locations and depths of excavation in different areas, typical monitoring pipes CX-4 and CX-6 were selected for analysis. The corresponding deep horizontal displacement curves are shown in figure 5 and figure 6.

(1) The corresponding deep horizontal displacement curves of CX-4 and CX-6 shown that the horizontal displacement increased from the bottom of the pipe to the top of the pipe, which conforms to the general law of deformation of foundation pits in multi-level grading excavation way.

(2) There was a certain horizontal displacement change rate in the direction of the foundation pit. The change rate of the shallow layer was greater than the change rate of the deep layer.

Figure 5. Curve of CX-4

Figure 6. Curve of CX-6
4. Fitting of deformation monitoring results

4.1. Fitting of surface vertical displacement

According to monitoring data, deformation of the foundation pit did not exceed the control index during the monitoring period. The foundation pit was safe. The deformation trend of the foundation pit can be predicted with curve fitting. Monitoring points CJ-16 and CJ-36 were taken as examples.

Based on the characteristics of settlement curves, the Bidoseresp function was used for fitting. Models converged after several iterations. Their determination coefficients ($R^2$) were 0.987 and 0.999. Equation (1) is the fitting curve of CJ-16. Equation (2) is the fitting curve of CJ-36. $X$ stands for time and $Y$ means settlement in the formulas. These fitting curves are shown in Figure 7.

$$Y = 39.573 - 44.552 \left[ \frac{0.226}{1+10^{(0.071X-0.063)}} + \frac{0.774}{1+10^{(0.012X-0.955)}} \right]$$ (1)

$$Y = 30.913 - 38.360 \left[ \frac{0.602}{1+10^{(0.053X-0.394)}} + \frac{0.398}{1+10^{(0.013X-1.109)}} \right]$$ (2)

![Figure 7. Fitting curves of CJ-16 and CJ-36](image)

(1) On the basis of the fitting curve, the settlement of CJ-16 kept increasing. The 250-day prediction of settlement was 36.72 mm. The settlement of CJ-36 remained stable. The 250-day prediction of settlement was 30.80 mm.

(2) As arranged, the excavation and pouring of the foundation pit could be completed within 250 days, and the predicted settlement values were still within the control index range.

4.2. Fitting of deep horizontal displacement

The Bidoseresp function could also be used for fitting of deep horizontal displacement. Maximum horizontal displacements of different vertical depths measured in previous times were counted and fitted with the function. Their determination coefficients ($R^2$) were 0.916 and 0.961. Equation (3) is the fitting curve of CX-04. Equation (4) is the fitting curve of CX-06. $X$ stands for time and $Y$ means horizontal settlement in the formulas. These fitting curves are shown in Figure 8.

$$Y = -2.205 + 30.010 \left[ \frac{0.176}{1+10^{(217.484-2.344X)}} + \frac{0.824}{1+10^{(0.735-0.003X)}} \right]$$ (3)

$$Y = -0.214 + 30.579 \left[ \frac{0.277}{1+10^{(17.994-0.191X)}} + \frac{0.723}{1+10^{(0.166-0.007X)}} \right]$$ (4)
(1) According to the fitting curves, horizontal displacements of these two monitoring pipes kept slowly increasing. The 350-day prediction of CX-04 was 19.74 mm. The 350-day prediction of CX-06 was 29.26 mm.

(2) Compared with the control index, the predicted values are smaller, and the rate of displacement growth was slow. The foundation pit was safe from this point of view.

5. Conclusion

(1) During the monitoring period, the settlements of typical monitoring points were 10~30 mm. The deep horizontal displacements of typical monitoring pipes were 13.45~21.16 mm.

(2) It could be found that the deformation of the foundation pit has obvious spatial distribution characteristics. The deformation of the part with large construction disturbance was larger and the deformation of the part with less construction disturbance was the opposite.

(3) A mathematical model was used to fit deformation monitoring results. These functions had a high degree of fitting to the monitoring data, and could well predict the deformation of the foundation pit. According to the forecast results, the foundation pit might be safe in the foreseeable future. This prediction method could be used in foundation pit monitoring and provide effective assistance for engineering practice.

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