Research on deformation control and prevention measures of pile anchor support system in foundation pit

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Abstract. With the rapid development of urban modernization, the pile anchor support system has been widely used in the deep foundation pit project. Because the deformation of the pile anchor support system directly affects the overall stability of the foundation pit and brings serious potential safety accidents to the construction of the deep foundation pit, avoiding the deformation of the pile anchor support system can effectively prevent the occurrence of the construction safety accidents of the deep foundation pit. Based on many years of construction experience, the deformation rule of pile anchor support system of deep foundation pit is taken as the research object. This paper starts from the scheme design of pile anchor support system and the monitoring data of the foundation pit, and combines with the actual deformation of the pile anchor support system in the construction site, summarizes the causes and prevention measures of the deformation of the pile anchor support system in the construction stage. The research results show that in the initial stage of construction, the top of the pile anchor support system inclines forward to the pit and gradually changes into a bow shape. This kind of deformation is related to the increase of excavation depth and the erosion of active soil pressure area by surface water. In the later stage of construction, the deformation of the top of the foundation pit converges and the bottom of the pile anchor support system protrudes into the pit, which is related to the erosion of the passive soil pressure area by rainwater and the embedded depth of the pile foundation.

1. Introduction
Pile anchor support system is an indispensable part of deep foundation pit construction. Due to the diversity of soil layer and the variability of external environment in the process of foundation pit construction, the stress of pile anchor support system is complex, and the safety accidents caused by the deformation and instability of pile anchor support system occur frequently. Therefore, the design and construction of pile anchor support system in deep foundation pit project has been highly valued by the construction industry, and also listed as the key hidden danger investigation project in the construction process. How to avoid or reduce the safety accidents caused by the deformation and instability of the pile anchor support system in the construction is the concern of every construction workers.

Ren J et al.(2008) carried out field monitoring and research on the deformation rule of foundation pit, focusing on the horizontal deformation of foundation pit, the internal force of anchor cable and the change rule of axial force of steel support. It is concluded that the depth of excavation and the time of non-support exposure have great influence on the deformation of pile anchor support system. Through
on-site monitoring, Yao A et al.(2011) analyzed the deformation of pile anchor support system under the action of asymmetric load on both sides of deep foundation pit, and the change trend of axial force of steel support, as well as the influence of foundation pit excavation on surrounding buildings. Through the field measurement and numerical simulation, Zhang J (2013) analyzed the deformation rule of the deep foundation pit internal supporting piles in the soft soil area, and carried out the three-dimensional finite element numerical simulation of the deformation rule of the deep foundation pit pile anchor support system, then analyzed the change of the pile anchor support system. Zheng G (2014) measured the horizontal displacement of the pile anchor support system in the whole process of deep foundation pit excavation, and analyzed the deformation trend and reason of four kinds of retaining structures by establishing the finite element model. He H (2015) used FLAC3D software to simulate the excavation process of the foundation pit, studied the deformation rule and the influencing factors of the foundation pit under the pile anchor support system of the foundation pit, and concluded that the displacement of the pile anchor support system of the foundation pit changed synchronously with the increase of the excavation depth.

Based on the construction experience in recent years, through observation, statistics and research, combined with the deformation rule of the pile anchor support system of a deep foundation pit project, this paper analyzes the deformation results of different stages of representative monitoring points, summarizes and analyzes the causes of the deformation trend of the pile anchor support system, innovative measures are put forward to prevent the deformation of pile anchor support system.

2. Damage of deformation of pile anchor support system
The hidden danger of safety accidents in the deformation of pile anchor support system is accidental, potential, causal and frequent. In the construction stage of the pile anchor support system, with the increasing of the excavation depth of the foundation pit, the earth pressure and water pressure have changed one after another, and the internal force of the pile anchor support system has changed, resulting in the deformation and instability trend of the pile anchor support system.

With the extension of the exposure time of the pile anchor support system, the deformation of the support system eroded by the surface water is increasing, which is easy to cause the foundation pit instability. Once the situation develops seriously, it will become the main culprit of the safety accident. The safety accident directly causes great loss to the people's lives and property, causes great damage to the victims themselves and their families, and has a bad impact on the social and economic development.

3. Analysis of deformation monitoring data in different stages of pile anchor support system
In this paper, the east side pile anchor support system (B-B) of a project foundation pit is taken as the research object. The pile deformation is monitored by CX series borehole inclinometer. The monitoring points CX1, CX4, CX8 and CX11 are taken as representative points to study the deformation rule of the pile anchor support system in the construction stage of deep foundation pit (see Figure 1). In this paper, the deformation data of different monitoring points in different construction stages are analyzed, and the deformation rules of pile anchor support system are summarized (see Figure 2 and Figure 3). According to the actual deformation comparative analysis of the foundation pit pile anchor support system in the field construction stage (see Figure 4, Figure 5, Figure 6). Look for the causal relationship between the similarity and difference of the deformation of pile anchor support system.
Figure 1. Distribution diagram of deformation monitoring points

(a) Monitoring point CX1
(b) Monitoring point CX4
(c) Monitoring point CX8
(d) Monitoring point CX11

Figure 2. Deformation statistics of different monitoring points in different construction stages
Figure 3. Deformation statistics of different monitoring points in different construction stages
4. Cause analysis of deformation of pile anchor supporting system

According to the change rule of the monitoring point data in different stages of the foundation pit, combined with the scheme design of the pile anchor support system and the deformation of the pile anchor support system in different stages of the construction site, this paper analyzes the causes of the deformation trend in different stages of the pile anchor support system.

4.1. Causes of deformation of pile anchor support system in the initial stage

With the increase of the excavation depth of foundation pit soil, the stress of pile anchor support system gradually changes from the earth pressure balance before excavation to the passive earth pressure area, which reduces the ability to resist the side pressure of soil. The earth pressure in the active earth pressure area (the soil area outside the foundation pit) of the foundation pit directly acts on the pile anchor support system, which causes the top of the pile anchor support system to bear the load of the active earth pressure area. With the increase of the exposure time of the foundation pit in the natural environment, the active earth pressure area is easily disturbed by surface water, rainwater and construction load, resulting in the change of the soil structure in the active earth pressure area. The shear strength and stability of the active soil pressure area are weakened, the soil is sinking and shearing, and the middle part of the pile anchor support system is gradually increased under the influence of soil pressure, resulting in the deformation of the foundation pit gradually becoming bow type.

4.2. Causes of deformation of pile anchor support system in the later stage of construction

In the later stage of construction, the pile anchor support system has all borne the earth pressure and water pressure of the active earth pressure area. Because the foundation pit has been exposed to the natural environment for a long time, the passive earth pressure area of the foundation pit (the soil area inside the foundation pit) is affected by the rainwater immersion, and the soil properties change. The capacity of passive earth pressure zone to resist lateral earth pressure is reduced, and the displacement and deformation of pile anchor support system to resist the increase of earth pressure occur.

The embedded depth design of the pile anchor support system is based on the soil property of the initial geological exploration data. Because the pile anchor support system is exposed to the natural environment for a long time, the stratum is disturbed many times due to the construction, and the soil mechanical properties change. According to the overall stability checking calculation of circular sliding strip method (see Figure 7), the stability of pile anchor support system is affected by the change of soil quality.
Figure 7. Schematic diagram of overall stability checking calculation of circular sliding strip method

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K_{ss} = \sum \left( \frac{q \tan \theta_j}{(q_j + \Delta G_j) \sin \theta_j} + \sum R_{ij} \cos (\theta_j + \alpha_i) + \gamma_j s_{sl} \right) s_{sl}
\]

(1)

It can be seen from the formula (1) that the soil mechanical calculation parameters in the overall stability check of the pile anchor support system are limited by the test conditions and deviate from the actual soil mechanical performance parameters on site. The soil mechanical performance parameters such as cohesion \(c\), internal friction angle \(\phi\), soil density \(G\) at the sliding arc directly affect the stability check of the pile anchor support system. For a long time, the soil is affected by the external environment such as surface water, groundwater and stratum disturbance, which leads to the decrease of the stability of the whole system of pile anchor support.

5. Prevention and control measures for deformation of pile anchor support system

For the initial excavation stage of foundation pit, the soil shall be compacted in the active soil pressure area of pile top, and the degree of compaction shall be greater than 0.9. When the soil is soft clay, miscellaneous fill, humus and other poor soil, the height of soil layer at the top of the active earth pressure area shall be minimized to reduce the load on the top of the foundation pit. Within the scope of the upper soil layer of the active earth pressure area easily disturbed by the external environment (rain water, construction load), the geotextile, geogrid and geomembrane shall be laid in layers to increase the bearing capacity and overall stability of the soil. The concrete surface shall be hardened at the top of the foundation pit. The hardened surface at the top of the foundation pit shall not be provided with a dividing joint or a joint liable to cause surface water infiltration. The holes and recesses at the side of the foundation pit shall be backfilled. The top of the active earth pressure area shall be sloped from the inside of the foundation pit to the outside of the foundation pit to prevent the surface water from eroding the active earth pressure area and changing the soil mechanical properties of the active earth pressure area. At the same time, the foundation pit slope shall not bear static and dynamic loads, so as to reduce soil disturbance in the active soil pressure area.

After the foundation pit is excavated to the construction design elevation, the foundation slope toe shall be ballasted by adopting the pier type soil reinforcement measures at the bottom of the pile anchor support system (when the foundation pit area is large, the skirt type soil continuous reinforcement measures shall be adopted), so as to improve the ability of the passive soil pressure area to resist the lateral earth pressure, increase the embedded depth of the pile anchor support system in a disguised way, and improve the stability of the pile anchor support system. The passive soil pressure area at the base of pile anchor support system should be compacted with low strength and low permeability materials or hardened with concrete to reduce rainwater erosion, ensure the stability of soil mechanical properties in the passive soil pressure area and improve the resistance to lateral deformation of the passive soil pressure area.
The bottom of the foundation pit should be provided with a circular closed drainage ditch and a collecting well, and the open drainage measures should be taken to reduce the disturbance of rainwater to the base. The distance between the drainage ditch and the water collecting well and the bottom edge of the pile anchor support system should not be less than 500mm (determined according to the actual construction site conditions), and the drainage ditch and the water collecting well should be waterproof to ensure that the base is drained and the soil quality is stable.

6. Conclusion

In the initial stage of the pile anchor support system, the deformation gradually inclines to the inside of the foundation pit with the increase of the excavation depth of the foundation pit, which is easy to cause the surface cracking. Therefore, it is necessary to strengthen the stability design of the pile anchor support system, reduce the excavation depth once, prohibit over excavation, slow down the stress conversion of the pile anchor support system, and reduce the deformation and damage of the pile anchor support system.

During the construction stage of the pile anchor support system, because the active earth pressure area is easy to bear load and the surface water erosion changes the soil properties, the soil self-reliance of the active earth pressure area is reduced, resulting in the increase of the earth pressure and water pressure in the middle of the pile anchor support system, then resulting in bow shaped deformation. It is advisable to compact and harden the land at the top of the foundation pit, and treat it with waterproof. Therefore, in the construction process, the interference of external factors on the active soil pressure area should be reduced to reduce the deformation of pile anchor support system.

In the later stage of construction, due to the long-term exposure of the passive soil pressure area to the external environment, the soil mechanical properties are reduced. The active soil pressure area is affected by shallow water, the soil self-reliance is reduced, the internal stability of the pile anchor support system is reduced, and the basement bulges and deforms. Therefore, it is advisable to adopt the measures of base soil surcharge reinforcement, passive earth pressure area tamping drainage waterproof measures, increase the ability of passive earth pressure area to resist lateral earth pressure, so as to reduce the deformation of pile anchor support system.

With the development of science and technology and the rapid development of construction industry, the foundation pit support system is constantly improved and innovated, and the safety is constantly improved. However, due to the complex and changeable physical properties of the soil and the great influence of the external environment, it is suggested that the construction of deep foundation pit should concentrate on accelerating the progress of underground structure and backfilling as early as possible to avoid safety accidents.

In this paper, the importance of the pile anchor support system in the foundation pit engineering is described from the damage of the deformation of the pile anchor support system. The innovative use of the actual deformation of the site combined with the point-to-point monitoring data analysis and comparison. The common problems are analyzed in depth, the point of view is pointed out, and the measures to prevent the deformation of the pile anchor support system are put forward, which can be used for reference and discussion by professionals in the field of construction, and also have a certain promotion value.

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