Analysis of Permanent and Intensive Design of Supporting Structure of Composite Foundation

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Abstract: All kinds of underground projects and their structures usually exist permanently. At present, the foundation pit engineering is usually supported by temporary support measures. After the construction of the main structure is completed, the foundation pit project will be demolished and left in place, causing a great waste of materials. Transforming the supporting structure into the main structure is helpful for realizing the permanence of supporting structure and reducing the waste of materials, which meets the requirements of sustainable development strategies. Building foundations often coexist with the supporting structures and basic structures of the surrounding proposed projects. Designers should face up to and pay attention to the situation of underground engineering or to the coexistence of structures. They need to consider the respective functions of geotechnical and structural engineering and design a suitable construction method. This paper mainly analyzes the concept of permanent of the supporting structure and its main measures.

With the development strategy of our country, the process of urbanization is getting faster and faster, and the buildings in the downtown area of the city has developed. All underground projects and their structures co-exist permanently, resulting in the interaction and mutual influence of adjacent underground structures. At present, design standard system in our country has only a single structure analysis and guidance, and lacks research on the coexistence and interaction of underground structures. Considering the coexistence and interaction of underground structures, we should pay attention to the development of intensive design theory and technology, and transform support structure into the main structure to realize the permanent support structure, which can reduce investment and the waste of materials. It is a link to protect the geological and social environment and is an important direction for the construction of economic and social ecological civilization and sustainable development. Studies have shown that in non-soft soil areas, pile-anchor support structures are widely used in foundation pit support projects. Permanent support structures based on pile-anchor support structures rely on the infinite and horizontal rigidity of underground beam-slab components. The horizontal extension of beam-slab realizes the connection between the supporting pile and the main underground structure, forming a combination of supporting pile, support, and underground structure, providing a simple and feasible method for the permanence of the supporting structure.

1. Concept of Permanence and Intensification of Supporting Structure

Foundation pit support engineering refers to the construction to ensure the smooth construction of the underground structure and the safety of the surrounding environment of the construction site. With the development of cities, the number of underground structures has been increasing, and the corresponding depth of foundation pits has also been increasing, and foundation pit supporting structures based on retaining wall-type have been widely used. The foundation pit supporting structure adopted at present is generally temporary construction measures, such as underground shopping malls, underground garages, subways, etc. The underground part of the main structure is permanent. After the main construction is completed, the temporary supporting structure will be left. It will cause waste of resources and environmental pollution, and is not conducive to the sustainable development of urban underground space. There are few studies on the application of foundation pit supporting structure to the construction of the main underground structure of buildings. It is of great significance to give full play to the permanent value of the supporting structure and realize the sustainable development of the project. Therefore, we must pay attention to the research and development of effective methods to the permanence of supporting structure.

Intensive design is the combination of the main structure and the supporting structure. At present, the support method of temporary enclosure structure is often used. It is built during the construction of the main structure and is demolished or abandoned underground after completion. It not only causes great waste, but also is not conducive to the sustainable development of urban underground space. For the intensive support structure, the support structure can be combined with the main structure to realize the permanence of support structure, which conforms to the concept of sustainable social development.

2. Ideas for Permanent and Intensive Design of Supporting Structure of Composite Foundation

2.1. The Progress of Permanent Design of Support Structure of the Silo

The author takes the architectural structure of Jinan Grand Theater as an example and discusses the design ideas. Before the construction of the foundation pit, all the CFG Piles in the composite foundation outside the pit have been completed. However, due to the techniques and construction, the construction period of the underground engineering has been delayed again and again, which makes the stage silo surrounded by the CFG composite foundation. In the case of limited excavation space, anchor pile should be the preferred support structure. Considering the uniform distribution of CFG piles, in order to reflect the concept of "green construction" and realize the permanent support structure of the storage, the adjacent two rows of CFG piles on the excavation face are adjusted to double row supporting piles. In this way, it can be used not only as a supporting structure, but also as a composite foundation pile. The pile spacing is 2100 cm, the pile diameter is adjusted from 400 mm to 600 mm, the effective pile length is 22 m, the strength grade of the concrete is C30, and the vertical and horizontal crown beams are set on the pile top.

2.2. Intensive Design Analysis of Double Row Supporting Piles

The active area of the double-row supporting piles in the silo mainly contains the CFG composite foundation, and the passive area is the foundation of the pile group. Therefore, through the intensive analysis of the existing composite foundation, pile group foundation and supporting structure, the composite foundation and pile group foundation can reinforce the main structure, reduce the horizontal load of the active area borne by the supporting structure, and increase the lateral earth pressure in the passive area. In this way, the composite foundation and pile group con-exist, and the three rows of prestresses designed in accordance with the design of the soil foundation pit are optimized into one row, reflecting the intensification of the actual interaction of the group underground structure.

2.3. Durability Design Analysis

For the permanent design of retaining pile, its durability should be checked. The crack width is one of the important indexes of durability checking calculation, and the cross section of supporting pile is circular. The cylindrical section component accounts for a large proportion in the construction engineering. Compared with the rectangular section and other components, it has few provisions in various specifications. *The Code for Design of Concrete Structures* and the *Code for Design of Concrete Structures of Port Engineering* in China only provide formulas for calculating the maximum crack width of tension, bending and eccentric compression of rectangle, T-shaped, inverted T-shaped and I-shaped sections. However, that of circular section component is clarified in *the Code for Design of Concrete Structures of Waterway Engineering.*

2.4. Permanent and Intensive Design and Structural Treatment of Supporting Structure

As the vertical stiffness of the supporting pile and crown beam is enhanced, the stiffness of the foundation is significantly different. In order to avoid the impact on the foundation structure, the deformation of different parts is adjusted through the difference of cushion thickness. Cushion layer is one of the important parts of composite foundation. It can not only ensure that the pile and soil bear the load together, but also adjust the ratio of pile and oil stress and reduce the stress concentration on the bottom of the foundation. Raft and composite foundation, as a cooperative stress system, set different thickness cushion layers on the foundation with different stiffness, which will directly affect the reverse penetration degree of pile, so as to adjust the uneven settlement of raft caused by the difference of foundation stiffness and reduce the internal force of foundation.

2.5. Basic Assumptions of the Model

(1) The change of stress before excavation is not considered, and the initial ground stress of the soil is calculated according to static earth pressure.

(2) The influence of pile and anchor construction on soil disturbance is not considered.

(3) The superstructure is equivalent to uniformly distributed load applied on raft.

2.6. Calculation Model and Parameters

The Hardening-Soil (HS) constitutive model is selected. The advantage of this model is that it takes into account the hardening of the soil under small deformation conditions, and adopts a hyperbolic stress-strain curve, which reflects the nonlinear nature of the soil and distinguishes the difference between loading and unloading, and its stiffness depends on the stress history and stress path. The model adopts the method of truncating the boundary and takes two strips of soil with double-row piles for modeling. Considering the influence of the adjacent double-row piles, the width of the soil strips is extended to the position of the adjacent piles, so the width of soil strip is taken as 6 m. The excavation depth is 12.75 m, the inner width of the pit is 20 m, the plane size of the entire model is 80 m × 6 m, and the depth is 50 m. The soil is simulated with 10-node tetrahedral elements that can accurately calculate stress and failure loads. The raft is simulated by a 6-node triangular shell element, vertical and horizontal crown beams and waist beams of the double-row pile are simulated by 3-node beam element, and the CFG piles and cast-in-place piles are simulated by embedded beam elements. The prestressed anchor rod uses the "point-to-point anchor" element and the "embedded beam" element to simulate the free section and the anchor section respectively. The soil layer adopts a single homogeneous soil body, which is borrowed from the third layer of silty clay in the Jinan West Railway Station area, and the cushion layer is made of graded sand and gravel.

2.7. Calculation of Projects Conditions

The construction steps of the model are as follows:

(1) Generating the initial stress.

(2) Clearing the initial displacement, activating the beam element and pile element in the model, and simulating the construction of the supporting structure and CFG pile.

(3) Applying a uniform load of 15 kPa (construction load)

(4) Excavation to the underground for 3 m.

(5) Excavation to the underground for 6 m, and set up a pre-stressed anchor cable at the underground for 5.7 m.

(6) Excavation to the underground for 9.4 m.

(7) Excavation to a foundation of 12.75 m.

(8) Backfill of foundation pit, construction of cushion and raft.

(9) Applying uniform load of 290 kPa (design composite foundation bearing capacity characteristic value) to simulate the effect of superstructure.

3. Influence of Intensive Support Structure

In order to study the intensive effect of supporting structure, the calculation results can be compared with the natural foundation without considering composite foundation and pile group foundation. According to the analysis of Li Lianxiang and others, it can be concluded that with the increase of depth, the earth pressure in the active zone and the passive zone has gradually increased. Due to the existence of prestressed anchors, the earth pressure in the active zone turns at the anchor position, and the earth pressure decreases. In addition, the earth pressure in the active area of the actual model is lower than that of the natural foundation, which indicates that the composite foundation has obvious lateral reinforcement effect on the active soil area. In the actual model, the earth pressure in the passive area is higher than that in the natural foundation. Because in the actual model, the reinforced concrete uplift pile is set at the bottom of the silo, and the soil layer below the pit bottom is reinforced by the pile group foundation, and the passive earth pressure coefficient of the soil increases, and the earth pressure in the passive zone of the supporting structure is strengthened. The vertical and horizontal crown beams are set on the top of the pile, the overall stiffness is relatively large, and the crown beam at the end of the excavation is displaced and blended in the later, thus the lateral displacement of the crown beam along the supporting surface shows an overall change, and there is no obvious turning point at the connection between the supporting pile and the crown beam. While the bending moment is not affected by the overall stiffness, showing a wave shape, and the turning point is the connection point of the pile and beam.

4. Conclusion

Through the research and development of the support structure of composite foundation and the specific layout of the main structure, the construction process design of the permanent support structure of foundation pit, it can reduce the investment in funds and materials, reduce energy consumption, which is in line with the national emerging sustainable development strategy. Compared with the general supporting structure design, the intensive design of permanent supporting structure of foundation pit needs to consider the durability of supporting structure, the influence of underground structure interaction on the lateral pressure of supporting structure, and the improvement of relevant structures. We should pay attention to the co-existence of underground engineering or structure, and consider the respective functions of geotechnical engineering and structural engineering.

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