Analysis of Situ Test Results of Earth Pressure and Pile Internal Force under Pile-Anchor Support in a Deep Foundation Pit in Xi'an

Ruiben Yang1,*, Xinsheng Li1, Dongzhou Xie2 and Hongte Meng3
1 College of Geological Engineering and Geomatics, Chang’an University, Xi’an 710054, Shaanxi, China
2 Institute of Rock and Soil Mechanics, Chinese Academy of Sciences, Wuhan 430071, Hubei, China
3 China Water Resources Beifang Investigation, Design and Research Co. Ltd. (BIDR), Tianjin 300222, Tianjin, China
Email: yangrb729@126.com

Abstract. At present, in deep foundation pit engineering, on the one hand, practice is ahead of theory, and on the other hand, theory can not correctly reflect the actual construction process and environmental effects. In order to further study the distribution and change law of earth pressure and internal force of pile body in deep foundation pit pile-anchor supporting system, field monitoring test of earth pressure and pile body reinforcement stress was carried out. The monitoring results show that before excavation, the distribution of earth pressure has a great relationship with the layering of the soil, and it is distributed in sections along the depth. Compared with the theoretical static earth pressure, the measured data of the upper depth is relatively small; after excavation, the overall earth pressure is distributed along the depth in a "z" shape under the non-limiting state. As the excavation progresses, the magnitude of the reduction of the earth pressure varies from place to place, and the magnitude of the decrease of the soil with better properties is not large; after the excavation, the stress and earth pressure of the pile reinforcement correspond to each other, and the distribution is also nonlinear. The existence of anchor tension has an obvious effect on improving the internal force of the pile. The selected earth pressure calculation methods have some discrepancies in the calculation of the earth pressure value of the project, and they need to be further improved. The research in this paper can provide reference and reference for the calculation of earth pressure and support design of pile-anchor supported foundation pit.

Keywords. Foundation pit; pile-anchor support; earth pressure; pile internal force; earth pressure calculation.

1. Introduction
At present, the classical Coulomb and Rankine soil pressure theory is still used in the design of foundation pit support in our country, Which is clear, easy to use, combined with a lot of engineering experience, and construction monitoring, and it is widely used. However, it is not uncommon for engineering accidents to be caused by unclear understanding of earth pressure, and the development of the national economy requires more accurate and reasonable design theories. Therefore, the development of earth pressure calculation theory needs to be carried out urgently to understand the non-limit state, nonlinear distribution, and distribution of earth pressure. The influence of non-single factors
needs to be further deepened.

The research and exploration of earth pressure by domestic and foreign experts and scholars has mainly focused on theoretical derivation, model testing, numerical simulation and other aspects for several years, and certain results have been achieved. In the calculation of non-limiting earth pressure considering displacement, the relationship curve of earth pressure changing with displacement was mostly based on geotechnical tests earlier, and then its physical mechanism and unique relationship were summarized [1-6]; There are many researches on the calculation of non-limiting earth pressure of non-cohesive soils in rigid retaining walls, and they are in-depth and rich [7-12]. Afterwards, using the theoretical concept of shear strength exerted value, many researchers considered the influence of soil displacement changes on the calculation of earth pressure, and put forward and deduced some calculation formulas of non-limiting earth pressure theory. Xu Riqing et al. [13] deduced and proposed the calculation method of non-limiting active earth pressure of cohesive soil, and compared with the model test, the results are quite consistent. Li Chaoyang et al. [14] deduced the non-limit active earth pressure calculation formula of flexible pile cohesive soil by summarizing and considering various earth pressure influence factors, and compared it with the classical Rankine calculation theory. In addition, In recent years, scholars have made efforts to study the calculation of the earth pressure in the pile anchor support, the unloading stress path of the excavation of the foundation pit, the additional earth pressure of the wall displacement, and the accurate design of the retaining structure of the foundation pit [15-18]. In terms of the calculation and monitoring of the internal force of the pile-anchor supporting pile, many studies focused on speculating and deducing the change and development of the internal force based on the horizontal displacement of the pile, the change of nearby ground settlement, and the analysis of finite element data.

Based on the field monitoring test of soil pressure and pile internal force under deep foundation pit pile-anchor support, combined with observation data of foundation pit dewatering and pile top displacement, this paper analyzes and discusses the soil pressure and pile internal force of layered soil under pile-anchor support, force changes and distribution laws. Several existing non-limiting soil pressure calculation methods are selected, calculated and compared with the actual measured values, and the design calculation methods that are in line with the actual working conditions of the foundation pit engineering are explored.

2. Earth Pressure Field Monitoring Test

2.1. Experimental Ideas

In the non-limiting soil pressure theory research problem, the field measurement of the soil pressure of the foundation pit under the cohesive soil flexible support system is closer to the actual situation than the model test, and the data of the structure in the actual working state can be obtained. Analogous rock-soil bearing capacity test, the bearing capacity value obtained from the in-situ test is always greater than that of the remodeled disturbed soil sample. The reason is inseparable from the strength of the original structure of the soil. Distribution is particularly important.

Due to the strict limitation of the displacement of the sidewall of the foundation pit at the actual construction site, the flexible supporting structure and the supported soil are coordinated, and the soil pressure of the foundation pit is in a non-limiting state [15], as shown in Figure 1. To ascertain the specific value, time and space, the reasonable arrangement and smooth burying of the earth pressure cell is very important. In addition, on-site earth pressure measurement has always been subject to material and technical difficulties, large investment, long period, and measurement accuracy is greatly affected by environmental factors.

This test relies on a large-scale deep foundation pit excavation project in Xi’an. Compared with the model test with a single test condition, this test relies on the actual in-situ test of the project, which is unmatched by the model test in terms of scale, time, and site effects. The actual engineering conditions are more complicated. On this basis, the results obtained may be caused by the coupling of multiple factors. Discussing the law of its distribution changes is of great benefit to promoting the development
of non-limiting earth pressure calculation theory.

![Earth pressure-displacement curve](image1.png)

**Figure 1.** Earth pressure-displacement curve.

![Sketch map of test site](image2.png)

**Figure 2.** Sketch map of test site.

![Layout of monitoring test sensors](image3.png)

**Figure 3.** Layout of monitoring test sensors.

### 2.2. Project Overview and Test Plan
The Xi’an area is located in the middle of the Weihe Basin in the faulted depression. The foundation pit in this test is located on the first-level alluvial terraces on the east side of the Fenghe River. The excavation depth is about 17.1~19.8m, and the circumference is about 530m. The supporting structure is a composite flexible pile supporting mode with anchor rods, and the foundation pit adopts the open excavation method. This test refers to the foundation pit support design drawing and the corresponding geotechnical engineering survey report of the site. The specific physical and mechanical parameters of the soil layer beside the pile are shown in table 1. The site contains aquifers and requires precipitation during excavation. The water level at the location is about 16.9m. The foundation pit is next to the building load (the first phase of the project), as shown in figure 2. The height of the first phase of the project is about 24m. Its structure is a steel structure, and the foundation is a pile foundation.

This test was carried out on the supporting piles (section A-B, small box position in figure 2) of the foundation pit on the east side of the first phase of the project. The excavation depth of this section of
the foundation pit is 18.1m, the supporting structure is pile-anchor support, the supporting pile is 25.0m long and the pile diameter is 0.9m. There are 5 anchor cables.

In this test, the WY-E06B vibrating wire earth pressure box is used for earth pressure monitoring. The earth pressure box is shown in figure 3(a). The vibrating wire sensor has good stability and high sensitivity, and is used in construction, railway, transportation, water and electricity, Dams, tunnels and other engineering fields. The working principle of the vibrating wire earth pressure cell is to determine the earth pressure by the natural frequency of the steel wire. The WY-CXX type steel bar stress meter is used to measure the internal force of the pile body. The steel bar stress meter is shown in figure 3(b). The working principle and working process of the vibrating wire steel bar stress meter are basically the same as those of the vibrating wire earth pressure cell. The difference is that the earth pressure box can only measure pressure, while the steel bar strain gauge can measure both pressure and tension. The main parameters are shown in table 2.

As shown in figure 4, it is a schematic diagram of the installation and burial of the soil pressure box and the reinforcing steel stress gauge in this experiment. In the figure, the soil pressure box is buried from top to bottom on the outside of the pit to measure the earth pressure in the active area on the unexcavated side outside the pit. And the steel bar stress gauge near the inner side of the pit is welded to the pile body to measure the internal force of the pile body. Number 16 earth pressure boxes and steel bar stress gauges with different line lengths in sequence, according to the buried depth of the earth pressure box according to T1, T2, ..., T7, T8, and according to the buried depth of the steel bar stress gauges in turn according to G1, G2, ..., G7, G8 are numbered, and the numbers are respectively attached to the surface of the earth pressure box, the steel bar strain gauge and the corresponding wires.

### Table 1. Mechanical parameters of soil layer.

| Number | Geotechnical name | γ(KN/m³) | C(kPa) | φ(°) |
|--------|------------------|----------|--------|------|
| (1)    | Fill soil        | 15.0     | 5      | 10   |
| (2)    | Loess like soil  | 17.6     | 26     | 21   |
| (3)    | Silty clay       | 18.2     | 28     | 22   |
| (3)-1  | Medium sand      | 19.0     | 2      | 30   |
| (4)    | Silty clay       | 19.2     | 28     | 22   |
| (4)-1  | Medium sand      | 19.0     | 2      | 30   |

### Table 2. Main parameter of sensors.

| Sensor           | Type          | Range (MPa) | Deviation (kPa) | Installation method |
|------------------|---------------|-------------|-----------------|--------------------|
| Earth pressure cell | WY-E06B     | 0.6         | 1               | Hanging cloth method |
| Rebar stress gauge | WY-CXX     | ±260        | 1               | Welding method     |

![Figure 4. Photos of sensors.](a) (b)
2.3. Implementation Process

(1) Send all test equipment to the construction site, and communicate and coordinate with the construction unit. The steel bar strain gauge should be installed first, and then the earth pressure box should be installed.

(2) The steel bar stress gauge is installed by welding and the following steps, as shown in figure 5(a). Transport the reinforcement cage to a flat area, arrange the points at equal intervals from the pile end according to the layout drawing, and mark them with a marker. Install the rebar at both ends of the reinforcement strain gauge, and place it on the reinforcement cage according to the number. The strain gauge is bound to the main reinforcement of the steel cage with a fine loop of wire. The strain gauge and test lead should be bound on the bottom side of the structural steel bar to avoid damage to the strain gauge and lead during vibrating. Weld the rebar on both sides of the strain gauge with electric welding. On the main bar, use a wet cloth to wrap the stress gauge during welding to prevent excessive temperature from damaging the stress gauge. 10cm should be reserved for the wire at the meter.

(3) The earth pressure box adopts the hanging method and installs according to the following steps, as shown in figure 5(b). Turn the steel cage 90°, and install the earth pressure box on the other side of the welded steel strain gauge. Spread the nylon cloth smoothly on the construction site, and cut it to 27mx1m. The supporting pile length is 25m, the pile diameter is 0.9m, and 1m nylon cloth should be reserved at the pile end. Cut the nylon cloth into 8 small square nylon cloths of 0.25m×0.25m, and sew 8 small pockets on the center line of the paved nylon cloth at equal intervals, mark the corresponding earth pressure number on the mouth of the bag, pay attention to the seam When making, start from the end of the pile and sew one every 3m. Put the earth pressure box into the corresponding pocket in turn with the stressed side facing out. After placing it, fill the pocket with fine sand. If there is no fine sand on site Sand, it is not necessary to fill, and finally sew the pockets of the earth pressure box. Paste the wires of each earth pressure box to the nylon cloth with transparent large tape, and paste them to the top of the pile in turn. The wires at the earth pressure box are not It should be too tight, and the wire should be reserved for 20cm to prevent the side pressure from breaking the connection between the earth pressure box and the wire when the concrete is poured. Spread the nylon cloth and the earth pressure box together on the steel cage. Nylon cloth should reserve 1m of surplus at the end of the pile so as to wrap the end of the pile, and fix the two long sides of the nylon cloth on the adjacent steel bars with ties or plastic buckles, but should not be tied too tightly, and should be reserved enough The space for grouting can squeeze the earth pressure box into the soil.

(4) After all the sensors are installed in the steel cage, put the steel cage into the drilled hole, and then pour the concrete. After the concrete is poured, bundle all the wires together and put them in the wire box. Use the reader to read the sensor data and check whether each sensor is installed successfully.

After the arrangement of various monitoring equipment is completed, data collection starts, and the collection frequency is determined by the excavation process of the foundation pit. Data collection
should be adjusted or optimized in conjunction with the construction process. When the test pile side soil is excavated or the anchor cable is constructed, data collection should be carried out within 1 day after construction. When data is collected each time, in addition to collecting and using a reader to record stress data, the time of each data collection, excavation depth, construction progress and other information should also be recorded. The change law of earth pressure should be analyzed in time. If there is a sudden change in earth pressure that does not conform to the normal law, vigilance should be increased, the monitoring frequency should be intensive, and the monitoring data of the horizontal displacement of the pile top and the ground settlement of the monitoring unit should be combined.

3. Test Results
This study collected and summarized the measurement data of soil pressure and pile internal force for a series of working conditions of foundation pit excavation. The origin software was used to draw the relationship between the two kinds of stress, depth, and time. Can have a complete and clear study and understanding of the earth pressure under the pile-anchor supporting system of deep foundation pits and the internal force of the pile body.

3.1. Data Processing and Analysis
In this field test, a total of 8 soil pressure monitoring points and 8 pile internal force monitoring points were set up on the selected supporting piles of the foundation pit, for details, see the monitoring point layout figure 4. The monitoring data of the important working condition change points are selected for analysis. And the change law of the soil pressure and the stress of the pile body reinforcement during the excavation of the foundation pit is summarized.

(1) The determination of earth pressure is the prerequisite for the design of deep foundation pit supporting structure, and its accuracy directly affects the rationality of the design. The earth pressures measured in this test at different excavation depths are of great significance to support system design, support system deformation prediction, support structure safety, and economic rationality of foundation pit support. In the earth pressure test in this paper, 8 measuring points are arranged, all of which are distributed on the non-airside side (the side of the foundation pit wall), with depths of 3.1m, 6.1m, 9.1m, 12.1m, 15.1m, 18.1m, and 21.1m, 24.1m, see figure 4 for details. Based on the actual measurement data of each measurement point before the excavation of the foundation pit as an example, the static earth pressure change is analyzed in terms of time, stratum distribution, and water level.

It can be seen from figure 6(a)(b). (1) During the construction of the bored pile, the measured static earth pressure is much larger than the earth pressure of the other groups (except T8). After the concrete is solidified, all The measured earth pressure value is closer to the actual situation, and the measured earth pressure value decreases slowly with time. (2)After the earth pressure is stabilized, the last static earth pressure is selected for analysis, and the distribution of the soil layer is plotted. It is found that the magnitude of the earth pressure is obviously affected by the stratum, and the change of the distribution form is consistent with the stratum change, which is a segmented distribution and not a continuous change. From the perspective of depth as a whole, it is roughly a zigzag change. (3)Compared with the theoretical earth pressure, it is found that at positions above 2/3 of the depth of the foundation pit, the theoretically calculated earth pressure is slightly larger than the actual measured value, while the results in the following parts are opposite.

Analyze the reasons for the above phenomenon: (1) When the pile is poured into concrete, a series of chemical reactions between the concrete and water are still going on. The contact relationship between the construction pile and the surrounding soil is relatively complicated. Most of the pressure measured by the earth pressure box is applied by the concrete to the soil. This phenomenon detailed explanations are subject to further analysis and research. Regarding the abnormality of the T8 earth pressure box, the analysis may be due to its deep location, which is the bottom position of the cast concrete, and the concrete is not in close contact with the surrounding soil, so the earth pressure can be measured well. After that, the measured value of earth pressure gradually decreases, which may be related to the solidification of the pile body and the pressure dissipation caused by the previous chemical reaction; (2)
Due to the difference in physical and mechanical properties of the layered soil on the site, the earth pressure of each layer of soil is also different and are not the same. If the values of cohesive forces and friction angle of the lower layer soil are significantly greater than the upper layer, the earth pressure will be lower than the upper layer [7]; (3) Because the physical and mechanical parameters and the coefficient of static earth pressure used in the calculation are comprehensively selected from the experimental and empirical values of the soil in the site. They cannot be consistent with the actual values. In addition, the actual distribution of earth pressure does not increase linearly with depth. Inferring from this law, it is likely to conform to the characteristics of the static earth pressure theory within a certain depth range, but the increase in the lower earth pressure may decrease; the presence of groundwater at a depth below 15m increases the total earth pressure.

(2) After the excavation of the foundation pit, the soil is displaced in the direction of the pit, and the earth pressure changes from the static earth pressure to the active earth pressure, as shown in Figure 1. At this time, the earth pressure is in a non-limiting state, which is the external load received by the supporting structure when it is working, and is an important reason for the internal force and deformation of the supporting structure. Therefore, the monitoring and analysis of earth pressure during this period is particularly important for the design and construction of supporting structures. Taking the measured data of each measuring point after excavation as an example, the earth pressure changes will be analyzed from the aspects of stratum distribution, excavation of foundation pit, application of anchor cables, and theoretical comparison.

It can be seen from figure 6(c) (d): After the excavation of the foundation pit, the distribution and change of the measured earth pressure. (1) On the whole, the earth pressure gradually decreases with the increase of the excavation depth, and the shape of the change along the depth still presents a zigzag shape. Excavation to the deepest part of the foundation pit, the reduction of soil pressure in each layer is different, the reduction of soil pressure of loess-like soil, medium sand is smaller, and the reduction of soil pressure of silty clay is larger; The earth pressure below the bottom of the foundation pit decreases first and then increases with the excavation of the foundation pit; (2) With the increase of the excavation depth, the earth pressure value decreases as a whole, and changes toward the active earth pressure value, which is in a state of non-limiting earth pressure. Compared with the active earth pressure of Rankine, the measured earth pressure at the end of excavation is not very consistent. The measured earth pressure of the upper soil body is obviously higher than the theoretical value, and the lower soil pressure is slightly lower than the theoretical value;

In figure 6(e), the earth pressure is connected, and then the different excavation depths and anchor cable positions are drawn, and the laws can be compared and analyzed. After the excavation depth is about 4m, precipitation is carried out. When the water level drops to a depth of 26m, the earth pressure will decrease to a certain extent. And at the place where the anchor cable is applied, the earth pressure decreases greatly, but there is a certain time lag.

Analyze the reasons for the above phenomenon: (1) from the perspective of mechanism, the decrease in earth pressure is mainly caused by the displacement of the soil body into the pit due to the excavation of the foundation pit. As the excavation depth of the foundation pit continues to increase, the soil outside the pit is displaced to the inside of the pit due to additional earth pressure [14]. However, due to the existence of the supporting system, the soil is coordinated with its deformation, the displacement is controlled, and the earth pressure is in a non-limiting state. The reduction of soil pressure with different physical and mechanical parameters is quite different. According to this test, for the Xi’an area, the range of variation is silty clay>medium sand>loess-like soil; for the part below the bottom of the foundation pit, the earth pressure first decreases and then increases mainly because the active earth pressure state changes to the passive earth pressure state. (2) Rankine earth pressure theory does not consider wall friction, so its value is too small [10]. The measured value may indicate the true state of the development of non-limiting earth pressure. (3) The decrease of water level causes the water pressure to dissipate and the total earth pressure decreases. The anchor tension provided by the anchor cable is the direct cause of the reduction of the local earth pressure.
Figure 6. Tidying and analysis for test data.

(3) The internal force of the pile body is an important indicator reflecting the force status and safety status of the supporting structure of the foundation pit. A reasonable analysis of the measured results is of great significance for studying the force characteristics of the supporting structure and ensuring the smooth implementation of the project. In the pile internal force test in this paper, a total of 8 measuring
points are arranged, all of which are arranged on the side of the empty space (the side of the foundation pit), with depths of 3.1m, 6.1m, 9.1m, 12.1m, 15.1m, 18.1m, 21.1m, 24.1m, see figure 4 for details. During the actual measurement, it was found that the steel bar stress gauges G1 and G6 failed due to unknown reasons. Taking the measured data of each measuring point as an example, the analysis is carried out from three aspects: the distribution of the stress of the steel bars along the pile at each stage of the excavation of the foundation pit, the relationship with the excavation of the foundation pit, and the application of anchor rods.

It can be seen from figure 6(f) that as the excavation depth of the foundation pit increases, the displacement of the pile top gradually increases. The distribution and change of the stress of the pile body steel bar with depth and time: (1)In the initial stage of excavation, with the increase of the excavation depth, on the whole, the compressive stress is at the depth of about 5m to about 12m, showing an increasing trend. The law of change with depth first increases and then decreases; the overall change law of the stress of the steel bar at the depth of 12m to the bottom of the pile is slowly increasing from 0, with little change, and no change along the depth; (2)Mid-term excavation, the excavation depth is about 10-13m, and the compressive stress at the depth of about 5m to about 12m decreases as a whole. Along the depth, it first increases and then decreases and gradually increases. From the depth of 12m to the bottom of the pile, the compressive stress of the steel bars increases as a whole, and the distribution law along the depth is gradually decreasing to 0 from top to bottom; (3)In the later stage of excavation, the excavation depth is about 13-18m. From about 5m to about 12m, the overall compressive stress gradually increases again, and gradually decreases from top to bottom along the depth to near 0. From about 12m to the bottom of the pile, the overall compressive stress of steel reinforcement suddenly increases, and the distribution is regular along the depth. In order to increase from top to bottom, it first increases and then decreases to 0; (4) There are also obvious changes in the stress of the steel bar caused by the application of the anchor cable. At the place where the anchor cable is applied, the stress will be reduced considerably.

There is no real-time monitoring data for the depth of the pile from 0 to 5m. However, Related studies [21] show that if there are anchor cables and other components that limit the displacement of the pile top, tensile stress may occur in the stress of the steel bar on the top of the pile. Analyze the reasons for the above phenomenon: (1) At the beginning of excavation, the load on the pile body was mainly imposed by earth pressure. At this time, two anchor cables were applied, and the effect was not obvious. With the excavation, the soil continued to move into the pit. The upper pile support is stressed, and its internal force gradually increases. The lower part of the pile at the anchoring section has not yet received force. (2)In the middle of excavation, the soil on the upper part of the pile has displacement, which causes the earth pressure to decrease, and it is in harmony with the deformation of the pile. At this time, 4 anchor cables have been applied. The cable effect is generated. The external load on the upper pile body decreases, so the internal force of the pile body decreases. Due to overall tilt of the lower pile body, the passive earth pressure on the inside of the pit decreases from top to bottom along the depth to zero at the bottom of the pile; (3) In the later stage of excavation, the soil displacement reaches the maximum, the pile tilt reaches the limit, all anchor cables have been applied, and the effect has been achieved. Due to the coordinated deformation of the upper pile body, the internal force experienced slightly increased. In the middle part, the internal force of the pile body is greatly reduced due to the existence of anchor tension of the anchor cable. However, due to the inclination of the lower part, the passive earth pressure on the pile further increases, and the internal force of the pile body further rises to zero at the bottom of the pile. (4) The existence of anchor tension of anchor cable restricts the displacement of the soil, thereby reducing the soil pressure, which has a great effect on the improvement of internal force of pile.

3.2. Analogy of Existing Non-Limiting Earth Pressure Calculation Methods

There are still no complete answers about the calculation method of the earth pressure on the pile-anchor supporting system. Under flexible support, the study of the development of earth pressure considering displacement is essentially the search for the state of non-limiting earth pressure and its accurate calculation. Therefore, this paper selects two theories from many non-limiting earth pressure theories,
and verifies and compares them through calculation and test data, in order to achieve the research purpose of discussing engineering application.

(1) In the study (Xu Riqing, Liao Bin, Wu Jian, et al.) of the active earth pressure calculation method, starting from the stress Mohr circle, the formula of the relationship between the internal friction angle of the cohesive soil and the wall displacement in the intermediate state is derived. At the same time, the external friction angle and cohesion of the wall-soil contact surface are considered. According to the geometric relationship of the cohesive soil stress Mohr circle, the relationship between the soil cohesion and the wall displacement is obtained. Finally, the horizontal layering method is used to obtain the active earth pressure calculation formula of the cohesive soil in the non-limit state [12]:

\[
p = \left(\gamma z + q_0\right) - \frac{\tan \theta}{\tan (\theta + \varphi_m)} - \frac{1}{\tan (\theta + \varphi_m)} \left(\varphi_m + c_m\right)
\]

Equation (1) $\gamma$: Soil density, $z$: depth, $q_0$: upper loads, $\theta$: Assuming the angle between the fracture surface and the vertical direction, $c_m$, $\varphi_m$: Soil strength considering wall displacement.

Figure 7 is the comparison between the soil pressure calculated in Theory 1 and the measured value. From the figure, it can be seen that the shape of the calculated value curve is quite consistent with the measured value, and the law and trend are very similar. This reflects the calculated value curve expressing the soil pressure. The characteristics of body stratification; The calculated value is generally slightly larger than the measured value. The preliminary consideration may be that the anchoring force provided by the anchor cable is not considered in the calculation theory.

Therefore, in practical applications, the theory has a good consistency in reflecting the earth pressure under the excavation of multi-layer soil foundation pits. However, the effect of anchor tension under the pile-anchor support system is not considered. So when the measured value is compared, there are still discrepancies in local locations. As for how to add anchor tension to its calculation theory to make it more realistic, relevant derivation studies may need to be further carried out.

(2) In the study (Li Chaoyang, Xie Qiang, Kang Jingwen, etc.) of the non-limiting active earth pressure of the flexible pile cohesive soil, consider the soil arching effect behind the pile, the pile-soil internal friction angle and the cohesive force development value under the non-limit state, and the pile After the friction angle and cohesive force play value in the soil body, starting from the cohesive soil stress Mohr circle, the static balance is established by the micro-layer analysis method, and the potential sliding surface of the soil body behind the pile is searched. The calculation formula of non-limiting active earth pressure of flexible pile cohesive soil is derived [13]:

\[
E_m = \sqrt{\left(p_{yi} K_i - c_{mi} \cot \varphi_{mi}\right)^2 + \left(\left(p_{yi} K_i - c_{mi} \cot \varphi_{mi}\right)\tan \delta_{qmi} + c_{qmi}\right)^2}
\]

Equation (2) $p_{yi}$: Vertical stress on the soil surface, $K_i$: Positive pressure coefficient of pile-soil interface, $c_{mi}$, $\varphi_{mi}$: Soil strength considering wall displacement, $c_{qmi}$, $\delta_{qmi}$: Cohesion and friction angle between pile and soil considering wall displacement.

Figure 8 shows the comparison of the soil pressure calculated by theory 2 with the measured value. It can be seen from the figure that the calculated value curve shape is at the upper part, which is quite different from the measured value. The theoretical value is smaller than the measured value; below about 6m, the curve is extremely Close to the measured value, the calculated value is close to the actual measured value.

This theory is seriously distorted when reflecting the soil pressure of the upper soil under the pile-anchor support system. It is speculated that it may be caused by the greater cohesion of the soil in the process of deriving the formula. However, the theoretical value of the lower layer is compared with the actual measurement. It is quite consistent. In practical applications, this type of theory is more in line with the actual value of the earth pressure of the pile support, but the anchor tension stress is still not well reflected.
4. Concluding Remarks
Through the statistical analysis of on-site monitoring data of deep foundation pit soil pressure and pile internal force in Xi’an area, and the comparison of two soil pressure calculation theories, the following conclusions are obtained:

(1) For the excavation of cohesive soil foundation pits, the soil pressures of layered soils with different properties are distributed in sections along the depth, and the overall distribution is in the shape of a “Zig”. The magnitude and change of the value are closely related to the strength parameters of the soil, the change of the water level, and the excavation stage of the foundation pit. The soil pressure under the pile-anchor supporting system is obviously affected by the anchor tension along the depth curve.

(2) In the deep foundation pit supporting system, the temporal and spatial variation and distribution of the internal force of the pile body are in a one-to-one correspondence with the earth pressure, and they develop simultaneously. Regarding the internal force of the pile body, its changes are more complicated, not one direction or trend. It changes with time and depth. The increase and decrease of internal force at the same position of the pile body may alternately occur, so special attention should be paid to this part in the design.

(3) Select the existing non-limiting earth pressure calculation methods, apply calculations and compare them, and the results show that the theory can roughly reflect its changing laws. Among them, Xu Riqing et al. [12]’s calculation method reflects the layered changes of soil close to reality; Li Chaoyang et al. [13] in the study of non-limit active earth pressure of flexible pile cohesive soil, the calculated value is very reflective at a certain depth in fact, it has certain value and significance for construction reference. However, because the two calculation methods have not considered the existence of anchor tension in the derivation process, they are slightly inconsistent with the stress conditions of the engineering conditions in this experiment, so the earth pressure calculation curves are not completely consistent.

References
[1] Liu Y F. 2010 Field Test and Numerical Simulation Research on Single Support Pile-anchor Support for Deep Foundation Pit [D] Qin Huangdao Yan Shan University.
[2] Lu K L and Yang Y. 2009 Approximate calculation method of active earth pressure considering displacement [J] Rock and Soil Mechanics 30 (2) 553-557.
[3] Lu K L and Yang Y. 2010 Preliminary study of active earth pressure under nonlimit state [J] Rock and Soil Mechanics 31 (2) 615-619.
[4] Mei G X and Zai J M. 2001 Earth pressure calculating method considering displacement [J] Rock and Soil Mechanics 22 (4) 83-85.
[5] Xu R Q. 2000 Calculation method of earth pressure considering displacement and time [J] Journal of Zhejiang University (Engineering Science) 34 (4) 370-375.
[6] Yang B, Hu L Q. 2000 Test study on Relationship between Lateral Earth Pressure Acting on Retaining Structures and Horizontal Displacement [J] Building Science 16 (2) 14-20.
[7] Wang Y Z, Li X G and Chen N N. 2005 Active earth pressure on a retaining wall and lateral coefficient of earth pressure [J] Rock and Soil Mechanics 26 (7) 1019-1022.
[8] Xu R Q, Gong C, Wei G, Wang J C. 2005 Theory of earth pressure against rigid retaining walls considering translational movement effect [J] Journal of Zhejiang University(Engineering Science) 39 (1) 119-122.
[9] Chen Y K, Wang Y M, Xu R Q, etc. 2004 Numerical analyses of active earth pressure on rigid retaining wall [J] Chinese Journal of Rock Mechanics and Engineering 23 (6) 989-995.
[10] Xu R Q, Chen Y K, Yang Z X, etc. 2002 Experimental research on the passive earth pressure acting on a rigid wall [J] Chinese Journal of Geotechnical Engineering 24 (5) 569-575.
[11] Wang W Z and Wu Y Z. 1992 Study on earth pressure and its distribution behind gravity retaining wall [J] Highway Engineering 60 22-29.
[12] Xu R Q, Liao B, Wu J, et al. 2013 Computational method for active earth pressure of cohesive soil under nonlimit state[J] Rock and Soil Mechanics 34 (1) 148-154.
[13] Li C Y, Xie Q, Tang J W, et al. 2018 Active earth pressure of cohesive soil against flexible pile under nonlimit state [J] Journal of Civil and Environmental Engineering 40 (5) 64-70.
[14] Wang C H and Wang X X. 2019 Experimental study on physical model of additional earth pressure theory [J] Journal of Nanchang University(Engineering & Technology) 41 (1) 40-50.
[15] Wu L L. 2015 An experimental study and numerical analyses of the relationship between additional earth pressure and displacement for retention structures [D] Tianjin: Tianjin University.
[16] Sheng Z Q and Cui T. 2018 Engineering characteristics of foundation soil under the action of stress path of foundation pit excavation [J] Building Science 34 (7) 1-11.
[17] Chen J, Zhou T H. 2015 Theoretical Study and Field Monitoring Analysis on Lateral Soil Pressure Acting on Pile—Anchor Excavation Retaining Structure [J]. Building Science 31 (9) 108-114.
[18] Sheng Z Q, Teng Y J, Li P. 2021 Discussion on several problems in design of retaining structures of deep excavation [J] Chinese Journal of Geotechnical Engineering 43 (1) 94-101.