Research on earth pressure monitoring data of soil-stone assorted foundation pit

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Abstract Earth pressure is the most important type of load acting on the supporting structure of a foundation pit, and it is also a key factor in the design of foundation pit supporting. However, in engineering practice, the calculated value differs greatly from the actual value, which puzzles many engineers. This paper analyzes the field measured data of the earth pressure of the foundation pit in Minghucheng (Jinan city), and compares the calculated values of the Rankine active earth pressure and the passive earth pressure theory. The analysis finds that: (1) The measured value is between the active earth pressure and the passive earth pressure, and as the excavation of the foundation pit and the inward displacement of the supporting structure, the measured earth pressure value becomes smaller and approaches the active earth pressure. (2) When the pre-stressed anchors is applied, due to the fastening effect of the anchors, the earth pressure behind the supporting pile has a tendency to increase. (3) The theoretical value of Rankine's active earth pressure in the soil-rock combination is obviously lower than the measured values.

1. Introduction

The theory of earth pressure has been in use since the Coulomb theory proposed in 1773 and the Rankine theory proposed in 1857. These two classic earth pressure theories divide earth pressure into three types: active earth pressure, passive earth pressure and static earth pressure, namely three modes of earth-moving wall, wall earth-moving and relatively static wall-soil, which are most commonly used in design. The theory of earth pressure is widely used, such as retaining walls, foundation pit supporting structures, underground tunnel structures. Since the active earth pressure and passive earth pressure are the earth pressures in the two extreme states of the soil, they are not consistent with the actual situation, so some scholars have proposed the non-limit state earth pressure, such as Zhou[1] etc. Pressure calculation of deep foundation pit pile-anchor supporting structure stress state. Mei[2, 3] proposed an earth pressure calculation method considering the influence of displacement, which reflects the characteristics of earth pressure changing with the displacement of the retaining wall. The calculated result differs from the measured value by 4%, which is beneficial to engineering applications.
In foundation pit support, pile-anchor support is often used, and the supporting pile is affected by the earth pressure of the soil layer outside the pit. With the excavation of the foundation pit, the supporting structure and the soil outside the pit are displaced into the pit, and the earth pressure on the supporting structure will show a more complex change form\(^4\). Chen\(^5\) et al. monitored and analyzed the earth pressure of large foundation pit excavation in thick alluvium, and Zhao\(^6\) et al. monitored and analyzed the earth pressure of deep foundation pit in the loess area. Jiang\(^7\) et al. monitored the earth pressure of unsupported excavation in the North China Plain. In the monitoring, it was found that the change of earth pressure was affected by many factors such as site conditions, construction load, measuring point layout, support type.

This article analyzes the monitoring data of the foundation pit project in Minghucheng, Jinan City as an example. The project site is a typical soil-rock dual combination foundation pit, with a softer soil layer on the upper part and weathered rock layer on the lower part. Through the analysis of earth pressure, the distribution law of earth pressure in soil-rock combination foundation pit is studied.

2. Site engineering property and earth pressure monitoring method

The project is a commercial complex foundation pit project, with an excavation depth of 13.0-16.8m, an east-west length of 271.9m, a north-south length of about 79.2m, and an excavation circumference of 675.1m. There are urban roads and 3-6 floors above ground in the surrounding area using pile-anchor supporting structure. The plan of the foundation pit and the location of the earth pressure measuring points are shown in Figure 1.

![Fig.1 Location of earth pressure monitoring point](image)

The stratum in the site is mainly silty clay, clay and strongly weathered rock formations, and the engineering safety level is level 1. The supporting form of the foundation pit is bored piles and pre-stressed anchor cables. The vertical section of earth pressure monitoring point 1 and monitoring point 2 is shown in Figure 2.
Monitoring point 1 is arranged with 8 vibrating wire earth pressure boxes, and monitoring point 2 is arranged with 9 earth pressure boxes, and the earth pressure is calculated according to the following formula.

\[ P = K(f_n^2 - f_0^2) \]  \hspace{1cm} (1)

Where \( P \) is the monitoring earth pressure (kPa), \( K \) is the instrument parameter of the earth pressure box (kPa/Hz²), \( f_n \) is the natural vibration frequency of the earth pressure box during monitoring (Hz), and \( f_0 \) is the initial natural frequency of the earth pressure box (Hz).

According to the classic Rankine’s theory of earth pressure, the active and passive earth pressure of clay soil are calculated as follows:

\[ P_a = \gamma z \tan^2(45^0 - \frac{\varphi}{2}) - 2c \tan(45^0 - \frac{\varphi}{2}) \]  \hspace{1cm} (2)
\[ P_p = \gamma z \tan^2(45^0 + \frac{\varphi}{2}) + 2c \tan(45^0 + \frac{\varphi}{2}) \]  \hspace{1cm} (3)

For non-cohesive soil,

\[ P_a = \gamma z \tan^2(45^0 - \frac{\varphi}{2}) \]  \hspace{1cm} (4)
\[ P_p = \gamma z \tan^2(45^0 + \frac{\varphi}{2}) \]  \hspace{1cm} (5)

Where \( P_a \) is the active earth pressure, \( P_p \) is the passive earth pressure, \( \gamma \) is the soil gravity, \( \varphi \) is the friction angle in the soil, \( c \) is the soil cohesion, and \( z \) is the soil depth.
3. Analysis of earth pressure monitoring data

The soil pressure monitoring values of monitoring point 1 and monitoring point 2 are summarized in Table 1.

| Monitoring point | Depth of earth pressure cell | Measured earth pressure | Rankine’s theory |
|------------------|-----------------------------|-------------------------|-----------------|
|                  | Initial | Excavation 4m | Apply prestressed anchor cable | Active pressure | Passive pressure |
| Point 1          |         |               |                             |                |                |
| -1.8             | 7.29    | 11.95         | 13.74                      | 5.53           | 215.05         |
| -4.3             | 38.98   | 48.21         | 38.76                      | 33.97          | 375.03         |
| -6.2             | 41.85   | 47.22         | 27.65                      | 31.60          | 415.56         |
| -8.2             | 63.77   | 58.75         | 40.06                      | 52.57          | 680.99         |
| -10.5            | 112.17  | 92.83         | 80.68                      | 67.15          | 812.24         |
| -12.1            | 127.72  | 164.35        | 164.88                     | 54.93          | 1288.65        |
| -15.7            | 149.81  | 147.09        | 151.61                     | 73.30          | 1538.84        |
| -20.7            | 171.55  | 195.95        | 191.89                     | 53.27          | 2798.98        |
| -27.7            | 7.29    | 11.95         | 13.74                      | 5.53           | 215.05         |
| Point 2          |         |               |                             |                |                |
| -2.9             | 7.29    | 11.95         | 13.74                      | 5.53           | 215.05         |
| -5.1             | 38.98   | 48.21         | 38.76                      | 33.97          | 375.03         |
| -7.1             | 41.85   | 47.22         | 27.65                      | 31.60          | 415.56         |
| -10              | 63.77   | 58.75         | 40.06                      | 52.57          | 680.99         |
| -12.5            | 112.17  | 92.83         | 80.68                      | 67.15          | 812.24         |
| -15.7            | 127.72  | 164.35        | 164.88                     | 54.93          | 1288.65        |
| -18.7            | 149.81  | 147.09        | 151.61                     | 73.30          | 1538.84        |
| -21.6            | 171.55  | 195.95        | 191.89                     | 53.27          | 2798.98        |

Comparing the measured values of monitoring points 1 and 2 with the calculated values of Rankine theory are shown in Figure 3 (a) and (b). It is noticed that the initial earth pressure value lies between the Rankine active earth pressure value and the passive earth pressure value. The reason is that the Rankine earth pressure theory is proposed based on the ultimate failure state. The active earth pressure is the minimum principal stress when the soil is destroyed, and the earth pressure is the maximum earth pressure when the soil is destroyed. The initial value of monitoring should be closed to the static earth pressure in theory when the foundation pit is not excavated. With the excavation of the foundation pit, the earth pressure value becomes smaller. Then, the soil body is displaced into the pit, and the earth pressure value gradually approaches the active earth pressure value.

![Fig.3 comparison of earth pressure between measured value and theoretical value](image-url)
In the design of foundation pit support, if the earth pressure of the supporting structure is calculated by active earth pressure, it can be seen that the earth pressure is too small. It is recommended to calculate the static earth pressure.

It can also be seen from Figure 3 that when a pre-stressed anchor cable is applied at a depth of about 6m at the monitoring point and a pre-stressed anchor cable is applied at a depth of about 5m at the monitoring point, the earth pressure box at the anchor cable position monitors that the earth pressure increases, indicating at this time, the application of the pre-stressed anchor cable caused the surrounding pile to shift out of the pit, and the earth pressure increased, but it did not reach the initial earth pressure value.

According to the geological survey data of this project, there are strong weathered and fully weathered rock formations below 10m from the surface. When calculating the active earth pressure by formula (2), the calculated value of earth pressure is obviously lower due to the subtracted term $2c \tan(45^0 - \varphi / 2)$, as shown in Figure 3. The measured value of earth pressure generally increases linearly with depth. Therefore, for the formation with soil-rock combination, when calculating the underlying rock formation, the calculation result of the Rankine earth pressure calculation formula is too low, which should be considered carefully.

4. Conclusion
The earth pressure of a foundation pit retaining pile in a soil-rock combination in Jinan was monitored on site and compared with the theoretical value of Rankine earth pressure. The study found that the measured earth pressure of the site lies between the theoretical value of active earth pressure and passive earth pressure; with the excavation of the foundation pit, the earth pressure value decreases; when the pre-stressed anchor cable is applied, the earth pressure value at the anchor cable increases; When the rock combination is calculated by Rankine's theory, the active earth pressure is obviously lower.

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