Research on detection technology of squeezed branch and disk pile under boulder geological condition

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Abstract. The detection methods of the cavity and cavity size and pile quality of squeezed branch and disk pile are not perfect. Based on the 65 pier of a viaduct in Zhongshan City, this paper uses caliper, cross hole acoustic wave method, core pulling method and tube wave method to detect the squeezed branch and disk pile, and compares and analyzes the advantages and disadvantages, applicable conditions and detection results of each method. It can be seen from the test results that both caliper and cross hole acoustic wave method can detect the length of squeezed branch pile, while core pulling method and tube wave method can detect the quality of pile body and the thickness of sediment at the bottom of pile. The test results are basically consistent and verified with each other, and the specific data such as the length of branch and the thickness of sediment are slightly different. In this paper, caliper, cross hole acoustic method, core pulling method and tube wave method are verified and analyzed to provide ideas and support for the later detection of squeezed branch and disk pile.

1. Introduction
In the design and construction of pile foundation, increasing the length and diameter of pile is the most important way to improve the bearing capacity of pile foundation. The squeezed branch and disk pile uses the theory of biological bionics, and the squeezed branch and disk equipment is used to form the branch and disk in the specific stratum, so that the side resistance is transformed into the end resistance, and then the bearing capacity of pile is improved.

Figure 1. Stress mechanism of ordinary pile
Figure 2. Stress mechanism of squeezed branch pile
Through field test and theoretical analysis, many domestic scholars have obtained that the construction quality of the branch plate has a great influence on the bearing capacity of the branch plate pile\textsuperscript{[1-2]}. Therefore, it is very important to determine the size of the branch plate and the quality of the pile to determine the bearing capacity of the pile. The pile quality detection methods usually include drilling core method, ultrasonic method, high strain stress reflected wave method and low strain stress reflected wave method\textsuperscript{[3-7]}. At present, the detection method for the integrity of squeezed branch pile, especially the integrity of branch pile, is not mature. In the relevant standard\textsuperscript{[8]}, it is proposed to use caliper to detect the diameter and length of branch pile. This detection method has certain limitations and can not detect the coagulation Li Jian\textsuperscript{[9]} and others used caliper, core pulling method, thermal anomaly method and acoustic wave transmission method to detect the integrity of squeezed branch pile after soil pouring. They proposed that these methods can detect the integrity of squeezed branch pile, but each method has its own shortcomings and limitations. Pipe wave is a new method to detect the integrity of pile body. It is a detection method of "one pile, one hole, one pipe wave", which can comprehensively and accurately judge the integrity of pile body. Compared with coring method, it is more comprehensive, economic and convenient\textsuperscript{[10]}.

In order to reduce the construction difficulty, shorten the construction period, and avoid the pile crossing the boulder layer, three squeezed branch piles are set up. Each pile is set with 4 rows of 8 star branches, with a diameter of 1.6m, a length of 0.75m, and a spacing of 2.8m between each layer, staggering 22.5°. Based on the 65 # pier, the support length is detected by caliper and cross hole acoustic method, and the pile integrity is detected by core pulling method and tube wave method. The feasibility of various detection methods is verified by comparing each detection result.

Figure 3. Vertical layout of squeezed branch pile

Figure 4. Layout plan of squeezed branch plate pile support (unit: cm)
2. Detection principle and preparation

2.1. Caliper testing
Caliper is a kind of equipment for measuring hole diameter, which is composed of downhole mechanical structure and signal conversion device. The mechanical structure and signal conversion device are connected by cable. At present, the four arm caliper is commonly used in the market. Its working principle is that the four arm is placed at the bottom of the hole through the cable, the four arm is opened and in close contact with the hole wall, and the four arm is slowly pulled up through the cable to change the hole diameter. The opening and closing amount of the four arms at the branch position reflects the change of the aperture, which can be converted into the form of resistance and fed back to the acquisition equipment. After data processing, the borehole diameter, branch length and branch position can be obtained.

![Figure 5. mechanical umbrella caliper](image-url)

2.2. Cross hole acoustic method
In the cross hole acoustic wave method, two acoustic detection tubes are set inside and outside the pile respectively. The ultrasonic pulse transmitter excites high-frequency elastic pulse wave in the concrete, and the receiver is used outside the pile to receive the wave characteristics in the process of propagation in the concrete and soil layer. The ultrasonic pulse wave will produce obvious wave at the interface of the medium with large difference, and the pile body can be obtained by drawing the curve. The interface between concrete and soil can be used to determine the support length and position.

When there is difference in wave impedance between one medium and another, ultrasonic wave will produce transmission, reflection and refraction. In the detection of the pile, the pile body of the pile is a concrete component, and the outer part of the pile is the soil layer around the pile; ultrasonic wave, as an ultra-high frequency seismic wave, is the smallest travel time along the ray propagation according to ferma principle, that is, the shortest path of two-point propagation time in viscoelastic uniform medium is the straight line connecting two points. The cross hole ultrasonic observation system shown in figure 6 can calculate the extrusion thickness of the pile by using the relationship between the initial arrival time of the horizontal transmission wave of ultrasonic, the longitudinal wave velocity V2 of concrete members and the longitudinal wave velocity V1 of soil around the pile.
2.3. Core pulling method
At present, core pulling method is the most commonly used method for pile foundation detection. The specific operation method is to core the pile with hydraulic drilling rig, and judge the pile length, concrete strength and pile integrity according to the state of the core sample. The specific requirements are as follows: (1) for the pile whose diameter is less than 1.2m, the number of core samples can be 1 ~ 2, and when the pile diameter is between 1.2m and 1.6m, the number of core samples should be 2. For pile foundation with pile diameter greater than 1.6m, three core samples shall be taken; (2) if one core sample is taken, sampling shall be conducted within the range of 10cm ~ 15cm from the pile center; when two or more core samples are taken, sampling shall be conducted evenly and symmetrically within the range of 0.15 times pile diameter and 0.25 times pile diameter from the pile center; (3) for end bearing pile, sampling number shall not be less than one.

2.4. Tube wave method
In a borehole filled with liquid, the wave propagating along the axis of the borehole is called tube wave. Tube wave method is to use "tube wave" as the detection physical field in the borehole, and judge the integrity of the pile body according to whether the tube wave is abnormal. Compared with the traditional pile integrity detection method, the pipe wave method has the following advantages: (1) "one pile and one hole", that is, only one hole needs to be reserved on each pile; (2) the pipe wave has the characteristics of strong energy, slow attenuation, and the propagation speed is closely related to the shear wave speed of surrounding rock beside the hole, so the survey results are highly reliable; (3) the pipe wave detection has low requirements for equipment and short detection time, Low cost.
2.5. Layout of test holes
When the cross hole acoustic method is used to detect the length of the support, a drilling hole should be set in the pile body and outside the pile respectively. Li Jian and others have arranged the detection pipes in the pile body and inside the pile respectively to detect the integrity of the support plate on Chaoshan ring expressway. In this project, the detection pipe is not buried in the pile, and the core hole is also used as the pipe A detection tube is embedded between No.1 pile and No.2 pile as the detection tube outside the pile during the acoustic wave test. The specific arrangement is shown in figure 8.

![Figure 8. layout of core pulling hole and detection pipe outside pile](image)

3. Test results of branch length
The project adopts caliper and cross hole acoustic method to detect the support length, in which caliper is used to detect the support length after the expansion of support plate equipment and before concrete pouring, and cross hole acoustic method is used to detect the support length after concrete pouring.

3.1. Testing results of caliper
According to the test results, the maximum and minimum branch length of No.1 pile are 71.54cm and 62.54cm respectively, and the maximum and minimum branch length of No.2 pile are 72.01cm and 61.43cm respectively, which are all less than the design value of 75cm. The reason is analyzed. Because each branch is located at different angles, the angle of the four arms of the caliper is not consistent with the angle of the branch when it is extended, so the measured value is less than the design value.

3.2. Testing results of cross hole acoustic wave method
The profile curves of No. 1 and No. 2 piles are shown in figure 9 and figure 10.
According to the test results, the maximum length of No.1 pile is 86.10cm, the minimum length is 57.80cm, the maximum length of No.2 pile is 89.50cm, the minimum length is 50.90cm, and the maximum length is greater than 75cm required by the design. Due to the dislocation between the upper and lower branches, the minimum length is less than 75cm required by the design.

3.3. Comparison of detection results of branch length
In this project, caliper and cross hole acoustic method are used to detect the branch length, and the detection results are shown in table 1.

Table 1 Comparison of test results of branch length

| Detection mode | Caliper (cm) | Cross hole acoustic method (cm) | Comparison of test results (cm) |
|---------------|-------------|-------------------------------|--------------------------------|
| Pile 1        | Eight Star Branch 1 | 62.97                         | 57.8                           | -5.17                           |
Caliper meter is a kind of testing method of squeezed branch pile cavity size mentioned in the current specification. Its advantages are simple testing method, intuitive and reliable data. Its disadvantages are that it can only detect the cavity size after the hole is formed, and it is not necessary to use caliper meter to detect the support length size after the concrete is poured. The advantages of cross hole acoustic method are that it can detect the support length size after the pile is formed, and its disadvantages are that it needs to bury acoustic measuring pipe in advance, and the number of meters.

According to the need for secondary treatment, the results of treatment have human subjective factors. From the above test results, it can be seen that the test results of caliper and cross hole acoustic method are slightly different. The reason is that each branch has its fixed angle, and the angle deviation between caliper and cross hole acoustic method is all, so the test results are slightly different.

4. Pile integrity test results

The core pulling method and tube wave method are used to test the integrity of the pile.

4.1. Test results of core pulling method

Three core samples were taken from No.1 pile. The concrete core samples were continuous, complete and well cemented. Only a small amount of pores and aggregates were found on the side. The distribution of aggregates was uniform. The fracture surface was consistent. The quality of pile body met the requirements. However, there were 4cm, 5cm and 15cm thick sediments at the bottom of No.1 core sample, No.2 core sample and No.3 core sample respectively. The core pulling results are shown in figure 11.

![Figure 11](image)

Two core samples were taken from No. 2 pile, of which No. 1 core sample had continuous groove at 8.60-9.10m, and a small amount of pores were found at the side; there was continuous groove at 1.30-1.68m, and a small amount of pores were found at the side, and no sediment was found at the bottom of the pile. The results of core pulling are shown in figure12.
4.2. Test results of tube wave method

The existing core pulling hole is used to test the pile quality by tube wave method. The test results of No. 1 pile and No. 2 pile are shown in figure 13 and figure 14.

Figure 13. Pipe wave test results of No.1 pile

Figure 14. Pipe wave test results of No.2 pile

According to the pipe wave test diagram, there is pipe wave virtual phenomenon at the bottom of No.1 pile. According to the pipe wave test mechanism, it can be judged that there is sediment or serious defects at the bottom of No.1 pile, and there is virtual phenomenon at the shaft of No.2 pile, but the virtual degree is not large, so it can be judged that there are light and micro defects at the shaft of No.2 pile.

4.3. Comparison of pile integrity test results

In this project, core pulling method and tube wave method are used to detect the quality of pile body. Core pulling method is a common method to detect the quality of pile body and the thickness of sediment at the bottom of pile. Its advantage is that the detection results are intuitive and reliable. Its disadvantage is that one or more boreholes need to be selected for coring according to the size of pile diameter and the bearing characteristics of pile foundation. There is a phenomenon of porous pile. Tube wave is a new type of pile body. The advantage of the quality detection method is that the pile quality can be detected by burying a drilling hole in the pile body, while the disadvantage is that the detection result processing has human subjective factors. Through the comparison of the two methods, both the core pulling method and the tube wave method can detect the integrity of the pile body. The test results show that there is sediment at the bottom of No. 1 pile and there is slight defect in No. 2 pile. The thickness of sediment at the bottom of the pile detected by the tube wave method is slightly thicker than that by the core pulling method.
5. Concluding remarks
In this paper, caliper, cross hole acoustic method, core pulling method and tube wave method are used to detect squeezed branch and disk pile, and the advantages and disadvantages and applicable conditions of the four detection methods are analyzed. The detection results are compared and analyzed. Caliper and cross hole acoustic method can detect the length of squeezed branch and disk pile, core pulling method and tube wave method can detect the pile quality and sediment thickness, and the detection law is basically the same. The specific data are slightly different. As a new type of pile foundation, the detection methods of the branch cavity, the size of the branch cavity and the quality of the pile body are not perfect. In this paper, the four detection methods of caliper, cross hole acoustic wave method, core pulling method and tube wave method are verified, which provide new ideas and methods for the later detection of the squeezed branch disk pile.

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