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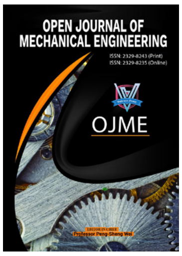

ARTICLE

ANALYSIS ON THE COMPREHENSIVE APPLICATION OF LOW STRAIN REFLECTION WAVE METHOD COMBINED WITH ACOUSTIC TRANSMISSION METHOD OR DRILLING CORE METHOD IN FOUNDATION PILE DETECTION

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ABSTRACT

The low-strain reflected wave method has the characteristics of convenience, rapidity and low cost to detect the integrity of foundation piles, and it occupies a certain proportion in the non-destructive testing of bridge pile foundations. This paper will introduce the principle of the low-strain reflected wave method and explain the comprehensive application analysis of the low-strain reflected wave method combined with the acoustic wave transmission method or the core drilling method through three engineering examples.

KEYWORDS

Bridge engineering, foundation pile detection.

1. INTRODUCTION

In the construction of bridge engineering, the pile foundation is a very important underground hidden project. The pile foundation construction process is complicated. If the construction quality is not properly controlled, quality problems such as segregation, mud inclusion, diameter reduction, and broken piles are prone to occur, which in turn affects the overall construction quality and safety of the bridge structure. Therefore, it is very important to strengthen the pile foundation detection. In the "Guangdong Province Highway Engineering Foundation Pile Inspection Implementation Opinions", the frequency of non-destructive testing is 100%. The low-strain reflected wave method is one of the nondestructive testing techniques. Except for special bridge piers, the detection frequency accounts for 50%. The low-strain reflected wave method has the characteristics of convenience, rapidity, and low cost. However, the limitations of the low-strain reflected wave method are also obvious. Low strain cannot detect multiple defects of foundation piles, and no pile bottom reflection or variable section piles cannot be detected. For these problems, the integrity of the pile cannot be assessed by the low-strain method alone. It must be combined with other methods for testing and comprehensive assessment. This paper will discuss the comprehensive analysis of low-strain method combined with acoustic wave transmission method or core drilling method in foundation pile detection based on my own work experience and engineering examples.

2. THE BASIC PRINCIPLE OF SOUND WAVE TRANSMISSION DETECTION TECHNOLOGY

This paper focuses on the comprehensive analysis of the low-strain reflected wave method combined with the acoustic wave transmission method or the core drilling method to detect the pile foundation. Here is just a brief introduction to the basic principles of the acoustic transmission method and the core drilling method. The principle of low-strain reflected waves will be emphasized. The basic principle of the sound wave transmission detection technology: in the concrete, the high frequency elastic pulse is excited by the ultrasonic pulse emission source. The pulse wave will have different wave characteristics in the process of propagating in the concrete. This fluctuation characteristic is recorded by a high-precision receiving system. By recording the wave characteristics of ultrasonic waves at different heights and different sides, and processing and analyzing, the size, nature and spatial position of the internal defects of the concrete in the inspection area can be judged, and the overall concrete can be evaluated. The compactness parameters of the concrete in the detection area can be obtained according to the initial arrival time of the ultrasonic wave, the frequency change of the wave, the energy attenuation characteristics and the degree of waveform distortion. When there is a damaged or discontinuous interface in the concrete, when the ultrasonic wave reaches the wave impedance interface formed by the defect surface, the reflection and transmission of the wave will occur. When there are serious defects such as holes, honeycombs, and looseness in the concrete, diffraction and scattering of waves will occur. The acoustic energy is attenuated, and the acoustic time of the penetrating acoustic signal will be prolonged. The wave speed and amplitude decrease due to attenuation. The ultrasonic frequency, especially the main frequency, also undergoes a series of changes such as frequency drift due to the attenuation of sound energy. The ultrasonic transmission method is to determine the integrity of the concrete of the pile body according to the changes of the characteristic values of various acoustic parameters propagating in the concrete. This method can more accurately determine the position and size of the defect, as well as determine the nature of the defect preliminarily. It provides theoretical support for determining the quality grade of pile foundation concrete [1].

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3. THE PRINCIPLE OF THE CORE DRILLING METHOD

Principle of core drilling method: core drilling detection method belongs to local damage detection method. The core drilling method is a semi-damaged on-site detection method that directly drills a concrete core sample from the pile body and a certain depth of the core sample of the rock and soil layer at the bottom of the pile for state and strength inspection. Through this method, it can be judged whether the integrity of the pile body, the strength of the concrete, the length of the pile foundation, the sediment at the bottom of the pile and the properties of the bearing layer can meet the design. When the core drilling method is used to detect the pile foundation engineering, it is based on the overall analysis and evaluation of sampling from different parts, which is prone to missed judgments. The shortcoming is also that "replacing the surface with points" leads to "blind areas" in the inspection. At the same time, the inspection will magnify some defect problems such as the soft interlayer problem of the holding layer or the problem of karst holes. And it is difficult to drill through the pile body when detecting slender piles, so it is difficult to judge the quality of the pile foundation [2]. However, compared with other detection methods, the reliability and accuracy are relatively high. The particularity of its detection content is irreplaceable by other methods.

4. PRINCIPLE OF LOW-STRAIN REFLECTED WAVE METHOD

The reflected wave method is based on the one-dimensional wave theory. The pile is assumed to be a one-dimensional elastic continuous rod. Vertical excitation is performed on the top of the pile body to generate elastic waves. The elastic wave propagates down the pile body. When the interface of the pile body has obvious differences (such as pile bottom, broken pile and severe segregation, etc.) or the section of the pile body changes (such as diameter reduction or expansion), the wave impedance will change, resulting in reflected waves. The reflected signal is received by a sensor mounted on the top of the pile. By amplifying, filtering and data processing the received reflected signal, the reflected information from different parts of the pile body can be identified. Using the correspondence between the longitudinal wave velocity, the length of the pile and the reflection time when the wave propagates in the pile body, through the analysis and calculation of the reflection information, the integrity of the concrete of the pile body is judged and the actual length of the pile is checked according to the average wave speed, and the pile body is judged. Defect extent and location. In the analysis of the reflected wave method, we also need to know the wave impedance. Wave impedance is a function of pile cross-sectional area, material density and elastic modulus. The formula is $Z = EA/c = \rho cA$, where Z is the wave impedance of the pile (unit N·s/m); c is the elastic wave velocity of the pile (unit m/s); E is the elastic modulus of the pile (unit N / m^2); ρ is the pile mass density (kg/m^3); ρc is the acoustic characteristic impedance or acoustic impedance rate of the pile (kg/m^3); A is the cross-sectional area of the pile body (unit m^2).

Stress waves are propagating in the pile. When a transient pressure pulse is applied to the pile, a compressive stress wave will be generated on the pile body and the particle in the pile will move. It is stipulated that the downward movement speed of the particle is a positive sign, and the upward movement speed is a negative sign. The pressure of the pile body is positive, and the tension is negative. When the stress wave propagates to the impedance change interface (Z1/Z2), reflected waves and incident waves will be generated. The subscripts i, r, and t represent the incident wave, reflected wave, and transmitted wave, respectively. v and σ are the particle vibration velocity and section stress at the interface, respectively. According to the force balance at the interface, the velocity continuity condition and Newton's third law: vi + vr = vt; A (σ i +σ r) = A2 ·σ t. According to the kinetic energy conservation condition, the following formula can be finally obtained: $n = \frac{Z_1}{Z_2}; F = \frac{1-n}{1+n}$; $T = \frac{2}{1+n}$.

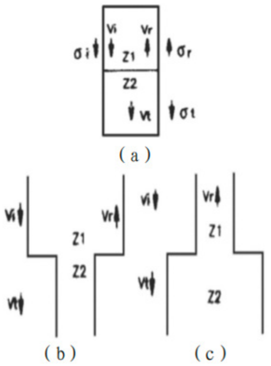

Figure 1: Schematic diagram of wave impedance

F and T are called reflection coefficient and transmission coefficient, respectively. It is completely determined by the ratio n of the wave impedance Z of the two media. n mainly depends on the mass density, wave speed and cross-sectional area of the material. The sudden change of these parameters will cause abrupt value of wave impedance. Therefore, the transmission coefficient T is always positive, that is, the phase of the transmitted wave and the incident wave are always the same. The positive or negative of the reflection coefficient F is related to the size of n. The defects of the combined pile are discussed as follows: (1) The wave impedance is approximately unchanged. The quality and integrity of the pile remained unchanged, as shown in Fig. 1(a). At this time, Z1 ≈ Z2, then n ≈ 1, F ≈ 0, and T ≈ 1. Almost no reflected waves. Almost all stress waves are transmitted through the interface to the lower section. (2) Reduced wave impedance: pile body shrinkage, segregation, fracture, mud inclusion, looseness, cracks, cracks, etc. Its schematic diagram is shown in Figure 1(b). The lower wave impedance becomes smaller. At this time, Z1 > Z2, then n > 1, F < 0, T > 0. The reflected and incident waves are in phase. (3) The wave impedance increases: the diameter of the pile body expands, and the wave impedance of the lower section becomes larger. Its schematic diagram is shown in Figure 1(c). At this time, Z1 < Z2, then n < 1, F > 0, T > 0. The reflected wave is out of phase with the incident wave. It can also be seen from the above analysis that the low-strain reflected wave method has shortcomings. When the cross-sectional area of the pile body is a gradual change type, or when the pile axis is inclined or bent, no reflected wave is generated. When the wave impedance of the pile bottom is similar to the wave impedance of the rock formation at the pile end, the quality of the pile body cannot be judged. Because the arrival time of the reflected signal is related to the location of the reflection. Therefore, the average wave speed and pile length of the wave operation can be obtained under certain conditions. According to the formula: $\Delta T = \frac{2L}{\mathrm{c}}$, it can be obtained: (1) Assuming that the exact pile length L is known, if the reflected wave at the bottom of the pile is obvious, the average wave speed can be calculated from the arrival time of the reflected wave ΔT: $c = \frac{2L}{\Delta T}$. Under certain conditions, the average wave speed represents the quality of the concrete of the pile body. (2) If the wave velocity of the pile concrete is known, the length of the pile can be obtained:

$$L = \frac{c \bullet \Delta T}{2}$$

Since the concrete wave velocity of a pile is affected by many factors, the

Table 1: Relationship between one-dimensional longitudinal wave velocity and concrete strength

Concrete strength grade	C15	C20	C25	C30	C35
Average wave speed/(m/s)	2900	3200	3500	3800	4100
Wave speed range/(m/s)	2 700 ~3 100	3 000 ~3 400	3 300 ~3 700	3 600 ~4 000	3 900 ~4 300

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average wave velocity of each pile on site is different. (3) Knowing the time difference Δtx between the wave velocity c and the reflection of the defect wave, the defect position of the pile body is

$$x = \frac{1}{2000} \bullet \Delta t_x \bullet c$$

[3]. Table 1 below is the relationship between one-dimensional longitudinal wave velocity and concrete strength [4].

5. ANALYSIS OF RELEVANT ENGINEERING EXAMPLES

5.1 Project example 1

The three foundation pile detection principles are described above. The low-strain reflected wave method is specifically analyzed. The direction change of the reflected wave and the incident wave when encountering different wave impedances is expounded. Next, three engineering cases will be used for specific analysis. The first is the pile foundation of a pedestrian bridge project in Foshan, Guangdong. The project overview is to demolish the original pedestrian bridge and build a new one. The owner wants to use the old foundation piles, but he does not know how the integrity of the foundation piles of the old bridge is. The geological conditions from top to bottom are as follows: the exposed layer of plain fill is 0.5-5.6 m thick; the pebbly cohesive soil has been exposed to a thickness of about 0.8-6 m; the exposed layer of fine sand and silt soil is 0.6-4.2 m thick; strong weathering The limestone exposed layer is 1.2-7.1 m thick. The pile numbers of the two piles are 4# and 2#. It is 1.0 m in diameter and is over 28 days old. The pile foundation type is friction pile. The length of the pile and the strength of the pile body are unknown. According to the requirements of the specification, the signal collected on site shall be no less than 2 points. Tested by the low-strain reflected wave method, see Figure 2. The pile foundation type of the 4# pile is friction pile. Z1 > Z2 The reflected and incident waves are in the same direction. It can be seen that the pile bottom signal is still relatively obvious. The pile body has no obvious defect signal. 2# pile is similar. Pile bottom signal is obvious. The pile body has no obvious defect signal. The problem now is not knowing the length of the pile and the strength of the pile body. There is no way to determine the pile length and wave speed. Without basic data, low strain alone cannot detect pile integrity. It is recommended that the owner use the core drilling method for comprehensive judgment. Figure 3 is the core sample of the 4# pile, and Figure 4 is the core sample of the 2# pile. 4# pile core sample: the core sample is continuous and complete. The surface is smooth. Good bonding. Aggregate distribution is uniform. The core sample is long columnar. Fracture anastomosis. The representative value of the compressive strength of the core sample is 35.8 MPa. The pile end concrete is in general contact with the bearing layer. No sediment was seen at the bottom of the pile. The lithology is fine sand with silt. Contains a small amount of clay and silt. The actual pile length detected by the drill core is 11.03 m. 2# pile core sample is continuous and complete. The surface is smooth. Good bonding. The aggregate distribution is basically uniform. The core sample is long columnar. The fracture is basically the same. The representative value of the compressive strength of the core sample is 28.1 MPa. The pile end concrete is in general contact with the bearing layer. No sediment was seen at the bottom of the pile. The lithology is fine sand with silt. Contains a small amount of clay and silt. The actual pile length detected by the drill core is 13.04 m. By drilling the core we know that the pile body has no major defects. This verifies that the bearing layer of the pile bottom and the pile bottom reflection of the reflected wave method are quite consistent. Pile length is known. Then the wave speed of the 4# pile is 3900 m/s. The wave velocity of the 2# pile is 3 500 m/s, which is consistent with the core strength of the core drilling method. Therefore, combining the low-strain reflected wave method and the core-drilling method, it can be determined that both the 4# and 2# piles are Class I piles.

5.2 Project example 2

The second is a bridge in Zengcheng, Guangzhou, Guangdong. The project overview is a small and medium-sized bridge. Geological conditions:

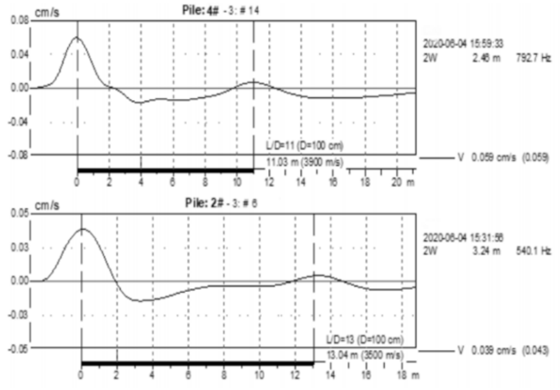

Figure 2: Low strain diagram

Figure 3 Core sample diagram

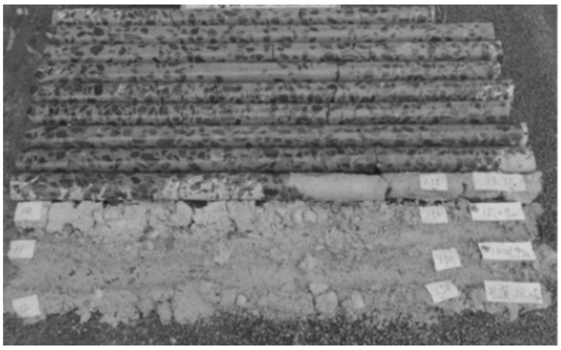

Figure 4: Core sample diagram

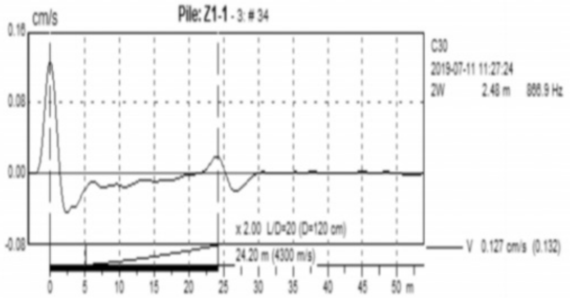

Figure 5: Low strain diagram

Figure 6: Core sample diagram

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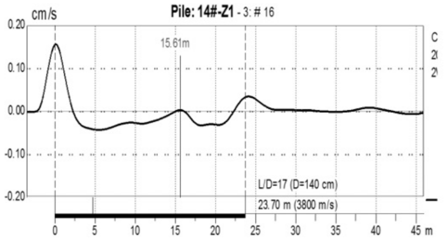

Figure 7: Low strain diagram

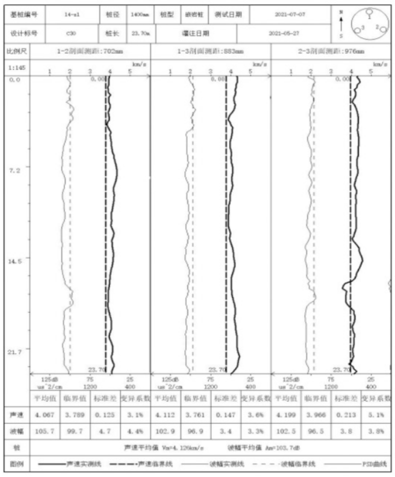

Figure 8: Acoustic map

The original ground to the elevation of 38.526 m is silty clay. Elevation 38.526 m to 31.506 m is gravelly cohesive soil. Elevation 31.026 m to 20.526 m is fully weathered granite. Weathered granite from 20.526 m to 13.526 m elevation. The station number of this pile is Z1-1. The pile construction length is 24.2 m. Its design strength is C30. The diameter is 1.2 m. Age is more than 28 days. The type of pile foundation is rock-socketed pile. Acquire no less than 3 signals as required by the specification. See Figure 6, the pile has obvious co-reflection signal. The wave speed is 4 300 m/s. The pile body has no obvious defect signal. The pile foundation type of this pile is a rock-socketed pile. The same direction signal appears at the bottom of the pile, which may be unsocketed or too large sediment. On-site inquiry learned that the construction process is rotary drilling construction. It is preliminarily judged that the co-reflection signal is pile bottom sediment. Since the thickness of the sediment cannot be measured at low strains, the core drilling method is required for verification (Figure 6). The concrete core sample of the pile body is blue-grey. The core sample is continuous and complete. Good bonding. The surface is smooth. Aggregate distribution is uniform. The core sample is long columnar. Fracture anastomosis. There is no obvious defect in the pile body and the low-strain detection is still consistent. The representative value of the compressive strength of the core sample is 45.6 MPa, which also conforms to the low-strain wave velocity of 4 300 m/s. It also meets the requirements of concrete design strength grade (C30). The average thickness of the pile bottom sediment is 137.5 mm. Does not meet design requirements (≤ 50 mm). The lithology of the pile bearing layer is moderately weathered gneiss granite. The core is short columnar. Its engineering geological properties are consistent with the design. From this process example, it can be analyzed that the strength of the sediment is much smaller than that of the concrete. So Z1 > Z2 the reflected wave and the incident wave have the same direction. However, the low strain cannot quantitatively analyze the thickness of the sediment. It's only possible to know that it's a bug. Even the type of defect is difficult to judge. Comprehensive analysis should be combined with the design of pile type, pile forming technology, geological conditions, and construction conditions [5]. Therefore, if you want to further analyze the type and size of defects, you need to combine other methods for comprehensive judgment.

5.3 Project example 3

This engineering example is a comprehensive application analysis of the low-strain reflected wave method and the acoustic transmission method. Pile foundation of a high-speed project in Guangdong. The project overview is a ramp bridge. The geological condition is that the original ground to the elevation of 36.35 m is silty clay. Elevation 36.35 m to 25.56 m is gravel clay soil. Elevation 25.56 m to 19.81 m is fully weathered granite. The stake is 14#-Z1. The pile construction length is 23.7 m. Its design strength is C30. The design diameter is 1.4 m. The type of foundation pile is friction pile. Acquire more than 3 signals according to specification requirements. Figure 8 and Figure 8 can be. The pile bottom signal is obvious. Taking the second signal in the same direction as the pile bottom, the wave velocity of the pile is 3800 m/s. About 15.6 m from the pile body, there is a reflected wave in the same direction as the incident wave. Judging Z1 > Z2 according to the wave impedance. There may be a loose state of segregation at this site. However, the peaks are not particularly large, indicating that the defects are not particularly large. In order to analyze the defects comprehensively, the sonic transmission method was carried out on the pile. The test results are also quite consistent (Figure 8.) The detection results of the acoustic wave transmission method: the sound speed and amplitude are slightly lower at about 17.0-17.5 m in the 1-2 section and the 2-3 section. There is a phenomenon of segregation and looseness. As can be seen from this engineering example, the defect locations detected by the two methods are somewhat different. This is due to the different types of waves, solid media and boundary conditions between the two methods. In the case of comprehensive analysis, the defect position of the acoustic wave transmission method is generally more accurate.

6. CONCLUSION

Through the discussion and analysis of the above three engineering projects, when the low-strain reflected wave method is used to analyze the integrity of the pile body, although it has the characteristics of convenience and speed, the defects of the low-strain reflected wave method are relatively obvious. Misjudgments can easily occur if you are not careful. More experience should be accumulated in on-site inspection, and sometimes there is no way to judge the integrity of foundation piles by only one method. It is necessary to combine the acoustic wave transmission method or the core drilling method for comprehensive analysis in order to accurately analyze the integrity category of the pile. In actual operation, sometimes the entrusting party does not understand very well. It is clearly entrusted with low-strain reflected wave testing, so why do we need to do sound testing or core drilling? This requires our inspectors to patiently explain to the client the inherent limitations of the low-strain method. At the same time, try to use the low-cost acoustic transmission method for comprehensive analysis.

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