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Applications of Ultrasonic Detection Technology in Bridge Concrete Pile Foundation Detection

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Abstract: In this paper, the application strategy of ultrasonic detection technology in the detection of concrete foundation piles is analyzed using a construction project as an example. It includes a basic overview of the project, an overview of ultrasonic testing technology in bridge concrete pile foundation testing, and an analysis of its practical application in the concrete pile foundation testing of this project. The objective of this analysis is to provide some reference for the application of ultrasonic testing technology and the improvement of the quality of bridge concrete pile foundation testing.

Keywords: Bridge engineering; Concrete pile foundation; Ultrasonic detection technology; Ultrasonic detection principle

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1. Introduction

Ultrasonic detection is the most typical and commonly used technology in the detection of concrete pile foundations in modern bridge projects [1]. It is crucial to understand the basic principles, the parameter relationships, and the main methods involved in this technology, and apply them in concrete pile foundation detection for bridge projects. In this way, its technical advantages can be fully utilized, and accurate detection data can be obtained.

2. Project overview

The construction project of a cable-stayed bridge with three spans and central double cable planes in the form of high and low towers is used as an example in this study. The total length of the bridge project is 459 m, the continuous beam is 4*20 m, and the heights of the towers are 70 m, 192 m, and 110 m, respectively. The overall bridge is a two-way four-lane bridge with a width of 24.5m. The main pile foundation used in this project is a bored pile with a pile diameter of 2800 mm and a length of 20 m. In order to ensure the quality of pile foundation construction, the main piles were inspected through ultrasonic testing technology [2]. Four acoustic tubes were buried inside the pile foundation, and ultrasonic testing was carried out in the fourth week after the completion of the pouring construction. This article is an analysis of the application of ultrasonic detection technology in the detection of pile foundations.

3. Overview of ultrasonic testing technology in bridge concrete pile foundation testing

(1) Basic detection principles

The basic principle of ultrasonic detection technology involves emitting frequency-modulated elastic pulse waves through an ultrasonic pulse source and directing them into the concrete structure of the pile foundation being examined [3]. Then, the wave characteristics of the pulse wave propagating in the concrete are received and recorded accurately through a receiving system. Finally, the internal continuity and integrity of the concrete pile foundation are evaluated after the data are collected and processed.

(2) Parameter relationships

In the process of testing concrete pile foundations through ultrasonic testing technology, in order to ensure the effectiveness of the testing work, staff need to accurately analyze the obtained testing parameters This includes examining the acoustic parameters derived from the ultrasonic testing process and correlating them with concrete strength and other physical characteristics, such as deformation ability, to ensure the reliability and effectiveness of the testing work. The ultrasonic waves in the concrete pile foundation will penetrate the entire cross-section of the concrete pile foundation along the longitudinal axis, and the acoustic parameters fed back after the ultrasonic signal is sent out can scientifically reflect the internal integrity and overall strength of the concrete structure [4]. According to the theory of waves in elastic media, the longitudinal wave is calculated according to the following formula:

$$V_P = \sqrt{\frac{E(1-\mu)}{\rho(1+\mu)(1-2\mu)}} \quad (1)$$

Among them, V_P represents the longitudinal wave speed; E represents the dynamic elastic mode of the propagation medium itself; μ represents the Poisson's ratio of the propagation medium; and ρ represents the density of the propagation medium.

When ultrasonic waves travel through concrete as the propagation medium, a portion of the wave gets absorbed by the material, leading to gradual attenuation during the diffusion process. Consequently, the sound wave exhibits a systematic weakening trend from its emission point outward. The concrete pile's quality significantly affects various acoustic parameters. If the ultrasonic wave experiences attenuation, reflection, or encircling behavior within the concrete pile foundation under testing, it indicates encountering a barrier. Such occurrences suggest the presence of defects within the concrete of the pile foundation [5]. Through the different acoustic parameters obtained during the inspection, scientific judgments can be made on the continuity and integrity of the internal concrete structure of the pile foundation, so as to accurately evaluate whether the pile foundation is safe in practical applications. If the ultrasonic wave exhibits a consistent curve within the concrete of the measured pile foundation, displays a clear main frequency peak, and does not present noticeable irregularities, it signifies that the ultrasonic wave is not obstructed. Consequently, it suggests that the concrete structure within the pile foundation is intact, showing no apparent defects [6].

(3) Main detection methods

Ultrasonic transmission testing is the most typical and commonly used ultrasonic testing method in bridge engineering. In particular, the dual-hole ultrasonic transmission detection method is the most important detection method in on-site detection of concrete pile foundations in modern bridge projects [7]. During the inspection process, the staff needs to embed the acoustic detection tube in the main inspection part of the concrete pile foundation and conduct careful observation through the flat observation method or the oblique observation method. During this process, the staff also needs to reasonably determine the number of acoustic detection tubes to be buried based on the diameter of the pile to be measured. Normally, if the pile diameter of the pile foundation to be tested is ≤ 800 mm, 2 acoustic detection tubes would be needed; if the pile diameter is between 800-2000mm, 3 or more acoustic detection would be needed; if the pile diameter exceeds 2000 mm, 4 or more acoustic tubes would be needed. According to the above standards, combined with the pile diameter parameters of the concrete pile foundation to be tested in this project (2800 mm), so 4 acoustic detection tubes were embedded in it during the inspection. The arrangement of the acoustic detection tubes is shown in **Figure 1**.

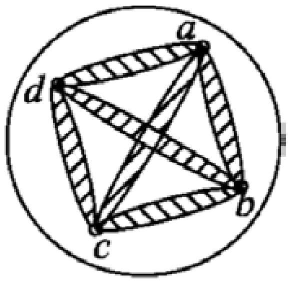

Figure 1. Schematic diagram of the arrangement of acoustic tubes inside the concrete pile foundation to be tested

4. Practical application of ultrasonic testing technology in bridge concrete pile foundation testing

4.1. Test preparation

Scientific and reasonable preparation is a key measure to ensure the smooth implementation of concrete pile testing and the accuracy of testing results. Therefore, the staff must make preparations before the inspection work begins. In this bridge project, the preparation work for ultrasonic testing of concrete pile foundations mainly includes the following aspects:

(1) Technical research

In this process, the staff would need a comprehensive understanding of the fundamental characteristics of the concrete pile foundation in the bridge project. This knowledge serves as the basis for strategically placing four acoustic tubes within the concrete pile foundation, designed in a square layout. Such an arrangement is particularly suitable for implementing the dual-hole ultrasonic transmission detection method [8]. Simultaneously, the staff integrated their prior ultrasonic testing experience and acquired knowledge from exceptional ultrasonic testing and analysis technologies to enhance this layout. They concentrated on exploring effective strategies to eliminate overlaid waves. Eventually, they devised a project-specific on-site ultrasonic testing plan for concrete pile foundations [9].

(2) Test environmental controls

In order to ensure a good on-site testing environment, the curing effect of pile foundations was tested regularly to ensure that it is suitable for ultrasonic testing technology. Afterward, some excavation and pile head breaking operations were carried out, and the surface of the pile head was smoothened to prepare for ultrasonic testing. During this process, the staff also carefully removed the impurities in the acoustic detection tube to prevent them from interfering with the test results and ensure maximum accuracy.

(3) Selection of testing equipment

ZBL-U5600 portable ultrasonic detector was selected as the testing equipment. This equipment is an improved version of the ordinary ultrasonic testing instrument for concrete structures with better versatility. The detection of internal defects, integrity of concrete pile foundations, quality of concrete bonding surfaces, and mechanical properties of concrete were carried out [10]. For ultrasonic transducers, a radial vibration transducer that can achieve longitudinal wave emission was used. Ultrasonic testing was carried out only after proper preparations.

4.2. On-site inspection

In this project, the on-site ultrasonic testing of concrete pile foundations mainly includes the following three aspects: (1) Ensuring that the acoustic tubes are parallel to each other and testing each acoustic tube installed in the concrete pile foundation to be tested. After testing, it was found that although the pre-embedded acoustic tubes were not perfectly parallel, those errors were within the controllable range. Therefore, the tubes were considered parallel. (2) Measuring the distance relationship between each acoustic tube and measuring the actual distance between the acoustic tube and its outer wall in the concrete pile foundation. The distance between the acoustic tubes inside the concrete pile foundation to be measured was 2360 mm. (3) Measuring the actual diameter and wall thickness of the acoustic detection tube. The diameter of the acoustic detection tube used in this project was 57mm and its wall thickness was 3.5 mm. Considering that the thickness of the acoustic tube wall may have a certain impact on the ultrasonic detection data, this data is mainly used in subsequent error analysis during specific detection.

When the ultrasonic detection work officially started, the staff first inspected the flat measurement method. Precise measurements required the simultaneous enhancement of both transmitting and receiving transducers to acquire comprehensive and scientifically sound measurement data. To minimize measurement errors, the staff utilized a level for calibration during simultaneous elevation. Subsequently, to ensure proper wave emission control, the staff made real-time adjustments to the frequency and amplitude according to the specific requirements. Frequency control was primarily managed with the transmitter data, while the amplitude was mainly controlled with acoustic wave monitoring. The acquired instrument monitoring results were used for comparative control. When abnormalities or defects were detected, staff were required to record height data. Following the completion of the initial ultrasonic testing, subsequent testing on the remaining pipelines was conducted through pairwise measurements. The ultrasonic testing data obtained was then transmitted to the presenter to establish a preliminary ultrasonic testing data model. Finally, a reasonable transformation from qualitative analysis to quantitative analysis of ultrasonic detection data is achieved.

4.3. Data analysis

The analyses that were performed in this project included sound velocity data analysis, wave amplitude data analysis, and signal power spectral density (PSD) analysis. The overall quality of the concrete pile foundation was then evaluated based on the results of the analysis. **Table 1** shows some of the data analysis results from the ultrasonic testing of the integrity of concrete pile foundations in this bridge project.

Table 1. Data analysis results from the ultrasonic testing of the integrity of concrete pile foundations in this bridge project

Serial number	Measuring point	Depth	Sound velocity	Duration of sound	Main frequency	Amplitude	PSD
1	200#	17.6 m	3.825 km/s	173.0 ms	41.2 kHz	97.1 μV	5.00W/Hz
2	201#	17.8 m	3.825 km/s	173.0 ms	41.2 kHz	96.4 μV	0.00W/Hz
3	202#	18.0 m	3.804 km/s	174.0 ms	41.2 kHz	96.0 μV	5.00W/Hz
4	203#	18.2 m	3.825 km/s	173.0 ms	43.1 kHz	97.6 μV	5.00W/Hz
5	204#	18.4 m	3.743 km/s	177.0 ms	41.2 kHz	96.5 μV	80.00W/Hz
6	205#	18.6 m	3.704 km/s	179.0 ms	41.2 kHz	93.8 μV	20.00W/Hz
7	206#	18.8 m	3.664 km/s	180.0 ms	37.3 kHz	95.6 μV	5.00W/Hz
8	207#	19.0 m	3.583 km/s	187.0 ms	39.2 kHz	93.4 μV	245.00 W/Hz
9	208#	19.0 m	3.590 km/s	185.0 ms	41.2 kHz	96.3 μV	20.00 W/Hz
10	209#	19.2 m	3.590 km/s	185.0 ms	39.2 kHz	97.9 μV	0.00 W/Hz
11	210#	19.4 m	3.581 km/s	186.0 ms	41.2 kHz	97.2 μV	5.00 W/Hz
12	211#	19.6 m	3.535 km/s	188.0 ms	41.2 kHz	96.7 μV	20.00 W/Hz
13	212#	19.8 m	3.553 km/s	187.0 ms	41.2 kHz	96.5 μV	0.00 W/Hz
14	213#	20.0 m	3.553 km/s	187.0 ms	41.2 kHz	95.4 μV	0.00 W/Hz

From the above data analysis, it can be seen that the ultrasonic sound speed of the pile foundation decreased in the area between 18.8–20.0 m, but the overall decreasing trend was not obvious and did not exceed the limit range of this project. After further analysis, it was found that there was an amplitude attenuation area inside the pile foundation, and the amplitude in this area was slightly higher than the standard attenuation amplitude (6 dB) obtained in the flat measurement. This indicates that there were slight quality defects inside the concrete pile foundation, but they were within a controllable range and did not affect its application effect.

5. Conclusion

In conclusion, ultrasonic detection technology stands as a popular method for assessing the integrity of concrete pile foundations in modern bridge projects. Its numerous advantages, including easy operation, high efficiency, accuracy, and minimal damage, have garnered significant attention. Therefore, this technology should be applied wisely in accordance with the prevailing conditions to attain precise inspection results.

Disclosure statement

The author declares no conflict of interest.

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