Journal of Architectural Research and Development, 2024, Volume 8, Issue 1
http://ojs.bbwpublisher.com/index.php/JARD
Online ISSN: 2208-3537
Print ISSN: 2208-3529

Acoustic Non-Destructive Testing Technology in Concrete Bridge Inspection and Pile Foundation Detection

Wei Fu*

China Merchants Chongqing Highway Engineering Testing Center Co., Ltd., Chongqing 400060, China

****Corresponding author:*** Wei Fu, sunmingjia83123@163.com

Copyright: © 2024 Author(s). This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY 4.0), permitting distribution and reproduction in any medium, provided the original work is cited.

Abstract: This article takes the actual construction project of a certain concrete bridge project as an example to analyze the application of acoustic non-destructive testing technology in its detection. It includes an overview of a certain bridge construction project studied and acoustic non-destructive testing technology and the application of acoustic non-destructive testing technology in actual testing. This analysis hopes to provide some guidelines for acoustic non-destructive testing of modern concrete bridge projects.

Keywords: Concrete bridge; Bridge detection; Acoustic detection; Non-destructive testing technology

Online publication: January 23, 2024

1. Foreword

In inspecting concrete bridge projects through acoustic non-destructive testing technology, inspectors should first clarify the basic connotation of this technology and its application principles, then rationally apply this technology based on the actual engineering overview. In this way, the acoustic non-destructive testing technology can maximize its application advantages in concrete bridge testing, thereby achieving scientific and accurate acquisition of testing results and providing a scientific inspection of the construction quality of concrete bridges and a valid reference for the effective implementation of improvement work.

2. Project overview

The total length of a road bridge is 550 m, its top width is 22.5 m, and its bottom width is 11.5 m. During the closing and tensioning construction of the concrete continuous box girder of the bridge project, it was discovered that there were multiple cracks in the concrete floor at the mid-span and side span of some bridge piers, which were still not resolved after multiple reinforcements. In order to effectively ensure the overall construction quality of the bridge project, the project team and construction unit decided to conduct quality inspection using acoustic non-destructive testing technology. This article is an analysis of the application of this technology in the inspection of this concrete bridge project.

3. Overview of acoustic non-destructive testing technology

3.1. Basic connotation

Acoustic non-destructive testing technology is a method to detect the concrete structure of bridge engineering through the different propagation characteristics of sound waves in other media. Regarding the current inspection of concrete structures in bridge projects, the most commonly used acoustic non-destructive inspection methods are reflection inspection and transmission inspection. Among them, the acoustic wave reflection detection method uses a single pulse signal to detect flaws in the concrete structure of bridge engineering. Since there are many signal interference factors and limited detection depth, it is only suitable for surface flaw detection of bridge concrete structures and shallow structural crack detection. Compared with the acoustic wave reflection detection method, the acoustic wave transmission detection method has more significant advantages in penetrating concrete structural materials. By applying this non-destructive testing technology, the quality of the internal concrete structure in bridge projects can be scientifically and accurately detected [1]. Therefore, acoustic transmission testing is the most commonly used method in today's acoustic non-destructive testing of concrete structures in bridge projects.

3.2. Application principle

Sound waves are a type of elastic pulse wave. In concrete elastomer structures, the fluctuations generated when sound waves pass through can be regarded as the manifestation of the superposition of transverse waves and longitudinal waves. Usually, if the bridge's concrete structure is dense enough and has no cracks, the propagation of sound waves will be consistent, and there will be no large fluctuations. However, if there are cracks or cavity defects in the concrete structure, the propagation medium of sound waves will change. At this time, its propagation speed and propagation rules will be significantly different. When sound waves reach the interface of other media, their propagation speed and energy intensity will change. Under such circumstances, the sound wave propagation rules received by the sound wave receiving system from different density parts of the concrete structure will also show apparent differences. In today's acoustic non-destructive testing of concrete structures in bridge engineering, ultrasonic and impact-echo are the two most commonly used sound waves, which have strong similarities. However, impact-echo is only used in detection compared to ultrasonic waves. A test surface is required, and the sound waves applied in it are also lower, which can effectively prevent clutter interference and further improve the accuracy of the test results. With these advantages, the impact-echo non-destructive testing method has been widely used in the concrete testing of modern bridge projects. When using this method to conduct non-destructive testing of concrete structures in bridge projects, inspectors should first make a scientific determination of the quantitative relationship between wave speed and concrete strength. As sound waves are the product of the complex superposition of transverse waves and longitudinal waves, the inspector should first determine the wave speed of the concrete structure in the bridge project when determining the quantitative relationship between the two. The calculation formula is as follows:

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

$$v_s = \sqrt{\frac{\mu}{\rho}} \quad (2)$$

Among them, v_P represents the propagation speed of longitudinal waves in the concrete structure of the bridge; E represents the elastic modulus of the concrete structure material of the bridge; v_s represents the propagation speed of transverse waves in the concrete structure of the bridge; σ represents the Poisson's ratio of the bridge engineering concrete structure material itself; μ represents the material density of the bridge engineering concrete structure; ρ represents the shear modulus of the bridge engineering concrete structure material [2]. Usually, the relationship between the compressive strength of a concrete structure and the longitudinal wave velocity in it is as follows:

$$R_b = av_p^b \tag{3}$$

Among them, R_b represents the compressive strength of the concrete structure itself; a and b represent echo fitting parameters. The value range of a is between 0.25–0.40; the value range of b is between 3.00–3.50. The propagation speed of longitudinal waves in concrete structures of different strengths can be calculated through formula (3).

4. Analysis of the application of acoustic non-destructive testing technology in concrete bridge testing

For the concrete structure in this bridge project, during the specific acoustic non-destructive testing, the Poisson's ratio during the wave speed calculation process was 0.18, and the density of the concrete material in the structure was 2610 kg/m^3. According to the concrete structure quality testing standards determined in the design of this project, when the concrete strength is between C30–C80, the longitudinal wave speed should reach between 3.7–4.8 km/s; and when the concrete strength is between C15–C25 time, the longitudinal wave speed should reach 3.3 km/s and above, otherwise it indicates that the strength of the concrete structure is insufficient. If the wave speed distribution is not uniform enough, it suggests that there are quality defects inside the concrete structure, such as cracks, holes, etc. The following is an analysis of the application of acoustic non-destructive testing technology in the quality inspection of concrete structures in this bridge project.

4.1. Application of acoustic non-destructive testing technology

During the acoustic non-destructive testing of the concrete structure of this bridge project, the inspectors mainly conducted acoustic non-destructive testing of the concrete quality at the top, bottom, left, and right web locations. During the testing process, all instruments and equipment should be operated strictly by the requirements specified in the instructions. At the same time, the acoustic non-destructive testing results of different testing parts should be comprehensively analyzed to evaluate the quality of the concrete structure in the bridge project [3].

In evaluating acoustic non-destructive testing results, the testing personnel must compare the wave speed parameters obtained through the impact-echo non-destructive testing method with the specified standard values of wave speed parameters. If the actual wave speed parameters can meet or exceed the specified standard values, and the wave speed has good uniformity, it means that the transmission effect of sound waves in the concrete structure is good, and there are no apparent defects inside the structure; otherwise, it means that there are quality defects inside the concrete structure, and the construction unit needs to take into account the actual situation for further processing [4]. **Table 1** shows the basic performance testing standards for acoustic non-destructive testing of concrete structures in this bridge project.

Table 1. Basic performance testing standards for acoustic non-destructive testing of concrete structures in this bridge project

Serial number	Grade	Elastic modulus	Lowest wave speed	Serial number	Grade	Elastic modulus	Lowest wave speed
1	C12	22.0 GPa	3.3 km/s	8	C50	34.5 GPa	4.3 km/s
2	C20	25.5 GPa	3.3 km/s	9	C55	35.8 GPa	4.4 km/s
3	C25	28.1 GPa	3.3 km/s	10	C60	36.1 GPa	4.5 km/s
4	C30	30.3 GPa	3.7 km/s	11	C65	36.5 GPa	4.6 km/s
5	C35	31.5 GPa	3.9 km/s	12	C70	37.2 GPa	4.7 km/s
6	C40	32.6 GPa	4.1 km/s	13	C75	37.6 GPa	4.8 km/s
7	C40	33.7 GPa	4.2 km/s	14	C80	38.1 GPa	4.8 km/s

For the four concrete structures that are subject to acoustic non-destructive testing in this bridge project, their strength standards in engineering design are as follows:

(1) For the roof of the bridge, the concrete structural strength should reach C50 and above.

(2) For the base plate of the bridge, the concrete structural strength should reach C40 and above.

(3) For the left and right webs of the bridge, the concrete structural strength should reach C50 and above.

According to the above concrete structure strength design standards, during specific acoustic non-destructive testing, inspectors should strictly follow the basic performance testing standards and engineering design standards of concrete structures to conduct strength testing and internal quality testing based on wave velocity distribution, to obtain sufficiently scientific and reasonable test results [5].

4.2. Acoustic non-destructive testing results analysis

After conducting impact-echo non-destructive testing on the concrete structure in this bridge project following the above testing content and testing standards, the testing results and analysis obtained are as follows:

Firstly, we conducts an analysis of the acoustic non-destructive testing results of the bridge roof. The non-destructive testing area of the roof of this bridge project is about 1350 m^3. A study of the results obtained by the impact-echo non-destructive testing shows that within the sound wave non-destructive testing area, the average propagation speed of sound waves in the concrete structure is 4.72 km/s. The overall strength performance of the concrete structure has reached the established strength standard of C50 concrete. In the middle of the roof, the impact-echo velocity inside the concrete can reach 4.85 km/s, indicating that the strength performance of the concrete structure here has reached the established strength standard of C60 concrete [6]. At the same time, analysis of the test results found that the wave velocity distribution of the concrete on the bridge's roof was relatively uniform, indicating that the overall concrete structure was complete with no excessive internal defects. Although the detection found that the wave speed at the two wings of the roof is relatively low, with a fluctuation range between 4.1–4.4 km/s and a coverage area between 1.5–2.0 m, the main load-bearing part of the roof of the bridge project is in the central area. During construction and application, the two wings have no excessive bearing capacity requirements. Hence, the concrete strength in this part fully meets the design standards of this bridge project [7].

The second step is the analysis of the acoustic non-destructive testing results of the bridge floor. The non-destructive testing area of the base plate of this bridge project is about 550 m^2. Analysis of the results obtained by the impact-echo non-destructive testing shows that within the acoustic non-destructive testing area, the average propagation speed of sound waves in the concrete structure is 4.2 km/s. The overall strength performance of the concrete structure is within the established strength standard range of C40–C50 concrete, and the wave speed distribution is uniform [8]. However, during the actual detection, it was found that the wave speed of the impact-echo fluctuated greatly inside the concrete structure in the detection area. Only the wave speed in the middle part was 4.34 km/s, and the wave speed in the other half of the area was 4.14 km/s. Based on this situation, the inspectors determined that the strength of the concrete structure at the bottom plate of the bridge project was relatively low, and after the test, it was covered and cured. After treatment, acoustic non-destructive testing was performed again. In the latter inspection, it was found that the concrete strength of all parts of the bridge floor reached the design standards of this project [9].

Next, we analyze the acoustic non-destructive testing results of the left web of the bridge. The non-destructive testing area of the left web of this bridge project is about 332 $m^{2.}$ Analysis of the results obtained through impact-echo non-destructive testing shows that within the acoustic non-destructive testing area, the average propagation speed of sound waves in the concrete structure is 4.52 km/s, and the overall concrete structure strength performance has reached the established strength standard of C50 concrete. At the same time, inspection found that the wave speed distribution of the structure was very uniform, with no apparent low wave speed areas. It can be judged from this that the strength of the concrete structure of the left web in the bridge project fully meets the engineering design standards, and there are no obvious quality defects such as cracks and voids.

Lastly, there is the analysis of the acoustic non-destructive testing results of the right web of the bridge. The non-destructive testing area of the right web of the bridge project is also about 332 m^2. The analysis of the results obtained by the impact-echo non-destructive testing shows that within the sound wave non-destructive testing area, the average propagation speed of sound waves in the concrete structure is 4.65 km/s, the overall concrete structure strength performance has reached the established strength standard of C60 concrete [10]. At the same time, the wave speed distribution is relatively uniform in most locations in the structure. Only a low-sound speed area appears in the upper part. Its width is about 1.1 m, and the average wave speed in the area is 4.30 km/s. Due to the area occupied by the low wave speed zone accounts for a small proportion of the overall concrete structure, its structural strength has reached the established strength standard of C50 concrete. The wave speed distribution in the low wave speed zone is also relatively uniform, indicating its strength. It is slightly lower than other parts, but the internal quality of the structure is defective, so the concrete structure was also judged to be qualified in this acoustic non-destructive inspection.

5. Conclusion

In summary, in the construction process of modern bridge projects, non-destructive testing of concrete structures is a vital testing technology measure. In specific non-destructive testing work, acoustic non-destructive testing technology based on impact-echo is the most suitable. Through the reasonable application of this technology, inspectors can not only make a proper inspection of the strength of the concrete structure in the bridge project but also timely discover the quality defects existing within the structure, thereby providing reinforcement and improvement of the concrete structure for subsequent bridge projects and a strong reference basis for quality issue management. Based on this, inspectors should combine the actual project profile and design standards to detect the concrete structure through impact-echo non-destructive testing technology in the specific non-destructive testing of bridge projects. Only in this way can we obtain scientific test results to provide strong support for the construction quality assurance of the concrete structure of the overall bridge project.

Disclosure statement

The author declares no conflict of interest.

References

[1] Guo L, 2023, Overview of Non-Destructive Testing Technology in Road and Bridge Inspection. Stone, 2023(07): 105–107.

[2] Wang X, 2022, Application Analysis of Non-Destructive Testing Technology in Bridge Inspection. Northern Architecture, 2022(06): 26–30.

[3] Chen Z, 2022, Application of Acoustic Wave Detection Technology in Concrete Bridge Detection. Engineering Construction and Design, 2022(21): 180–182.

[4] Zhu J, 2022, Analysis and Research on Applying Acoustic Wave Detection Technology in Concrete Bridge Detection. Science and Technology Information, 2022(20): 84–87.

[5] Zeng Y, 2022, Application of Acoustic Wave Detection Technology in Concrete Bridge Detection. Transportation Manager World, 2022(13): 97–99.

[6] Yu C, 2023, Application of Acoustic CT in Quality Inspection of Concrete Bridges. Transportation World, 2023(14): 153–155.

[7] Cai Q, Wang T, 2023, Experimental Research on Testing the Stress of Compressed Concrete Using Ultrasonic Method. Highway Transportation Science and Technology, 40(5): 50–57.

[8] Ma B, 2022, Research on Monitoring and Positioning Early Structural Cracks in Concrete Bridges Based on Coda Wave Interference, dissertation, China University of Mining and Technology.

[9] Zhang X, 2021, Research on Applying Elastic Wave CT Technology in Non-Destructive Testing of Bridge Concrete Structures. Transportation World, 2021(21): 66–67.

[10] Zhang M, 2023, Application of Acoustic Transmission Method in Test Inspection of Road and Bridge Pile Foundation Projects. Architectural Development, 7(3): 40–42.

Publisher's note

Bio-Byword Scientific Publishing remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.