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Concrete Structure Ultrasonic Testing Technology Research Latest Progress and Development Trend

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ABSTRACT: Many concrete structures in use have safety problems due to material deterioration, actual construction defects, structural damage, etc. Therefore, nondestructive testing is required to determine the presence of defects. Ultrasonic technology is an important tool in nondestructive testing, which can detect defects in concrete and be combined with other methods or models to make it more accurate. At present, ultrasonic inspection technology has been more research at home and abroad, both in theory and in engineering, and there has been great progress. This paper summarizes the latest progress of ultrasonic inspection technology for concrete structures at home and abroad respectively, and points out the future development trend.

1. INTRODUCTION

Concrete is one of the most commonly used building materials today, mainly for bridges, tunnels, walls, and shells. In the initial stage of concrete, many quality defects, such as cracks and pores, often appear. Resulting in poor performance of concrete, which can cause accidents in serious cases, resulting in casualties and economic losses. In order to improve the performance of concrete, scholars at home and abroad have conducted a lot of research on concrete. A series of new types of concrete such as doped multi-walled carbon nanotubes [1], cellulose fibers [2], absorbent polymers [3], and crystalline admixtures [4] have emerged to make up for the defects of concrete in various aspects.

After continuous development, ultrasonic inspection technology is not only becoming more and more mature, but also more and more widely used. Scholars at home and abroad have used ultrasonic testing technology in a large number of fields, such as conducting food inspection [5], non-destructive testing of wood [6], and main fatigue testing of steel [7]. Ultrasonic techniques are used to measure concrete without altering its structure and other functions, and to derive a series of properties of concrete, such as permeability, frost and corrosion resistance, based on the interconnection between the test results and its own properties. To determine whether its strength meets the design requirements and ensure its safety in use.

This paper briefly introduces the basic principles of the research on ultrasonic testing technology for concrete structures and its advantages and disadvantages, summarizes the ultrasonic testing technology for concrete structures at home and abroad in recent years, and discusses the contents of various studies. Through the current situation of domestic and foreign research, the trend of research on ultrasonic inspection technology for concrete structures is being explored. And the application of ultrasonic inspection technology in concrete structures is summarized.

2. ULTRASONIC INSPECTION TECHNOLOGY

2.1. The basic principle of ultrasonic detection

Ultrasonic inspection is mainly a nondestructive testing method that uses the propagation characteristics of ultrasonic waves in the material being inspected to analyze the reflected, projected, or scattered waves received to determine the defects or characteristics of the material being inspected. The general steps of ultrasonic detection of internal defects in concrete members are shown in Figure 1.

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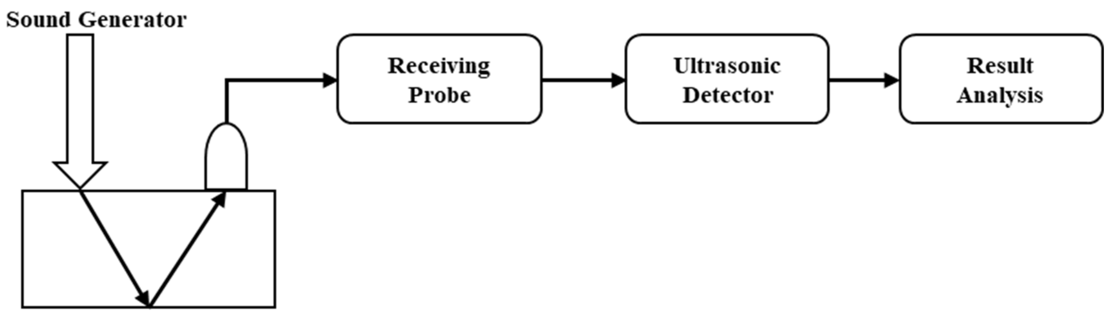

Fig 1. Ultrasonic detection of concrete defects flow chart

The most basic method in ultrasonic inspection techniques is the wave velocity method. The wave velocity method refers to the fact that the speed of travel of a wave through a material is closely related to the basic properties of that material [8]. To facilitate work as well as research, a large number of formulas for ultrasound in infinite media have been summarized.

If in an infinite solid medium, the longitudinal wave sound velocity is

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

If in an infinite solid medium, the transverse wave sound velocity is

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

If in an infinite solid medium, the surface wave sound velocity is

$$V_R = \frac{0.87+1.12\mu}{1+\mu}\sqrt{\frac{G}{\rho}} \quad (3)$$

Where, V_L - ultrasonic longitudinal wave velocity (m/s); V_S - ultrasonic transverse wave velocity (m/s); V_R - ultrasonic surface wave velocity (m/s); E - modulus of elasticity (MPa); ρ - the material density of the medium; μ - Poisson's ratio of the medium.

Of course, there is no such thing as an infinite medium in practice, but the above equation can be used for calculations when the dimensions of the medium are large enough compared to the propagated wavelength[9].

2.2. Advantages and disadvantages of ultrasonic inspection technology

Ultrasonic inspection has a series of advantages, such as a large detection thickness, high sensitivity, high speed, low cost, no damage, and the ability to locate and quantify material defects. The four main points include the following: First, a wide range of applications, the measurement results of various metals or non-metals are highly accurate; second, strong penetration performance, able to get accurate data in the detection process; third, high accuracy and resolution of defect identification, the data results obtained are more accurate; fourth, high detection efficiency, ultrasonic detection equipment is small, easy to carry, and can work at any time[10]. However, the use of ultrasonic inspection methods for defect detection does not visually reflect the defects, and the technical difficulty of detection is susceptible to the influence of subjective and objective factors. It is necessary to have extensive experience to identify the various defect categories.

3. RECENT ADVANCES IN ULTRASONIC INSPECTION TECHNOLOGY FOR CONCRETE STRUCTURES

3.1. Current status of domestic research

In terms of ultrasonic detection technology for concrete structures, domestic scholars have conducted various studies. Zhao Jun et al. [11] used concrete with strength grade C40 and cured for 28 d after pouring, and reserved a 50 mm × 50 mm cavity defect in the joint surface of the assembled column. Through ultrasonic testing technology and the study of experimental results, the ultrasonic data in the specimen and its waveform profile were obtained, the crack distribution pattern in the specimen was studied, and an effective calculation model for predicting the size of the cavity was proposed. However, its calculation model is relatively simple and there are differences between the data and the actual, and the calculation model can be further improved. Wei Zhe [12] demonstrated the high accuracy of ultrasonic wave velocity measurement inside concrete using ultrasonic methods in the test of actual size reinforced concrete members, and the compressive strength values of concrete estimated by these two methods are closer to the actual measured values. Zhang Hailong et al. [13] used an ultrasonic flaw detection technique to study the characterization of the change in porosity inside concrete. In order to accelerate the aging of concrete, multiple freeze-thaw cycles were performed. The wave velocity of the specimens was measured using ultrasonic inspection techniques and combined with T2 spectra to analyze the changes in the internal porosity of concrete. It was shown that the increase in the number of freeze-thaw cycles showed an exponential relationship with pore development, so it is practical to characterize it using ultrasonic detection techniques.

In addition, many scholars have also conducted a lot of research on it in the last two years. Shao, Huajian et al. [14] designed four concrete specimens with different strengths, C20, C30, C40, and C50, respectively. The wave velocity and amplitude of the specimens were measured using ultrasonic detection techniques, as well as the wave velocity and amplitude under specific wet and dry cycling the wave velocity and amplitude of the specimens were measured under specific wet and dry cycles, and their variation characteristics and patterns were analyzed. Although the variation of wave velocity indicates that defects such as microcracks appear inside the concrete, the variation of wave amplitude indicates that the compactness of concrete increases after wet and dry cycles. Therefore, the overall compressive and tensile strengths of different strength classes of concrete showed a trend of increasing and then decreasing after several dry and wet cycles. Xiao Shuaipeng et al. [15] used C25 and C40 concrete and kept the experimental environment moderately constant, and conducted thermal fatigue tests on concrete in the temperature range of 20°C, 30°C, and 40°C. Through ultrasonic nondestructive testing techniques, it was concluded that the ultrasonic velocity showed a decreasing trend, indicating an increase in internal crack defects in concrete. The results showed that the porosity of C40 concrete was less than that of C25 concrete, but the relative variation value of porosity was greater for C40 concrete. Liu Jianzhen et al. [16] investigated the relationship between the surface roughness of concrete and the time domain signal and frequency integral of ultrasonic waves. Through ultrasonic testing of concrete samples with three different roughnesses, a positive correlation was found between surface roughness and the time-domain signal versus frequency integral of ultrasonic waves. The findings of this study can lay the foundation for quality monitoring and evaluation of bonded concrete structures. Huang, Hao [17] used equation (4~6) the scattering attenuation technique of ultrasonic waves to conduct a comprehensive inspection of the concrete interior and complete detection of its internal structural defects. It was found that the use of ultrasonic detection technology can better detect different types of defects in the three frequency bands and can more accurately detect concrete defects in complex situations. Xu Weifeng [18] introduced three ultrasonic detection methods, including the planar detection method, the pre-buried sound pipe detection method and the hybrid detection method. Among them, the plane detection method generally has two methods, the radial pair measurement method and axial oblique measurement method, as shown in Figure 2; pre-buried sonic pipe detection method generally also has two methods, pre-buried pipe in the pair measurement method and pre-buried pipe in the oblique measurement method; mixed detection method that is, the simultaneous use of the pair measurement method and oblique measurement method to improve the detection accuracy.

$$\eta = \begin{cases} xy^{-1} \\ xyz^2\ \beta \geq y \\ xy^3z^4 \end{cases} \quad (4)$$

$$\Delta A - \frac{1}{k_0^2} - \frac{A}{p^2} + A\frac{p}{p^{\varepsilon}} = 0 \quad (5)$$

$$\Delta A - \frac{1}{k_0^2}\frac{p}{p^2} - 2k_0^{r-1}\frac{1}{p}(-\Delta A)^{\frac{r}{2}}A + 2pk_0^r \tan\left(\frac{r\pi}{2}\right)(-\Delta A)^{\frac{r+1}{2}} = 0 \quad (6)$$

Where, η - scattering coefficient value; x - fixed parameter values; y - defect size range; z - frequency of sound waves; β - Wavelength of sound waves; A - pressure value of ultrasound; k_0 - propagation speed of ultrasonic waves; r - attenuation coefficient; ε - Ratio of the range of impurities to the length of the sound wave; p - specific values when scattering occurs.

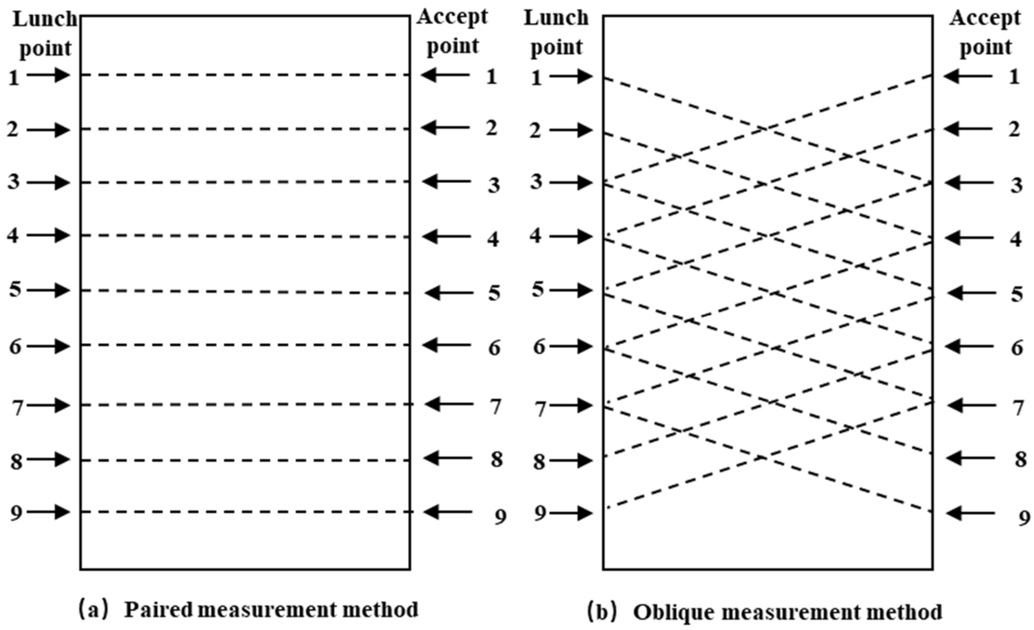

Fig 2. Schematic diagram of ultrasonic plane detection method

3.2. Currennt status of foreign research

In terms of ultrasonic inspection techniques for concrete structures, foreign scholars have conducted various studies. Maryam et al. [19] used ultrasonic and other nondestructive testing for two types of transit pads, carbon fiber reinforced concrete transit pads and plain concrete transit pads. The ultrasonic testing showed that the plain concrete transit mat degraded faster than the carbon fiber reinforced concrete transit mat. Rafaella et al. [20] used cross-correlation function for feature extraction of ultrasonic test data to evaluate the stress state of concrete specimens when subjected to compressive loading. The cross-correlation function is a tool used to assess the similarity between two data series. Cristiano et al. [21] examined the compactness of historical concrete of ancient buildings by means of ultrasonic and other testing methods. The test results showed good reproducibility and provided a method for the conservation management of historic concrete buildings of ancient architecture. Babar et al. [22] used an ultrasonic testing method to detect the porosity variation of fibrous concrete. The results showed that the ultrasonic pulse sound velocity values decreased with increasing fiber content, indicating that the homogenization of fiber concrete mixes may decrease. And the rate of decrease in ultrasonic pulse sound velocity was inversely proportional to the increase in fiber volume. Firas et al. [23] investigated the effect of high temperatures on the performance of lightweight geopolymer concrete with fly ash-glass powder mixes. The correlation between temperature, ultrasonic pulse sound velocity and compressive strength of lightweight concrete was investigated using ultrasonic testing techniques. Shuvo et al. [24] investigated the effect of coarse aggregate particle size and admixture on various aspects of concrete properties and tested them by non-destructive testing techniques such as ultrasonic testing techniques. The study showed that 45% of the recycled concrete aggregates had low ultrasonic pulse velocity values at days 7, 28, and 56. Chi et al. [25] used ultrasonic pulse velocity detection technique for slag cement mortar and retrograde nondestructive evaluation. And summarized a series of a large number of empirical equations between different specific types of velocity and concrete strength, as shown in Table 1. Ryulri et al. [26] studied and established a 64-channel non-contact ultrasonic freeze-thaw damage evaluation system, and proposed a concrete damage evaluation algorithm based on leakage ultrasonic velocity. The effectiveness of the proposed system and algorithm was verified by numerical analysis and experiments for different freeze-thaw damage levels.

Table 1. Empirical equation of concrete strength fc and wave velocity V_P

Author	Compressive strength range	Expression Type	Strength prediction model	Correlation coefficient (R^2)
Bogas et al.[27]	25-90MPa (7-28 days)	Power Function	$f_c = (\frac{V_P}{K_u \cdot \rho^{0.5}})^{2/3}$	R^2=0.85
Biswas et al.[28]	40-75MPa (7-28 days)	Exponential Functions	$f_c = 27.87 \cdot e^{0.000198 \cdot V_P}$	R^2=0.79
Najim[29]	25-50MPa (28 days)	Linear Equations	$f_c = 0.0136 \cdot V_P - 21.34$	R^2=0.70
Trtnik et al.[30]	0-50MPa (1-7 days)	Exponential Functions	$f_c = 0.0854 \cdot e^{1.2882 \cdot V_P}$	R^2=0.64
Demirboga et al.[31]	2-55MPa (3-120 days)	Exponential Functions	$f_c = 0.0049 \cdot e^{0.0021 \cdot V_P}$	R^2=0.96
Le et al.[32]	25-35MPa (7-91 days)	Exponential Functions	$f_c = 1.82 \cdot e^{0.0007 \cdot V_P}$	R^2=0.94
Turkmen et al.[33]	5-50MPa (3-90 days)	Exponential Functions	$f_c = 0.0301 \cdot e^{0.0017 \cdot V_P}$	R^2=0.94

4. CONCLUSION AND OUTLOOK

Ultrasonic inspection technology has a wide range of applications in the field of nondestructive testing of concrete, which can effectively reflect the cavities, cracks, and corrosion inside the concrete through the detection of acoustic properties such as wave velocity [34]. The structural health of concrete is detected without affecting the concrete structure. In addition, the physical properties of concrete can be effectively measured by ultrasound, which has a great effect on the safety of concrete structures. Ultrasonic testing also has a wide range of applications, including a variety of metallic materials, non-metallic materials and composite materials.

However, there are still some problems with ultrasonic concrete inspection technology, such as the inability to accurately discern the type of defects inside the concrete, the location and size of the distribution area, etc. [35]. Therefore, it is expected that the future development trend of concrete ultrasonic testing technology is as follows:

(1) In-depth research and development of multi-scale concrete model ultrasonic testing methods, not only allow the concrete simulation for the aggregate and cement mortar to be composed of two media model, but also take into account the actual role of microscopic pores, cracks, the establishment of a multi-scale concrete models.

(2) The establishment of different concrete strength, different kinds of defects in the standard wave database, testers can be based on test results directly determine the type of defects, used to predict the impact of defects for concrete.

(3) Further research on ultrasonic detection of the size of the internal pore area of concrete, the use of higher resolution ultrasonic detection methods for detection, and improving the calculation model of the internal pores of concrete. Improving the prediction accuracy of the pore area inside the concrete.

(4) Research and development of matching equipment and procedures with an ultrasonic detector, which can predict the evolution trend of the internal structure of concrete while detecting it, and real-time monitoring to achieve the role of advance prediction and further improve the safety of concrete structures.

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