

# A Review of Research on Detection Methods for Internal Defects in Concrete

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## Abstract

**This article introduces the commonly used detection methods for internal defects in concrete; A review was conducted on the research progress of impact echo method and infrared thermal imaging method. The principles of impact echo method and infrared thermal imaging method were studied, and the problems existing in existing methods were pointed out. The results indicate that the detection methods for internal defects in concrete have made certain progress in both theoretical research and engineering applications. However, further improvement and refinement are still needed. The most important step in the improvement plan is to determine the damage situation of reinforced concrete components. From multiple perspectives, non-destructive testing is undoubtedly the main development object for detecting concrete damage in the future.**

## Keywords

**Detection; Impact Echo Method; Infrared Thermal Imaging Method; Concrete.**

## 1. Introduction

Concrete is currently the most widely used and widely used building material in the world. It plays an irreplaceable role in the construction fields of construction engineering, highway engineering, bridge and tunnel engineering, water conservancy, and special structures. However, due to design defects, lax construction quality control, natural disasters, or structural aging, concrete structures inevitably suffer from damages such as cracks, honeycombs, holes, wear, and erosion during use, thereby endangering the safety of the entire structure. Therefore, achieving rapid and large-scale detection of concrete defects has become a global concern and unresolved issue. At present, the most common concrete testing methods are divided into two types: destructive and non-destructive testing. The destructive testing methods include direct drilling core sampling method and direct drilling measurement method. The non-destructive testing methods include hammer impact method, ultrasonic method, impact echo method, infrared thermal imaging method, fiber optic sensor method, etc. Analyzing and comparing the advantages, disadvantages, and applicability of various detection methods, combined with the current problems that need to be solved, this article chooses the impact echo method and infrared thermal imaging method to detect internal defects in concrete.

The impact echo method uses small steel balls to excite the surface of concrete as a vibration source, allowing the stress pulse waves generated by them to propagate on the surface and inside of the tested concrete medium. After receiving these waves through sensors, spectral analysis methods (FFT, MEM) are used to convert time-domain signals into frequency-domain signals, identify the relationship between the received signal and the quality of concrete, and achieve the purpose of non-destructive testing. The impact echo method is a commonly used detection method in engineering to detect the location and type of internal defects in concrete. It can also achieve good detection results for deep defects.

The infrared thermal imaging method uses a heating plate to change the internal temperature of the concrete, and finally outputs the detection results in the form of a color image. The color image does not represent the true color of the target, but only reflects the distribution of different temperatures. The infrared thermal imaging method is also a suitable detection method in current engineering to detect the location and type of internal defects in concrete, which can achieve good detection results for shallow defects.

Due to the different depths of defects that can be tested by the impact echo method and infrared thermal imaging method, the results presented are different in effectiveness. The impact echo mainly relies on the P-wave signal to present the voltage time signal waveform. For waves propagating on the surface, the acceptance accuracy is not high and they are easily interfered by reflected waves. The infrared thermal imaging method has strict requirements for defect depth, and the defect position is too deep to present results. The effect is better for shallow defect positions. At present, coupling multiple non-destructive testing methods is the development trend of non-destructive testing, and the coupling method of impact echo method and infrared thermal imaging method is also very rare. Therefore, the research on the coupling method of impact echo method and infrared thermal imaging method for detecting internal defects in concrete is meaningful.

## **2. Current Research Status at Home and Abroad**

### **2.1. Impact Echo Method**

In the past few decades, a series of non-destructive testing methods have been widely applied in the testing of concrete and other structural materials [3]. Among them, acoustic method is the oldest and most widely used non-destructive testing method. Acoustic method is based on the propagation and reflection laws of stress waves in solids, such as using a hammer to strike the surface of an object and listen to the sound of vibration to detect whether there are voids, cracks, or other defects inside the object. However, acoustic method can only achieve the ability to preliminarily locate the location of defects.

Since the early 1940s, the ultrasonic pulse echo method has been widely developed and applied [4]. So far, it has become a comprehensive and reliable non-destructive testing method for metals, plastics, and other homogeneous materials. However, there is a lack of successful examples of ultrasonic testing in concrete testing, such as being limited in detecting internal defects and thickness in thin layers of concrete, as high-frequency stress waves (usually above 100kHz) are strongly absorbed by anisotropic materials [5-8].

In the early 1970s, the impact echo method began to be used for integrity testing of deep foundations, such as pile foundation integrity testing: low-frequency stress waves (below 1kHz) were excited with a hammer, which can be used to determine the length of the pile.

In the early 1980s, in order to solve the problem of high-frequency stress waves being absorbed by anisotropic materials in ultrasonic methods, research engineers from the United States National Bureau of Standards (NBS) used short duration mechanical impacts of small steel balls to excite high-frequency stress waves as a source of stress wave vibration for testing plate shaped concrete structures and other structures [9]. Research has found that the frequency of stress waves generated by carefully selecting the diameter of steel balls can reach up to 80kHz, and stress waves can propagate through concrete structures and reflect at defects and interfaces. So researchers at the National Bureau of Standards in the United States refer to it as the impact echo method, which is a non-destructive testing method for concrete and masonry structures.

Between 1987 and 1997, the shock echo method for measuring P-wave velocity was further developed at Cornell University in the United States. In December 1997, the American Society

for Materials and Materials (ASTM) released a standard method for determining P-wave velocity and concrete structure thickness using the impact echo method [10].

The impact echo method can be used to determine the location and range of defects [11]. Common defects include voids, cracks, delamination, voids, honeycombs, and looseness, which are present in plain concrete, reinforced concrete, and post tensioned prestressed concrete structures. The impact echo method can be used to determine the location of voids in most types of post tensioned prestressed grouting channels [12], and can directly determine voids in the roadbed below the same concrete pavement [13]. A short impact of a steel ball on the surface of concrete generates a stress wave, which propagates into the interior of the structure and emits at defects or other interfaces. The sensor receives and generates a voltage time signal. By using fast Fourier transform (FFT) and other spectral analysis methods, the time-domain graph is converted into a frequency-domain graph to obtain an amplitude frequency graph (spectrum). This signal describes the instantaneous vibration caused by multiple reflections of stress waves inside the structure. The dominant frequency in these vibrations is related to stress waves reflected from different depths inside the structure [14-17]. After digitization by the acquisition system, the analog signal is transmitted to the computer and converted into a spectrogram through mathematical operations. The peak value of the spectrogram is the dominant frequency, which can be used to calculate the thickness of the structure or the depth of defects [18].

Although the time from invention to application of the shock echo method was quite brief, it was quite successful.

## 2.2. Infrared Thermal Imaging Method

In the early 1960s, foreign scholars began to study infrared technology. Subsequently, infrared thermal imaging technology gradually merged with the field of building inspection. In recent years, foreign scholars have mainly carried out a lot of research on infrared thermal imaging technology in the field of engineering inspection. A large number of researchers, represented by Professor Xavier P.V. Maldague from the University of Laval in Canada, have conducted extensive research on infrared non-destructive testing [19].

During the 13 years from 1985 to 1998, Weil, Gary J, and others from EnTech Limited in the United States conducted extensive and detailed infrared testing work on large concrete structures. Mainly focused on the detection and recognition of internal defects, relevant research has been conducted, and it has been found that infrared non-destructive testing technology has a good application effect on defect detection and recognition [20-21].

In addition, in 1999, A In 2001, D J. Titman mainly explored the application of infrared non-destructive testing, especially conducting corresponding research on the internal defects of concrete structures under different detection conditions. Guidance was provided on the optimal detection time, conditions, perspectives, and limitations of infrared detection methods under different operating conditions [23].

In 2003, Ch Maierhofer, A Brink et al. conducted an application study on non-destructive testing of concrete using infrared thermal imaging, and analyzed the layered peeling state of concrete bridges at different temperatures through imaging. The results showed that even at low environmental temperatures, using infrared thermal imaging to identify delamination in concrete structures and defects in internal structures is feasible [24].

In 2012, J L. Bodnar et al. used infrared thermal imaging non-destructive testing technology to conduct thermal imaging of internal defects in thin specimens under random external excitation, and conducted relevant analysis based on this. The results showed that this method is feasible under external excitation conditions [25].

The development of infrared non-destructive testing in China started relatively late, and corresponding research began in the 1970s. In recent years, research on defect recognition and detection has mainly carried out the following work:

In 2003, Yuan Xin, Xie Huicai, Chen Gaofeng, and others discovered that in order to obtain clearer and more easily recognizable defect thermal images, a strong external auxiliary heat source could be used during experimental testing. In 2004, the research results of Huang Pei and Xie Huicai showed that this method can accurately determine the position, shape, and size of defects [26]. In 2005, Gao Xiang studied the application of infrared technology in void detection of concrete pavement. Through the comparison of numerical simulation and experimental results, a preliminary qualitative relationship between the maximum thickness and void shape detected and the surface temperature distribution was obtained [27].

Meanwhile, in 2006, Huang Hongmei, Wang Hongguang, Wei Zhen, and others conducted application analysis of finite element numerical simulation in quantitative research of infrared detection using ANSYS software. Through error analysis, the research results indicate that the finite element numerical simulation method is highly effective in quantitatively studying infrared detection [28].

In 2011, Chen Wei, Ding Sha, Chen Bo, and others used infrared thermal imaging and temperature sensor monitoring equipment to detect concrete specimens containing defects. A non-destructive testing method for concrete based on infrared thermal imaging and finite element simulation of temperature field is established by combining experimental and numerical analysis methods. It indicates that both infrared thermal imaging method and temperature field finite element simulation can effectively detect defects in specimens, and the combination of the two can more comprehensively and accurately reveal the structural information inside concrete [29].

In 2014, Qi Lei and Guo Chaohui conducted finite element simulation on defective concrete bridge components with different defect shapes, sizes, depths, and thicknesses using ANSYS. Using the surface temperature and contrast of the tested component after heating as evaluation indicators, the influence of defect status on infrared non-destructive testing of concrete was analyzed, and the main influencing factors of infrared non-destructive testing of concrete were identified [30].

The development of infrared thermal imaging has been relatively successful in engineering applications, mainly due to its non-contact and fast imaging advantages. The infrared thermal imaging method is based on the principle of infrared radiation, relying on the difference in thermodynamic coefficients of substances in the defect area and the control (defect free) area. When an object itself has a temperature different from its surrounding environment, it will generate heat flow inside the object. During the diffusion and transfer of heat flow within an object, the discontinuous defects of the object being tested have an impact on heat conduction, which is reflected in the temperature difference on the surface of the object. Different temperature distributions are formed on the surface of the object, forming the so-called "hot zone" and "cold zone". Different temperature distributions are closely related to the operating status of the object being tested. The infrared thermal imager can precisely use the principle of thermal radiation to image the temperature field on the surface of the measured object in the form of pseudocolor.

### 3. Discussion

When using the impact-echo method to detect voids or defects in concrete, different diameters of steel balls will result in different contact times during impact, leading to different frequencies. Consequently, stress wave velocities propagated within or on the surface of concrete vary accordingly. Choosing the spacing between measurement points involves a trade-off: selecting

a larger spacing generates longer wavelength waves, while selecting a smaller spacing requires more time and effort. Likewise, the selection of impact positions influences the number of stress wave reflections within the structure, thereby affecting the characteristics of the synthesized waves.

The thermal conductivity of concrete using infrared thermal imaging method is poor. Therefore, under normal circumstances, ordinary infrared thermal imaging methods have low resolution and it is difficult to accurately obtain the internal damage and defect characteristics of concrete materials. In order to obtain better images, the detection often heats the concrete to a higher temperature. This approach is not only time-consuming and labor-intensive, but also prone to exceeding the heat resistance limit of concrete during normal use, which may cause internal damage to the concrete or cause internal moisture migration leading to stress changes, and have a certain impact on the workability of the concrete.

#### 4. Conclusion

With the continuous development of society, there are only a few concrete buildings, and I have a large number of the earliest batch of concrete buildings built. Due to limited research during construction, a large number of concrete buildings exposed various problems during their service life that did not meet the original design plan. How to further improve and perfect them is currently the most urgent option. The most important step in the improvement plan is to determine the damage situation of reinforced concrete components. From multiple perspectives, non-destructive testing is undoubtedly the main development object for detecting concrete damage in the future.

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