# Characteristics and Applications of Non-destructive Testing Technology in Bridge Engineering

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**Abstract.** The construction of bridge projects can promote economic exchanges between different regions and provide convenient transportation for people. The application of non-destructive testing technology has effectively improved the overall quality of bridge inspection work, providing a reliable guarantee for the development of the transportation industry. This paper elaborates on the specific principles, characteristics, and research status of ultrasonic testing technology, three-dimensional laser scanning technology, and radiographic testing technology in practical operations, and comprehensively compares the advantages and disadvantages of the three non-destructive testing technologies in bridge engineering. Ultrasonic testing technology has simple operation and low cost, but the detection results are not intuitive enough; three-dimensional laser scanning technology has high accuracy and good digital compatibility, but its cost is relatively high; Radiographic testing technology has a wide range of applications, and the detection results are relatively intuitive, but the detection efficiency is low. Finally, it is discussed that the current difficulties in using non-destructive testing technology in bridge engineering lie in high costs and inadequate integration. It is proposed to incorporate non-destructive testing technology into bridge design planning to form a more complete system.

**Keywords:** non-destructive testing; bridge engineering; ultrasonic testing; three-dimensional laser scanning; radiographic testing.

## 1. Introduction

The construction of bridge projects can promote economic exchanges between different regions and provide convenient transportation for people. In recent years, with the improvement of people's living standards, the pressure of bridge engineering has gradually increased. In order to reduce the cost increase and other issues caused by bridge renovation, staff should carry out daily inspection and maintenance work in an orderly manner. At present, visual inspection is the most commonly used method in bridge inspection, but due to limitations of human and environmental factors, its accuracy and reliability have certain limitations. With the development of technology, non-destructive testing can detect the state of bridges more scientifically and efficiently without damaging the bridge structure, so it should be promoted.

The development of non-destructive testing technology can be traced back to the early 19th century. In the early stages, radiographic testing technology was mainly used to detect defects in materials. However, with the introduction of other non-destructive testing technologies, including ultrasonic testing, magnetic particle testing, and eddy current testing, the scope of non-destructive testing technology has been expanded and enabled it to inspect various materials, engineering components, including bridges. In recent years, the integration of non-destructive testing technology with other technologies such as artificial intelligence and machine learning has further improved the ability of non-destructive testing. On the other hand, mechanical automation technology enables safe and accurate inspection of remote and inaccessible bridge areas.

The development of non-destructive testing technology has made significant contributions to bridge testing, allowing for a more thorough and reliable assessment of structural integrity throughout the entire lifespan of traditional bridges. This has led to the strengthening of safety measures and protection work, ensuring the lifespan of bridge structures, and minimizing the risk of catastrophic failures. Overall, the development of non-destructive testing technology has changed the field of

bridge inspection, providing engineers and inspectors with powerful tools to evaluate the condition of structures without causing damage.

Therefore, this paper briefly describes the non-destructive testing technology in bridge engineering, and elaborates on the specific principles, characteristics, and research status of ultrasonic testing technology, three-dimensional laser scanning technology, and radiographic testing technology in practical operation; Secondly, the advantages and disadvantages of three non-destructive testing technologies in bridge engineering were comprehensively compared, and corresponding evaluations were given; Finally, this paper discusses the current difficulties in using non-destructive testing technology in bridge engineering and proposes the corresponding resolutions.

## 2. Advantages of non-destructive testing technology in bridge engineering

To ensure the quality of bridge engineering, it is necessary to regularly inspect the bridge engineering. Non-destructive testing technology has many advantages, mainly reflected in the following aspects.

### 2.1. High reliability

The inspection work of bridge engineering has a certain degree of complexity and involves many links. Relying solely on manual inspection not only has low efficiency, but also has drawbacks such as large errors and inability to ensure inspection quality. The application of non-destructive testing technology not only effectively saves manpower, material resources, and financial resources, but also ensures high reliability of testing results. There are various types of non-destructive testing technologies with varying advantages. In specific testing processes, either a single technology can be applied or multiple technologies can be comprehensively applied to improve the accuracy of testing results.

### 2.2. High safety

Non-destructive testing technology has the advantage of high safety. The application of non-destructive testing technology in bridge engineering testing does not have any adverse impact on the quality of the project. On the one hand, compared to traditional testing methods, the application of non-destructive testing technology can reduce the risk of testing work; On the other hand, the application of non-destructive testing technology can avoid the loss of project structure caused by traditional testing technologies.

### 2.3. High detection efficiency

The application of non-destructive testing technology in bridge engineering testing can simplify the process, avoid errors caused by traditional manual testing methods, and greatly improve the overall efficiency of testing work.

## 3. Advantages of non-destructive testing technology in bridge engineering

By analyzing the basic concepts and advantages of non-destructive testing technology, it is not difficult to see that in future bridge engineering testing work, the use of non-destructive testing technology can effectively solve some of the problems existing in traditional testing technologies. In order to further improve non-destructive testing technology, the staff should conduct in-depth analysis.

### 3.1. Ultrasonic testing technology

#### 3.1.1. Principles

If there are defects inside the concrete, when ultrasonic waves propagate to the defect medium, a series of changes such as diffraction, transmission and refraction, would occur at the defect interface, resulting in changes in the propagation path and thus changing its acoustic parameters [1]. When

ultrasonic waves pass through different defect areas of concrete, the acoustic parameters would undergo certain regular changes due to changes in the propagation medium. By determining the variation patterns of different acoustic parameters, the internal situation of concrete structures can be determined. When there are defects such as voids and cracks in the internal structure of concrete, it could cause a decrease in the ultrasonic velocity and correspondingly increase the sound time. The magnitude of the wave amplitude is also an important parameter reflecting the internal situation of concrete structures. When ultrasonic waves encounter defects, the wave amplitude also significantly decreases. When encountering internal defects in concrete, the superposition of waves could distort the waveform, which can reflect the internal defect situation of concrete from the waveform. The frequency is not only related to concrete defects, but also the testing distance, so it is not yet mature to use frequency to determine concrete defects [2]. By comparing and analyzing the acoustic parameters of the concrete structure with those of normal concrete, the location and range of defects in the concrete structure can be determined.

### 3.1.2. Characteristics

(1) High detection rate of area-type defects and low detection rate of volume-type defects.

In the actual ultrasonic testing process, area-type defects such as cracks can fully reflect ultrasonic waves, which is beneficial for the instrument to receive reflected waves and ensure strength, making it easy to record; However, volumetric defects such as pores, due to their large surface curvature, are prone to ultrasonic scattering, resulting in a lower intensity of reflected waves received by the instrument, making it difficult to confirm.

(2) Relatively low detection cost and fast detection speed.

In ultrasonic testing, the testing cost mainly comes from the cost of ultrasonic testing instruments and labor. The detection process is convenient and fast, with a fast detection speed, and ultrasound is harmless to the human body, but relevant technical training is required for technical personnel.

(3) Suitable for uniform material components with larger thickness.

Ultrasonic testing requires the material of the component to be as uniform as possible, in order to reduce the impact of the material itself on ultrasonic propagation. In bridge engineering, ultrasonic testing has great difficulty in detecting reinforced concrete structures, but it has application prospects for detecting pile foundations.

(4) Unable to obtain intuitive images of defects, making qualitative analysis difficult and quantitative accuracy low.

The direct results of ultrasonic testing are displayed on the display screen, but the final results need to be identified by experienced testing personnel to confirm the type of defect. The display of the testing results is not intuitive and is easily influenced by subjective factors. Due to the difference in detection rates between area-type defects and volume-type defects in ultrasonic testing, it is difficult to qualitatively determine the types of defects detected. Moreover, due to the accuracy of instrument equipment, the accuracy of defect quantity quantification will also be affected to some extent.

(5) Difficult to save test results.

Because the direct result of ultrasonic testing is the image of the monitor, which is not intuitive enough and not easy to record, the testing results are not easy to save.

### 3.1.3. Research status of ultrasonic testing research

Dong (2016) analyzed the principle of the ultrasonic method for detecting the size of internal voids in concrete and determined the formula for the diameter size of voids through geometric principles [3]. These studies have great reference values. For example, under ideal conditions, they set known defect sizes and types, simulate the propagation paths of ultrasonic waves within different concrete, determine their path propagation geometry, formulate defect size formulas, and verify through experiments that the actual dimensions comply with the formulated defect size formulas. Ultrasonic non-destructive testing technology can be applied to a series of concrete structures such as pile foundations, steel tube concrete, and mass concrete, achieving effective evaluation of crack depth, internal defects, and steel structure voids in concrete structures. Due to its low cost and high efficiency,

it can be applied to the detection of reinforced concrete bridge decks and pile foundations in bridge engineering.

### 3.2. Three-dimensional laser scanning technology

#### 3.2.1. Principles

Three-dimensional laser scanner measures the distance from the instrument to the object through a distance measurement system and uses the instrument's angle measurement system to obtain the horizontal and vertical angles of the scanner to the object. By analyzing data such as distance, horizontal and vertical angles, the 3D coordinates of the object are calculated [4]. At the same time, the scanner utilizes its own vertical and horizontal motor rotation devices to scan the measured object in all directions, continuously scanning and measuring a certain sampling density space to obtain dense point cloud data of the measured object. After obtaining information through a scanner, the information is stored in a data point cloud to achieve the establishment of 3D modeling. This process requires a series of processing operations, mainly including data acquisition, data processing, and 3D modeling. Obtain data through contact or non-contact measurement, compress and eliminate excess information, integrate data obtained from multiple measurement stations into a coordinate system for coordinate correction, filter data before 3D modeling, divide the point cloud area into multiple sub-regions, extract surface features and 3D coordinates, and achieve the purpose of 3D modeling by establishing a triangular mesh.

#### 3.2.2. Characteristics

(1) Wide applicability, high sampling rate, high accuracy, and high detection rate.

At present, the sampling rate of scanners can reach tens of thousands to millions of points per second, with extremely high sampling rates. At the same time, three-dimensional laser scanning equipment provides data acquisition methods with different densities, and its single-point positioning accuracy can reach up to 2mm, which can accurately locate internal defects in components. In terms of detection rate, three-dimensional laser scanning quickly obtains point data in all aspects simultaneously in both horizontal and vertical directions, resulting in a high detection rate.

(2) High testing costs with the requirement of more instruments

Three-dimensional laser scanning system includes the hardware part for data acquisition and the software part for data processing. In addition to requiring a 3D laser scanner, it can also be used in conjunction with an external camera and GPS system. The combination with other devices has expanded the scope of use of 3D scanners and made the obtained information more rich and accurate. Paired with a GPS system, not only can single-point positioning accuracy be improved, but it is also more flexible to use, greatly expanding the application range and simplifying the detection workload of large-span bridges to a certain extent. However, at the same time, instrument prices and labor costs also continuously increase the detection cost.

(3) Good digital compatibility.

The detection results obtained through three-dimensional laser scanning technology can be directly represented by digital signals, with full digital features, which are convenient for post-processing and output. It has good sharing with software such as Revit, AutoCAD, SketchUp.

(4) Visualization of detection results.

The data measured by a 3D laser scanner not only includes information on X, Y, and Z points, but also includes color information on R, G, and B, as well as information on object reflectivity. This comprehensive information can provide a solid foundation for the establishment of digital models.

#### 3.2.3. Research status of three-dimensional laser scanning technology

Three-dimensional laser scanning technology can effectively, real-time, and accurately obtain spatial data of target objects, and has been applied in the field of civil engineering construction in recent years. Wang [5] used the NovaMS50 3D laser scanner to collect bridge deck point cloud data, and the results showed that the data processed by the scanner was relatively close to the theoretical values. Li [6] used three-dimensional laser scanning technology to detect a damaged road surface and

studied the advantages and disadvantages of laser scanning technology in road flatness detection. They found that this technology can be effectively used for road flatness detection. Yang [7] developed a new monitoring method using three-dimensional laser scanning technology and applied it to the actual construction deformation monitoring of building engineering. Through conducting simulated deformation tests, the data results obtained were compared with the monitoring results of actual engineering. It was found that the data accuracy of 3D laser scanners still cannot meet the requirements of building engineering monitoring standards, and traditional detection tools and methods should be combined for application. However, the application of three-dimensional laser scanning in bridge detection is relatively limited and lacks practical application experience. However, based on previous research and the application of this technology in roads, tunnels, and civil engineering, analyzing the application of three-dimensional laser scanning technology in bridge detection plays an important role in the development of bridge detection towards informatization.

### 3.3. Radiographic Testing Technology

#### 3.3.1. Principles

Radiographic non-destructive testing is one of the conventional non-destructive testing technologies. During testing, the negative film can be placed at the required position of the structure to be tested, and sensitive negative films can be used to complete the testing. It can accurately identify the position and degree of voids in the structure, as well as the location of steel bar fractures. In specific detection, x, γ and other rays are used to penetrate the object to be detected, and there is no damage to the surface, and the image data after the ray penetrates the object is obtained, and the quality defect is visually assessed.

#### 3.3.2. Characteristics

(1) High detection rate of volumetric defects, while the detection rate of area defects is easily affected.

In the actual radiographic testing process, the detection rate of volumetric defects in components is high. The influencing factors on the detection rate of area defects include defect shape and size, radiographic thickness, radiographic angle, radiographic geometric conditions, source and film types, and image quality indicator sensitivity.

(2) High detection cost and low speed.

Radiographic testing requires selecting different types of radiation based on the engineering situation, and corresponding testing instruments are required. Radiographic instruments with strong penetration ability are more expensive, greatly increasing the testing cost. At the same time, radiographic testing requires exposure time, which takes several hours from the start of penetration to evaluate the results, resulting in low efficiency.

(3) Able to obtain projection images of defects, with accurate qualitative and quantitative analysis of defects

Among various non-destructive testing methods, radiographic testing is the most standard for qualitative and quantitative analysis of defects. In terms of quantification, the determination of the length and width of volumetric defects is also very accurate, with an error of approximately a few tenths of a millimeter. However, for area-type defects, if the size of the defect end (height and opening width) is very small, the extension of the image tip on the negative may not be clearly distinguished, and the quantitative data may be too small.

(4) Harmful to human body

However, radiation poses certain hazards to the human body, and operators must carefully isolate and protect themselves during the testing process. Given the complexity and specificity of the operation of radiographic testing technology, it is required to conduct a comprehensive analysis of the necessity and feasibility of applying the technology before testing, in order to form a reliable implementation plan and avoid troubles and dangers in the application of the technology.

### 3.3.3. Research status of radiographic testing technology

Radiographic testing technology, with its advantages of accurate defect localization and quantification, easy recording of results, and intuitive defect display, is still an important means of quality control for many industrial products. With the application of radiation in various industrial fields, radiographic testing technology has shown a rapid development trend. In the aerospace industry, radiation technology is used to detect the structure of precision castings, sintered materials, and composite materials; in the mechanical industry, it can detect defects such as small pores, inclusions, and cracks in castings and welds; In addition, it has extensive applications in fields such as ceramics, architecture, food, mining, and petroleum. However, the application of radiographic testing technology in bridge inspection is relatively limited and lacks practical application experience [8].

## 4. Discussion

Overall, the ultrasonic testing technology, three-dimensional laser scanning technology, and radiographic testing technology discussed in this paper all have their advantages and disadvantages, and there are complementary advantages and disadvantages (Table 1).

Currently, the integration process between bridge engineering and non-destructive testing technology is slow. On the one hand, the application of non-destructive testing technology in bridge engineering is influenced by factors such as cost and materials; On the other hand, some non-destructive testing technology instruments are heavy and require manual operation. The methods of conveniently and quickly transporting the testing instruments to the location where they need to be tested determine the efficiency of the testing process and the accuracy of the testing results. In the future, flexible selection and combination of different non-destructive testing technologies should be made based on the actual engineering situation, in order to maximize the advantages of each technology, avoid disadvantages, and achieve the most accurate and visible testing results while emphasizing economic benefits [9,10].

**Table 1.** Comparison of Three Non-destructive Testing Technologies.

| Method | Principle | Advantage | Shortcoming |
|---|---|---|---|
| Ultrasonic testing technology | A non-destructive testing method that utilizes the difference in acoustic performance of materials and their defects to examine the energy changes in the reflection of ultrasonic propagation waveforms and penetration time to detect internal defects in materials. | 1) Large detection range, high sensitivity, high efficiency, and simple operation<br>2) Widely applicable and cost-effective | 1) Difficult to accurately identify and quantify defects<br>2) Limitations on the shape and complexity of the specimen |
| three-dimensional laser scanning technology | It utilizes the principle of laser ranging to quickly reconstruct the 3D model of the measured object and various map data such as lines, surfaces, and volumes by recording the coordinates, reflectivity, and texture information of a large number of dense points on the surface of the measured object. | 1) Wide applicability, high accuracy, and high detection rate<br>2) Good digital compatibility and visualized results | 1) The testing cost is very high |
| Radiographic testing technology | When a ray passes through a substance, its intensity decays due to the scattering and absorption of the substance. The degree of intensity decay depends on the properties of the material, the type of ray, and its penetration distance. | 1) Suitable for almost all materials<br>2) Intuitive test results and easy to analyze<br>3) Easy to save test results for a long time | 1) High testing cost Long detection time and low efficiency<br>2) Safety protection issues need to be considered |

## 5. Conclusion

In bridge engineering, due to the main methods used in bridge construction, such as welding, bolt connection, and riveting, the main types of defects in the above connection methods are surface pores, surface cracks, slag inclusion, incomplete fusion, incomplete welding, surface undercut, etc. Based on this, in order to determine the internal defects of the bridge, inspection personnel can first use the radiographic inspection mode to conduct focused and regular inspections on the starting and ending positions of the bridge welds and the positions of intersections.

Radiographic testing technology can determine the shape of bridge defects, such as steel structure bridge butt weld defects, by analyzing long-term effective negative films. In addition, to improve the intuitive and effective detection of defects in steel structure bridges, relevant inspection personnel can use penetration testing technology to detect non-porous materials with high surface finish in bridges, ensuring the timely identification and treatment of opening defects in bridge surface materials. In bridge structures such as cable-stayed bridges, arch bridges, and suspension bridges, cables have a wide range of applications, and the effective metal-bearing area of cables is directly related to the installation of the overall bridge structure. Based on this, inspection personnel can use non-destructive testing methods on the basis of surface and internal structure inspection of bridges. Based on the key points of non-destructive testing for bridges, long-term and point-by-point surface scanning inspection of bridge cables is carried out. The non-destructive testing technologies for bridge cables mainly include ultrasonic testing, radiographic testing, and other types. From the perspective of overall planning, in large-scale key bridge projects, three-dimensional laser scanning technology with high accuracy, high detection rate, and good digital compatibility should be considered to visualize the entire project inspection results, timely identify problems, and facilitate overall management.

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