Non-destructive Inspection Technology for Concrete Structures

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Abstract

The need to develop non-destructive technologies that allow safe and effective inspection and analysis of infrastructure facilities is increasing with the degradation of old infrastructure facilities such as cable tunnels and utility holes and the aging of professional engineers. This article describes the importance and direction of research and development of non-destructive inspection technology for testing concrete structures as well as macroscopic ultrasonic and electromagnetic methods that are under development.

1. Introduction

NTT inspects cable tunnels, which are concrete structures, through a process of regular inspections at intervals of 3 to 5 years to identify the status of surface degradation quantitatively in terms of a rank indicating the degree of degradation. The need for repair is judged based on the degree of degradation. When there is degradation that cannot be identified by visual methods or for which the cause needs to be pursued, detailed inspections are carried out, the need to take action is determined, and appropriate repair measures applicable to the cause of degradation are selected. The inspection procedure is described in **Table 1**.

Regular inspections are usually performed visually to check the degradation status of the concrete surface such as cracks, leaks, or exposed reinforcing steel.

Table 1. Procedure for inspecting cable tunnels.

	Regular inspection	Detailed inspection
Description	Surface degradation phenomena are checked to create basic quantitative data for equipment management. Usually performed at 3–5-year intervals. Interval can be shortened depending on degradation status.	Carried out when there is degradation that cannot be identified by visual inspection or when the cause of degradation must be clarified to judge whether countermeasures are needed and to select the optimum method.
Techniques	Looking and hammering	• Destructive methods (surface removal and core sampling) • Non-destructive inspection
Typical inspection items	Cracks, water leakage, exposed steel	Cracks, flaking, cavities, strength, corrosion, neutralization, depth, salt concentration, etc.
Evaluation criteria	Classified into six levels according to degree of degradation	Judged individually according to degradation status

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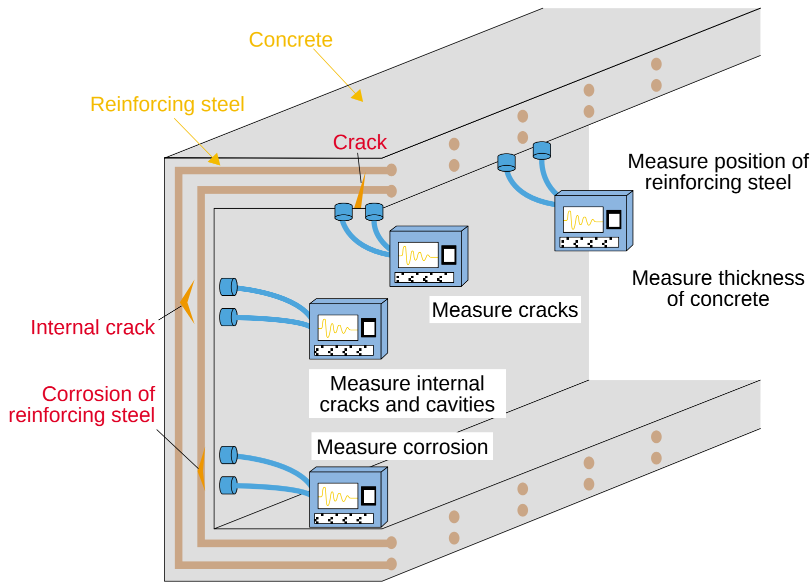

Fig. 1. Main items in a detailed cable tunnel inspection.

Detailed inspections, on the other hand, check for degradation occurring inside the concrete, such as corrosion of reinforcing steel or internal cracks, by destructive testing of a concrete sample and by chemical analysis of a core sample to determine the degree of degradation.

Both types of inspection are important, but detailed inspection is especially important for evaluating the safety and long-term reliability of facilities. The main items of a detailed inspection are shown in **Fig. 1**. It is important to develop ways to perform these inspections non-destructively to assure the safety of aged facilities. Thus, we need diagnostic methods as well as visual inspection and non-destructive inspection technology is necessary to reduce the strain on aged structures and enable inspections to be performed safely.

2. Current status and issues for non-destructive inspection technology

Non-destructive inspection technologies commercially utilized at worksites can be categorized as impact acoustic methods, impact-generated elastic wave methods and ultrasonic methods using sound waves, electromagnetic wave methods, electromagnetic induction methods using electromagnetic waves, test hammer methods utilizing repulsive force, and half-cell potential methods that measure electrical characteristics. **Figure 2** shows the items of concrete structures that can be inspected using these general inspection technologies as well as the position of each method in terms of performance and accuracy. It shows that we must select the optimum method to suit the degradation phenomena to be analyzed when inspecting structures because these general inspection methods have limited applicability because of their technical characteristics. Moreover, the measurement conditions may be limited or accuracy may be unstable depending on the environment. We are currently focusing on research and development for inspection technologies using ultrasonic and electromagnetic waves as the most promising technologies for resolving such problems and we are focusing on situations where we can apply the know-how accumulated by NTT Laboratories and Group companies. As shown in Fig. 2, these ultrasonic- and electromagnetic-wave-based non-destructive methods approach the performance and accuracy of destructive methods.

3. Direction of research and development of non-destructive inspection

Figure 2 also shows targets for research and development of non-destructive inspection technologies. With ultrasonic inspection, we are focusing on measuring the compression strength and corrosion of reinforcing steel in concrete as an important research and development theme for upgrading macroscopic ultrasonic inspection technology that we have provided to business in FY 2005. With this technology, we

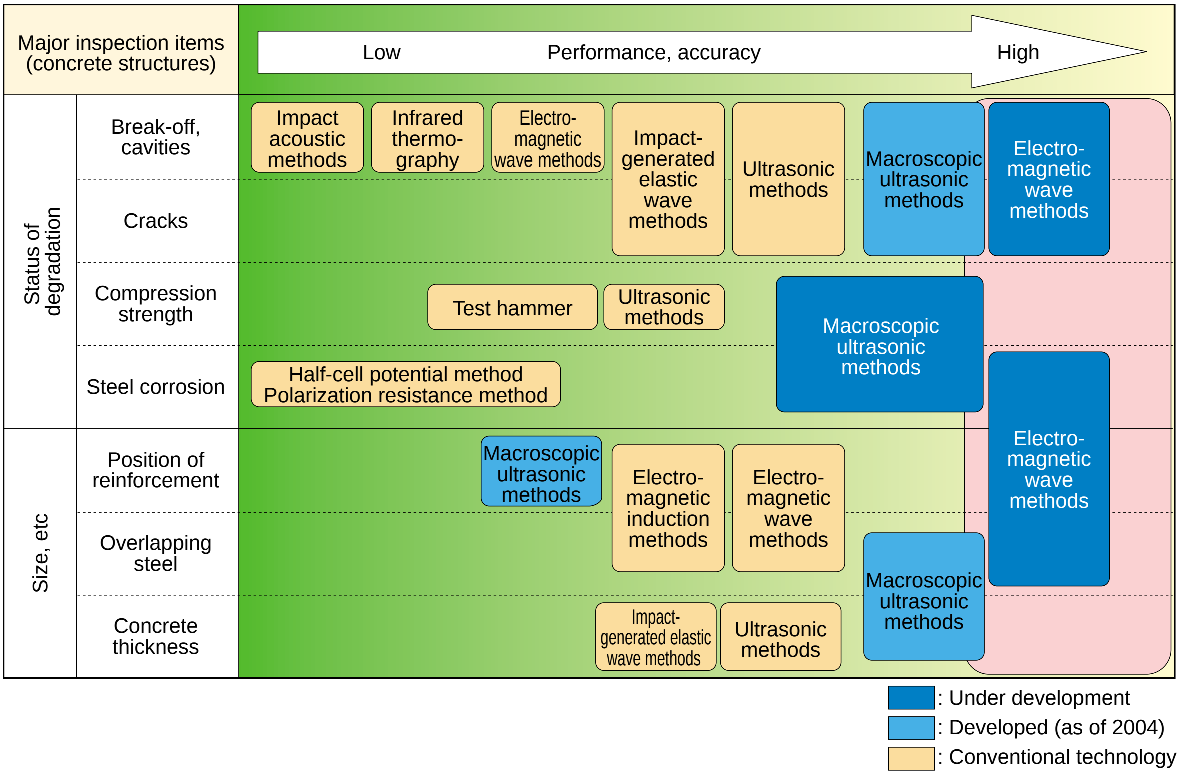

Fig. 2. Types of non-destructive inspection and future development targets. For reference, the range of destructive methods (surface removal and core sampling) is shown in pink.

are aiming to develop a flexible system that can measure various inspection specimens with high accuracy using a single piece of equipment without requiring other measurement equipment to be brought in. Electromagnetic inspection technology is a new development theme that utilizes high-frequency gigahertz waves not currently commercially available. With this new technology we aim to achieve more accurate diagnosis of defects in two dimensions (2D).

Those technologies will allow us to eliminate destructive inspection from the worksite and will greatly contribute to reducing inspection costs and repair costs (repetitive repairing) and will result in improvements in inspection accuracy, as well as improvements in the safety of facilities. They are ones that can be applied to making various measurements made by a single system, allow measurement with accuracy equivalent to that of destructive inspection, allow the continuous capture of 2D information, and ensure that cables are unaffected by high humidity and high temperature inside underground facilities.

4. Macroscopic ultrasonic method

4.1 Overview

The conventional ultrasonic inspection method for analyzing concrete structures injects ultrasonic waves into the concrete to analyze the state within it from the reflected waves or waves transmitted from or through substances having different elastic properties from those of the concrete. When ultrasonic waves are injected into the concrete, the received waves contain a lot of noise because they are scattered by water, air bubbles, or aggregate in the concrete. Therefore, accurate diagnosis has been impossible because of the difficulty of distinguishing between the target waves reflected from the reinforcing steel and waves reflected from the bottom of the concrete structure. On the other hand, macroscopic ultrasonic inspection allows us to detect only the target reflected wave in a short time of just about 10 seconds by averaging the measurements thousands of times while moving an ultrasonic probe and using a noise filter to eliminate unwanted frequency components (**Fig. 3**). As shown by the example of received ultrasonic waves in **Fig. 4**, we can clearly identify the reflected waveform from the bottom of the concrete by performing averaging

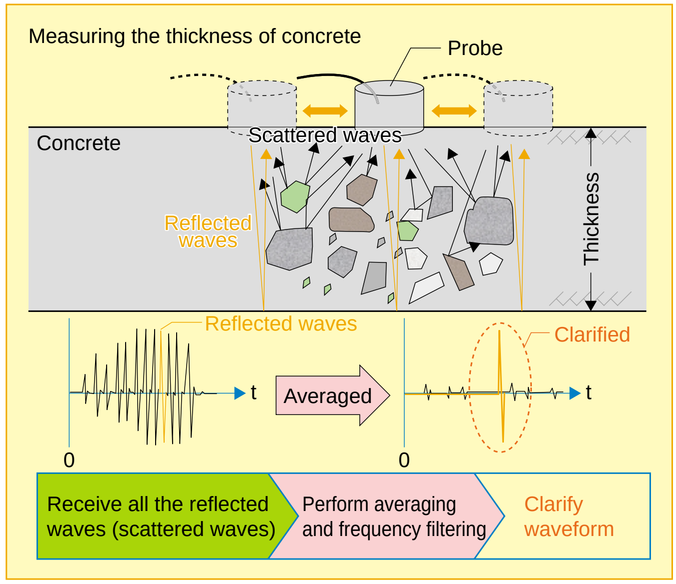

Fig. 3. Concept of macroscopic ultrasonic inspection technology.

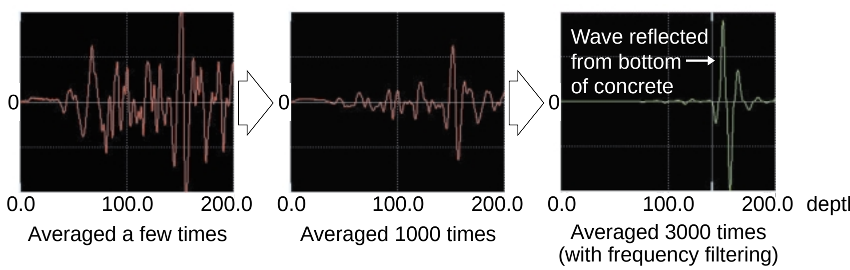

Fig. 4. Example of averaging processing (measuring thickness of concrete).

(in this case, 3000 times) and filtering operations. Here, "macroscopic" means that all the reflected waves including noise caused by scattering and so on are received instead of only the reflected wave being microscopically detected in a pinpoint manner.

4.2 Degradation analysis system for reinforced concrete (RC)

The RC degradation analysis system that we provided as a practical inspection system to business in FY 2005 is a non-destructive inspection system utilizing macroscopic ultrasonic inspection technology. Photographs of the system's appearance and manner of use for measurement are shown in **Figs. 5** and **6**, respectively. Measurement items and applications are shown in **Table 2**. For this device, we developed functions that enable initial settings of voltage, gain, axis scale, and frequency filter setting values required for the operation of averaging received waveforms to be automatically set to the optimum values for the items to be measured. As shown in **Fig. 7**, we have

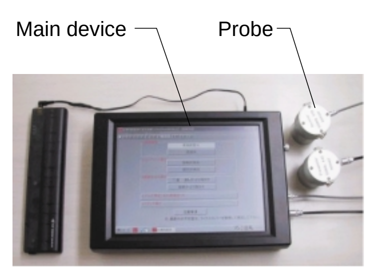

Fig. 5. RC degradation diagnosis system.

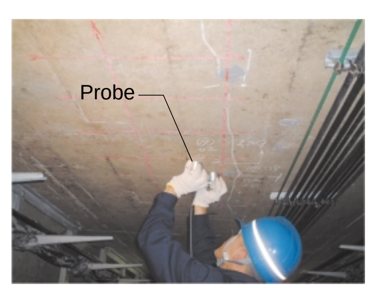

Fig. 6. Example of use for measurement.

also developed a one-click function that can automatically recognize the measured waveform and display the measurement results as numerical values. These functions can shorten the work time and minimize measurement errors caused by differences in the skill levels of inspectors because high-level specialist knowledge is not needed. Furthermore, the system can be used in small spaces such as cable tunnels or utility holes and in high-humidity environments because it can be made small, waterproof, and battery driven.

4.3 Attempting application to new measurement items

When judging the durability (reduction in strength) of concrete structures, we need to know the corrosion status of the reinforcing steel and the compression strength of the concrete itself. We are now developing ways of measuring these values using the macroscopic ultrasonic inspection method. In this section, we describe the progress of this development for this technology.

Table 2. Items to be measured and applications.

Items to be measured	• Depth of crack • Place and depth of break-off and cavity • Concrete thickness • Overlapping depth of surface reinforcing steel • Overlapping depth of duplicated reinforcing steel
Applications	• Internal degradation diagnosis for existing equipment • Confirmation of material dimensions for existing equipment • Confirmation of material dimensions when construction was completed

4.3.1 Measuring the degree of corrosion of reinforcing steel

We prepared concrete specimens with different degrees of reinforcing steel corrosion and recorded the waveforms and frequency spectra of waves reflected from the reinforcing steel using several measurement methods such as changing the probe distance. We found that the frequency characteristics in the high-frequency region differed depending on the degree of corrosion (**Fig. 8**). This difference is probably caused by fine cracks near the reinforcing steel created by corrosion and by the pressure of expanding gas generated by corroded products. We will accumulate more data through basic experiments to establish inspection and analysis technology.

4.3.2 Measuring the compression strength of concrete

We are developing technology for estimating the compression strength of concrete from the velocity of ultrasonic waves traveling inside the concrete, utilizing the characteristic of ultrasonic waves that the elastic modulus changes in proportion to the velocity of ultrasonic waves. We tried to measure this phenomenon using an actual structure on site. However, although we could recognize a positive correlation between sound velocity and compression strength, we concluded that it is difficult to estimate the compression strength from only the velocity of ultrasonic

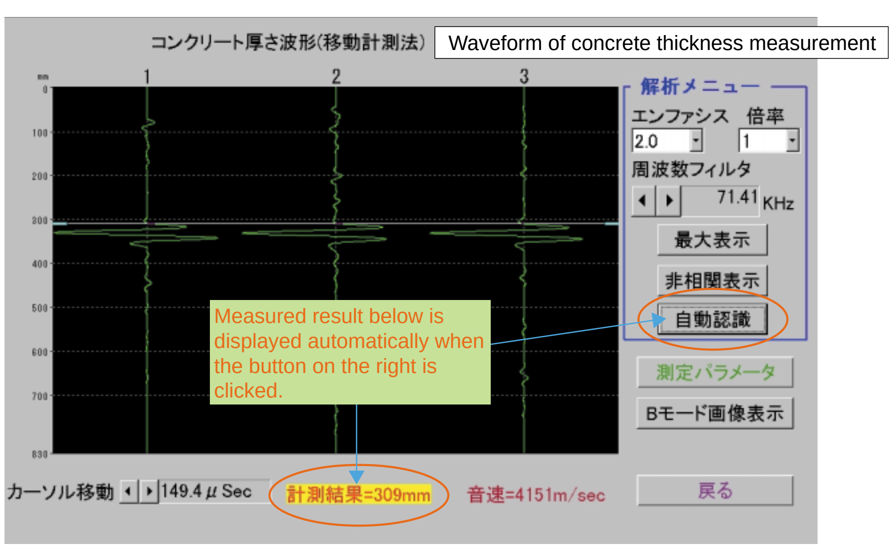

Fig. 7. Display of values of results of automatic recognition.

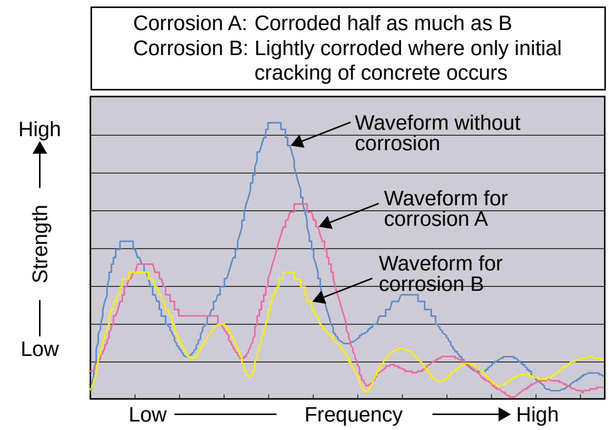

Fig. 8. Frequency spectrum of wave reflected from reinforcement.

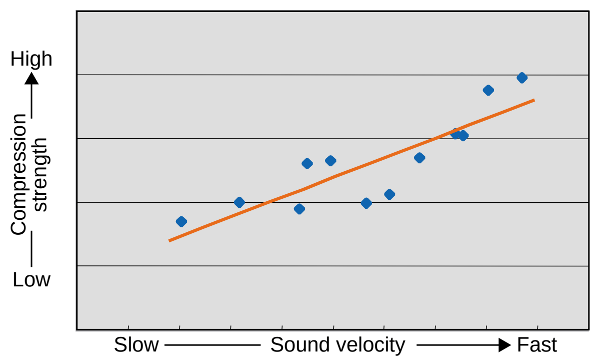

Fig. 9. Compression strength of concrete versus velocity of ultrasonic waves.

waves because the correlation (= 0.72) was not very strong (**Fig. 9**). We will further study and analyze factors that affect ultrasonic wave velocity to improve the measurement accuracy by developing an error compensation algorithm, for example.

5. Electromagnetic wave methods

5.1 Overview

The usual electromagnetic wave method used for investigating a concrete structure measures the distance to a reflective object (for example, reinforcing steel in concrete) from the round-trip time of reflected electromagnetic waves using the property that electromagnetic waves are reflected by any substance with different electrical characteristics (relative dielectric constant) from the medium. The concept of this inspection method is shown in **Fig. 10**. The main problems with this conventional method are that the measurement depth is limited by attenuation of the electromagnetic waves and environmental noise and that the depth measurement accuracy is insufficient.

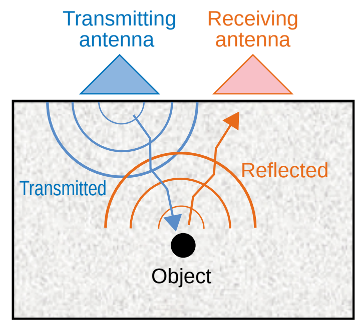

Fig. 10. Concept of electromagnetic inspection.

Fig. 11. Light Espar.

Fig. 12. Measurement in progress.

5.2 Light Espar

Light Espar [1] is a non-destructive inspection system using electromagnetic waves provided by Airec Engineering Corp., a company in the NTT Group. Its external appearance is shown in **Fig. 11**, and an example of an actual measurement in progress is shown in **Fig. 12**. An example of the resulting search image is shown in **Fig. 13**. Measurement items and applications are shown in **Table 3**. Improvements in the amplification of reflected waves and data analysis software in this system resolve the problems with the

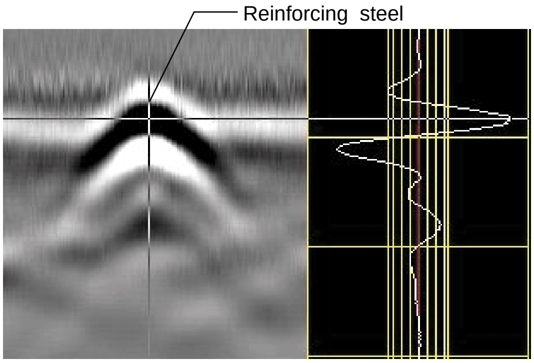

Fig. 13. Example image of search result.

Table 3. Items to be measured and applications.

Items to be measured	• Arrangement of reinforcing steel • Position of break-off and cavity in concrete
Applications	• Searching for break-off and cavity in existing equipment • Checking the arrangement of reinforcing steel in existing equipment • Checking the arrangement of reinforcing steel after construction

conventional technology. This system is currently utilized in the field for investigating reinforcing steel and cavities inside concrete structures.

5.3 Development of new measurement methods

Focusing on the characteristics of electromagnetic wave methods, which allow non-contact and continuous searching, we have started development of non-destructive inspection technology that can measure the degree of degradation inside concrete very accurately and efficiently. Although the normal electromagnetic inspection method for investigating concrete structures uses the 1–2-GHz band, we are investigating higher frequencies to improve the resolution and capture more precise electromagnetic characteristics of concrete and reinforcing steel. Our aim is to enable quantitative diagnosis of the degree of degradation inside concrete structures.

6. Future topics

After an accident involving concrete falling from the walls of a Shinkansen tunnel in 1999, major construction companies and inspection facilities manufacturers conducted a lot of research on non-destructive inspection technologies utilizing various methods. However, no systems have been introduced at actual work sites for various reasons such as physical limits (because most are based only on results obtained from test specimens), measurement accuracy, and worksite applicability. We believe that it is important to establish an optimum measurement method by accumulating experimental data so that it will be available in the field, as well as to implement field tests to confirm worksite applicability. In the future, we will identify suitable applications and create manuals for facilities inspection using non-destructive inspection technologies.

In conclusion, the technology we are now developing can be used to diagnose the degree of degradation of general concrete structures or confirm the dimensions of structural materials. We believe this technology can contribute to society through the maintenance and management of Japan's social infrastructure because it can be applied to facilities besides those in NTT's infrastructure, such as private buildings and structures and public buildings and structures such as bridges and tunnels. From this standpoint, we will continue to work to advance the development of technology.

Reference

[1] http://www.airec.co.jp/products/html/000021.html

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