NDT FOR CONCRETE USING THE ULTRASONIC METHOD

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Abstract

Numerous methods have been proposed that use the propagation speed of ultrasonic waves to inspect the quality of concrete structures in a non-destructive manner. Probes cannot be positioned on the back side of the concrete walls of tunnels and other underground structures, so a method for evaluating the inside of the concrete using the surface sonic speed is necessary. This paper reports on the macroscopic ultrasonic method, which allows measurement of concrete thickness, crack depth and other characteristics using the concrete surface sonic speed.

1. Introduction

In 1985, Nippon Telegraph and Telephone Public Corporation was privatized as Nippon Telegraph and Telephone Corporation (NTT). It is Japan's largest telecommunications company. The NTT Group consists of 397 affiliated companies (201,000 employees) under a holding company, and supports Japan's telecommunications industry.

Since 1995, the NTT Group has worked to transform itself from a business structure focused mainly on the telephone business to one that focuses on a diverse array of services for the broadband era. This includes providing ubiquitous service using optical fiber cables.

The underground infrastructure facilities that support these new services and next-generation networks must ensure stability. The underground infrastructure facilities owned by NTT include approximately 600 km of cable tunnels (dedicated underground tunnels for communications cables), approximately 800,000 utility holes, and cable conduits stretching for a total length of approximately 630,000 km. Most of the cable tunnel facilities were constructed from the 1970s through the 1990s, so many of these facilities are 20 to 30 years or more old, and noticeable signs of facility degradation due to superannuation are beginning to appear. The same is true for the utility holes and cable conduits.

In consideration of the fact that degradation advances with age, there are

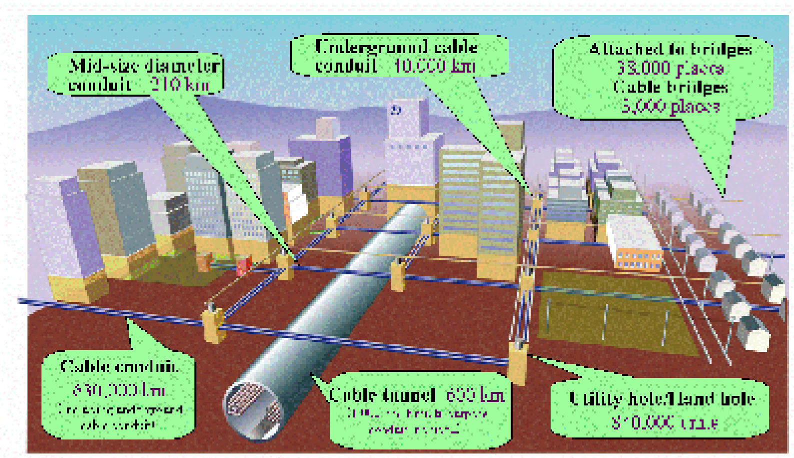


Fig.1 overview of NTT's infrastructure equipment

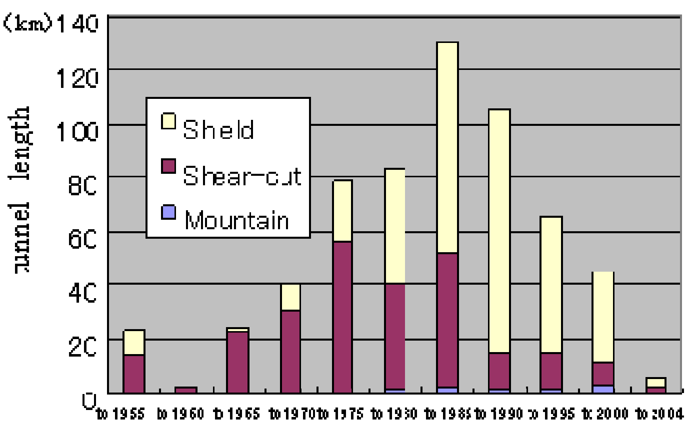


Fig.2 Years elapsed after tunnel construction

Fig.3 Cable tunnel degradation conditions construction

concerns that expenses needed for inspection, diagnosis, repair and reinforcement related to maintenance management will increase in the future.

Against this background, facility management that properly maintains and manages infrastructure facilities is becoming an important theme, and inspection and diagnosis technology that is positioned upstream in the maintenance and management cycle is becoming particularly important. For these reasons, the NTT Group aims to realize information network infrastructure facilities that allow safe and stable use by developing non-destructive inspection technology that enables accurate and efficient inspections.

2. Current State of Facility Inspections and Need for Non-Destructive Inspection Technology

Concrete structure inspections (hereafter “cable tunnel inspections”) first aim to understand surface degradation phenomena in the form of quantitative data for each degradation rank using periodic inspections performed in 3 to 5-year cycles. Here, the need for repairs is determined according to the degradation rank.

Table.1 Procedure for inspecting cable tunnels

	Regular inspection	Precise inspection
Description	Check surface degradation phenomena to create basic quantitative data for equipment management. Inspect in 3 to 5 year intervals. Shorten interval depending on status of degradation.	Carried out when there is degradation that can’t be identified by visual inspection or clarification of cause of degradation is required to judge necessity of taking countermeasures and to selecting the optimum method.
Techniques	Visual inspection, hammering	Core sampling, Non-destructive inspection
Typical inspection items	Crack, Water leakage, Iron exposure, etc.	Crack, Flaking, Cavities, Strength, Corrosion, Neutralization, Depth, Salt concentration, etc.
Evaluation criteria	Classify into six levels from A to F rank according to degree of degradation	Judge individually according to status of degradation

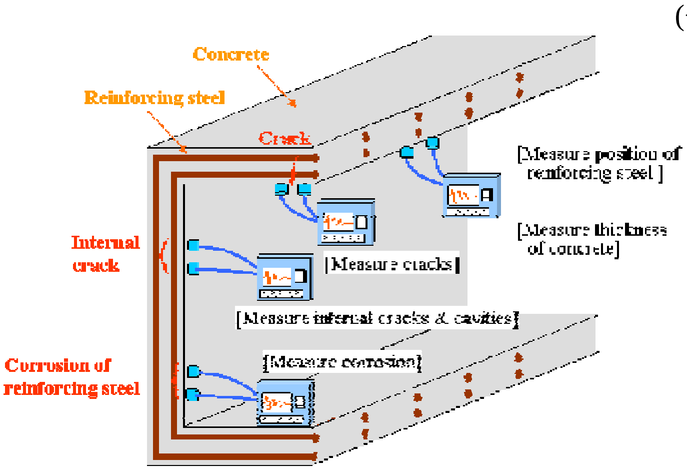


Fig.4 Main items in a detailed cable tunnel inspection

Next, detailed inspections are performed when the cause of the degradation cannot be determined visually or when it is otherwise necessary to determine the cause. Detailed inspections are used to judge whether countermeasures are necessary, or to select an appropriate repair method based on the cause of the degradation. Table 1 provides a detailed explanation.

Periodic inspections are mainly visual, and look for signs of degradation in the concrete surface, such as cracking, water leakage, rebar exposure, etc. In contrast, detailed inspections confirm degradation inside the concrete, such as cracking, internal damage or rebar corrosion, by destroying part of the concrete to obtain core samples. In addition, detailed inspections also confirm the advance of material degradation using chemical analysis methods.

Detailed inspections are particularly important when evaluating the safety and long-term reliability of facilities that show visible signs of degradation. Figure 4 shows the main detailed inspection items. The ability to perform these inspections in a non-destructive manner is important for ensuring the safety of facilities in an advanced stage of age-related degradation.

This need can be illustrated using the medical analogy of a doctor making a diagnosis. Inspecting (<=> examining) the inside of the concrete (<=> the inside of the body) by internal means as well as visually (<=> by inquiry) is the most effective way to diagnose a facility. In addition, non-destructive inspection technology (<=> non-invasive examination techniques) is necessary to reduce the burden on superannuated structures (<=> patients), and to perform facility inspections safely, etc.

3. Current State and Issues Concerning Non-Destructive Inspection Technology

Typical non-destructive inspection technologies that are commercially available can be grouped into the tapping method, impact-elastic wave method and ultrasonic method, which use elastic waves; the electromagnetic wave and electromagnetic induction methods, which use electromagnetic waves; the rebound hammer method, which uses the degree of reaction; and the self-potential method, which measures

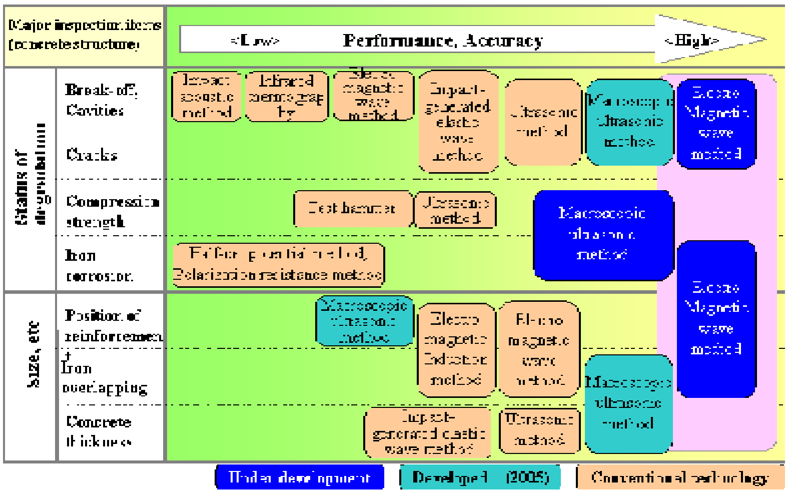


Fig.5 Types of non-destructive inspection and future development targets

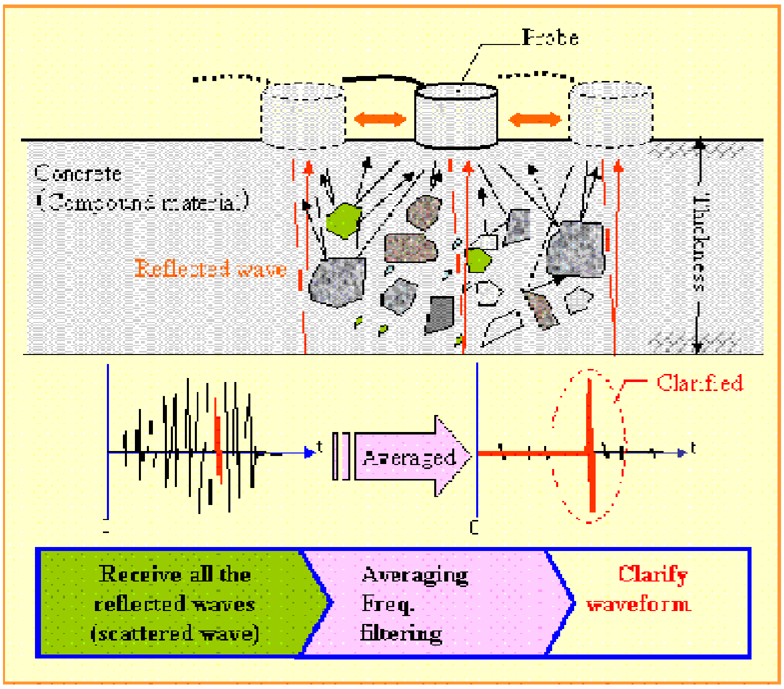


Fig.6 Concept of macroscopic ultrasonic inspection technology

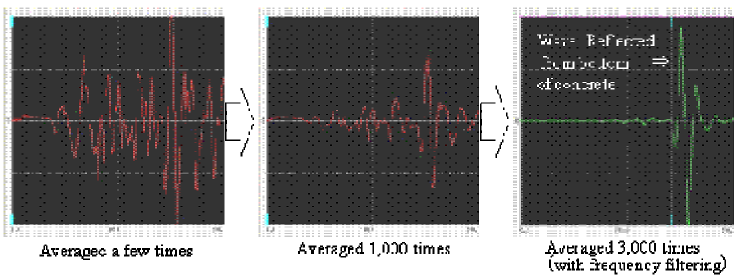


Fig.7 Example of averaging processing (measuring thickness of concrete)

electrical characteristics.

Figure 5 shows the concrete structure inspection items to which these general methods can be applied, and maps the approximate superiority of each method in terms of performance and accuracy.

1Number footnotes consecutively with superscript numbers.

As seen in this figure, the items that can be measured using these typical methods are often limited by technical characteristics and other factors, making it necessary to use different technologies to inspect structures according to the degradation phenomena. In addition, there are also issues such as limits to measurement conditions and unstable accuracy in some environments.

The most promising technology for resolving these issues, and one that that can also make use of the know-how accumulated thus far by various research centers and the NTT Group is that comprising ultrasonic methods. The NTT Group is therefore currently pursuing R&D centered on ultrasonic methods.

The NTT Group is aiming to achieve the following three items:

(1) Technology that can be applied to various measurement items using a single apparatus.

(2) Technology that can measure degradation with an accuracy equivalent to that of destructive inspections.

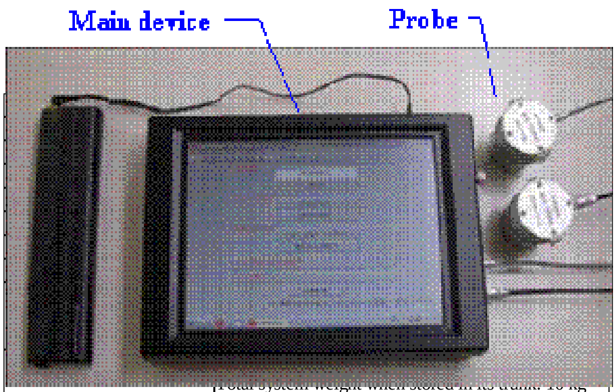
(3) Measurement technology that is not affected by the high humidity environments inside underground facilities.

Realizing items (1) through (3) will make it possible to eliminate destructive inspections in the field, reduce facility inspection costs, reduce repair costs (repeated repairs) by improving inspection accuracy, and contribute to increasing facility safety.

4. Apparatus

4.1 Overview of the Macroscopic Ultrasonic Method

The typical ultrasonic method used to investigate concrete structures emits an ultrasonic wave into



Operating environment	Operating temperature 0 to 40°C, drip-proof

Fig.8 RC degradation diagnosis system

Fig.9 Example of use for measurement

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 equip. • Confirmation of material dimensions when construction completed

the concrete, and diagnoses the internal condition of the concrete from the transmitted waves that propagate through the concrete and the reflected waves from substances that have different elastic properties.

However, when ultrasonic waves are emitted into concrete, the effects of water, air bubbles and aggregate contained in the concrete cause the ultrasonic waves to scatter, so the received ultrasonic waves contain high noise levels. This makes it difficult to determine the target reflected waves from rebars or the concrete bottom surface, so accurate diagnosis is not possible.

On the other hand, the macroscopic ultrasonic method is able to detect the target reflected waves, and only those waves, in approximately 10 seconds. This is achieved by performing averaging several thousand times while moving the ultrasonic probe, and eliminating noise using a frequency filter that can detect the desired component waves (Fig. 6).

Figure 7 shows the ultrasonic reception waveform when measuring the concrete thickness. This shows that a clear reflected wave from the concrete bottom surface can be obtained by performing averaging 3000 times and applying frequency filter processing.
Macroscopic here means that the target reflected wave is not found in a pinpoint or microscopic manner, but rather that all reflected waves, including scattered waves and other noise, are received.

4.2. Reinforced Concrete (RC) Degradation Diagnosis System

The RC degradation diagnosis system developed in 2005 is a non-destructive inspection system that uses the macroscopic ultrasonic method.

Fig. 8 shows the overall system, Fig. 9 shows the measurement conditions, and Table 2 gives the measurement items and examples of use.

4.2.1 Specifications

Fig. 8 shows a photograph of the system, and Table 3 lists the main specifications.

The system has a drip-proof structure that can withstand the operating environment inside cable tunnels (high humidity, water drips), and is battery-operated, so a 100 V power supply is unnecessary. In addition, the entire system can be contained in a case so that it can be carried into cable tunnels.

4.2.2 Addition of an automatic setting function for measurement parameters

One issue for ultrasonic measurement is the measurement parameter settings. These measurement parameter settings have been input based on the measurer's experience, which created variance in the setting values between measurers, and putting in the settings took time.
The newly developed system compares and verifies the measurement parameters with past test results,

Table.3 RC degradation diagnosis system hardware specifications

and then automatically sets the optimum measurement parameters or provides them as initial values, thus shortening the measurement time.

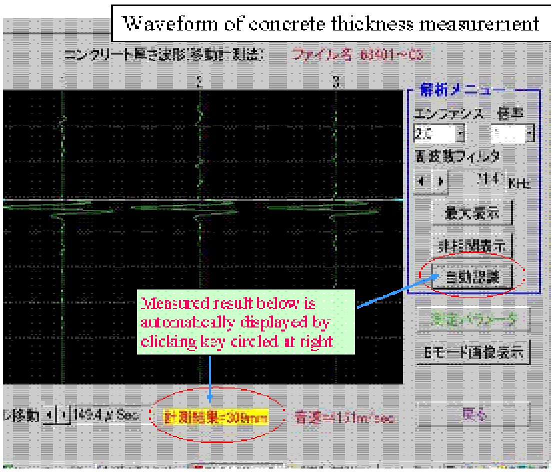
Table 4 shows the measurement parameter setting ranges.

The initial voltage value is automatically set to the optimum value by making a tentative measurement. Concretely, this is done by successively lowering the voltage from the initial value of 500 V, and

Table.4 RC degradation diagnosis system measurement parameter setting ranges

setting the voltage value to the first voltage that falls below half of the maximum amplitude so that the maximum amplitude of the ultrasonic waveforms that can be measured does not overflow.

The frequency filter default value is automatically set to the optimum value based on past test data and other information. For example, when measuring the concrete thickness, the frequency decreases as the thickness increases, and vice versa. This frequency is 50 kHz for a thickness of 1 m. Entering the “estimated thickness” allows the operator to obtain a more accurate value.



g.10 Display of values of results of automatic recognition

As shown in Figure 10, by clicking [Auto Recognize], the system automatically recognizes the measured ultrasonic waveform and displays the measurement results in numeric form.

This not only shortens the work time, but makes a high level of specialized knowledge unnecessary, thus minimizing measurement error due to

Table.5 Measurement items and automatic recognition methods

differences in the technical skill levels of measurers.

4.2.3 Development of a geometric waveform pattern recognition method

An additional issue for ultrasonic measurement is that the accuracy of reading ultrasonic waveforms is affected by the skill level of the measurer. This is because confirmation of ultrasonic waveforms and the decision as to whether or not the waveform thought to be the measurement subject can be

Table.6 Measurement results (concrete thickness)

recognized are entrusted to the measurer.

The newly developed system incorporates methods for recognizing waveform patterns based on past test result data, and displays highly accurate measurement results. This makes it possible to eliminate measurement error due to differences in the technical skill level of measurers.

Table 5 lists the measurement items and automatic

Table.7 Measurement results (cracking depth)

recognition methods.

The Hough Transform processing used in the surface placement method for measuring sonic speed is applied as image processing technology. This is a type of edge detection method mainly used to detect the geometric regularity (straight lines, circles, etc.) of objects.

Tables 6 and 7 show example results obtained using this system. The error from the actual measurement values averages 2.5% for concrete thickness, and 2.2% for cracking depth. This confirms that highly accurate measurements are possible.

5. Conclusion

The macroscopic ultrasonic method is a revolutionary technology for eliminating high noise levels caused by scattered waves inside concrete. Furthermore, the addition of automated parameter settings and waveform pattern recognition to this technology has been confirmed to enable highly accurate measurement of concrete thickness, cracking depth, rebar covering depth, cavities and other items.

6. Future Plans and Issues

When judging the yield strength (drop in strength) of concrete structures, it is also necessary to understand the rebar corrosion conditions and the compressive strength. Efforts are currently underway to develop technology for measuring these items using the macroscopic ultrasonic method.

Regarding the measurement of rebar corrosion conditions, concrete test pieces with differing degrees of rebar corrosion were prepared, and the rebar reflected waves were recorded using multiple measuring methods, such as varying the probe intervals. Relative comparison of the frequency spectrums showed that the frequency response differs according to the degree of rebar corrosion (Fig. 11).

In the future, the authors intend to pursue development by repeating fundamental tests and accumulating data with the aim of establishing a measurement method.

This newly developed technology can be used to diagnose degradation and confirm component dimensions for all concrete structures. This means that it can be applied not just to NTT infrastructure facilities, but also to architectural structures such as buildings and public structures such as bridges and tunnels. The authors believe that this technology can contribute to the maintenance and management of current infrastructure, and intend to continue R&D activities in this area.

Measurement item		Automatic recognition method
Sonic speed	Surface placement method	Point at the maximum distance from the reference line (Application of Hough Transform processing*)
	Transmission method	3% of the maximum amplitude value (threshold method)
Concrete thickness		3% of the maximum amplitude value (threshold method)
	S/N ratio	Number of intersections between the 50% line of the maximum amplitude value and the measured waveform => 9 or more = NG
Cracking depth		3% of the maximum amplitude value (threshold method)
Rebar covering depth		None (Automatic recognition is possible, but the results are inconsistent, so manual correction is necessary.)

Test piece	Actual measurement value (mm)	Value measured using newly developed method (mm)	Error from actual measurement values (%)
A	100	99	-1.0
B	203	208	+2.0
C	303	309	+2.0
D	404	406	+0.5
E	502	477	+0.5
F	604	598	-1.0
Average value			2.5 (absolute value)

Test piece	Actual measurement value (mm)	Value measured using newly developed method (mm)	Error from actual measurement values (%)
G	50	52	+4.0
H	100	102	+2.0
I	100	101	+1.0
J	87	88	+1.0
K	72	74	+3.0
Average value			2.2 (absolute value)

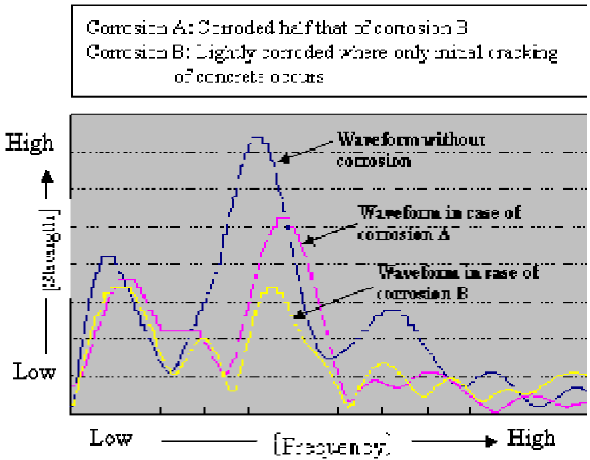


Fig.11 Frequency spectrum of wave reflected from reinforcement