Development of deterioration diagnosis technique (Impact Elastic Wave Inspection Methods) by elastic wave for sewer RC pipes

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[Background of Development]

Sewer pipelines in Japan have reached about 460,000 km (as of the end of fiscal year 2013) in total length, and about 80 percent of those sewer pipes are 450 mm or less in diameter. In order to maintain this huge stock of sewer pipelines in a rational manner, it is necessary to establish a system for inspecting, reconstructing and repairing sewer pipes by methods appropriate for their characteristics.

One characteristic of sewer pipelines is that since sewer pipes are buried in the ground, it is not easy to inspect them. Smaller-diameter pipes are particularly difficult to inspect because they are too small for a human inspector to enter for visual inspection for internal damage such as cracks. Common practice, therefore, is to use a robotized traveling-type in-pipe inspection system equipped with a closed circuit television (CCTV) camera. Inspection results obtainable from such a system, however, are only image data showing the surface condition, and those results lack objectivity because they are qualitative data. Furthermore, CCTV image data needs to be postprocessed manually prior to evaluation, and evaluation results may vary depending on the expertise and experience of inspectors. For these reasons, the development of a quantitative and relatively simple deterioration diagnosis technique has been hoped for.

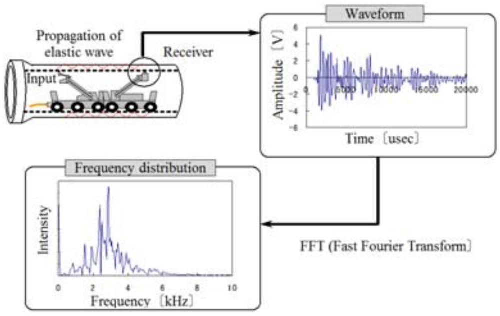
Crack
(Concrete Pipe)

Corrosion
(Concrete Pipe)

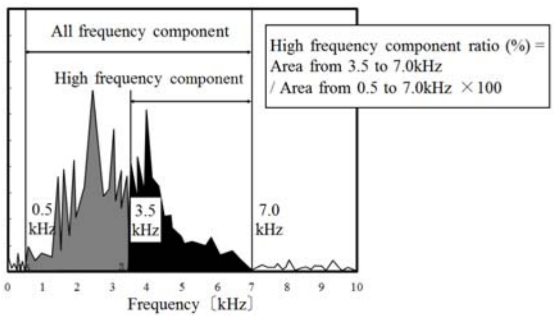
In tackling this challenge, developers have come up with a nondestructive testing method using impact-induced elastic waves. Impact elastic waves are easy to input and contain more low-frequency components than ultrasonic waves. This means that impact elastic waves are less subject to damping and propagate through concrete more efficiently. If elastic waves can be transmitted and received by using a device that can be put into a sewer pipe, it will open up possibilities for deterioration diagnosis by use of quantitative criteria obtained from waveform measurement results. The development process proceeded by following the steps described below. In that process, a total of 20 patent applications were filed and 17 technologies have been registered and patented (patented in five countries besides Japan).

1) Quantification of deterioration through basic experiments

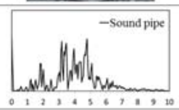
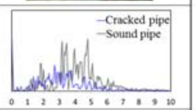
Test specimens were prepared by introducing artificial cracks into concrete pipes, and the waveforms obtained by impacting those specimens with a hammer were compared with the waveforms obtained from intact pipes. By examining the ratio of high-frequency component in the waveform frequency distribution, it was found out that the degree of deterioration (degree of cracking) can be estimated.



Measurement and frequency distribution



Calculation to get high frequency component ratio

	Sound pipe	Cracked pipe
Appearance		
Frequency distribution		
High frequency component ratio	67.3%	38.3%
Remarks	Basic data	Reduction of high frequency component ratio

Difference in high frequency component ratios

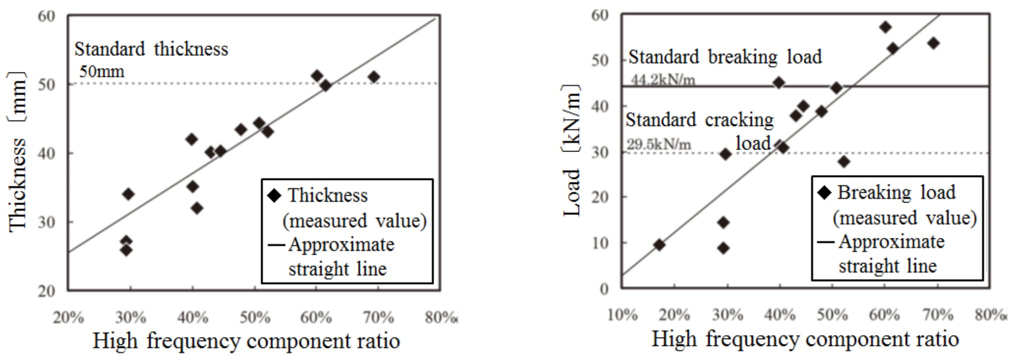
2) Development of in-pipe measuring system

A two-carriage in-pipe inspection robot consisting of a carriage equipped with an impulse-hammer impacting mechanism and a carriage equipped with an acceleration sensor system for waveform acquisition, inspired by an existing in-pipe sewer pipe CCTV inspection system, was developed. The newly developed system is designed to be towed by a CCTV inspection robot.

Construction of inspection robot

3) Reconsideration of quantification criteria

The quantification criteria have made deterioration quantification possible. However, although degrees of deterioration can be quantitatively ordered, those criteria did not output load-carrying capacity, and, therefore, they could not be used for structural calculation for pipe renewal design. For this reason, it was decided to relate pipe deterioration with pipe wall thickness reduction and breaking load. Under this policy, a number of specimens having different wall thicknesses were prepared, and a formula for estimating pipe wall thickness and breaking load from the high-frequency component ratio of received waves was derived on the basis of a large amount of experiment data.



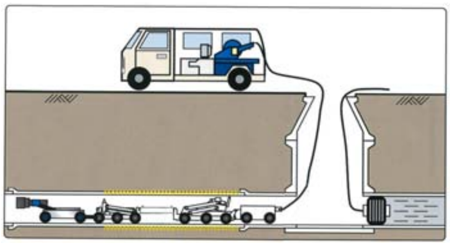
Relationship between high frequency component ratio and pipe wall thickness or breaking load (example of φ 600 mm pipe)

4) Optimization of the inspection robot and the evaluation of applicability under various conditions

Applicability of the inspection robot was evaluated by varying conditions such as burial depth, soil type and in-pipe water level to evaluate the applicability of the robot under real-world sewer pipe conditions. Impact detection time was optimized, and, in order to achieve easy operation, the robot was connected directly to the CCTV camera so that both components of the system can be controlled through single cable connection.

Burial depth	0 m	50 cm (1.66D)	1 m (3.33D)	2 m (6.66D)
Photo				

Experiment for confirming effect of burial depth



Measurement image

Work vehicle and inspection robot

5) Study on ways to utilize indicator data

Two indicators were defined: pipe integrity, which compares the obtained values with the specified values of an intact pipe, and pipe safety, which compares the obtained values with working load values under particular burial conditions. A calculation method that can be used when designing the renewal of an existing pipe has also been developed.

[Economic Efficiency]

The unit cost of inspection is about 2,000 yen/m, which is roughly the same as that of conventional CCTV camera inspection. Although this inspection method requires a certain amount of expense, it also helps reduce construction cost. The reason is that because the method makes possible structural calculation that takes the load-carrying capacity of the existing pipe into consideration, composite pipe construction can be used as a means of sewer pipe renewal. Calculation of the cost of inspection and pipe renewal in one area showed that a 16% cost reduction can be achieved. In order to reduce the cost of inspection equipment, design efforts were made so that the equipment for conventional CCTV camera inspection, such as inspection vehicles, control systems and cables, can be used as much as possible.

[Scope of Application]

At present, the newly developed inspection method is applicable only to reinforced concrete pipes for sewer applications (JSWAS A-1 and JIS A 5372). It is possible, however, to use the method in other fields and for other types of pipe by defining criteria or indicators according to pipe characteristics and acquiring relevant experiment data. It is believed that the new method is a promising inspection technique that can be applied to a wide range of infrastructure pipelines including water supply, irrigation, electricity and gas.

[Contribution to Society]

The newly developed method makes it possible to safely inspect an underground sewer pipe, by remote control from the ground surface, nondestructively and without uncovering the pipe by excavation. Since the load-carrying capacity of the pipe being inspected can be estimated, "pipe safety" under the actual burial conditions can be evaluated. By taking corrective measures in a timely manner at dangerous sites, the collapse of pipes that can cause road failures such as cave-ins can be prevented.