Corrosion Assessment of Aging Drinking Water Pipes by Impact Elastic-Wave Method

Yasuo Kobayashi¹, Yusuke Takahashi¹, Toshio Kamada², Akira Koizumi³ and Masahiro Fujiwara¹

¹ Japan Water Research Center, 2-8-1, Toranomon, Minato-ku, Tokyo, Japan (E-mail: kobayashi@jwrc-net.or.jp)
² Osaka University, 2-1, Yamadaoka Suita-City, Osaka-Pref., Japan (E-mail: kamada@civil.eng.osaka-u.ac.jp)
³ Tokyo Metropolitan University, 1-1, Minami-Osawa, Hachioji City, Tokyo, Japan (E-mail: akoiz@tmu.ac.jp)

Annotation
The majority of the water distribution pipes which take the greater part of Japanese drinking water utilities’ assets are made of iron such as gray/ductile cast iron or steel. It will be necessary to replace most of these pipes due to corrosion in the near future. In general, pipeline assessment which is done before replacement is carried out through digging to take visual observation; however, digging costs and environmental burden due to digging will become a problem. This study therefore undertakes a research into methods of pipeline assessment which reduce the digging necessity. In the study of the Impact Elastic-Wave Method, elastic-waves were applied to cast iron pipes whose external surfaces were in various states of corrosion (pitting, partial, uniform, etc.); the frequency component of the received waves showed that there was a tendency for the frequency component of the waves for corroded iron pipes to be distributed in a lower range than sound pipes. In addition, it also showed that it is possible to discriminate the thickness reduction of approximately one mm. These results demonstrate the possibility of applying this method to pipeline assessment without or with minimum digging.

Keywords
Impact Elastic-Wave Method, iron pipe corrosion, pipeline assessment

Main text
(i) Introduction
The drinking water distribution pipelines extend approximately 580,000km in Japan which make up the greater part of drinking water utilities’ whole assets. The pipelines of approximately 380,000km consist of iron pipes such as gray cast-iron pipes, ductile cast iron pipes and steel pipes. In the near future it will be necessary to replace the most part of these pipes due to corrosion with aging. In order to estimate the trends of the aging pipes in the future, the Japan Water Research Center (JWRC) calculated the “rate of aging distribution mains”, i.e. the rate of the total aging water distribution pipelines length which has reached their statutory useful life of 40 years to the total length of whole pipelines. The results of calculation show that while the rate is 7.55% as of 2008, this will rise to 40.7% in 2020 because the lots of pipelines which were installed between 1955 and 1965 will reach their statutory useful life all at once. Aging pipes that have exceeded their statutory useful life are not all necessarily deteriorated. However, because corrosion generally tends to have progressed in such pipes, the drinking water utilities must systematically replace such aging pipes in order to prevent the leakages from aging pipes, and to ensure a stable and sustainable water supply.
When the drinking water utilities set out plans for replacement of pipelines, the target pipelines are extracted according to the pipe material, the type of joint, installation year and ground condition, etc. Then, the utilities finally dig the ground and expose the pipe surfaces, and the state of pipes can be confirmed by visual observation. However, this method – direct diagnosis method – will cause a problem of digging costs and the environmental burden in the near future as the necessity of direct diagnosis increases. Therefore, there is a need for a pipeline assessment/diagnosis technology without digging or with least digging. Thus, a survey and basic research of the methods shown below were carried out in this study in order to establish a pipeline assessment technology which could massively reduce the necessity of digging.

- Impact Elastic-Wave Method
- Eddy Current Test with Magnetic Saturation Method
- Inner Wall Inspection Method using Water-proof Camera
- Others

Although many meaningful outcomes have been obtained as a result of the survey, this paper discusses the Impact Elastic-Wave Method.

This study is one of the outcomes of the joint research - the New Epoch Project - carried out over a three-year period from 2005 to 2007 subsidized by the Ministry of Health, Labour and Welfare and funded by participating companies. [1]

(ii) Methods

1) Basic principles of the Impact Elastic-Wave Method

The Impact Elastic-Wave Method is a method in which elastic waves are inputted to a surface of one end of the target object by inflicting a mechanical impact using a hammer, an iron ball etc., and the elastic waves are received with a sensor of an accelerometer etc., on another end of surface of the same object. The state of deterioration or characteristics of the object can be evaluated in a nondestructive manner using indicators such as the maximum amplitude of the receiving wave pattern, wave pattern decay time and frequency distribution.

The evaluation of deterioration for aging ductile cast iron pipes by this method focuses on the characteristic that when the rigidity of a pipe decreases due to a thickness decrease caused by corrosion, the vibration frequency of the pipe decreases accordingly.

Hence, by applying Fast Fourier Transform (FFT) to the wave pattern obtained after undertaking the elastic wave measurement, the frequency distribution peculiar to the pipe is computed, allowing the deterioration of the aging pipe to be evaluated (Figure 1).

In general, the energy of the elastic waves inputted by the impact is greater than the one of elastic waves oscillated through the electronic operations such as ultrasonic waves. Furthermore, the impact elastic waves contain the major components of long wavelength. These characteristics of the impact elastic waves mean little influence from the decay or scattering in rigid object, and it is
possible to extend the transmission distance of the elastic wave, and to measure large-scale structures as a target.

2) Objects of Study
This study considered the applicability of the Impact Elastic-Wave Method to deterioration assessment of iron pipes according to the following items.
(1) Applying to artificially cut sample pipes with several uniform thickness
(2) Applying to artificially cut sample pipe with simulated corrosion pitting
(3) Applying to excavated pipes with partial corrosion on external surface
(4) Applicability of the method to evaluate aging ductile cast-iron pipes

3) Experiment method
The outline of the experiment is shown on Figure 2. The installation situation of cut sample pipe, locations of the impact and the accelerometer sensor installed on the cut sample pipe are shown in Figure 2; the impact was inflicted at a location of 100mm from the end of the pipe, and the accelerometer sensor was located at 100mm from the other end. The accelerometer sensor with a response sensitivity of 0.003-10kHz for receiving elastic waves was used. The receiving wave pattern was mediated through an amplifier, and recorded on computer using a high-speed wave pattern collection system. The maximum amplitude of the receiving wave pattern and wave pattern decay time was measured from the receiving wave pattern obtained through the above method, and the frequency distribution is measured using FFT. [2]

![Figure 2: Experiment outline](image)

(iii) Results and Discussion
1) Applying to cut sample pipes with several uniform thickness
Cut samples are two types of lining ductile cast-iron pipes; one is with mortar lining and another is with epoxy powder-based coating. The specification of these samples was; nominal diameter of 150mm, length of 1000mm, and they were scraped outer surface so as to create a uniform thickness of 2.6mm~7.5mm. Impact was inflicted to the pipes and the frequency distribution of the receiving waves was measured. The results showed that for both the pipes, pipe with the mortar lining and pipe with the epoxy powder-based coating, as the pipe thickness decreased the peak frequency diminished. It was also confirmed that for both the pipes, the peak frequency varies according to pipe thickness (Figure 3).
2) Applying to cut sample pipe with simulated corrosion pitting
Impact was inflicted to a cut sample of ductile cast iron pipe (nominal diameter: 300mm; length: 1500mm) with a drilling hole (diameter: 100mm) to simulate corrosion pitting, and to a sound sample pipe (no hole drilled), and the frequency distribution measured. The results showed that the frequency component of the receiving waves for the pipe with a hole was distributed in lower range than that for the sound pipe Figure 4).

3) Applying to excavated pipe and pipe with simulated corrosion
The sample pipes were ductile cast iron pipes (nominal diameter: 150mm; length: 1000mm; time in service since installation: between 27 to 34 years) which partial reduction of thickness due to corrosion had occurred on the external surface. These were excavated and supplied by drinking water utilities. Impact was inflicted to the sample pipes and the frequency distribution of the receiving waves was measured. The results showed that the peak frequency of pipes with thickness reduction moves to lower range, and the presence of rust on surface had no influence on the measurement precision (Figure 5).
4) Applicability of the method to evaluate aging ductile cast-iron pipes

Based on the results from the study shown above, the example of 150mm-diameter, 1000mm-length ductile cast iron pipes were ranked according to degree of soundness, the relationship between these ranked levels and the peak frequencies obtained from the Impact Elastic-Wave Method is arranged and shown in Table 1, taking the criteria for the replacement of waterworks facilities by Japan Water Works Association as a reference [3]. As the table shows, since a correspondence relationship can be seen in the various models’ between the peak frequencies and the degree of soundness, the results from the Impact Elastic-Wave Method indicate that it is possible to discriminate a ranking of soundness of iron pipes with partial reduction of thickness and so on [2].

<table>
<thead>
<tr>
<th>Soundness Level A</th>
<th>Soundness Level B</th>
<th>Soundness Level C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pipe thickness(mm)</td>
<td>7.5-5.6</td>
<td>5.5-3.6</td>
</tr>
<tr>
<td>Model name and [minimum thickness (mm) - peak frequency (Hz)]</td>
<td>Sound Pipe [7.5-693]</td>
<td>2-A [5.5-576]</td>
</tr>
<tr>
<td></td>
<td>Pipe scraped by 1mm [6.5-556]</td>
<td>Pipe scraped by 2mm [5.5-527]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2-B [4.5-546]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pipe scraped by 3mm [4.5-507]</td>
</tr>
<tr>
<td>Peak frequencies (Hz)</td>
<td>-550</td>
<td>549-500</td>
</tr>
</tbody>
</table>

* Average thickness is the average value of the pipe thickness taken at 20 points along the excavated pipe.

Figure 5: Frequency distribution in excavated pipes with partial reduction of thickness before and after rust removal
Conclusions
In this study, the following results were obtained from the experiments using cut sample pipes and excavated pipes regarding the applicability of the Impact Elastic-Wave Method to the pipeline assessment of aging and corroded iron pipes.

(1) It is possible to detect pitting corrosion and partial thickness reduction due to corrosion through this method.
(2) It is possible to apply this method regardless of the presence of iron rust on the pipe surface.
(3) This method possesses sensitivity to detect thickness reduction to the 1.0mm of a 7.5mm-thick cut sample pipe, and there is a possibility to distinguish 1.0mm differences in thickness reduction.
(4) There is certain regularity in the decreasing trend in the peak frequency.
(5) It is possible to quantitatively evaluate thickness reduction of the pipes by measuring the peak frequency using the Impact Elastic-Wave Method.
(6) This method can distinguish a certain degrees of soundness of iron pipes using peak frequencies; even pipes have partial thickness reduction due to corrosion on the external surface.

In future, it will be necessary to confirm the applicability of this method for assessment of pipes installed in the ground and pipes actually in service, through field studies.

The authors would like to express their gratitude to all New Epoch project members who worked with us in undertaking the study.

References