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A METHOD FOR ASSESSING THE CROSS-SECTIONAL STIFFNESS OF BURIED REINFORCED-CONCRETE PIPE

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ABSTRACT

The internal loading method (ILM) has previously been proposed as a non-excavatory and non-destructive method for assessing the strength of sewage and agricultural pipes. In the ILM, an internal loading device is inserted into a reinforced concrete (RC) pipe, whereupon an outward load is applied and the resulting perpendicular deformation (relative to the load axis) is measured. The effectiveness of this method was investigated by performing a basic assessment of an artificially damaged RC pipe with

cracks. A reduced cross-sectional stiffness was detected via smaller gradients of the load–deformation curves, which can be regarded as an indication of lower strength. In the present paper, the ILM is applied to excavated (i.e., previously buried) and sound (i.e., unused) pipes and their cross-sectional stiffness values are compared. Of the two

assessed excavated pipes, one has deteriorated greatly whereas the other has deteriorated very little. Comparing the load–deformation characteristics of the various specimens (specifically, the loading force for a certain amount of deformation) reveals differences in stiffness of up to 50% between the excavated and sound pipes. It is found that the ILM can assess quantitatively the deterioration of an RC pipe that is still in service. The internal loading device used in this research has been operated manually, and there is considerable interest in automating (mechanizing) the process. To allow assessment of small- and medium-diameter pipes that cannot be accessed directly by people, we also examine issues related to automation. Since the loading device is supported by wheels other than the loading rod, the pipe deformation is impeded and a smaller gradient of the load–deformation curve is obtained.

Keywords: Reinforced concrete pipe, cross-sectional stiffness, load-deformation

INTRODUCTION

In Japan, the essential stock of agricultural pipes extends to 7,500 km and the total length of sewage pipes is 470,000 km. Most of these pipes were laid in Japan's period of high economic growth and are now suffering from deterioration and fatigue after a long period of service. Accidents caused by deterioration and fatigue are increasing year after year, making it urgent to build a system for maintaining pipe functions in a timely and proper manner [Ministry of Agriculture, Forestry and Fisheries (MAFF) 2017]. In particular, aging pipes may be a major cause of water leakage, the collapse of roads and streets, and other unexpected accidents, requiring urgent measures for functional maintenance [MAFF 2018]. To choose and implement the most appropriate maintenance method, it is important make it possible to evaluate the current proof stress of existing underground pipes exactly. Therefore, for this purpose, methods based on impact elastic waves and ultrasound have been studied and developed [e.g., Kamata et al. 2012; Koizumi et al. 2012]. However, it is very difficult for such methods to cover all pipe types, pipe diameters, and installation conditions, and works to develop a better evaluation method is ongoing. Against this background, the authors have proposed a new internal loading method (ILM) for evaluating the proof stress of underground pipes [Hyodo et al. 2015, 2018]. Studies of this approach to date have focused on proving its effectiveness at evaluating PVC pipes damaged by quasi-cracks. Those studies have shown that, because damage causes reduction in stiffness, the gradient of the load–deformation curve can be used as an evaluation index for the proof stress of a pipe. A similar evaluation has been conducted on reinforced concrete (RC) pipes, thereby confirming the effectiveness of this evaluation index [Hyodo et al. 2018]. However, these studies were of sound (i.e., unused) RC pipes and were conducted by operating the internal loading device manually (such a device is referred to hereinafter as a manual device). Implementing the ILM in an actual site containing pipes whose diameters are 700 mm or less (thereby preventing human access) requires consideration of an automated internal loading device (referred to hereinafter as an automated device) as the next step.

For this reason, this research involved excavating buried pipes that were in actual use and evaluating their cross-sectional stiffness. We also studied the use of an automated device manufactured in preliminary work to evaluate the proof stress of pipes, and performed a comparison between the manual and automated equipment.

OUTLINE OF INTERNAL LOADING METHOD

Figures 1 and 2 show the internal loading device and the concepts of ILM, respectively. The vertical loading shaft was equipped with a load cell (LCL-M-20kN, 0.15% rated output, Nippon tokushu sokki) that could measure up to 20 kN, while the horizontal displacement measuring shaft was equipped with high-sensitivity displacement gauges (CDP-10, 0.1% rated output) that could measure to a threshold of 0.001 mm. Loading was carried out by turning the bolt/nut located as shown in the center of Fig. 1 so that the loading shaft equipped with the load cell extended in the vertical direction. A steel jig measuring 20 mm long, 20 mm wide, and 25 mm high was provided on the loading shaft so that the loading area on the pipe were the same. This internal loading device had a pantograph structure. The center (at which deformation should be

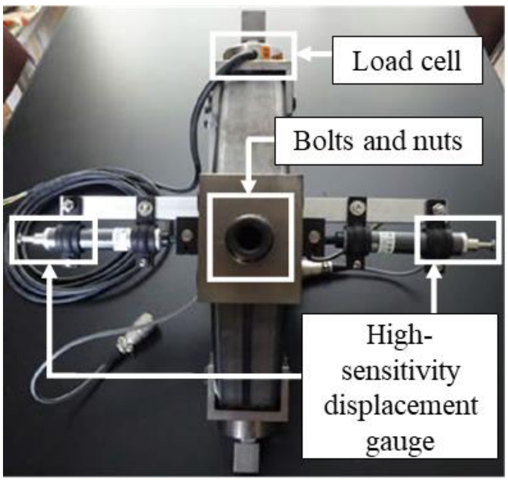

Figure 1. Outline of internal loading device.

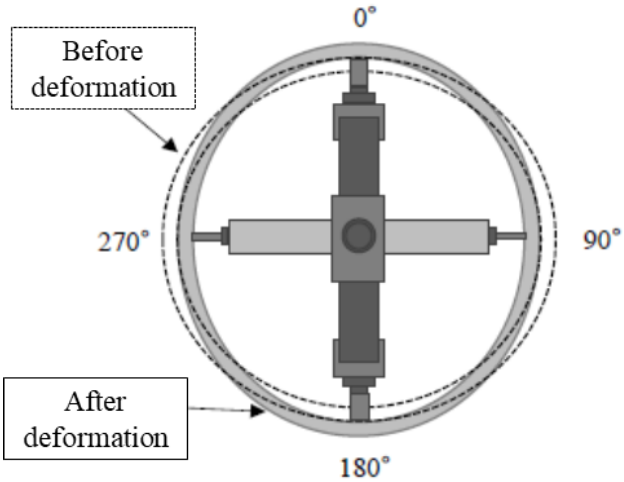

Figure 2. Internal loading device applying a load to a pipe.

measured) of the pipe was displaced as the pipe was deformed. The internal loading device was configured to have its center part moveable (or slidable) vertically, thereby enabling constant measurement of the pipe diameter. In addition, as shown in Fig. 2, the internal loading device exerted a load vertically (0° and 180° directions) and measured an amount of horizontal deformation (90° and 270° directions). The stiffness of the cross-section with no torsion (referred to hereinafter as the section stiffness) was evaluated from the load–deformation relationship given by measuring the amount of horizontal deformation under a vertical load from the pre-deformation shape indicated in Fig 2 by dashed lines to the post-deformation shape indicated by solid lines.

However, since the internal loading device applied a load on two points, namely the top and bottom of the pipe, the entire apparatus tended to rotate about the loading shaft when the bolt/nut was turned. To avoid such rotation, data from high-sensitivity displacement gauges mounted on the right and left sides were used to check for device rotation. Upon being installed inside the pipe, the internal loading device was set to apply an initial load of 800 N to secure itself. Both the load and the deformation were reset to 0 N and 0 μm, respectively, when the measurements commenced.

Table 1. Loads exerted on reinforced concrete (RC) pipes.

Pipe	Load conditions			
	0/3Fc (initial)	3/3Fc	3.5/3Fc	4/3Fc

*“Fc” indicates cracking load of 21.6 kN/m (52.5 kN/pipe) by Japanese Industrial Standards A 5372

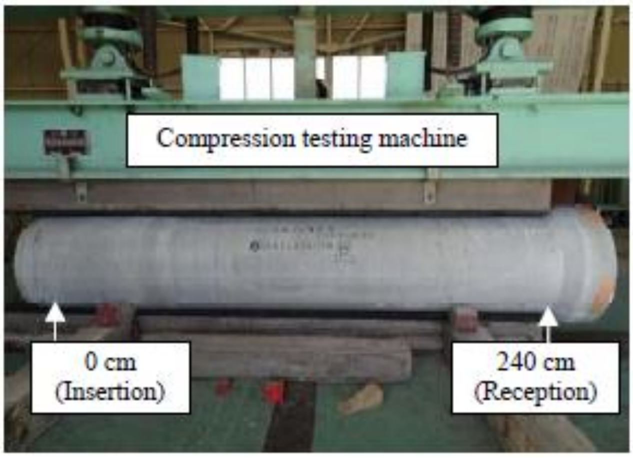

Figure 3. Compression testing machine applying a load to a pipe.

EXPERIMENTAL METHODS AND RESULTS

Cross-Sectional Stiffness of Cracked RC Pipes

Applying Load to Pipe Specimen: First, we evaluated the behavior when the cross-sectional stiffness of a sound pipe was reduced by cracking. The pipe specimen was damaged in accordance with the external pressure test described in JSWAS (Japan Sewage Works Association Standard) A-1 “Centrifugal reinforced concrete pipes for sewerage” with reference to a cracking load of Fc = 21.6 kN/m (52.5 kN/pipe) as described in JIS (Japanese Industrial Standards) A 5372 (Recommended specification for reinforced concrete products: 3-2 Centrifugal reinforced concrete) [Japan Hume Pipe Association 2018]. Table 1 describes the loads applied to the pipe and Fig. 3 shows how a load was applied. Having been subjected to a load, the pipe was removed from the external pressure testing machine for measurement of load relative to deformation by the ILM with the reception opening raised off the ground. After the measurement, the external pressure testing machine was again used to apply a load to the pipe and the load relative to deformation was measured using the ILM. This was repeated until cracks occurred on the pipe, the load–deformation relationship thus having been measured both before and after the cracks occurred. Because the measurement was intended to evaluate the history of the load relative to the deformation using the same pipe, the contact surface between the external pressure testing machine and the pipe was configured to be located at the same position under the various loading conditions.

Section Stiffness of Pipes Cracked By Compression Testing Machine: Fig. 4 shows the relationships between the load required for 30 µm of deformation and the measurement position for current JIS-compliant pipes. Damage by applying various loads cracks (of width 0.04 mm) occurred at 3.5/3Fc, showing that the load required for a predetermined deformation decreased significantly compared with that at 3/3Fc. The predetermined load decreased by approximately 30% at the section between the 0 and 120 cm positions, whereas it decreased by approximately 5% at the section between the 160 cm and 200 cm positions. Comparing 3.5/3Fc (following the occurrence of visually identifiable cracks) and 4/3Fc (at which more load is exerted), it is shown that the load required for the predetermined deformation is equal at most of positions, except the 160 cm and 200 cm positions. This is because the pipe specimen used in this experiment had cracks that occurred at 3.5/3Fc extending on its bottom to the 120 cm position from the insertion opening and also had another cracks occurring near the reception opening. In other words, as identified visually, it was

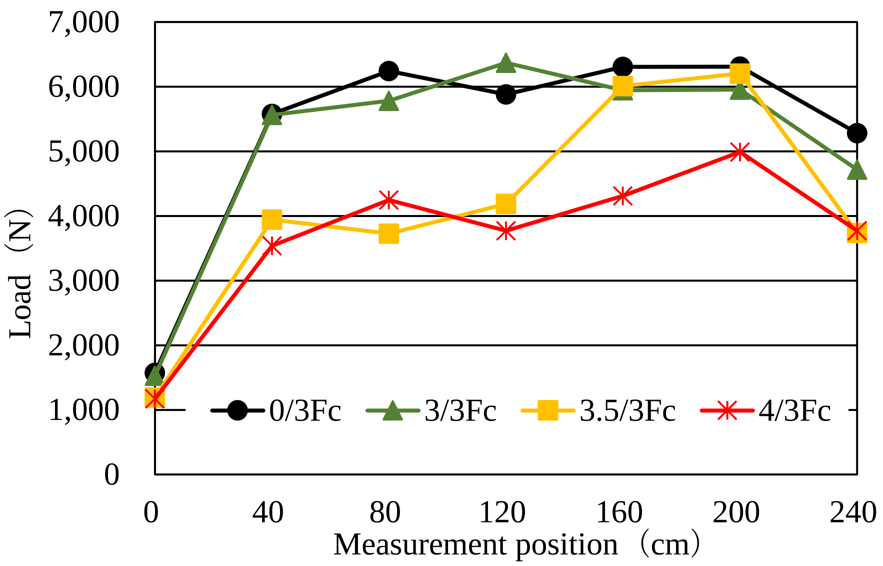

Figure 4. Relationship between load for 30 µm deformation and measurement position for RC pipes complying with current JIS for each load condition.

conceivable that cracks occurring at the insertion opening having the lowest load-bearing ability did not extend to the whole length of the pipe at 3.5/3Fc, but did extend wholly at 4/3Fc, thereby changing the behavior.

Cross-Sectional Stiffness of Excavated Pipes

Applying Load to Pipe Under Specimen: For the pipe with minimal damage, we selected one that had been laid 46 years previously and that showed neither cracks nor pipe thinning either internally or externally. The details of another pipe with large damage were unknown, but cracking and the reduction in pipe thickness were obvious. Both pipes were RC pipes that were used for agricultural purposes and the difference in degree of deterioration was clear.

Decrease in Cross-Sectional Stiffness of Excavated Pipes: The pipe with minimal damage was not confirmed to have lower cross-sectional stiffness than that of a sound pipe (Fig.5). The performance of the minimally damaged pipe was not degraded regarding external pressure, elastic modulus, and pipe thickness compared with a sound pipe, and the former appeared to have an equivalent cross-sectional stiffness.

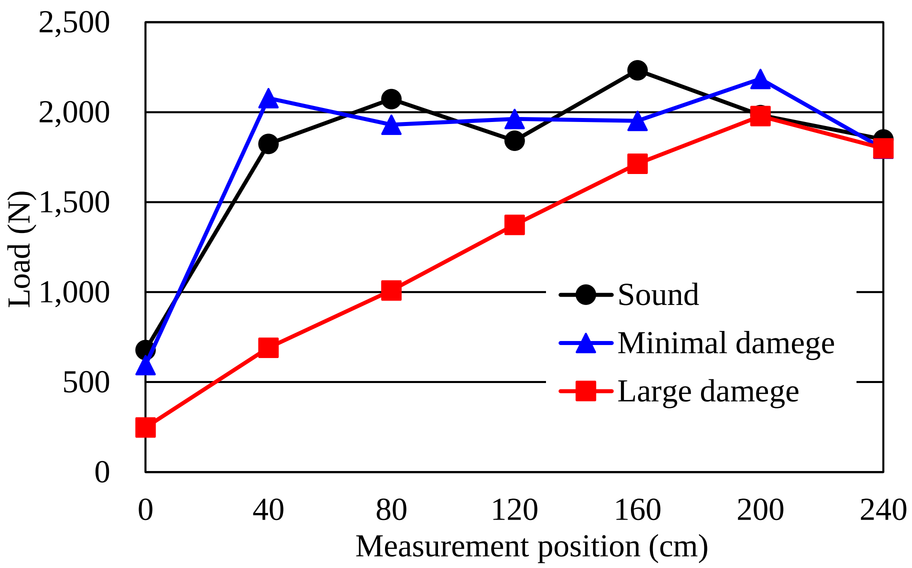

Figure 5. Relationship between load for 30 μm deformation and measurement position for pipes with various degrees of damage.

Detailed evaluation of the physical properties of this pipe is planned for the future. By contrast, it was confirmed that the pipe with large damage had a greatly reduced cross-sectional stiffness compared to a sound pipe. At the receiving side (200–240 cm) where the pipe thickness is large, no decrease in cross-sectional stiffness was confirmed, but the cross-sectional stiffness was reduced by roughly 50% in the vicinity of the insertion opening (0–80 cm). It is thought that this is due to the decrease in the pipe thickness and the decrease in the second moment of area due to cracks.

Evaluation of Cross-Sectional Stiffness of RC Pipes by Automated Internal Loading Device

Outline of Automated Internal Loading Device: Figure 6 shows the automated internal loading device. Like the manual device, the automated device had a pantograph jack structure. The load cell provided on the loading shaft and the high-sensitivity displacement gauges provided on the displacement measuring shaft were the same as those on the manual device. Loading was controlled by a motor mounted in a black cylinder. Like the manual device, the loading shaft and the displacement measuring shaft consisted of independent mechanisms. When installed inside the pipe, the automated internal loading device was towed by the self-propelled TV camera shown in Fig. 6. Upon reaching the target position, the device stretched its retracted

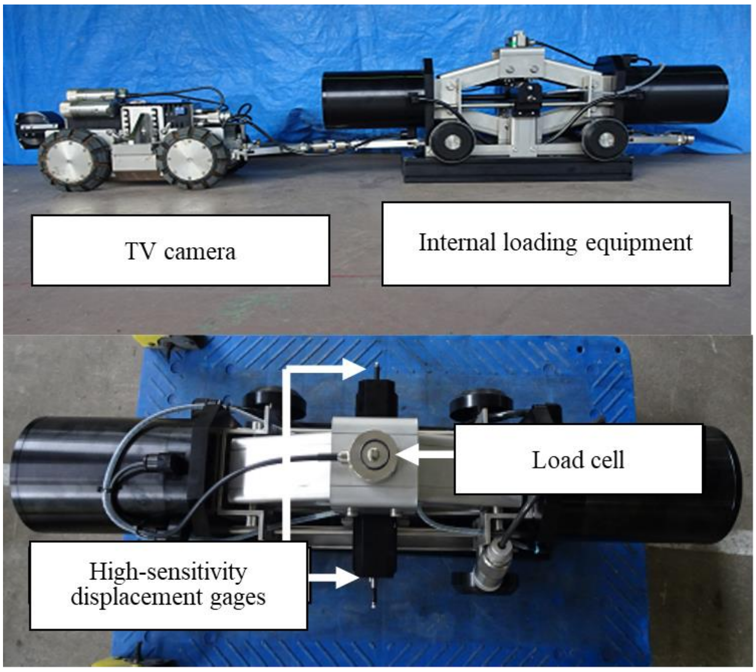

Figure 6. Photographs of internal loading device.

pantograph jack to apply an initial load of 800 N intended to prevent rotation, as was the case for the manual device. After applying the initial load, the right-hand and left-hand displacement gauges were extended to come into contact with the inner measuring surface of the pipe. With this arrangement, the load and deformation were read from 0 N and 0 μm, respectively, when measurement began.

Evaluation of Cross-Sectional Stiffness by Automated Internal Loading Device: Figure 7 shows the load–deformation relationships given by the manual and automated devices. The coefficient of determination was used to evaluate the linearity of the load – deformation relationship, and we obtained $R^2 = 0.999$ with the manual device and $R^2 = 0.990$ with the automated device. These results confirm a very strong linearity between load and deformation. The load–deformation gradient was 165.1 N/μm with the manual device and 207.5 N/μm with the automated device, indicating a difference of 20%. The difference of 20% lies outside the range of measurement error based on past studies [Hyodo et al. 2018] using the manual device, which showed differences up to 5% when measurements were conducted on the same pipe and at the same position.

Specifically, as shown in Fig. 2, the manual device and the pipe were in contact with each other at 0° and 180°. By contrast, as shown in Fig. 8, the automated device had two loading points (0° and 180°) like the manual device but was also in contact with the pipe at its four wheels. For this reason, both ends of the loading shaft and the four wheels (six points in total) are thought to share the load. Pressure sheet, which was designed to make coloration in red when subjected to a load of 130–300 MPa was used in this experiment. It showed coloration in red at all four wheels, showing that the load exerted through the upper loading jig was distributed to the wheels as well as to the lower loading jig. Figure 7 shows that the manual and automated devices produced similar data between 0 and 1,000 N and different data after 1,000 N. The automated device gave a load–deformation gradient of 174.7 N/μm ($R^2 = 0.993$) between 0 and 1,000 N and 242 N/μm ($R^2 = 1.000$) between 1,000 and 3,000 N. The former gradient is 5% higher than the manual device's load–deformation gradient of 165.1 N/μm but is roughly similar. The reason of this difference was not identified, but it is conceivable that the wheels shared part of the load between 0 and1,000 N, resulting

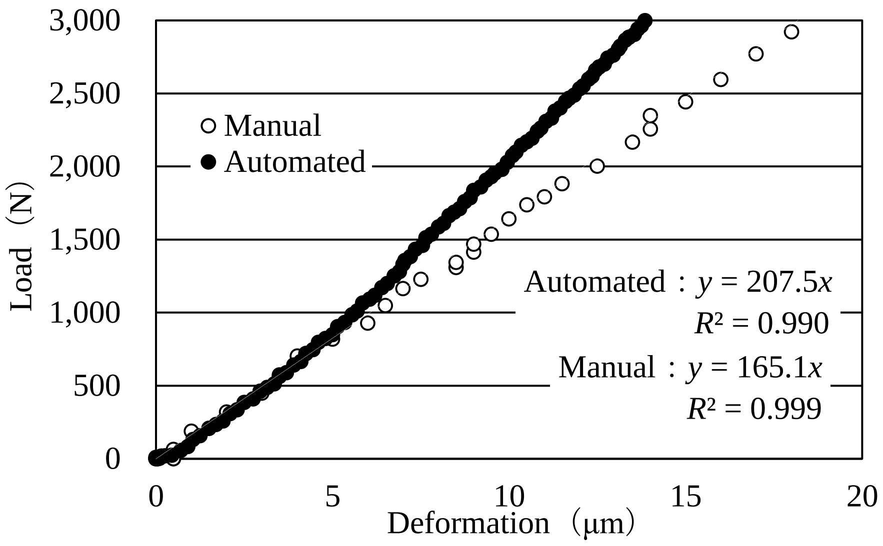

Figure 7. Relationships between load and deformation with manual and automated devices.

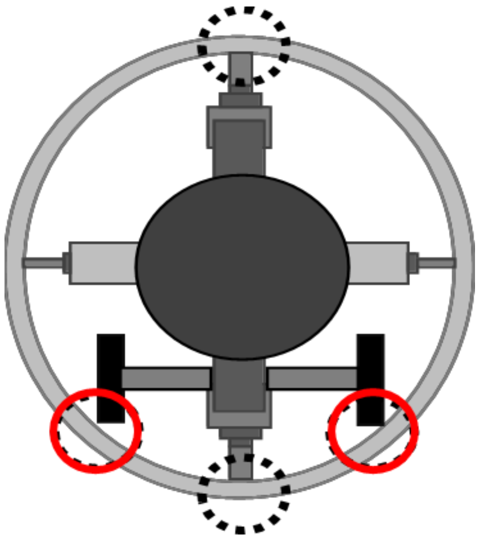

Figure 8. Positions of contact between pipe and automated device.

in a greater load required for deformation. All the wheels shared the load equally between 1,000 N and 3,000 N, thereby ensuring the approximate linearity of the data, but it is conceivable that the load exceeded that of the manual device. This seems to have been due to the fact that the wheels of the automatic device bear some of the load at the time of loading as shown in Fig. 8.

CONCLUSION

In the agricultural and sewage pipelines, it is not established as a method for evaluating strength. From this background, we have been studying mechanism of the ILM in previous studies as a method for evaluating strength of buried pipe. In this research, the ILM was applied to RC pipes that were cracked pipe specimen conditions and those that had been buried for actual use. For practical applications, we also automated the internal loading device and extract an it's problem. The results obtained are summarized below.

1) The ILM was shown to be able to evaluate the cross-sectional stiffness of sound and cracked RC pipes using direct indices. In particular, when the cracks could be confirmed visually, it was possible to detect that the cross-sectional stiffness was greatly reduced.
2) Although a long time had elapsed since being laid, the buried RC pipe with minimal damage (whose physical properties were roughly similar to those of a new pipe) had the same cross-sectional stiffness as that of the new pipe. By contrast, a buried RC pipe (whose physical properties had presumably deteriorated greatly compared with those of the new pipe) had a greatly decreased cross-sectional stiffness. ILM clearly evaluated this difference.
3) The automated internal loading device gave larger values of cross-sectional stiffness than were actually the case because the load due to the load was partially dispersed by the reaction forces of the wheels. In other words, it turned out that it was necessary to remodel the structure to remove the reaction force of the wheel.

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