AE monitoring of a concrete pipe for damage evaluation under cyclic loading

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ABSTRACT: Deterioration of a pipeline system is normally realized by an accident of water-leakage due to damage accumulation of pipeline materials. In this study, acoustic emission (AE) method was applied to cyclic-loading tests in pipes made of asbestos-cement materials, and quantitative damage evaluation was attempted on the basis of AE parameter analysis. In the cyclic loading test, the damage of the pipe was evaluated from the relationship between *the load ratio* (Ratio of **l**oad at the **o**nset of AE **a**ctivity to previous loa**d**) and *the calm ratio* (Ratio of **c**umulative AE **a**ctivity under un**l**oading to that of previous **m**aximum loading cycle). It is demonstrated that AE parameter analysis is effective for qualifying the damage levels of pipe materials.

1 INTRODUCTION

Recently, water-leak accidents have been reported in various places for cement-based pipe materials, such as PC (prestressed concrete), RC (reinforced concrete) and AC (asbestos-cement) (Nawa et al. 2002). In Most cases damage has accumulated in pipe materials due to aging deterioration, and for quantitatively evaluating pipe damage; a lot of research problems still remain unsolved. In general, material damage is evaluated by its strength, which is the average strength of the pipe materials obtained from external and internal loading tests as stipulated in the codes. However, fracturing behavior of structural materials progresses from micro-cracks in the most deteriorating material. Therefore, the actual pipe strength can not be evaluated accurately only from the average strength of the pipe materials obtained from the strength tests.

In this study, acoustic emission (AE) method is introduced into the external loading tests (compression tests, bending tests) and pipe damage is evaluated using AE monitoring in the fracture process under external pressure. The external loading tests are conducted in two methods: compression tests where uniformly-distributed load is applied to the pipe and bending tests where load is applied at the center of the pipe. The pipe damage is evaluated using AE parameters, *the load ratio* (Ratio of **l**oad at the **o**nset of AE **a**ctivity to previous loa**d**) and *the calm ratio* (Ratio of **c**umulative AE **a**ctivity under un**l**oading to that of previous **m**aximum loading cycle), which were calculated from the measured AE data.

2 EXPERIMENT METHOD AND MATERIALS

2.1 *Acoustic emission monitoring*

Acoustic emission refers to elastic wave motions observed during the energy release process, such as micro-fracturing within a solid body. In this study, AE sensors detected AE signals generated in the fracture process in pipe materials. Then, based on AE characteristics, the degree of damage is evaluated. For AE measurement, R15 sensors (manufactured by PAC) were installed on the inner surface of the asbestos cement pipes at four locations for the compression tests and eight locations for the bending tests (**Figs. 1** and **2**). DISP-AE system (manufactured by PAC) was used as a measuring device. AE events were amplified with 40dB gain in a preamplifier and 20dB gain in a main amplifier. From AE measurements, the previous load record was examined based on the Kaiser effect of AE, and the pipe damage was evaluated from the relationship between *the load ratio* and *the calm ratio* (NDIS2421, 2000).

2.2 *Experimental Materials*

The test pipe is an asbestos-cement pipe (ACP, Type 4) of 600 mm diameter, which had been used for 32 years. The pipe had been buried underground 1.10

meters below the road and as connected 73 meters long. Each 4.0 meter pipe was cut into two samples as two 1.0 meter samples for a compression test, and one 2.0 meter sample for a bending test.

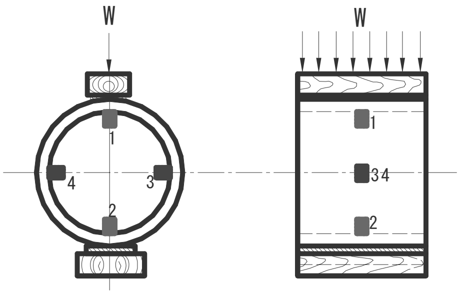

Figure 1 AE sensor arrangements in the compression test.

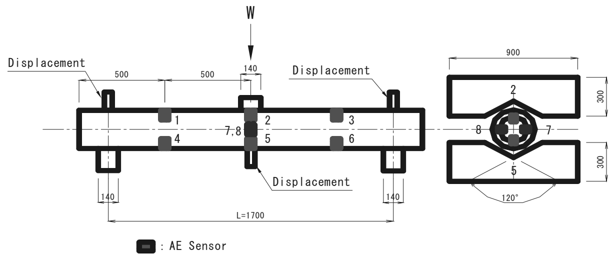

Figure 2 AE sensor arrangements in the bending test.

3 AE GENERATION BEHAVIOR IN FRACTURE PROCESS

AE behavior of a deteriorated pipeline was associated with material damage. AE events were analyzed by using AE parameters. In the compression tests, the strengths of the pipes varied widely from 25.6kN to 72.2kN, with the mean value of 55.4kN. Considering that the number of test specimens was small and the deviation of the strengths was as large as 54% the mean value, it is difficult to evaluate damage of the pipe simply only from the mean value of strengths. In contrast, results of the bending tests show a relatively small variation from 201kN to 227kN. Different patterns of AE generating behaviors were observed near the fracture surface and the other regions during the fracture process of the test pipe (**Figs. 3** and **4**). Since these differences in generating patterns were observed regardless of the tests methods (compression test, bending test) and loading cycles (simple loading, cyclic loading), it is considered that the fracture process of the test pipe is so localized that it can be monitored effectively using AE method. In the compression tests, the displacement varied linearly with stress. As the load increased, the number of AE events increased and the events were observed frequently near the ultimate load. The similar process of fracture of the concrete samples was reported in the previous paper (Shigeishi et al 2003, Suzuki et al 2006). In the bending tests, diagonal shear fracture was observed as active AE generation was observed at 44.5kN in the simple loading tests (**Fig. 5**). This load might be assumed as the most frequent previous load recorded which is discussed below as related to the Kaiser effect. In the cyclic loading tests, frequent AE generation was again observed at about 40kN, which corresponds to 35.4 N/mm^2 bending stress (**Fig. 6**). From these results, the test pipe is considered to have received 40 to 50kN external pressure constantly. From AE monitoring in the loading tests, the previous load recorded in the test pipe is assumed to be 40 to 50kN, which corresponds to 19 to 23 % of the maximum load (214 kN mean in the bending tests).

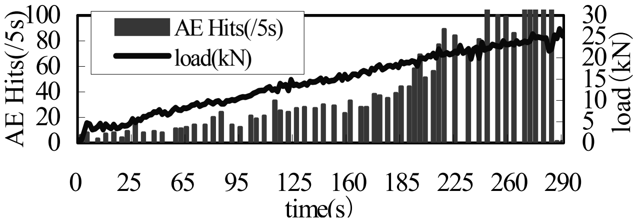

Figure 3 AE generation behaviors in the compression test (fracture position).

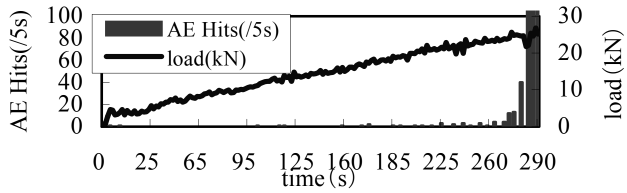

Figure 4 AE generation behaviors in the compression test (sound position).

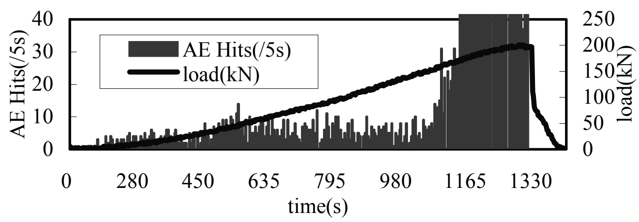

Figure 5 AE generation behaviors in the bending test.

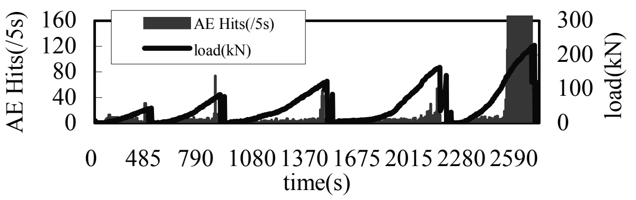

Figure 6 AE generation behaviors in the cyclic bending test.

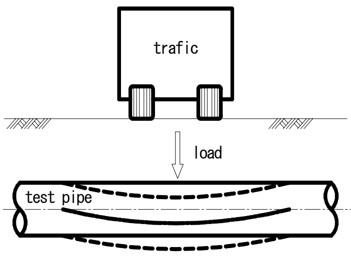

Figure 7 Loaded condition of a tested pipe.

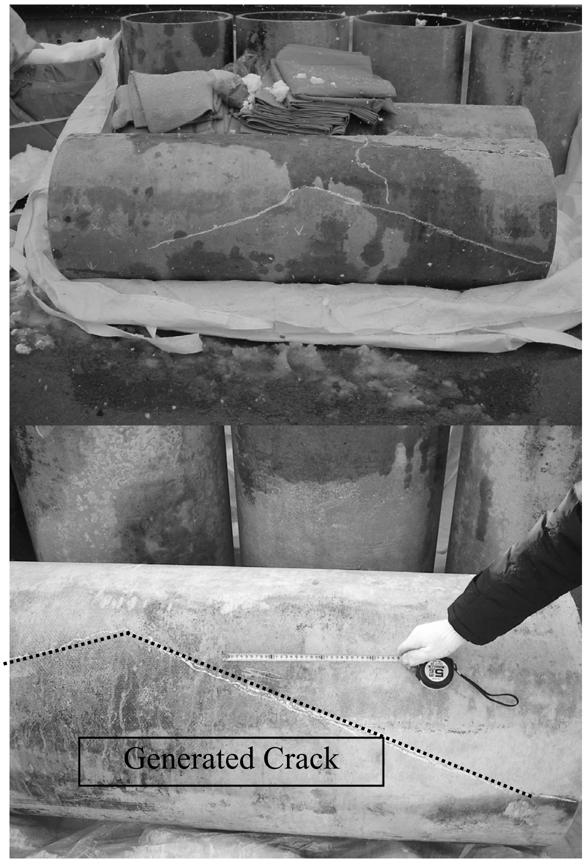

Figure 8 Result of Fracture in bending test.

4 DAMAGE EVALUATION BASED ON AE PARAMETER ANALYSIS

The degree of damage to structures is generally evaluated by the mean values of the mechanical properties of the structural materials, such as strength, elastic modulus, etc. However, the mean values of the mechanical properties obtained from the loading tests are not sufficient enough to evaluate the damage of the structures because the actual fracturing behavior of structures progresses from the most deteriorating material, although it is effective to grasp the overall conditions of the structures. From this point of view, the maximum load undergone by the pipes obtained from fracturing behavior and the mechanical properties of the deteriorating structural materials need to be examined in the evaluation.

A maximum previous load recorded in the asbestos-cement pipe was estimated by the Kaiser effect, and then the damage of the pipe was qualified from the relationships between *the load ratio* and *the calm ratio*. The Kaiser effect is defined to no-AE generation behavior until maximum previous load of the test specimen. AE events are detected after maximum previous load by the Kaiser effect.

In the bending tests, the most frequent previous load is found to be 40 to 50kN. The conditions under which the test pipe had been buried underground are shown in **Fig. 7**. Fracture outline are shown in **Fig. 8**. Because the traffic load applied on the pipe in the transverse direction, the bending tests were conducted. The relationships between the loads in the cyclic loading tests and *the calm ratios* are shown in **Fig. 9**. The high *calm ratio* implies accumulation of damages. When *the calm ratios* do not change due to increased loads, the Kaiser effect is observed. According to the bending tests, cyclic loadings of 0 to 80kN and 0 to 120kN do not show any differences in *the calm ratios*. This may suggest that the pipe had the maximum previous load around 100kN. **Figure 10** shows the relationship between the loads in the cyclic loading tests and *the load ratios*, indicating the decreasing trend. The *load ratios* less than 1.0 mean accumulation of damages. When *the load ratios* do not change due to increased loads, the Kaiser effect is observed in the pipe as a stable condition. The figure shows that *the load ratio* decreases sharply at around 100kN, which reflects the behavior of *the calm ratio.* Based on **Figs. 9** and **10,** it is found that the maximum previous load could be determined based on the Kaiser effect. Then, the test pipe was evaluated from the relationship between *the load ratio* and *the calm ratio*. It is realized that the deterioration was minor at the initial cycle, and it increases from the intermediate level to the heavy (**Fig. 11**).

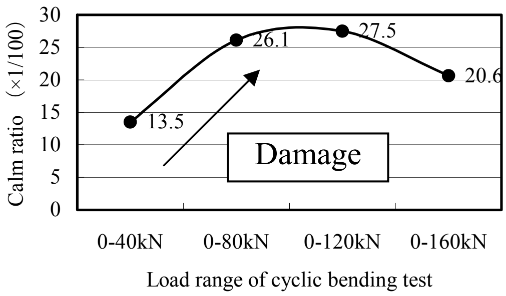

Figure 9 Calm ratios in the cyclic bending test.

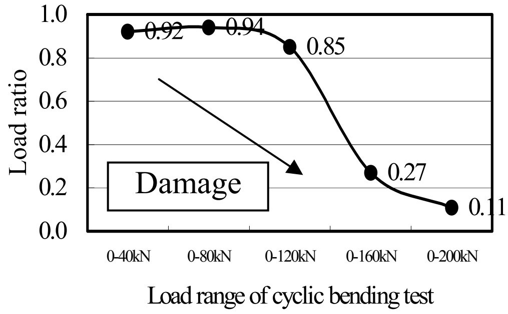

Figure 10 Load ratios in the cyclic bending.

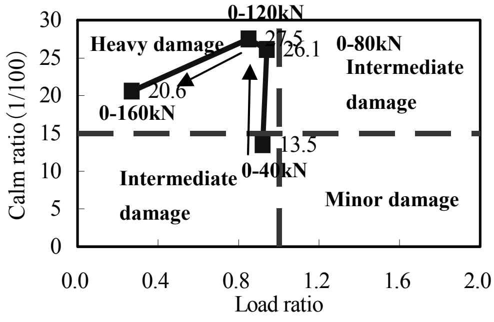

Figure 11 Relationships between the calm ratio and the load ratio.

5 CONCLUSION

In this study, compression tests and bending tests were carried out on the existing asbestos-cement pipe (Type 4) of 600 mm diameter and the pipe damage was quantitatively evaluated by AE monitoring of the fracture process in the pipe. From the results of the AE measurements, the previous load record and the damage of the pipe were examined. The tested pipe, which had been used for a long time, was confirmed to have been damaged due to aging deterioration (*load ratio*<1.0; damaged). The previous load record showed that the most frequent previous load record was 40 to 50kN and the load when the Kaiser effect disappeared was about 100kN at average (50% the maximum previous load record). The relation of *the load ratio and the calm ratio* implied the medium to severe level of accumulation of damage. It is difficult to evaluate damage and previous load record of pipes only with conventional external loading tests. However, this study confirmes as the results of the AE measurements, that the damage and the previous load record of the pipe, which had been used for 32 years, could be effectively evaluated based on the Kaiser effect of AE. The pipeline systems are generally buried underground below roads and are assumed to have received repeated loading for a long time. Therefore, AE measurement using the Kaiser effect is effective for evaluating previous load record and damage of existing pipes.

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