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DAMAGE EVALUATION OF ANTI-SEISMIC RUBBER BEARING USING ACOUSTIC EMISSION

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Abstract

To mitigate earthquake damage to highway bridges, many laminated rubber bearings were installed in Japan following the 1995 Kobe Earthquake. Recently, deterioration of these rubber bearings, which affects the seismic performance of the bridges, has been reported. However, an accurate assessment of damage to rubber bearings (for early warning) is difficult because of a covering rubber that interferes checking inside.

Acoustic emission (AE) method which is one of non-destructive inspections was conducted to evaluate internal damage of bearings. The AE activities and their parameters of the damaged bearings were compared with new bearings. The results showed that the internal damage of the rubber bearings could be estimated through the activities of the AE parameters and location analysis. However, laminate rubber bearing is one of the composite materials with rubber and steel plates. In order to detect the damage inside laminated rubber bearing is difficult because the elastic-wave propagation is complicated.

This study conducted the damage assessment of the rubber materials using AE method. AE parameter analysis and damage location analysis were conducted. The results confirmed that the AE method could detect the propagation of elastic-wave inside rubber materials. Furthermore, the location analysis indicated the internal voids with accuracy. AE method was proved to be useful tool for on-site assessment of a laminated rubber bearing to mitigate damage of the bridge before an earthquake occurred.

Keywords: Acoustic emission, Location analysis, Rubber bearing

1. Introduction

In Japan, a lot of laminated rubber bearings have been used in construction since the 1995 Kobe Earthquake. Recently, deterioration inside laminated rubber bearings has increased. However, there has not been much research regarding damage evaluation of laminated rubber bearing. It has been predicted that some huge earthquakes could occur in the near future. Therefore, the damage evaluation of laminated rubber bearings used for anti-seismic purposes is very important.

For damage evaluation of laminated rubber bearings, a visual inspection is often performed. Visual inspection is performed after deterioration is observed at the rubber surface, however, it is difficult to quantitatively evaluate due to the subjectivity of inspectors. In addition, previous study to evaluate the damage of rubber bearing has not reported. The objective of this study is to apply the acoustic emission (AE) technique which is one form of non-destructive testing against rubber bearing.To evaluate accumulated damage, the specimens were used after conducting preliminary tests. From the results, characteristic behavior of AE activities was confirmed in the specimens on which severe preliminary tests were conducted. It is indicated that the AE technique is useful to evaluate the damage of an anti-seismic rubber bearing.

2. Acoustic emission

On the occurrence of micro-fracture in the materials, elastic waves are released and propagated. Acoustic emission is a method to detect the elastic waves emitted from inside the materials. In our previous study, amplitude and energy are often used as AE parameters for concrete specimen [1, 2]. An example of an AE waveform is shown in Fig. 1. In this study, we confirmed the AE activities with the load time history and the AE energy which are related to the magnitude of the damage.

3. Experimental methods

3.1 Specimens and AE sensors

A schematic elevation of the specimen is shown in Fig. 2. All specimens were preliminarily tested at the Civil Engineering Research Institute for Cold Region, Japan, as shown in Table 1. Five AE sensors were attached between the rubber and steel plates as shown in Fig. 2 and Fig. 3. AE sensors were fixed using plastic tape and electron wax.

3.2 Load condition

We conducted cyclic compressive loading tests that simulated traffic vibrations. The loading condition is shown in Fig. 4. First, an axial force of 153.6kN was applied as the initial surface pressure which is a dead load equivalent reaction force of the floor slab. Then, 10%, 20% and 50% of the initial load were applied cyclically 10 times. More specifically, the load applied was varied from 153.6kN to 167.1kN, 180.6kN and 221.1kN as 10%, 20% and 50% loading, respectively.

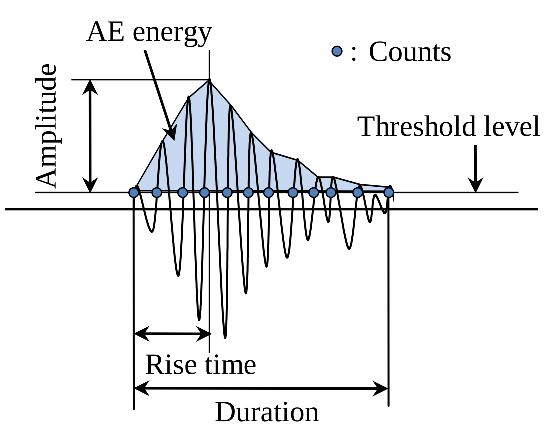


Fig. 1 – AE waveform

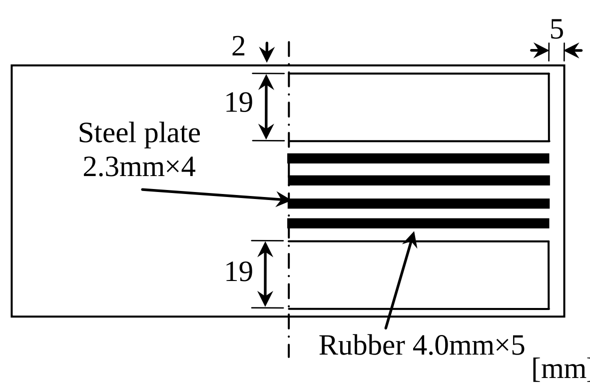


Fig. 2 – Dimensions of laminated rubber bearing

Table 1 – Preliminarily test conditions

<table>
<tr><th>No.</th><th>Conditions</th><th></th></tr>
<tr><td>Y-1</td><td>-30℃ ; PL175%+SR100%→PL175%+SS3kine
-10℃ ; PL175%+SR100%→PL175%+SS3kine
OT ; PL175%</td><td rowspan="6">PL ; Pre-Loading test
SR ; Simple Relaxation test
SS ; Simple Shear test
sin ; Sin wave loading test
MSR ; Multi-Step Relaxation test
EQ ; Earthquake
% ; Shear strain
OT ; Ordinary Temperature</td></tr>
<tr><td>Y-2</td><td>-30℃ ; PL175%+SR150%→PL175%+SS11kine
-10℃ ; PL175%+SR100%→PL175%+SS11kine
OT ; PL175%</td></tr>
<tr><td>Y-3</td><td>-30℃ ; PL175%+SR175%→PL175%+SS17.5kine
-10℃ ; PL175%+SR175%→PL175%+SS17.5kine
OT ; PL175%</td></tr>
<tr><td>Y-4</td><td>-30℃ ; PL175%+sin
-10℃ ; PL175%+sin
OT ; PL175%</td></tr>
<tr><td>Y-5</td><td>-30℃ ; PL250%+ MSR250%
-10℃ ; PL250%+ MSR250%
OT ; PL175%</td></tr>
<tr><td>Y-6</td><td>-30℃ ; EQ25mm→EQ25mm
-10℃ ; EQ25mm→EQ25mm
OT ; PL175%</td></tr>
</table>

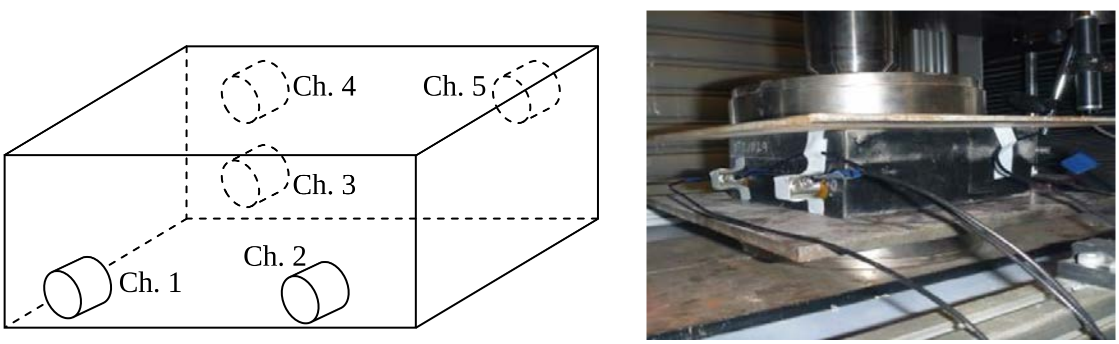


Fig. 3 – Locations of AE sensors (Left) and View of the experiment (Right)

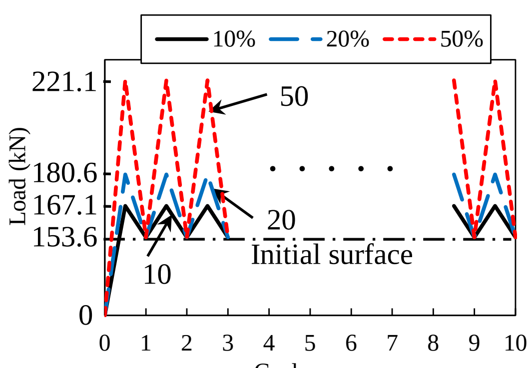


Fig. 4 – Loading condition

4. Results

4.1 AE activities

Results of the AE activities are shown in Figs. 5, 6 and 7. Here, AE hits for both an AE count of 1 and an AE energy of 0 are excepted as noise. From the results, a lot of AE hits were detected from the Y-5 specimen in each loading test compared with the results of the other specimens. The damage inside the Y-5 specimen must exist because 250% of the shear strain was conducted several times before this test as shown in Table 1.

In order to confine the predicted damage area, AE hits at each sensor were confirmed for specimens Y-3 and Y-5. Results of AE activities at each channel are shown in Table 2. In the case of Y-3, AE hits were detected only at Ch. 2. The number of AE hits, however, is not large as compared with Y-5. In the case of Y-5, AE hits at Ch. 1 and Ch. 3 were larger than the others. Especially, the largest number of AE hits was observed at Ch. 3. Thus, the damage inside rubber bearing must occur near the location of Ch. 3.

4.2 AE amplitude

The ratio of amplitude for the Y-5 specimen is shown in Fig. 8. The largest ratio of amplitude was about 60% at 40 dB which is the threshold level. A few large amplitudes were recorded. It is thought that the inside cracks did not progress because only compression loads were applied. Thus, the AE phenomenon was detected as the inside cracks opening and closing.

4.3 AE energy

Results of AE energy at Y-5 are shown in Figs. 9, 10 and 11. AE energy was about 400 at 10% loading. At 20% loading, the largest AE energy was confirmed. At

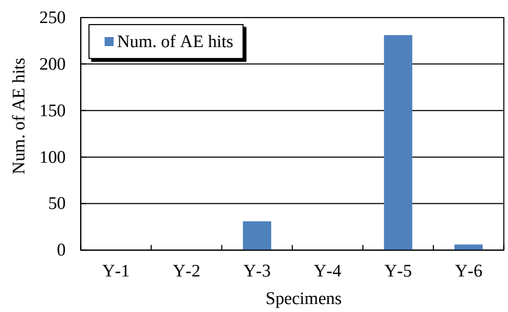


Fig. 5 – AE activities at 10% loading

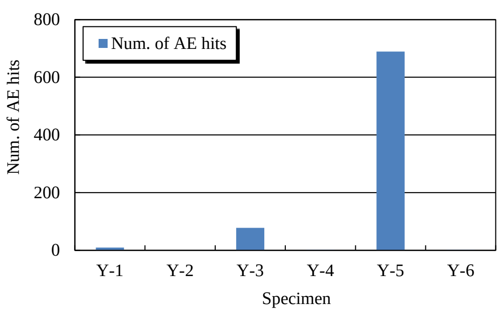


Fig. 6 – AE activities at 20% loading

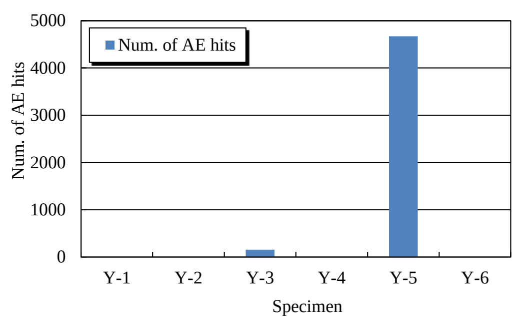


Fig. 7 – AE activities at 50% loading

Table 2 – AE activities at each sensor

	10% loading case		20% loading case		50% loading case	
	Y-3	Y-5	Y-3	Y-5	Y-3	Y-5
Ch.1	0	74	0	302	0	339
Ch.2	31	1	78	0	157	9
Ch.3	0	156	0	383	0	4322
Ch.4	0	0	0	2	0	0
Ch.5	0	0	0	2	0	0

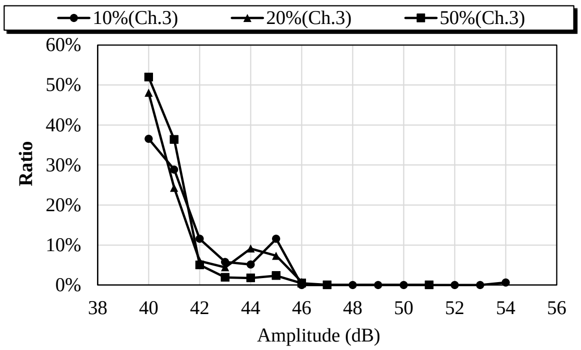


Fig. 8 – AE amplitude at Y-5 specimen

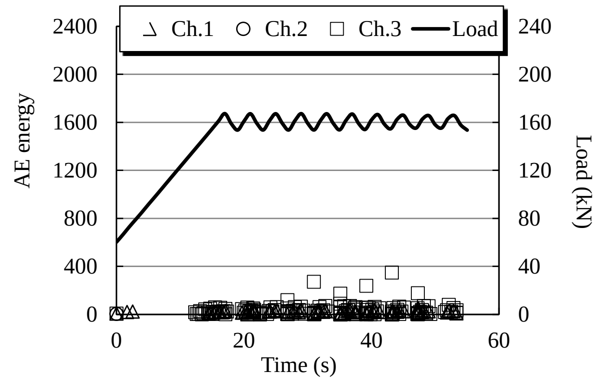


Fig. 9 – AE energy at 10% loading

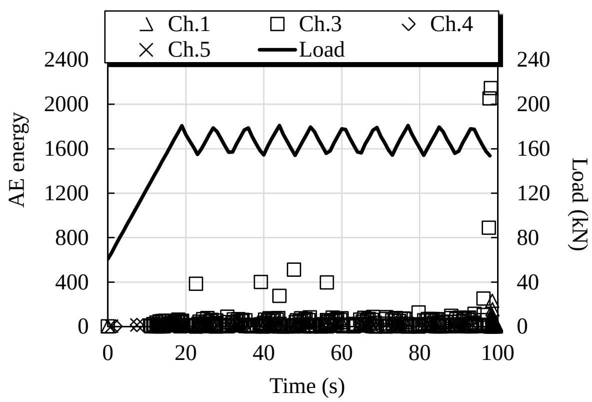


Fig. 10 – AE energy at 10% loading

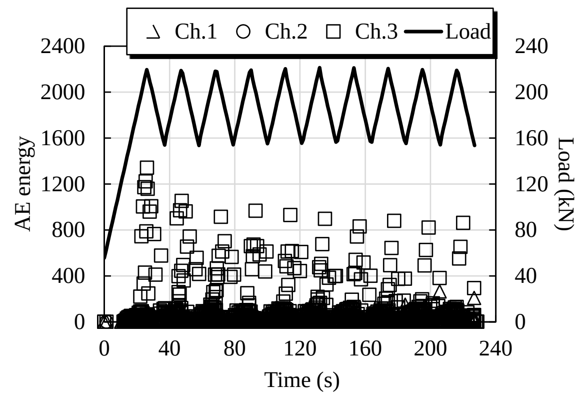


Fig. 11 – AE energy at 50% loading

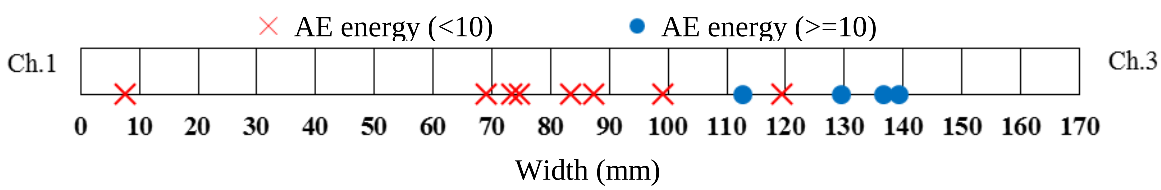


Fig. 12 – Results of location analysis

the stage of 50%, large AE energy was confirmed continuously. Additionally, large AE energy was detected at Ch. 3. The damage inside Y-5 around Ch. 3 was also indicated from AE energy.

4.4 Location analysis

One dimensional location analysis was conducted using Ch. 1 and Ch. 3 of specimen Y-5. Results of the location analysis are shown in Fig. 12. Elastic wave velocity was 687 m/s. A cross mark indicates that the AE energy is less than 10. A circle mark is indicates that the AE energy is more than 10. From the results, the AE sources were located inside the specimen. Furthermore, AE sources for which AE energy is more than 10 were located between 110 and 140. Thus, the rubber was damaged near Ch. 3 according to the AE technique.

4.5 Microscope observation

The specimens were cut after the tests and were observed by microscope. The cut location is shown in Fig. 13. Here, the magnification of the microscope was 500. The specimens observed were Y-5, which was estimated as damaged, and Y-6, which was estimated as non-damaged.

Results of observation are shown in Fig. 14. In the vicinity of Ch. 3 at Y-5 specimen, several voids are confirmed between the rubber and the steel plates. It was clarified that a lot of AE hits were detected because

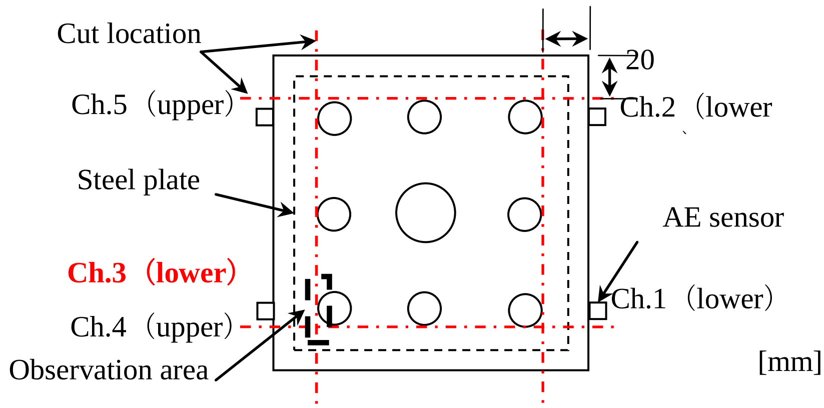
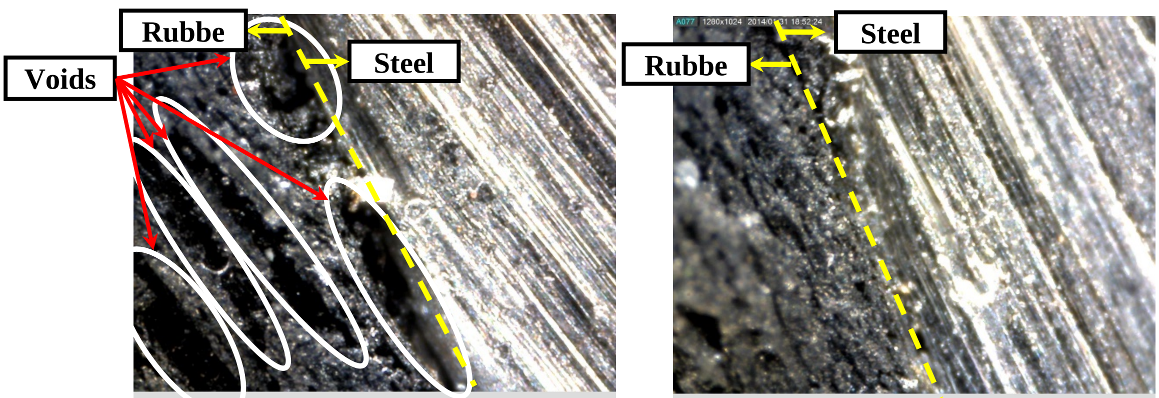


Fig. 13 – Cut location and observation area



(a) Y-5, around Ch. 3. (b) Y-6, around Ch. 3.

Fig. 14 – Microscope observation

these voids had opened and closed during the loading tests. On the other hand, no voids were confirmed for specimen Y-6. Thus, evaluation of the damage inside rubber is possible by using the AE method.

5. Conclusions

This study aimed to evaluate the damage inside laminated rubber bearing using an AE technique. As a result, a lot of AE hits were detected in the laminated rubber bearings on which severe preliminary tests were conducted. Additionally, a lot of AE sources which recorded large AE energy were located inside laminated rubber bearings. Furthermore, the damage location which was estimated by AE technique corresponded with the location of voids examined by microscope. AE technique could effectively evaluate the damage of anti-seismic laminated rubber bearings. However, the number of sample should increase to precisely evaluate at on-site.

6. Acknowledgment

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7. References

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