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# ACOUSTIC EMISSION OBSERVATION OF BENDING FAILURE IN BRICK-BUILT DEEP BEAM

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## Abstract

Acoustic emission (AE) phenomenon is an emission and propagation of elastic waves (AE wave) generated by releasing internal energy. The typical cause of AE generation is cracking of solid. AE techniques (AET) based on the pattern recognition of AE activities, AE signals and AE parameters such as AE energy and count have been used to evaluate the quality of materials. To develop an AET for non-destructive inspection of brick-built structures under the service, AE observations of the failure process (cracking) on brick-built deep beam specimens under cyclic multi-step bending load were carried out. Consequently, it is confirmed that almost AE sources are located near the separated joints which show crack between the brick, and AE activities have correlation with damaging progress of specimens.

## Key Words

Acoustic emission, non-destructive inspection, brick-built structure, cyclic bending.

## 1 Introduction

Masonry structures exist in all over the world, and it is not difficult to find out a masonry structure that has been used throughout long term over hundred years wherever we go. Masonry structure has the high endurance as a general rule. However, masonry structure rapidly comes to a collapse, when the small destruction is once started, and it will lead to complete collapse in almost case. Therefore, the request for the establishment of the non-destructive inspection technique is heightening recently in the maintenance of the structures. Especially, the diagnosing technique of the soundness is indispensable to use aged masonry structures eternally and safely.
Acoustic emission technique (AET) is the non-destructive testing technology which development and application advance in steel and concrete structure assessment or failure prediction in rock engineering. The research and application of acoustic emission (AE) in structural engineering field is widely carried out (Kishi, Ohtsu, Yuyama, et al., 2000). For example, there has been theoretical treatment of AE in order to make AET practicable has been considered in concrete engineering. (Ohtsu & Ono, 1984), (Ohtsu, 1987), (Yuyama, Okamoto, Shigeishi, & Ohtsu, 1995), (Shigeishi & Ohtsu, 2001). In contrast, there is few on AE in masonry structure engineering (Leaird, 1984),

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(Royles & Hendry, 1991), (Royles, Hendry & Melborne, 1992). Only author has performed AE measurement of actual stone masonry arch bridge (Shigeishi, Colombo, et al., 2001).

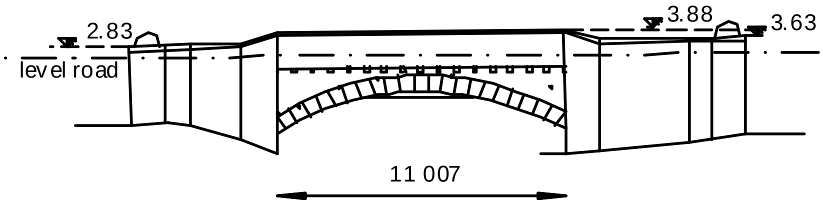


*Figure 1 Overview of the Boghall Bridge (Shigeishi, Colombo, et al., 2001)*

*Figure 2 AE measurement at the Boghall Bridge (Shigeishi, Colombo, et al., 2001)*

In this research, to examine applicability of AET for non-destructive inspection of brickwork structures under the service, AE observations of the failure process (cracking) on brick-built deep beam specimens under cyclic multi-step bending load were carried out.

# 2 Acoustic emission

## 2.1 General of AE

Acoustic Emission (AE) is the class of phenomena whereby an elastic wave, in the range of ultrasound usually between 20 KHz and 1 MHz, is generated by the rapid release of energy from the source within a material. The elastic wave propagates through the solid to the surface, where it can be recorded by one or more sensors. The sensor is a transducer that converts the mechanical wave into an electrical signal. Thus, information about the existence and location of possible sources is obtained.

AE differs from ultrasonic testing, which actively probes the structure; acoustic emission listens for emissions from active defects and is very sensitive to defect activity when a structure is loaded beyond its service load in a proof test.

AE analysis is a useful method for the investigation of local damage in materials. One of the advantages compared to other non-destructive evaluation (NDE) techniques is the possibility to observe damage processes during the entire load history without any disturbance to the specimen. Many of research and development of AET applications are process monitoring and global or local long-term monitoring of civil-engineering structures (e.g., bridges, pipelines, off-shore platforms, etc.).

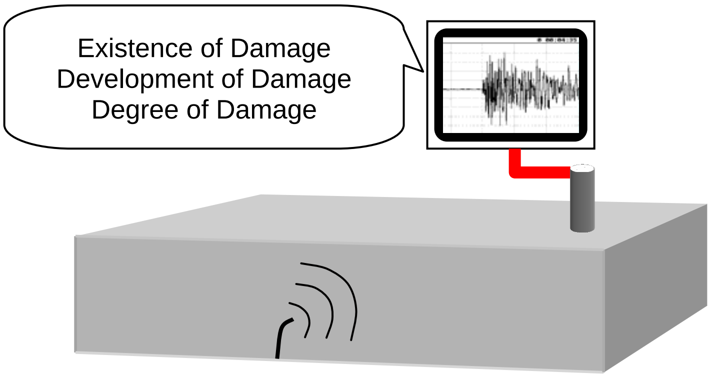


*Figure 3 Principle image of AE measurement*

## 2.2 AE activity

### 2.2.1 AE hit

Electrical response can be detected from an AE sensor resulting from particle motion produced by an elastic wave. Basically, there are two types of AE signals, burst type and continuous type signals. The number of AE hit is cumulative count of detection of one burst signal on a channel at any time or during any periods of AE measurement. AE activity which can be interpreted from the AE hit number or the rate of increasing AE hit.

### 2.2.2 Keiser effect

The Kaiser effect which was first investigated by Wilhelm Kaiser [1950] describes the phenomenon that a material under load emits acoustic waves only after a primary load level is exceeded. During reloading, the material behaves elastically before the previous maximum load is reached. If the Kaiser effect is permanent for the material, little or no acoustic emission will be recorded before the previous maximum stress level is achieved. However, the Keiser effect comes to be vanished after the material once suffer serious damage which produce plastic zone in the material (Felicity effect). An example is illustrated in the figure 4, which shows the load level versus AE hit rate with the displacement of the centre of span for an experiment where a reinforced concrete beam subject to bending was tested under a cyclic load.

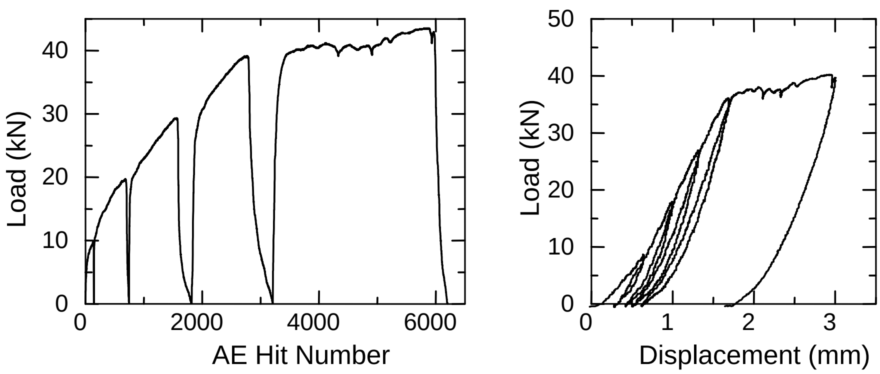


*Figure 4 Keiser & Felicity effect in a RC beam under cyclic bending test*

### 2.2.3 AE source location

The spatial position of an acoustic emission source which is a physical origin of one acoustic emission event (e.g., cracks, delamination, debonding, etc. ) can be

determined from arrival time measurement using an array of sensors. Several approaches to computed location are used, including: a). linear location - one dimensional source location requiring two or more channels, b). planar location - two dimensional source requiring three or more channels, c). 3D location - three dimensional source requiring five or more channels, d). adaptive location - source location by iterative use of simulated sources in combination with computed location. Linear and planar location techniques are most widely used.

# 3 Bending tests of brick-built beams and AE observations

## 3.1 Specimens

To examine the possibility of the practical application of AET, AE observation and AE source location was performed while the brickwork specimens were loaded and fractured. In this research, four six brick-built specimens, which were liken as deep beam, were used, and the bending load were monotonously or repeatedly applied to the specimens under different two loading configurations.

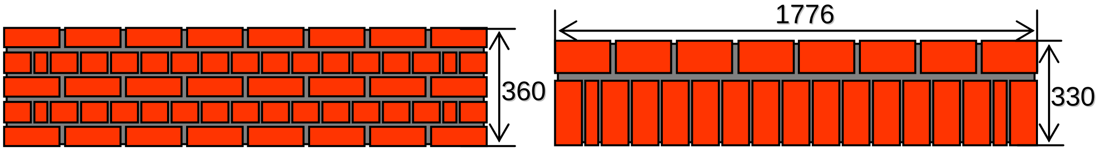


*Figure 5 Elevation view (left) and bottom view (right) of a specimen*

Each specimen has a dimension of 360 mm height, 330 mm width and 1 776 mm length. All bricks are qualified as the Category 4 for structural purpose specified by the Japanese Industrial Standard (JIS). The JIS Structural Purpose Category 4 Bricks should have 30 N/mm$^2$ or above of compressive strength and the water absorption rate of that should be 10 % or less. The joint filler is mortar made in mixture proportion of saked lime of 1, sand of 5, and water of 0.4 for cement of 1 at the mass ratio. The compressive strength of mortar was 3.5 30 N/mm$^2$ as an average result of compression tests by using 3 cylindrical specimens

## 3.2 Bending tests

Using these four brick-built deep beam specimens, the bending loading tests by monotonous loading and cyclic loading were respectively carried out on two different bending loading position summarised in Table 1.

*Table 1 Bending tests pattern list*

| Bending test configuration | Loading pattern | Loading position |
|---|---|---|
| MC | Monotonous | 1/2 length (centre) |
| CC | Cyclic | 1/2 length (centre) |
| ME | Monotonous | 1/4 length (one side) |
| CE | Cyclic | 1/4 length (one side) |

The loading position was selected in order to apply central loading and eccentricity loading shown in Figures 6 and 7. Moreover, monotonic loading or multi-step cyclic loading were applied to the specimen in each loading position. In addition, in order to prevent the sudden brittle fracture of the specimen, and assuming these specimens as a part of arch structure member, these beam specimens were pre-loaded with 40kN axial load during the bending.

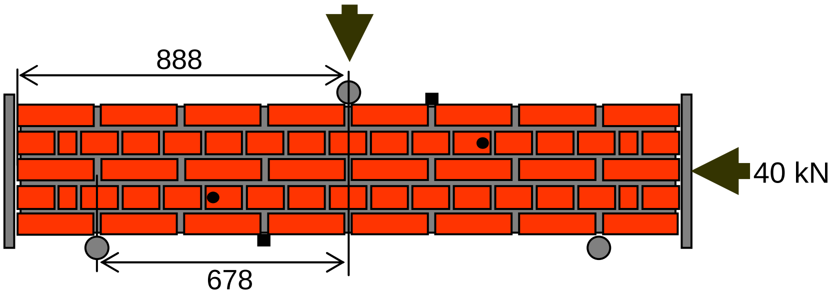


*Figure 6 Experimental setup of bending test by centre loading (MC, CC)*

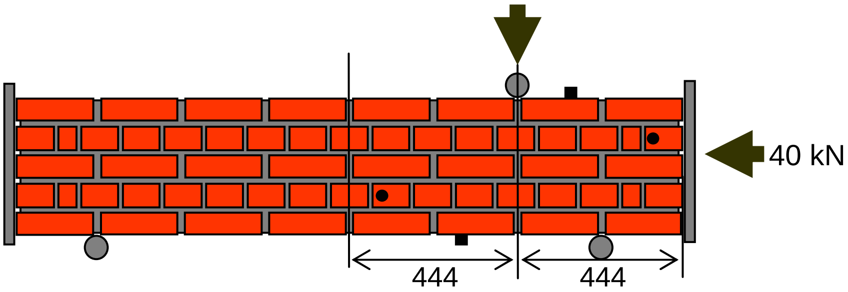


*Figure 7 Experimental setup of bending test by eccentricity loading (ME, CE)*

### 3.3 AE measurements set-up

AE measurements were carried out on the same condition in each bending tests. For the AE measurements, a six-channelled analogue AE signal measurement processing systems (LOCAN 320 AE ANALYZER, Physical Acoustics Corporation, NJ, US) was prepared. AE signal detected by the AE sensor (AE Sensor UT-1000, PAC) would be amplified 20 dB by the preamplifier plus 40 dB by the system integrated main amplifier (60 dB in total), and the threshold level to discriminate AE signal was set to 42 dB. The planar AE source locations also were carried out. The AE sensors positions are indicated by black dots (·) shown in Figures 6 and 7.

## 4 Results and Discussions

### 4.1 Observed cracking and AE hits

Figures 8, 9, 10 and 11 show the results on observable cracks occurred on the specimens and the transition of cumulative AE hits detected by all of sensors during the tests.

In case of the monotonous centre loading (MC; Figure 8), major crack propagation had started from the bottom surface of the specimen. Finally, the specimen came to the web compression failure by the effect of the axial force producing the delaminating in the joint of middle layer. The observable cracks in case of the monotonous eccentric loading (ME; Figure 9) were occurred similarly. In both case, the AE hits also increased, while the loading load was increased, and the increment of AE hits seemed to be the correlation on the increment of the load.

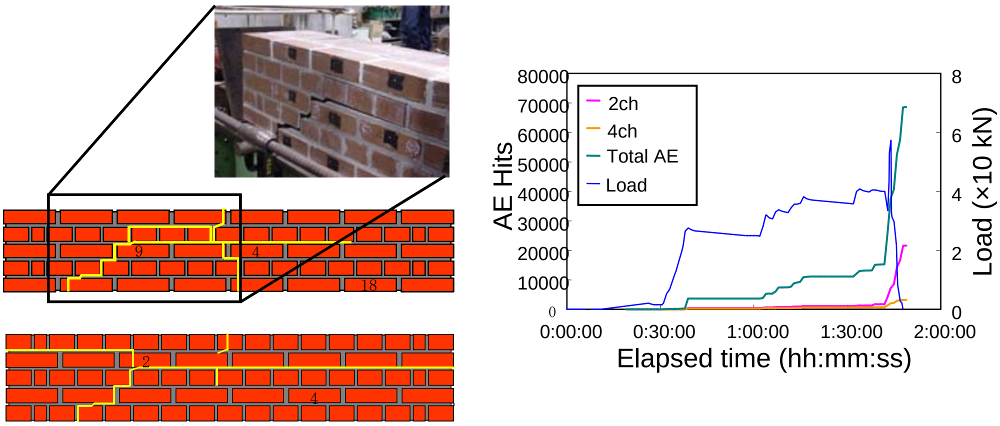


*Figure 8 Observable crack and AE hits by monotonous centre loading*

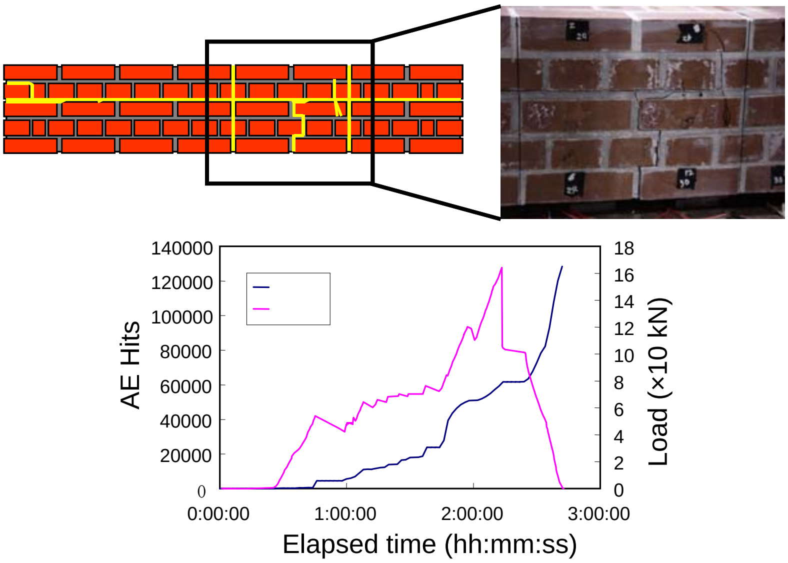


*Figure 9 Observable crack and AE hits by monotonous eccentric loading bending*

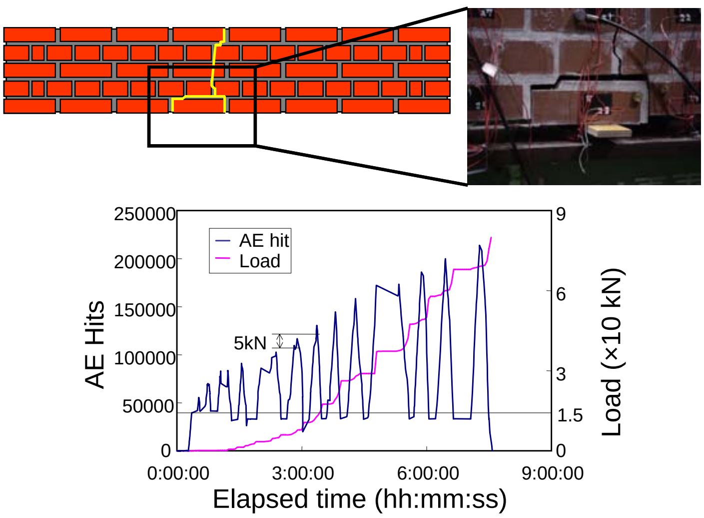


*Figure 10 Observable crack and AE hits by cyclic centre loading*

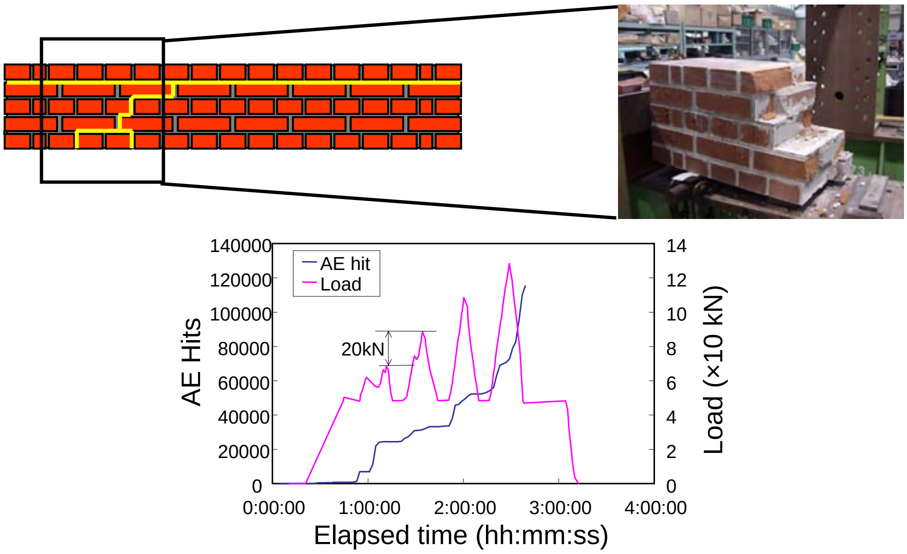


*Figure 11 Observable crack and AE hits by cyclic eccentric loading bending*

Otherwise, there is a different on the observable crack pattern between the result of monotonous eccentric loading (CC; Figure 10) and that of cyclic eccentric loading (CE; Figure 11). In case of CC loading, bending tensile crack had started from the bottom, and it simply reached to the top surface. However, in case of CE loading, the observable crack occurred from the bottom surface did not reached to the top surface, and the specimen lost the proof bending by delaminating of the joint at the middle brick layer. In both case, the cumulative AE hits always increased while the load increased and decreased alternatively. Therefore, on the brick-built structure, the Keiser effect could be observed, when the stress level is minute.

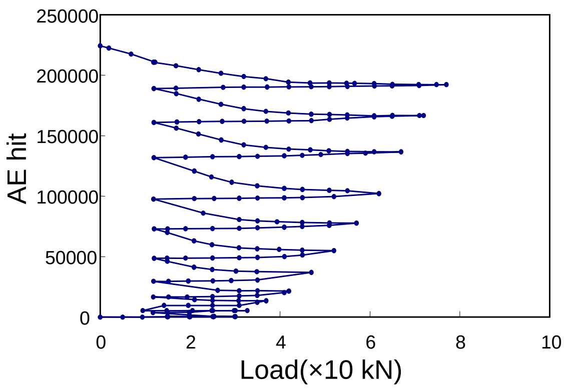


*Figure 12 Cumulative AE hits during the CC loading*

Figure 12 shows the cumulative AE hits on the bending load during CC loading test. The AE occurred only when the load increased at earlier cycles, and the AE hits could observed even in the either increasing or decreasing of the load in the middle of cyclic loading. However, at the final stage, the AE occurred only when the load decreased. It is suggested that AE activity changes by damage degree of the object.

## 4.2 AE source locations

Figure 13 shows the result of the planar AE source location calculated from the relative times of arrivals of AE signals between the sensors. It is remarkable that the AE sources are located along the separated joints which develop the observable crack.

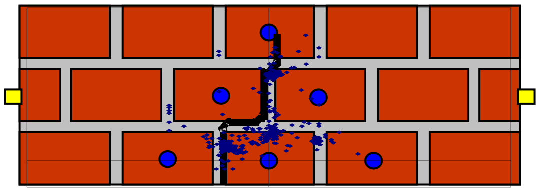

*Figure 13 Result of the planar AE source location on the ME loading test*

# 5 Conclusion

Masonry structure has the high endurance as a general rule. However, masonry structure rapidly comes to a collapse, when the small destruction is once started, and it will lead to complete collapse. Therefore, the request for the establishment of the non-destructive inspection technique is heightening recently in the maintenance of the structures. Acoustic emission (AE) phenomenon is an emission and propagation of elastic waves (AE wave) generated by releasing internal energy. In this research, to develop an AET for non-destructive inspection of brick-built structures under the service, AE observations of the failure process (cracking) on brick-built deep beam specimens under cyclic multi-step bending load were carried out. As results of the AE observation, the capability of AET for a non-destructive inspection of brickwork structures can be examined by followings:

- AE activities have correlation with damaging progress of specimens.
- AE sources can be located along the observable crack between the bricks

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