General Remarks on Applications

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Abstract Following Part A Basics, successful applications to concrete, civil structures, rock, metal, wood, biological structures, polymer composites, ceramics are described, as well as updated measurements. Associated with these issues, general remarks on AE measurements in engineering materials are summarized.

Keywords AE parameters · Noise · Post analysis · Set-up

1 Introduction

AE techniques have been applied to a variety of structures and infrastructures in the field of civil engineering. Successful applications to concrete, civil structures, rock, metal, wood, biological structures, polymer composites, ceramics are extensively described in the following chapters. When the techniques are going to be applied to existing structures or local members, inspection procedure shall be based on the codes and standards. Concerning applications to concrete structures, only two of them were established in Japan NDIS 2421 (2000) and (JCMS-III 2003). This is because concrete structures have long been considered as maintenance-free. In the world, most of codes and manuals on AE applications to engineering materials and associated structures are standardized in the governmental institutes and departments. Because deterioration and damage in the concrete structures are recently reported worldwide, these are no longer referred to as maintenance-free. Thus, in-situ inspection techniques of AE measurement and monitoring in concrete are actively under development. Accordingly, in 2019 three ISO standards (ISO16836, ISO16837, ISO16838) are established.

Based on these activities and recent developments, general remarks on AE measurements in engineering materials are discussed. Due to damage evolution and deteriorations in the structures, AE events are observed, nucleating microcracks under

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in-service conditions. An inspection method for active cracks or defects is a target for AE applications to materials and structures.

2 Basics of Measurement

AE sensors shall be sensitive enough to detect AE signals generated in the target structure, taking acoustic coupling into consideration (ISO16836). Sensitivity calibration of AE sensors shall be performed by employing the standard source or an equivalent piezoelectric sensor. AE sensor also shall be robust enough against temperature changes, moisture conditions and mechanical vibrations in the environments. Concerning coupling, several kinds of couplants are available. So far, no techniques are explicitly confirmed yet on long-term inspection and durability of couplants. This is because AE techniques are often on-site for field applications, depending on structural and environmental conditions.

In the devises for the measurement, a usual system is schematically illustrated (Fig. 8 of Chapter 2 History and Fundamentals). In principle, amplifiers shall be set up as close as possible to AE sensors. The internal noise of the amplifier shall be inherently low and less than 20 μV as the peak voltage converted as input voltage. The amplifier shall be robust enough against the environmental conditions and be protected properly. The frequency range, which are usually controlled by filters, shall be determined prior to the measurement, taking into account the performance of AE sensors and the amplifiers.

Several AE parameters are available to obtain from the measuring system. These are generally effective to identify deterioration mechanisms and useful to discriminate environmental noises. A measuring system records such parameters as count, hit, event, maximum amplitude, energy, rise time, duration, energy-moment, RMS (root mean square) voltage, frequency spectrum, and arrival-time difference. Some of them are illustrated in Fig. 1.

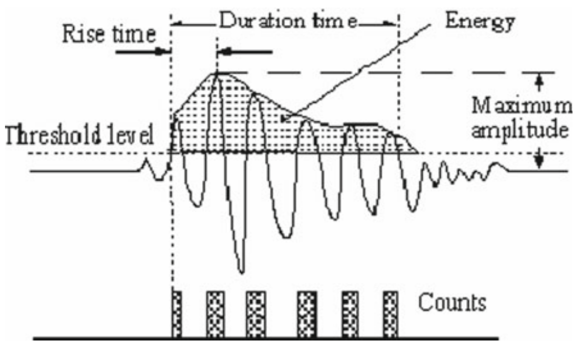

Fig. 1 AE parameters

3 Elimination of Noise

Elimination of the noises is one of the most concerned aspects in the applications. Usually, it is achieved by simply setting the threshold level over the noise level, or by applying a band-pass filtering and a post-analysis of the data. In any cases, the averaged amplitude of the noise should be managed to be lower than 10 μV as input.

3.1 Environmental Noise

In advance to AE measurement, the noise level shall be estimated on site. Then, counteract against external noises, such as wind, rain, sunshine and so forth shall be conducted to decrease the noise level as low as possible.

3.2 Separation of Noise

In the case that the noises have similar frequency contents and amplitudes to AE signals, or sources of the noises are unknown, characteristics of the noises shall be estimated prior to the measurement. Then, separation of AE signals from the noises shall be made. In this respect, the use of filters is useful after determining the proper frequency range.

3.3 Post Analysis

According to JCMS-III (2003) and ISO 16837 (2019), such AE parameters as *RA* value and the average frequency *Fa* are defined to classify cracks as stated in chapter "AE in Concrete". From these two parameters, traffic noises could be practically discriminated. In a buried water-pipeline, AE monitoring was conducted (Suzuki and Ohtsu 2005). Because the pipeline was located below road, traffic noises were often detected due to heavy vehicles. Consequently, AE monitoring was conducted when cars and trucks were passing. Results are summarized in Fig. 2.

AE events due to traffic noises are observed in the region where the average frequencies are low. In another test, the measuring system was turned off in each case of traffic passing, and then AE data detected were analyzed. Results are given in Fig. 3.

The zone of plotted data in Fig. 2 is fairly different from that of Fig. 3. In the latter case, the plotted data are distributed in the area where the average frequencies are high and RA values are low. It suggests that noises could be successfully eliminated by a post-analysis of AE parameters, even the case where filtering is not easily

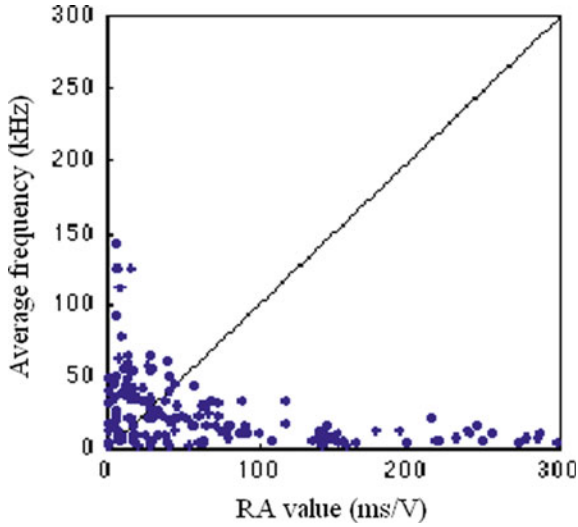

Fig. 2 AE events detected under traffic passing

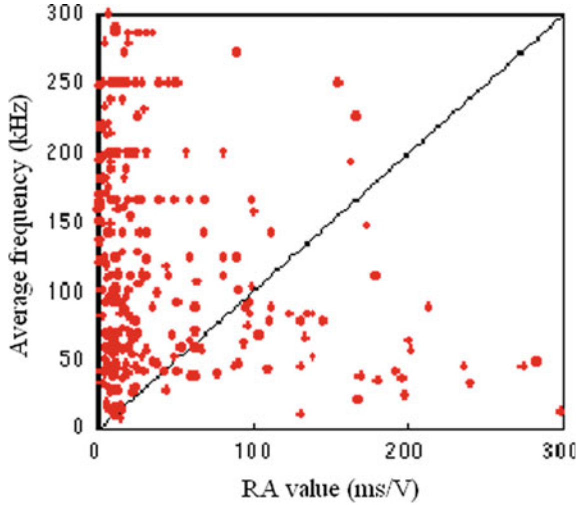

Fig. 3 AE data prevented from traffic noises

implemented. In addition, a spatial filter is available to eliminate the noises. This is a technique based on locating AE sources. In the case that the sources are located far from the zones surrounded by sensors, they are referred to as the noises.

4 Setup of AE System and Measurement

In order to set up the system and to carry out AE measurement, several requirements are found. For example, extensive research on AE in concrete has suggested the following requirements to properly set up AE system.

(1) A measurement system consists of AE sensor, amplifier, and filter. Total amplification by the pre-amplifier and the main amplifier is usually set from 60 to 90 dB. To decrease the noises, a band-pass filter between several kHz and 1 MHz is mostly desirable. The noises should be lower than 20 mV as input voltage after detected by AE sensors.
(2) Elimination of the noises is achieved by simply setting the threshold level over the noise level, or by a band-pass filtering and a post-analysis of the data. In any cases, the averaged amplitude of the noise should be managed to be lower than 10 μV as input.
(3) Sensor array is determined from the attenuation properties of AE waves, setting the distance where attenuation during travel is less than 30 dB. In most cases, the distance between the sensor and an AE source is shorter than 1 m. In relation to the attenuation property, the frequency range from 20 to 100 kHz is recommended for in situ monitoring of concrete structures. These are based on a relationship between measurable distance and detectable frequency as illustrated in Fig. 4. This is a case in concrete (ISO16836).

AE sensors are attached at proper locations to cover the target area. The period of the measurement shall be prescribed, depending on the following conditions:

(a) Propagation property of AE signals in the target structure
(b) Stress distribution in the structure under inspection.

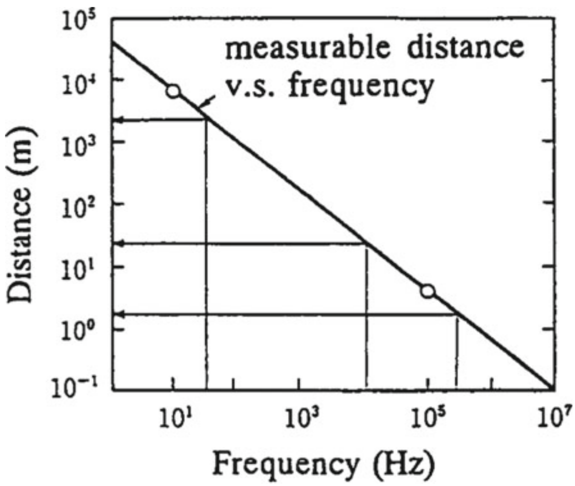

Fig. 4 Relation between measurable distance and frequency

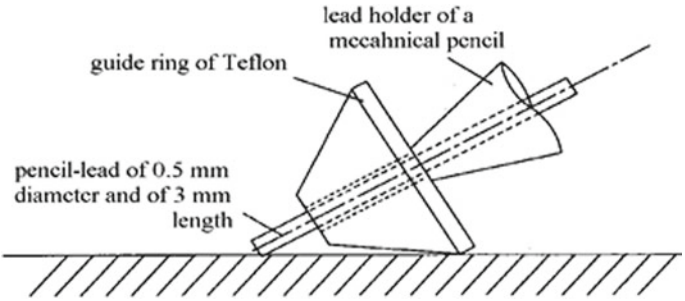

Fig. 5 Standard source of AE

Sensitivity of AE channels shall be conducted routinely by employing the standard source as shown in Fig. 5 (Hsu and Breckenridge 1981; Nielsen 1977).

Variation within the channels shall be less than 3%. Based on the spatial area to be covered, AE sensors of proper frequency characteristics shall be selected.

In advance of the test, attenuation properties of the target structure shall be estimated, by employing the standard source or the equivalent. Then, a sensor array shall be determined so as to keep the equivalent sensitivities in all the sensors. One information of the attenuation property in concrete is given in Fig. 4.

AE signals shall be detected properly for the period of the measurement. Concerning AE parameters detected, their trend, distribution, correlation, and locations are monitored and measured. In principle, AE tests are conducted under loads which must not cause any damages on functions of the structure during detection and location of active cracks.

The tests shall be carried out routinely or temporally under the following loads:

(a) Service load lower than the serviceable limit
(b) Incremental load lower than the serviceable limit
(c) Variable and repeated load during service.

Relations among AE parameters, at least AE hits, time, and loads shall be analyzed.

5 Concluding Remarks

Applied fields and structures of AE measurement are still under developing and expansion. This is because set-up conditions of AE measuring systems and target of analyses are different in each case and at each site. As a result, it is noted that AE techniques in practical fields are still under development. Thus, remarks on the measurements are briefly summarized. Successful applications are both intensively and extensively stated in the following chapters.

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