Fundamental and assessment of concrete structure monitoring by using acoustic emission technique testing: A review

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Abstract. Acoustic emission (AE) technique is one of the non-destructive (NDT) testing, where it can be used to determine the damage of concrete structures such as crack, corrosion, stability, sensitivity, as structure monitoring and energy formed within cracking opening growth in the concrete structure. This article gives a comprehensive review of the acoustic emission (AE) technique testing due to its application in concrete structure for structural health monitoring (SHM). Assessment of AE technique used for structural are reviewed to give the perception of its structural engineering such as dam, bridge and building, where the previous research has been reviewed based on AE application. The assessment of AE technique focusing on basic fundamental of parametric and signal waveform analysis during analysis process and its capability in structural monitoring. Moreover, the assessment and application of AE due to its function have been summarized and highlighted for future references

1. Introduction

AE technique is known particularly as one of the NDT testing technique. It has been widely used in engineering fields such as concrete monitoring extensively. AE is defined as the propagation of the elastic energy wave release due to internal energy such as a micro-fracture in concrete structure [1-5]. In general, AE is a technique that used to characterize the nucleation and growth of the cracking pattern [6-8], measure the deterioration of concrete structure [7-8]. Furthermore, AE activities include the structural deformation processes such as plastic deformation, crack expansion and other kind of material degradation formed. This activity in AE technique involves the use of sensors to detect the release strain energy generated from the growing crack of structure [9].

In the process of AE testing for concrete monitoring, the procedure of transient wave energy caused by the rapid release of energy in the materials within to the formation of elastic deformation, crack propagation due to internal and external forces charged for the material. When the internal and external stress is applied to the specimen, the strain is released. It will spread over all the material used in the form of elastic wave and cause the vibration on the surface of the subjected specimen. Then the elastic deformation can be detected when the resulted vibration will spread to AE sensors placed on the specimens, generate the electric charges at the surface and render an electric field between the materials. The vibration produce from the surface then converted into electrical signals, eventually the signal will amplify before displayed on the instrument [7]. The schematic process diagram shown in Figure 1.

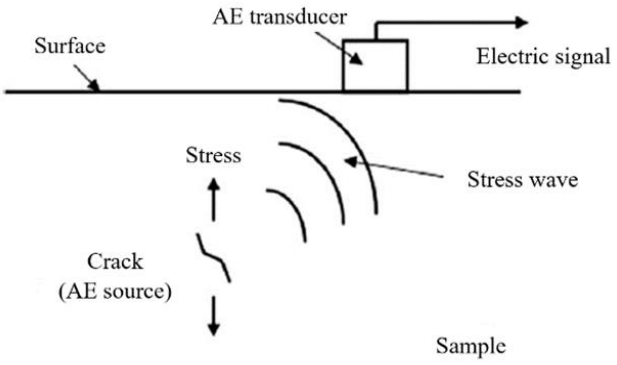

Figure 1. Illustration of waveform generate from crack growth and receiving sensor of AE parameter [7]

The application of AE techniques in concrete structure attracted a great deal of attention as one of the non-intrusive and real time monitoring in the engineering field [23]. AE is the importance of damage detection and assessment for concrete structural for its mechanical properties during its services, where the AE is designed to capture sound wave in materials while the absolute energy is released from cracking. This technique can detect the micro-cracking and material deformation. Other than that, this technique is important to detect active microscopic process [29] and stress wave generated in structural [47]. The parameter of AE technique is shown in Table 1 based on applications from the source event while monitoring process.

Table 1 Parameter of an acoustic emission and its application in source event [5]

Variables	Parameters	Obtained information
Time domain	Rate	Rate of damage occurring
	Peak amplitude	Intensity of source event, orientation
	Relative arrival time	Source location
	Duration	Energy of source event
	Count	Energy of source event
	Waveform	Structure of source event
	Energy	Energy of source event, type of damage
Frequency domain	Frequency spectrum	Nature of source event
Time-frequency domain	Spectrogram	Energy distribution of source event through time
	The time variation of each frequency component	The intensities of source frequency component

In this paper, the general review and fundamental of the acoustic emission technique as one of the non-destructive testing technique are presented. This paper generally explains the general knowledge and approach for the AE technique to monitoring mechanical properties of concrete structure either dam, building or concrete specimens in the laboratory. Other than that, determination of its approach in concrete experimental studies is generally explained based on AE used in laboratory testing and review of previous research based oh AE techniques due to their objective and outcome is discussed in this paper.

2. Comprehensive review on previous study of AE

An AE technique in concrete structure has been applied over than 50 years in history, where the first experimental studies have been made by Kishinouye on AE technique [21, 22]. On the other hand, Kaiser introducing the “Kaiser Effect” based on the AE technique in Germany [24]. Another researcher such as Schofield has been investigated the effect of energy produce based on AE technique testing of structure under applied stress in 1954 [25], and the comprehensive description of the AE has been

published by the American Society of Non-Destructive Testing [26]. Other than that, various surveying for application of the AE technique by Ohtsu for monitoring of the concrete structure [27, 28]. The researchers has been exploring the uses of AE techniques to obtain more data based on the concrete without damaging its properties and shape.

Generally, the fundamental concept of AE approach in concrete brings some features for this technique as an applicable non-destructive testing (NDT) in the future. In the AE approach, some of its important applied is to fulfill the objective for real time capability, high sensitivity of structure, global monitoring capability, source location characterize, sensitivity to any process or mechanism involve in a structure that generates stress waves and passive nature, where there is no need to supply the energy but it will produce from damage itself is utilized [5]. As one of the NDT technique used in engineering field, monitoring of the concrete structures to determine the damage using various material by using the AE technique have been studied by various researchers such as fiber reinforced concrete vessel [30], reinforced concrete structure [31-33], pre-stressed concrete structure [15], glass fiber reinforced composite bridge decks [16] and reinforced concrete systems with carbon fiber reinforced polymer [34].

Previous study also stated that, AE technique has been used widely to assess degradation of the material in concrete. It is also to evaluate the condition of the various system such as detecting the fatique cracks and its location in bridge structure [35-37]. Other than that, it is also used to monitor the stability of tunnel linings [38-39] and checking the condition of concrete parts such as beams and slabs [40-41]. As stated by Muralidhara et al, the concrete materials showed the different AE mode for its signal at different stage of fracture, and its AE parametric characteristics are reflected the stages of damage types. Between the AE activity and internal defects of concrete take parts in experimental process, the correlation is exist [42]. Li et al conclude that the damage of concrete structure can be evaluated by the AE parameter characteristic due to existing significant correlation between fracture signal and fracture process [43].

Due to its approach as structural health monitoring (SHM), previous investigation have been made by various researchers for application of AE technique in concrete investigations such as viaduct, dam and building itself [38]. Previous study by Minemura et al. [38], Bond et al. [6] and Shiotani [7] demonstrated the application of AE technique in the dam structure. Furthermore, monitoring study for dam also have been made by Nair et al. [8] and Yu et al. [44]. In other hand, Yuyama et al. study the failure in high-strength tendons of pre-stressed concrete bridge by using an AE technique [45]. Meanwhile, the study by Angelis et al. has been made for application of AE in determining the damage of steel fiber reinforced concrete under bending [35]. In addition, Angelis et al. [36] also studied the classification of cracking mode appear on structural surface and study for cracking also been made by Ohno and Ohtsu [37].

Other than that, approaching the AE technique in concrete structure also can determine the fracture zone and have been investigated by Uddin et al. [39], Kawasaki et al. [41] and Zongjin et al. [43] studied again for the fracture zone in concrete based on application of AE technique and determination the corrosion of the reinforced concrete structure. Stated by Seto et al. [46] and Luo et al. [9], AE activity is included structural deformation process for its sources such as plastic deformation, cracking expansion and material degradation. It also involves the use of sensors on the structural part to detect the released strain energy produced from cracking opening growth. Other previous study of concrete structure using AE approach is shown in Table 2.

Table 2 Laboratory experimental study on AE for concrete

Author(s)	Types of testings	Outcome(s)
[48]	Three point bending	Assessment of fracture mechanics properties such as fracture energy and cracking of fiber reinforced polymer concrete.
[42]	Three point bending	Classification of the fracture process zone size and true fracture energy in concrete.
[49]	Tension of concrete frame	Damage assessment of corrosion in pre-stressed concrete.

[50]	Three point bending	Evaluation of different fracture modes in concrete specimens.
[51]	Four point bending	Determination of damage classification in reinforced concrete beam.
[23]	Three point bending	Determination of fatigue damage severity on reinforced concrete beam.
[52]	Three point bending	Determination of fracture process zone in notched concrete.
[53]	Three point bending	Determination of crack opening, micro-cracking and evaluate the influence of the structural size using DIC and AE techniques.
[54]	Four point bending	Determination of micro-cracking, parameter of AE and RA in the mechanical behavior of the concrete beam.
[55]	X-ray Ct method Ultrasonic test Compression test	Determination of comparison cracking damage pattern in freeze-thawed concrete between AE and X-ray Ct image.
[56]	Four point bending	Evaluation of the propagation and classification of crack on concrete.

3. Assessment approach on AE for concrete material

AE technique is used for the structural analysis or real time damage monitoring. The generated of transient elastic wave during the rapid release of energy from the localized sourced of the material in structural. Some features for AE technique based on its fundamental concept making it as an applicable non-destructive testing, such real-time capability, high sensitivity, global monitoring, source location, sensitivity to any process or mechanism that produce stress waves and passive nature [5]. In civil engineering fields the AE technique is widely used for structural health monitoring (SHM) [3, 10-13]. The advantages of AE technique compared to the others NDT technique are the determination of the cracking positions and other evaluation for overall structure can be tested without interrupting the structural performance. Furthermore, the classification of cracking and its direction can be calculated by other different approaches such various types of formula analysis [14-17].

The application AE technique in structural monitoring can be classified into two categories such as global and local monitoring. Global monitoring provides the total insight of the structure into the situation. It also focuses overall health for the structure such as a general perception of the damage severity or identification of natural damage when AE analysis or waveform is applied in structure. Meanwhile, local monitoring is more to focus on a specific location in the structure such as growth of crack and corrosion with a specific number of sensor apply. Furthermore, the recording and analysis process of AE technique can be divided into two categories, namely a parameter based on the approach (classical) and signal based approach (quantitative) [14-18]. Both of this application can be used for global and local monitoring in the engineering field.

In AE technique for SHM in fields, there are two able basic forms of recording AE data which are waveform and parametric data. For the experimental of collecting AE data, hardware and software used are required to be fast to avoid any losses of data and provided large storage must be significant. The waveform is not a practical testing compared to parametric form a series of parameter to characterize the signal. Due to the parametric approach in structural monitoring approach, signal characterized parameter are used to evaluate the gradual damage and identify the nature of the damage.

Based on AE analysis of structural components, not all of the AE signal parameter can be obtained from the monitoring process [19-20]. Signal waveform analysis enables quick data mining and process from the signal since it minimize the amount of data obtain. Otherwise, the development a new generation of the sensors and its availability for capturing data, this type of analysis has become possible for the acquisition of multichannel raw waveforms. The famous feature of this approach is better performance in signal noise discrimination and offering better interpretation compared to parametric analysis. However, the parametric analysis are might provide more convenient analysis in some case of concrete structure monitoring [5].

4. Conclusion

This paper presents a basic and detail review based on AE application in structural monitoring, especially concrete structure such as dam, building and bridge. The AE analysis has become widely used since its first approach in civil engineering as non-destructive testing method, where this technique is used to determine the condition of various structures without damaging its shape. With AE analysis, it becomes applicable for testing to fulfill few objectives such as real-time capability, high sensitivity, global monitoring, source location, sensitivity to any process or mechanism that produce stress wave and passive nature wave. Furthermore, AE application in monitoring of concrete also can determine the classification of cracking and its direction within its nature source generated a vibration while monitoring. Throughout this paper, a simple basic fundamental of AE technique testing has explained the use of its signal produce and capability to receive, then record waveform generates by material or during the cracking growth process. Other than that, this paper generates the general assessment by approaching the AE technique as one of the non-destructive testing technique that have been used as SHM in every monitoring due to its economical procedure within it fundamental parameter, damage assessment criteria and type of assessment method that can be used from previous researchers. Furthermore, some of the important applied due to AE objective is for real-time capability, high sensitivity, global and local monitoring, characterization of source location, sensitivity and its passive nature behavior from a concrete structure.

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