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Damage evaluation of reinforced concrete beams with varying thickness using the acoustic emission technique

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HIGHLIGHTS

- We had studied a comparison between the visual observation and AE technique.
- We had examined the changes in the depth of beam and level of damage associated with AE parameters values.
- We had observed that by increasing the degree of damage, AE parameters values had increased except for the average frequency.
- We had observed that by increasing the beam depth, AE parameters values had increased including the average frequency.
- The severity index value increased as the depth of the beams and level of damage increased.

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ABSTRACT

The aim of this study is to investigate the ability of the acoustic emission (AE) in order to test the effect of beam thickness on the damage mechanism of the RC beams under four-point bending. The results showed that as the level of damage increased, the values of all AE parameters increased except for average frequency; moreover, all AE parameters increased with increasing beam thickness, including the average frequency. Thus, it has been established in this work that AE can be effectively used in monitoring the behavior of RC beams with variable thickness.

1. Introduction

Reinforced concrete structures (RC) can deteriorate in service as a result of heavy loads, fatigue and aging of the structures. Cracking is commonly observed in concrete structures. It is important to understand that, the phenomenon associated with cracking can be attributed to several factors. It might result in different short term and long-term performance effects compounded by design, imposed loads, and other climatic conditions relevant to the structure [1]. In general, cracking can be broadly classified into two major categories which are micro-cracking and macro-cracking [2]. The crack development in the composite materials can be related to the mechanical interaction that exists between the inclusions such as fine sand/coarse aggregates and the cement-based matrix. This has direct bearing on the strain softening and fracture energy of the material composite structure in the cement-based matrix [3]. Such defects require monitoring to satisfy durability and serviceability requirements [2]. Structural cracks, such as flexural cracks and shear cracks, are active only if the overload condition continues or if settlement occurs [1,2]. In the regions of constant bending moment, only tensile and flexural cracks occur without sliding along the crack. Moreover, flexural crack opening is usually produced by elongation of tension reinforcing bars only when there is no slip at their end [4]. Previous study has reported that the spacing between flexural cracks is influenced by the type of longitudinal reinforcements [5,6]. Extending of structural life and avoiding structural failure can be achieved by early detection of cracks. Furthermore, the control of cracking in concrete structures is very much desirable to satisfy durability and serviceability requirements [4,7].

Nowadays, in order to detect the deterioration in concrete structure, there are several testing methods that can be adopted. Among them, the destructive testing and non-destructive testing (NDT) are very popular. These methods have distinct working principles and demonstrates different effectiveness for different types of deterioration [8].

Previous researchers have used NDT methods such as Impact-Echo method [9], Ultrasonic Pulse Velocity Method [10], Infrared Thermography [11], acoustic emission technique [12], to detect and monitor building deficiency, that requires occasional monitoring to maintain the health of building structures. Among all the NDT methods, acoustic emission (AE) is considered to be the most promising technique [13].

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There are mainly two different aspects of the AE method that distinguishes it from other NDT methods. Firstly, the energy signal originates from the sample itself making its own signal (in response to stress) in case of AE. Secondly, AE can detect dynamic process, on account of its ability to detect movement or strain, whereas most of the other methods can sense only the existing geometrical discontinuities or fractures [14]. Other advantages of AE when compared to rest of the NDT methods are: AE is applicable for local, global, remote, and continuous monitoring, whereas the rest are applicable only with respect to local scanning, less intrusive while the others are more intrusive, less geometry sensitive while the others are more geometry sensitive, material anisotropy is good with respect to AE and AE can be used in all stages of testing such as, pre-service testing, in-service testing, leak detection and location, mechanical property testing and characterization, and online monitoring [15].

In the determination of location of cracks, the principle used is the Time-of-Arrival (TOA) approach [15,16]. Microscopic and macroscopic events are two main mechanisms that generate AE, and this technique is highly sensitive for detecting active microscopic and macroscopic events in homogeneous materials or composites [17]. In addition, AE monitoring strategies can be divided into two types, namely global and local. Local monitoring tackles a specific area of damage, such as monitoring in real time damage growth in laboratory specimen [18–20], whereas global monitoring helps in evaluating the health and integrity of the entire structure [21].

AE can be defined as a localized stress wave that propagates within the materials from active deformation [15,22]. AE events also can be produced by crack onset, fiber breaks, disbands, moving dislocations, plastic deformation, and several other factors [23]. Some of the key applications of AE technology include early detection of cracking in concrete structures [24], identify damage modes in glass fiber reinforced polyester [16], prediction of fatigue crack growth in steel bridge components [25], crack classification in concrete [20,26,27], detection of cracks and disbands in aircraft composite structures [23] and global and local monitoring [21,23].

The primary objective of the AE test is to detect the presence of emission sources and to provide as many information as possible about the source [28]. There are five commonly used signal measurement parameters which are amplitude, counts, measured area under the rectified signal envelope (MARSE), duration, and rise time. Each of the AE signal feature is shown in Fig. 1.

In quantifying the damage level of any kind of structural member, the three methods commonly used in concrete structures are intensity analysis (IA), b-value, and Felicity and Calm ratio [29]. The IA method is a technique that assess the structural significance and integrity of AE data hit and the deterioration level of a structure by computing Eqs. (1) and (2), which are Historical Index (HI) and Severity Index (S_r) [21,28,30,31]. The HI is defined as a measure of the change in signal strength through the loading phase of the test, while the S_r is the average signal strength among the largest numerical values of the signal received at a sensor. Signal strength is defined mathematically as the integral of rectified voltage signal over the duration of the AE waveform packet [14]. Besides concrete structure, this method also has been successfully utilized in other structural materials such as metal and fiber-reinforced polymer (FRP) [32,33].

$$\mathrm{HI} = \frac{N}{N-K}\left(\frac{\sum_{i=K+1}^{N} S_{oi}}{\sum_{i=1}^{N} S_{oi}}\right) \tag{1}$$

$$S_r = \frac{1}{J}\left(\sum_{m=1}^{J} S_{om}\right) \tag{2}$$

where HI = Historic Index, N = Number of hits up to time t, S_{oi} = Signal strength of the ith hit, K = empirically derived constant based on material, S_r = severity index, J = empirically derived constant based on material, S_{om} = signal strength of the mth hit where the order of m is based on magnitude of the signal strength. For concrete, K and J values are related to N according to the following relations:

$$K = \begin{cases} 0, & N \le 50 \\ N-30, & 51 \le N \le 200 \\ 0.85N, & 201 \le N \le 500 \\ N-75, & N \ge 500 \end{cases}, \quad J = \begin{cases} 0, & N \le 50 \\ 50, & N > 50 \end{cases} \tag{3}$$

This technique is assessed based on the AE signal strength data collected from each sensor. The maximum values for S_r and HI are normally plotted as intensity chart as seen in Fig. 2. The chart is divided into five intensity zones, which indicate the structural significance of the emission. The descriptions for all zones are given in Table 1.

Cracking pattern and the propagation of cracks are mainly dependent on the loading type and loading conditions. According to a recent study [24], the initial cracking position depends on the internal cracks and flaws during the loading. Moreover the mechanical behavior of reinforced concrete beam can be divided into five different stages, namely; micro-cracking, first visible crack, distributed flexural cracking, shear cracking, and damage localization. During the damage localization stage the initial cracks propagated upward to the compression zone and all cracks started to localize into major cracks, causing significant widening of the width in each crack.

In this study the maximum values for S_r and HI for each level of damage are plotted on the intensity charts. The AE signal features such as rise time, average frequency, amplitude, counts, and mea-

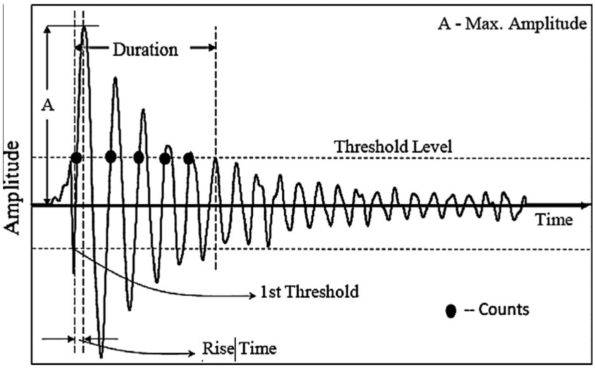

Fig. 1. Acoustic emission signal features [14,28].

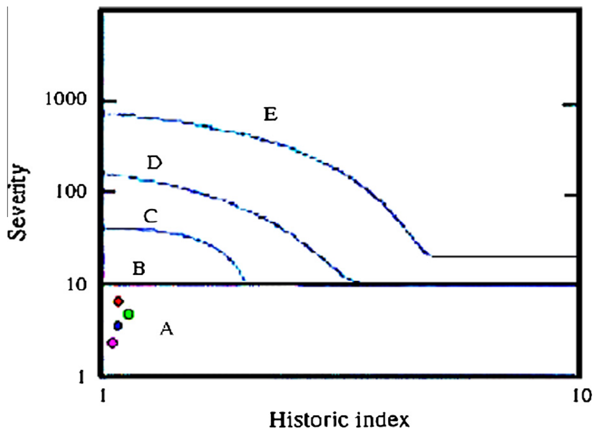

Fig. 2. Intensity analysis chart [31].