Evaluation of Reinforced Concrete Damage Using Intensity Analysis in Acoustic Emission Technique

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Abstract. Many concrete nowadays has been deteriorating before reach the maximum design life. Therefore, evaluation of damage level of concrete structure should be carried out to identify whether the crack that occurred in the concrete is dangerous or not. Thus, in this study reinforced concrete beams have been monitored by Acoustic Emission (AE) and evaluated using the intensity analysis. The capability of the AE technique to detect and locate the location of cracks was include in this study. This project had identified the cumulative absolute energy from the AE system in different mechanical behaviour of RC beam when subjected to load. Visual observation of the concrete failure were presented to compare with the AE results output. In addition, a statistical approach, intensity analysis were discussed in this study to evaluate the levels of damage of concrete.

Keywords: Reinforced concrete beam, acoustic emission, intensity analysis, damage level

1. Introduction

Nowadays, structural health monitoring has been widely used and a well known technique to inspect, detect and also to monitor the health condition of the concrete. Reinforced concrete (RC) structures were constructed for various purposes in a certain design life in the context of 'maintenance free' construction material [1]. However, in recent years, many RC structures had been deteriorated even before their design life due to corrosive circumstances, alkali-silica responses and other environmental effects. Therefore, structural health monitoring on the RC structures have to be done to ensure that the structures always in the good conditions.

Therefore, an efficient and accurate nondestructive testing (NDT) technique is necessary to detect damage from a variety of mechanisms at the earliest possible stage in the life of the structure [1]. There are several nondestructive method that have been recently applied to evaluate damage qualifications of structural members and Acoustic Emissions (AE) technique is one of those technique. This paper include the application of AE technique to determine the active crack of reinforced concrete beam. Intensity Analysis also was used throughout this research to obtain the grading of damage of reinforced concrete beam.

2. Fundamental of AE

Acoustic emission (AE) can be defined as the transient elastic wave generated by the rapid release of energy from a localized source or sources within a material [2]. The elastic energy propagates as a stress wave (AE event) in the structure and is detected by one or more AE sensors. The parameter analysis of an AE event evaluates and correlates AE features such as counts, amplitude, rise time, energy and many more [2].

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3. Intensity Analysis

Intensity analysis is the technique that evaluates the structural significance of an AE event as well as the level of deterioration of a structure by calculating two values which are called Historic Index (HI) and severity (S_r) [2]. According to [3], HI can be defined as analytical method of estimating the changes of slope in the cumulative signal strength against time by comparing the signal strength of the most recent hits to the total hits for that channel. While severity can be defined as the average signal strength among the largest numerical values of the signal [4]. The formula of HI and S_r are as presented in equation (1) and equation (2) [2-5]:

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

where, H(I) : Historic Index, N : Number of hits up to time t, S_{oi} : Signal strength of the ith hit, For concrete: K = 0 , N ≤ 50 ; K = N – 30, 51 ≤ N ≤ 200; K = 0.85N, 201 ≤ N ≤ 500.

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

Where, S_r : Severity index, for concrete material J : J = 0, N < 50; J = 50, J ≥ 50, S_{om} : signal strength of the mth hit where the order of m is based on magnitude of the signal strength.

4. Experimental Work & AE Instrumentations

In the laboratory work, three point bending testing were carried out on 100mm x 100mm x 500mm RC beam. AG-X testing machine was used for the three point bending testing with the speed of 0.5 mm/min. The point load was located at the centre of the beam while at each sides of the beam sensors type R6I were installed. In order to check the accuracy of the sensors, Hsu –Nelson method was applied on it [6]. The load was applied in a stepwise loading. It was held for three minutes prior applying low load and AE system was paused to observe and record any changes on the specimens. Figure 1 shows the instruments setup of the testing.
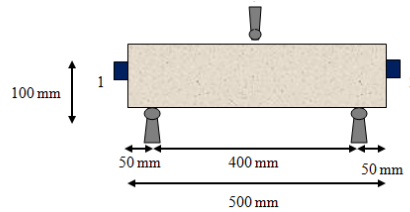

Fig. 1: Testing procedure and detail dimension

5. Result and Discussion

5.1. Visual observation

From the test and observation, the mechanical behaviour of the reinforced concrete beam can be divided into five stages which are micro-cracking, localized crack propagation, distributed flexural cracking, shear cracking and damage localization. All these five stages are shown in Figure 2. The microcracking (region I) was happened in between 0 kN to 10 kN. As the loading increased to 10 kN, the micro-cracks started to localize at the centre of the beam. At the second stages (region II), the cracks were propagated as the load increased. At the third stage (region III), the initial cracks were propagated from the tension region to the compression region during the increasing of the load. The new cracks were formed along the beam during this stage. Due to the small dimension of the specimens (500 mm), the specimens were tend to failed in shear when the load was continued applied and shown in region IV. Lastly, damage localization was the final stage of failure which happened at region V. In this region the crack starts to localize into major crack and it became wider as the load kept increasing until the beam failed. The cracking pattern can be observed in Figure 3.

5.2. Analysis from AEwin Software

Figure 4 shows the AE linear location in terms of Absolute Energy vs X Position graph during the first stage of failure which is microcracking. From the figure, it shows that the emissions were distributed with low absolute energy but it represents the microcrack of the beam. The highest peak of the graph is

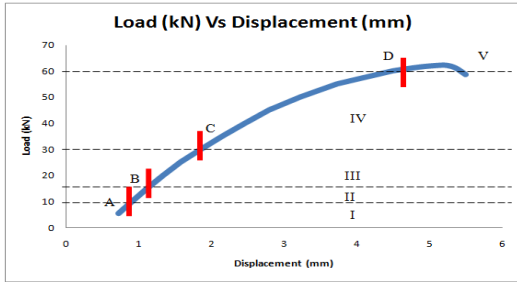approximately 5.3×10^5 aJ.
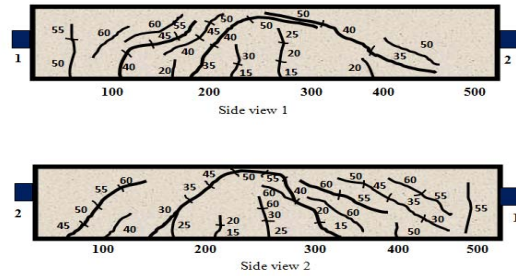

Fig. 2: Graph of load versus displacement

Fig. 3: Cracking pattern

5.3. Analysis from AEwin Software

Figure 4 shows the AE linear location in terms of Absolute Energy vs X Position graph during the first stage of failure which is microcracking. From the figure, it shows that the emissions were distributed with low absolute energy but it represents the microcrack of the beam. The highest peak of the graph is approximately 5.3×10^5 aJ.

In the second stages, there is a first visible crack was observed and it can be seen from Figure 5. From the visual observation, the damage location that was observed is 263 mm approximately. While by the AE system, the location was detected at around 260 mm which is located at Zone 1. The energy of the crack is around 9.7×10^5 aJ. From the graph, there were another two high peak at Zone 2 and Zone 3 which is approximately 8.5×10^5 aJ and 6.1×10^5 aJ respectively. The Zone 2 is located at 220 mm while Zone 3 at 330 mm.
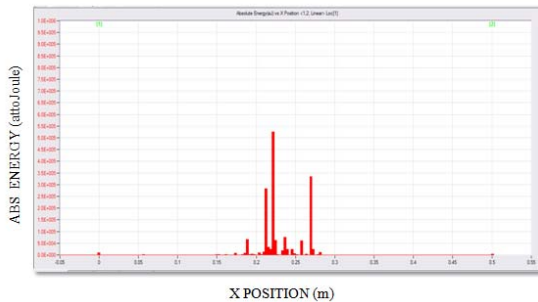

Fig. 4: The source location of all emission during microcracks for (0-10 kN).
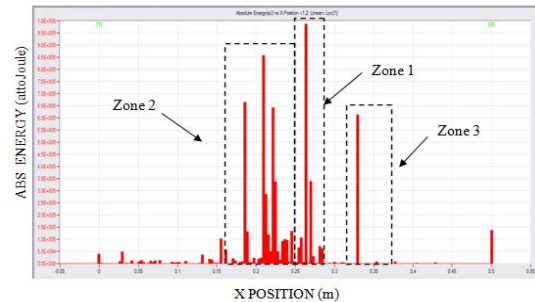

Fig. 5: Source location of total emission at the start of the localized crack propagation for (0-15 kN).

At Point B (15 kN), the initial cracks started to propagate upward. This can be shown in Figure 6 where the absolute energy in the Zone 1 was increased to 1.1×10^6 aJ. It also the same at Zone 2 where the absolute energy increased to 8.9×10^5 aJ. At the same time, there were new cracks that occured in this stage. In Zone 2, the crack at around 180 mm and 240 mm. Another crack also occured at 250 mm in Zone 1 and in Zone 4, the new crack occured approximately at 130 mm and 60 mm.
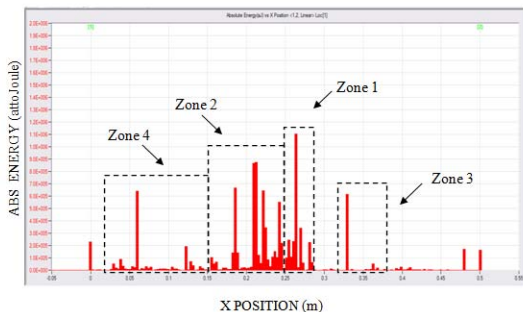

Fig. 6: The source location of all emission at the start of the distribution flexural crack for (0-20 kN).
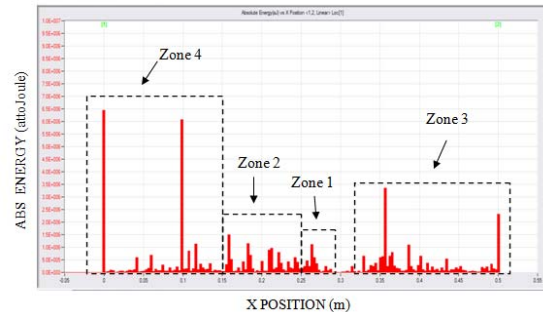

Fig. 7: Source location of total emission at the start of the localized crack propagation for (0-30 kN).

Figure 7 shows the source location plot of absolute energy for events up to 40 kN. At this stage the formation of the shear crack was occured where the absolute energy is highest at the support of the beam (Zone 4) which approximately 6.5×10^6 aJ. There also have another high absolute energy in Zone 4 at 100

mm (6.0×10^6 aJ). The crack at the other support in the Zone 3 also started to occurred with the absolute energy of 2.5×10^6 aJ and at 360 mm (3.3×10^6 aJ).

The damage localization stage can be observed visually at 60 kN and acoustically in Figure 8. At this stage the cracks are getting wider and clearer. The shear cracks at Zone 4 (at support and 100 mm) show an increasing value of absolute energy which is increased to 2.8×10^7 aJ for both cracks. The final stage will be the failure of the beam and the beam was failed in shear where it happened at the supports of the beam. It is shows in Fig 9 that the highest absolute energy level that has been measured was around 9.0×10^7 aJ and it is located at support 1. The beam failed when the load reached 62.17 kN.
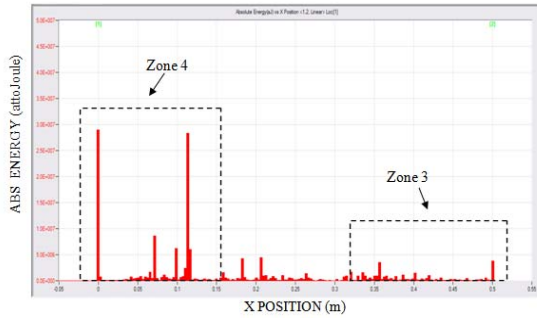

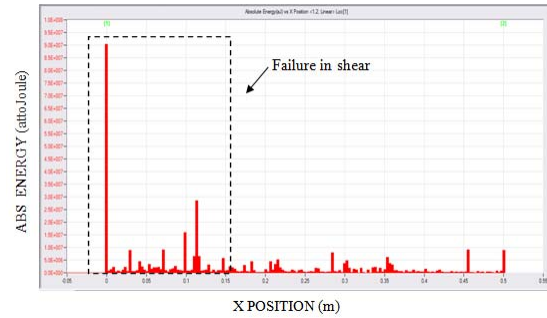Fig. 8: The source location of all emission at the formation of shear crack for (0-20 kN).

Fig. 9: Source location of total emission during damage localization (0-60 kN).

5.4. Intensity Analysis

The values of HI and S_r of every stages which obtained from equation (1) and (2) were plotted in the intensity chart as shown in the Figure 10. From the figure, as the stages was increased from stage I to stage V, the severity also increased. As in stage I, smaller loads was applied and it kept increasing until the beam failed which is in stage V. Thus, it can conclude that, the severity is increased in the increasing of load.

While for the values of HI, the values are variable in each stages. It can be observed from the figure, the HI value in stage I which is 0.658 is the smallest compared to other stages. It is because, during this stage, lower load was applied and only microcracking occured. Thus, the produced of the energy also lower. As the load increased at the stage II whereas the first visible crack occured, the produced of the energy also increased. Thus, the HI value at this stage is increased to 1.56. However, at stage III, the value of HI is decreased to 1.46. Although the load is increased at this stage, but the crack only propagated at the existing crack. Hence, the produced energy lower than stage II.
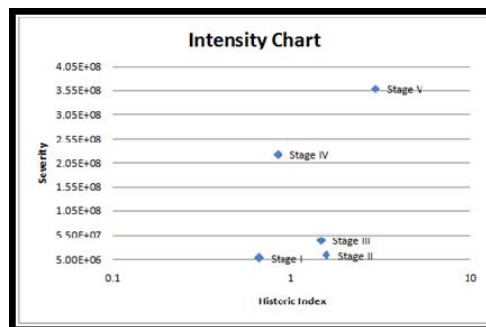

Fig. 10: Intensity Chart

The value of HI kept decreased as it reached the stage of shear crack formation. In the shear crack, the reaction is very slow and the crack can be classified as catastropic failure. Hence, the produced of emission is low and caused the HI value decreased. But, the HI value was increased in the failure stage to 2.94 due to the increasing load and higher energy produced. From the Figure 10, it also can show that, the intensity value for stage I was plotted at the lower left-hand while the intensity value for stage IV was plotted at the upper right-hand. Thus, the pattern of the intensity chart can be observed whereas the higher intensity values are plotted at the upper right hand while the lower intensity value are plotted at the lower left hand.

6. Conclusions

This study was carried out to investigate the relationship between AE absolute energy and the physical

behaviour of a reinforced concrete (RC) beam and to determine the ability of the AE to locate and monitor the crack propagation on RC beam. The following points summarise the most significant conclusions.

- By comparing with the AE result, it was observed that the first visible crack will occur when the cumulative absolute energy exceeds 1×10^6 aJ.
- In addition, the AE technique also able to locate the damage area and there were only result slightly different compared to visual observation. Thus, in conclusion, the ability of AE technique to detect, locate and monitor the behaviour of different stages of reinforced concrete beam are promising.
- Although there have no generalization that can be made at this stage, a pattern in the intensity chart was observed. From the observation, it show that the high intensity values were plotted at the upper right-hand while for the low intensity were plotted at the bottom left-hand.

7. Acknowledgements

8. References

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