Intensity Analysis Method for Measurement the Damage Severity of Concrete Structure by Utilizing the Acoustic Emission Technique

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***Abstract*—Evaluation methods such as acoustic emission (AE) are required for assessing the deterioration on concrete structures. This paper gives a brief on the evaluations of the acoustic emission to the health monitoring of reinforced concrete structure beam. Small scale size beam have been used for this investigation and the AE signal processing are the main principal data in this work for assessing by using the statistical technique, which is known as intensity analysis method (IA). This technique is capable to quantify and evaluate the damage severity on concrete structures. Eventually, by using the AE signal strength data, the results indicates are greater instruments in determining the damage mechanism level on concretes structure.**

***Index Terms*—Acoustic emission, intensity analysis, historical index, severity index.**

I. Introduction

Ordinary, reinforced concrete structures have been utilized around the world since the ancient time and basically the applications are more into buildings, bridges, and dam. Even nowadays, the popularity of the reinforced concrete structure applications has been maintained as a major and minor construction [1]-[4]. Upon to that matter, it has been facing several types of damages mechanisms and deteriorations during their service life. Therefore, their maintenance are becomes more significant part for evaluation and to preserve the integrity of structure.

In such deteriorations are the increments loading of structure due to the increasing of traffic flow and severe environmental effects such as, scaling, spall and corrosion. Therefore the process of the damages mechanisms on concrete will induced the interaction of duration between long term and short term process.

In order to maintain the structural integrity and monitor the defects in the concrete structure, nondestructive testing (NDT) is an effective method for investigation and evaluation the actual condition of structures [5]. One of the excellent techniques in the various types of NDT methods are Acoustic Emission (AE) [6], [7].

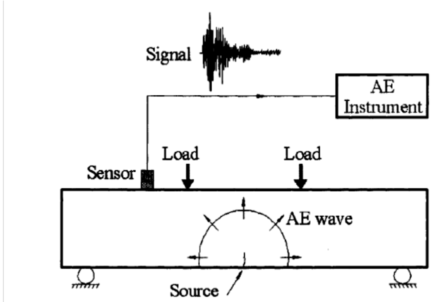

Fig. 1. Principle of AE[2].

This paper involves the application of AE technique as a NDT monitoring to measure the damage severity of the reinforced concrete beam. Throughout this research, IA method was utilized for analyzing the AE signal strength data.

II. Fundamental of AE

The term of AE is defined as the class of phenomena whereby transient elastic waves are generated by the rapid release of energy from localized sources within a material [8]. Today, AE technique was found to be the most efficiency and powerful tool in NDT for real time testing of the materials behavior deforming under stress and was established for damaged detection and monitoring of concrete structure [9]–[13].

Basically AE will produced the transient wave from the propagation and generations of cracking and stress in material respectively. This was revealed in the Figure 1, the principle of AE technique in concrete beam under stress condition

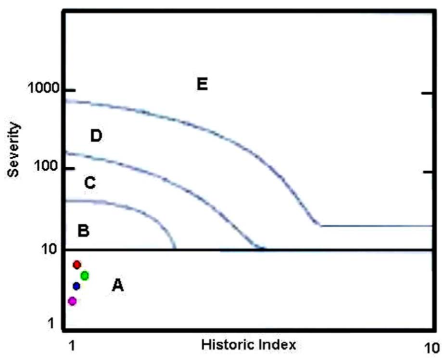

Fig. 2. Typical Intensity Chart for Bridge[16].

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TABLE I: SIGNIFICANCE OF INTENSITY ZONE [17]

Zone Intensity	Recommended Action
A–No significant emission	Insignificant acoustic emission
B- Minor	Note for reference in future tests. Typically minor surface defects such as corrosion, pitting, gouges or crack attachments welds.
C	Defects requires follow-up evaluation. Evaluation may be based on further data analysis or complementary nondestructive examination.
D	Significant defect requires follow-up inspection.
E	Major defect requires immediate shut-down and follow-up inspection

III. INTENSITY ANALYSIS METHOD

Mathematically, Intensity analysis (IA) method is the technique that evaluates the integrity of structural significance for 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) [14]. According to [10], this quantification method is known as the statistical analysis and it has been successfully utilized to FRP, metal, and concrete for evaluation system.

The equations for Historical Index and Severity have been shown in Eq. 1 and Eq. 2[10,15]:

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

where, H(I) : Historic Index, N : Number of hits up to time t, S_{oi} : Signal strength of the *i*th hit, For concrete: $K = 0$, $N \leq 50$; $K = N - 30$, $51 \leq N \leq 200$; $K = 0.85N$, $201 \leq N \leq 500$.

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

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

Therefore, the S_r and maximum HI value will be plotted on the intensity chart as presented in Fig. 2.

The chart is divided into intensity zones which indicate the structural significance of the emission. All of the zones descriptions are presented in TABLE I.

IV. EXPERIMENTAL WORK AND AE INSTRUMENTATION

Throughout this laboratory work Small scale beam size, cross section 100 mm X 100mm and length 500mm were included in this investigation and tested by three points bending. It was reinforced with high tensile strength size 2T10 and the steel bar was hanger with mild tensile strength of 2T8, while as for the size of stirrups is R6 that has been normally used in the small scale size. The cross section detailing for all categories have been indicated in Fig. 3.

Hydraulic jet and load cell have been installed in the middle of the beam and it consider as a Loading partition (P). The side surface of the beam specimens have been grinding and clean smoothly for applying the sensors type R6I Physical Acoustic Corporation (PAC).

Therefore after completing all the setting up of the AE instrumentation and AE Win software, the sensitivity of the sensor need to be check for the data accuracy. This method normally known as Hsu-Nielsen source method [8] After that the threshold setting was fixed up to 45 decibel (db) and the data hit parameters were setting up for all component such as, amplitude, frequency, signal strength, absolute energy, rise time and duration.

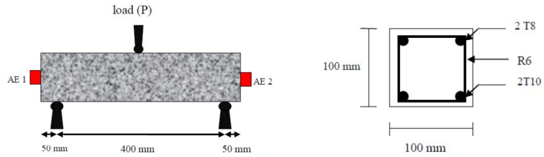

Fig. 3. Testing procedure and detail dimension.

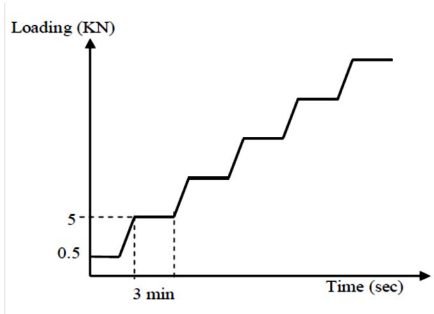

Fig. 4. Stepwise Loading conditions.

V. RESULT AND DISCUSSION

A. *Signal Strength Analysis*

In this paper, the main parametric correlation that will be emphasized is, signal strength versus time. This is the main part of intensity analysis which is related to the damages parameter besides the amplitude other component.

The AE signal strength data recorded during the loading phase are extracted for each beam and analyzed by channel sensors basis. The selected channels are according to the maximum value of cumulative signal strength and the values were plotted as indicate in Fig. 5.

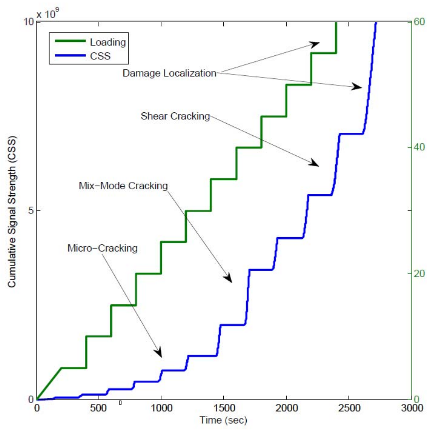

Fig. 5. Relationship on the CSS and Stepwise loading.

Fig. 5 indicated the relationship of amount of signal strength due to the stepwise loading condition corresponding to the real time testing.

Through the observation in Fig. 5 the signal strength values were increase slightly during the initial stage within 500 sec up to 1500sec. However, the values start to increase dramatically until at end of the graph line. One possible explanation for this occurrence could be caused by the high attenuating property of a heterogonous material like concrete and the crack formation.

During the initial of loading within 500 sec to 1000 sec the beams indicated the micro-cracking stage. This type of cracking are normally cannot view by naked eyes, but however when the loading are increase up to 60 %, the beam will show the mix-mode cracking which is involving the flexural and shear cracking. This indicated in Fig 5, where the mix mode cracking occur during 1700 sec to 2400 sec. When the loading get to 80 % of increasing, the next step of crack is shear cracking. This type of cracking is the final stages of cracking propagation as presented in fig 5 within 2400 -2600 sec.

The damaged localization occurred right after shear cracking process and is considered as inactive phase, where a significance increment in AE hit and energy rates are always formed during shear crack. This trend is clearly reflected in the intensity analysis chart as well

B. Intensity Analysis Method

S_r graph presented in Fig. 6 show the severity value increases gradually during the increment values of the signal strength at the initial stage.

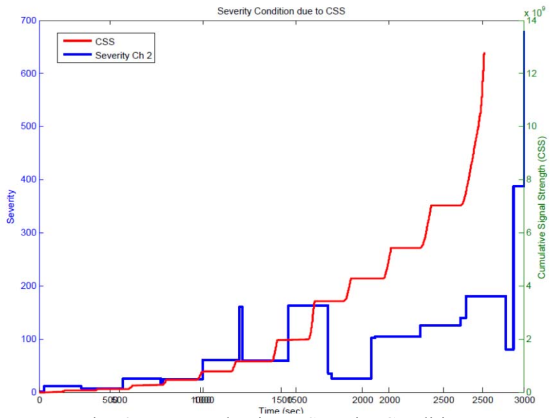

Fig. 6. Beam evaluation – Severity Condition.

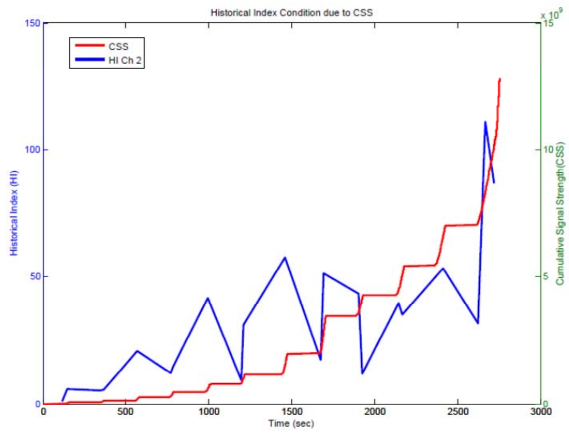

Fig. 7. Beam evaluation - Historical Index.

However, it shows dramatically increment when the cumulative signal strength reach the maximum value.

The severity values for this investigation are between 100,000 and 100 million. These ranges of values are similar with the previous research and this signifies the release of the high energy content in the beam specimens, where as the damages are continuously being more serious till to failure stage such as breakage of the concrete structure and shear failure [17].

Historical index is a good indicator of the onset for significant damage, as indicated in Fig. 7. This figure illustrated the relationships between HI and CSS functions of time and similar to the S_r condition figures. The characteristic of these figures are almost similar due to the condition of the reinforced concrete beam compared to the fiber reinforced concrete, perhaps the features of the slope HI and CSS are higher than normal concrete structure. Referring to these figures, there is a rapid increase in the slope of the CSS curve within intervals of 1000 - 2000s and at the final stage of the testing within 2500 – 3000s. These outcomes are almost similar to the previous research work by [17]. Throughout the time of interval, the values of HI are highly peak correspond to the slope increase of the CSS curve value. Upon to that matter, the previous research has discussed that peaks of HI and CSS curve can be employed to discriminate and identify the possible damaged mechanism and onset of failure [14], [17].

Therefore, the intensity analysis charts are divided into five zones (A, B, C, D, E) in order to classify the damage level of the beam specimens. According to the cumulative signal strength analysis, it was carried out based on the number of load phases. In this investigation, the total numbers of load phases are eleven and it was found that the charts plotted for all beam specimens were represented almost similar to the trend of phase distribution in the zones as presented in Fig 8.

Besides that, the theoretical calculations were pointed in this investigation and the beams are begins to show hairline cracks at the tensile portion of the specimens at about 12% of the ultimate load and about 50% to 70% of ultimate load the intensity values appear to imply the flexural and shear cracks.

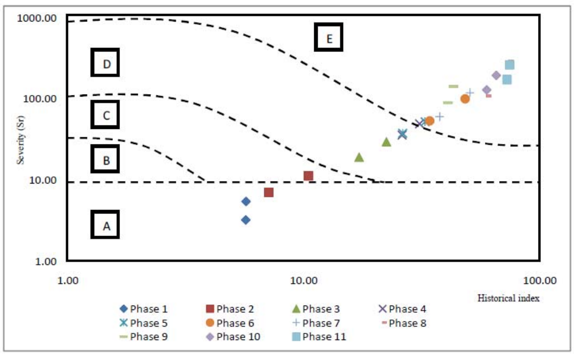

Fig. 8. Beam evaluation - Intensity analysis.

During this time, the intensity analysis values indicate the sufficient warning for estimation the severity of damage in the beams. Therefore, the entire Zones as indicate in the Fig 8 are proposed based on the calculation and brief observation above and it is also related to the AE signal strength data. This chart is valid for evaluating the reinforced concrete beams of the same dimension and subjected to the similar load condition.

VI. Conclusion

In a nut shell, the integrity of concrete structure members can be sufficiently quantified by using the intensity analysis and this method shows great potential in becoming an effective tool for evaluation and continuous monitoring for all fields of structure without considering any type of size or material.

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