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A STUDY ON DAMAGE ASSESSMENT OF RC BEAM WRAPPED WITH CARBON FIBRE SHEETS USING PARAMETERS OF ACOUSTIC EMISSION SIGNAL

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ABSTRACT

This paper presents damage inspection of reinforced concrete (RC) beam wrapped with carbon fibre sheet (CFS) using parameters of acoustic emission (AE) signals based on signals strength. RC is easily exposed to damage due to successive load. Hence, inspection of RC structures is vital to ensure the lifespan of the structure is fully controlled and safe. In doing so, experimental work on nine experiments on nine RC beams of 150 mm x 150 mm x 750 mm was carried out. The beam was subjected to three-point loading in conjunction with AE technique. Four AE sensors were set at selected position on the beam surface. The main aims of this study are to observe the crack propagation of the RC beam and to evaluate the crack development of control RC beam, RC beam wrapped with CFS in one layer and RC beam wrapped with CFS in two layers when subjected to increasing static loading. Three RC beams were statically loaded to failure and the remaining six beams were tested under increasing static loading. The increasing static loading were based on seven loading phases of 0.1Pult (Phase 1) to 0.7Pult (Phase 7). The inspection was based on the visual inspection of the crack development for each load phase and the relationship between signal strength and X-location. It is found that the signal strength against X-location generated good correlation for damage assessment of RC beam wrapped with CFS.

Keywords: acoustic emission, carbon fibre sheet, signal strength, static load test.

INTRODUCTION

Reinforced concrete (RC) structure is a familiar material used in the civil engineering construction such as bridges, buildings and dams. However, the weakness of these structures is commonly exposed to deterioration in the form of cracking problems. Cracks are usually developed during loading process. Thus, assessment on crack progression is significantly important. The assessment is vital to detect the crack initiation in the structures before it is getting worse. In addition, the cost repair can be minimized and helped to prolong the lifespan of the structure.

Damage assessment can be identified by analyse the Acoustic emission (AE) data together with the location of crack growth during testing (Md Nor *et al.,* 2013). AE is one of the non-destructive testing (NDT) techniques that have been widely used in monitoring the damage of a structure. This is because AE is the most preferable test to be used for crack determination without disturbing the nature of the structure. AE is the appropriate tool for damage detection. This is proved by Ohtsu *et al*., (2002), that AE technique has been used in the fields of civil engineering for structural health monitoring (SHM). AE has also been used to identify the damage behavior and failure mechanism of RC structure (Lee and Lee, 2002).

There are various approaches of AE analysis have been used for determination of crack progression in structure.

For example, average frequency and RA value, intensity analysis and *b-value*. In this study, the crack progression in the RC beam wrapped with carbon fibre sheet (CFS) is evaluated using the AE signal strength.

Fundamental of AE

Acoustic emission is the waves emitted from plastic deformation occurred in the structure. When cracking or any deterioration propagates in the structures, the transient waves are generated. Then these mechanical waves are going through the piezoelectric transducers of AE sensor to convert into electric signals. AE sensor consists of detection, measurement, recording, interpretation and evaluation. The signal is then amplified and all data collected can be analyzed for status of structures.

Generally, the transient wave will be generated from the deformation and propagations of cracking and stress in a structures. AE creates the transient wave from the elastic energy transmits as a stress wave in the structure and is detected by either one or more AE sensors (Shahidan *et al.* 2012). A stress wave also known as AE event. This AE event generated resulting from the disturbance movements, crack onset, growth and occurrence, fibre breaks, disbands and plastic deformation (Degala *et al.* 2009). Figure-1 shows a schematic diagram for AE monitoring process (ElBatanouny, 2012).

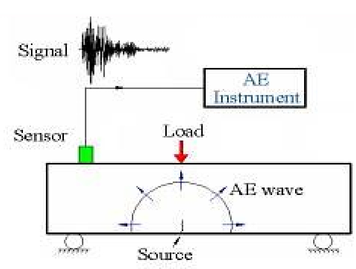

Figure-1. Schematic diagram for principle of AE.

One of the AE parameters is signal strength. The AE signal strength can produce the amount of relative energy released by the structure to show the damage development in a structure. According to ASTM, (2014), the signal strength is defined as "the measured area of the rectified AE signal with units proportional to volt-sec". Figure-2 shows the schematic of AE parameter adopted from Aldahdooh *et al*., (2013). The investigation by Behnia *et al.,* (2014) was reported about AE signal strength were also used for advanced structural health monitoring of concrete structure with the aid of acoustic emission.

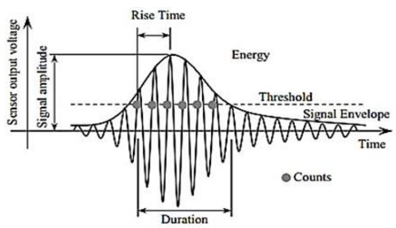

Figure-2. Schematic parameter of AE (Xu, 2008).

Signal strength is combined both amplitude and durations of AE signal. This analysis is a qualitative approach to quantify the damage progression. There are various approaches have been used in the AE analysis to correlate the signal strength. Md Nor *et al*., (2014) stated that the signal strength can be used to diagnose damage severity on RC beam. Then,a bath-tub curve is developed using signal strength of AE. From the bath-tub curve, fatigue damage development in the RC beam can be identified. In the present study is focused on the damage assessment on RC beam wrapped with CFS using parameter of AE signal strength. The damage evaluation is evaluated from the signal strength against X-location that occurred at each load phase. The main goal is to evaluate and correlate the damage evaluation on RC beam wrapped with CFS when subjected to increasing static loading. The CFS is used to strengthened the soffit of the RC beam.

Figure-3. Carbon fibre sheet.

The CFS has been used widely for rehabilitation of damaged concrete beams. According to Lee *et al.,* (2002) the main purpose of the CFS utilization is for rehabilitation and reinforcement of concrete structures. According to Takeda et al., (1996) stated that the CFS can be used for reinforcing existing RC structures. According to Takeda *et al*., (1996) a good result was obtained for both cracking strength and the yield strength of the strengthened beams.

METHODOLOGY

The RC beam specimens were prepared with concrete strength grade C40. The RC beams specimens were designed as a singly reinforced with 2T16 to strengthen the tension part and 2R8 to act as hanger bars. Each bar was bent at both end to form a standard hook of 30 mm at compression part and 60 mm at tension part. A total nine RC beam specimens of 150 mm x 150 mm x750 mm and 20 cubes of 150 mm x 150 mm x150 mm were prepared. The RC specimens were cured in curing tank for 7 and 28 days. The average compressive strength for 7 days was found to be 33.87N/mm^2 meanwhile for 28 days was 43 N/mm^2. CFS with required length was bonded on the RC beam using epoxy resin adhesive on the soffit. Then, the wrapped beam kept in room temperature for more than one week (Takeda *et al*., 1996). The steel plates with the required length were installed on selected location on the beam surfaces. Three point bending using a servo-controlled Universal Testing Machine (UTM) was used in conjunction with AE testing. It was performed under constant load rate 0f 0.02mm/s. Figure-4 shows the bending test were setup. Four AE sensors R6I - resonant 75 kHz were attached on the specimens. The sensors were placed with high-vacuum silicon grease as couplant to the beam surface. The visual inspection was also carried out to compare with the AE signals strength data in data acquired system. For the analysis using AE signal strength, it based on the collected data at Channel 4. The signal strength was measured in nano-volt-sec(nVs).

Figure-4. Three point of bending load of RC beam specimens in conjuction with AE technique.

Results for Rc beam specimen plain RC beam

Figure-5 shows the cracks patterns of the plain RC beam under seven phases of increasing static load test. The phase from number 1 until seven tells the progression

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of crack pattern corresponding to Phase 1 to Phase 7 of loading.

Visual inspection was conducted using torchlight in order to see the development of hairline cracks. Meanwhile the plotted graph of signal strength and X-location was generated from the located event data collected in AE system whereby the evaluation process was focused only at Channel 4 due to closest location to the sensor. In addition, this Channel 4 helps to give dominant data.

It is found that there was no crack detected by visual inspection for phase 1 when maximum loading (Pmax) of 11.5 kN was applied. This indicates that the load value 11.5 kN was very low thus it does not produce any cracks on beam surface. However, the result obtained from the relationship between plotted signal strength and X-location in phase 1 shows the highest value of energy produced was 4720 nVs at distance 0.38 m from the edge of beam specimen as shown in Figure-6.

Therefore, it is found that the result obtained from visual observation was compatible with the graph signal strength against X-location. Then, in phase 3, the initial development of shear crack was clearly seen by naked eyes. The highest value of signal strength here identified was 11400 nVs at at distance 0.4 m from the edge of beam specimen.

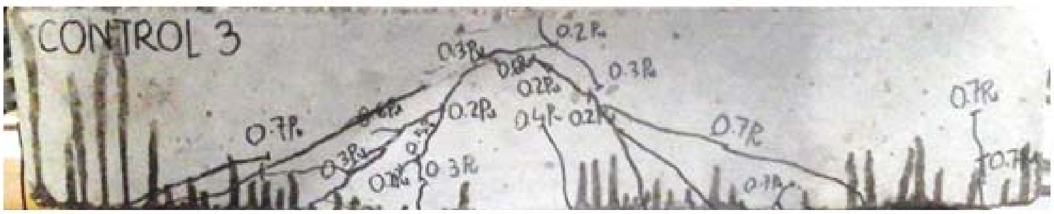

Figure-5. Visual observations on control 3 specimen.

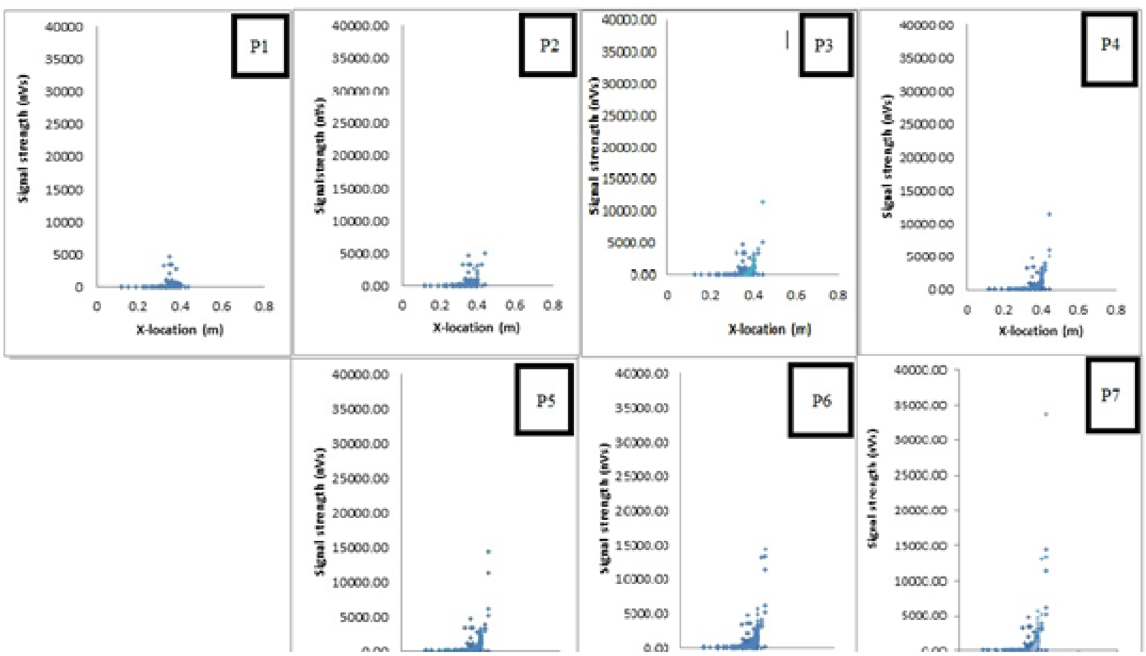

Figure-6. Relationships between signal strength against X-location for beam specimen control 3.

This result tells that in this phases, as cracks propagated and developed the signal strength can maintain the energy to 11400 nVs. Meanwhile when the testing reach to phase 7, it is found that the shear cracks was aggressively growth beyond the midspan beam surface when the load reach failure as shown in Figure 4.3. Therefore, based on the results obtained from visual inspection and relationship of signal strength against X-locations, it was clearly shown that the small increment of cracks progression can produce high energy value of signal strength detected by AE signals. The investigation on the RC beam wrapped with one layer was found good results to evaluate the damage inspection as the surface of CFS layer does not effect.

Results for Rc beam specimen with one layer of CFS

The starting values of static load test conducted for this specimen were 13.8 kN. There was no crack developed in phase 1.

Until phase 3, the first tensile cracks were detected by naked eyes. In this phase, the highest energy was 8580 nVs at distance 0.6m from the edge of beam specimen. Then, more tensile cracks were developed in phase 4 as shown in Figure-7. The results from graph signal strength versus X-location in phase 4 showed the increment value as shown in Figure-8. It is found that there is a strong connection between visual observation and this plotted graph. In phase 5, the growth of shear crack was detected. This indicates that the RC beam with one layer of CFS proved that the strong bonding between CFS layer and soffit RC beam.

Therefore, based on the results obtained from beam specimen B1 1CFS; it was also clearly shown that the small increment of cracks progression can produce high energy value of signal strength detected by AE signals. However, the CFS surface layer inspected still in a good condition. The investigation on the RC beam wrapped with one layer was very helpful to evaluate the damage inspection as the surface of CFS layer does not effect.

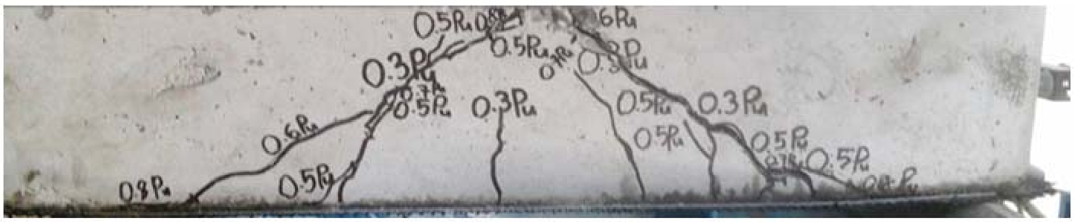

Figure-7. Visual observations on B1 1CFS specimen.

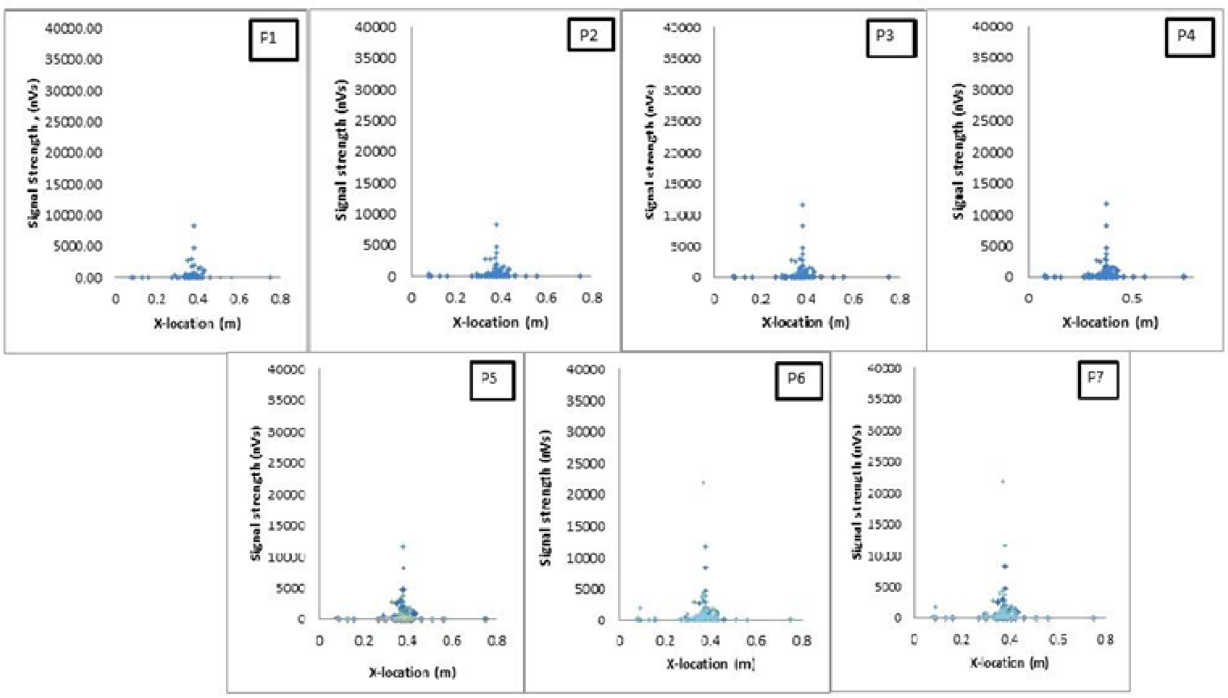

Figure-8. Relationships between signal strength against X-location for B1 1CFS specimen.

Results for RC beam specimen with two layer of CFS

Under loading value of 15.3 kN of phase 1, there was no crack occurred. However, the crack was firstly visible at the midspan of the beam specimen as shown in Figure-9. It was shear cracks growths at distance 0.37 m from the edge of beam specimen. The highest energy of signal strength produced in this phases identified was 1350 nVs.

In phase 4, there are too much tensile cracks developed in this moment. But, the CFS layer is still in a good condition without showing any effects. At the same time, the data from graph signal strength against X-location identified was occurred an increment value as shown in Figure-10. The highest value obtained was 2390 nVs at 0.19 m from the edge of beam specimen. Meanwhile, the utilization of two layers CFS in reinforced structure was found to be a good bonding as there is less deterioration obtained from this study.

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Figure-9. Visual observations on B2 2CFS specimen.

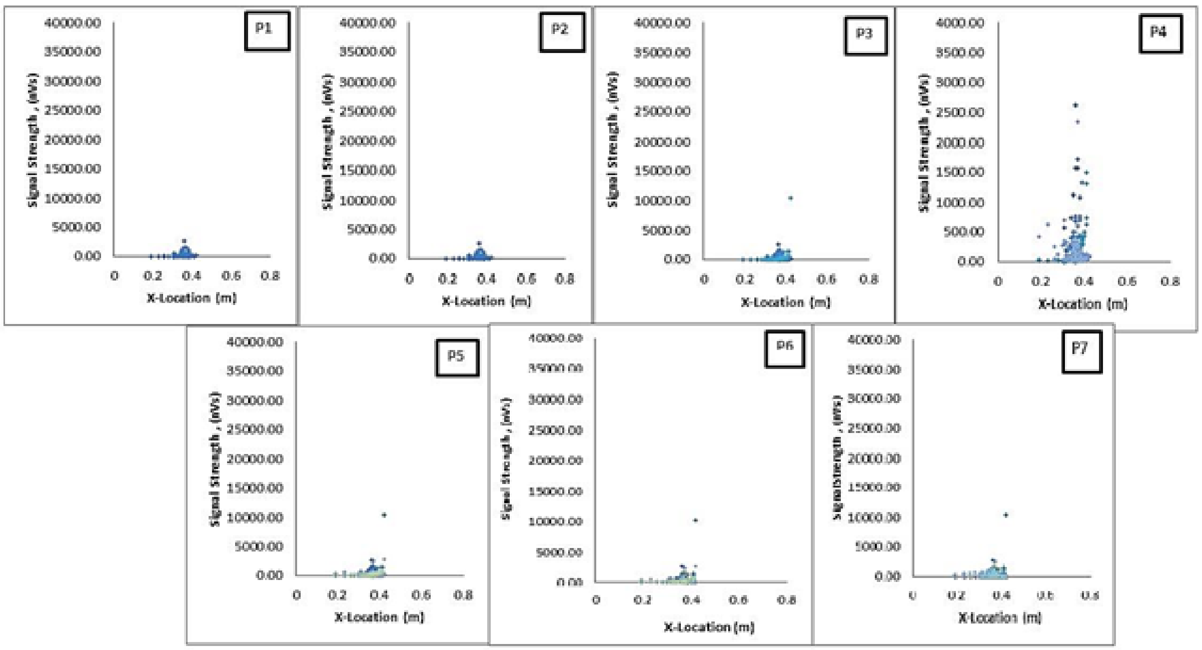

Figure-10. Relationships between Signal strength against X-location for B2 2CFS specimen.

CONCLUSIONS

In a nutshell, the investigations obtained from the testing of nine reinforced concrete beam when subjected to increasing static loads until failure which are consist of plain RC beam, RC beam wrapped with carbon fibre sheet in one layer, and RC beam wrapped with carbon fibre sheet in two layer, the following conclusions was drawn.

The performance of the plain RC beam correspondence to the AE signal based on parameter of signal strength under static loading was observed that on the P1 there was no crack occurred due to the very low load applied on the RC beam specimens. Besides that, from the result obtained, it was clearly shown that the highest energy of signal strength occurred almost at the same critical distance of the midspan of 0.4 m to the edge of the RC beam specimen. At the same time, the tensile part of the plain RC beam showed a little crack occurrence on the midspan due to the strong bonding of the primer epoxy layer on this specimens.

The performance of the RC wrapped with one layer of CF beam correspondence to the AE signal based on parameter of signal strength under static loading was observed that on the P1 and P2, the behavior of the RC beam does not show any crack occurrence until P3 first tensile crack was growth and can be seen with naked eyes. At P6 the shear crack was started growth by produced the highest energy value of signal strength about 960 nVs at the critical area of the midspan. At the same time, the condition of one layer CFS on RC beam was found to be a little stretched. At the failure stage, the width of the micro and minor cracking was getting wider and RC beam specimen almost broken but was supported with the strong wrapping layer of CFS.

The performance of the RC wrapped with two layer of CFS correspondence to the AE signal based on parameter of signal strength under static loading was observed on the P2, the shear crack was firstly growth and then for the next phase followed by the other hairline cracks. It indicates that the damage of the concrete structures in this phase was disturbed at the midspan of the specimen. This is also proved by the graph of signal strength versus X-location generated. At the same time, the condition of two layers CFS also was totally in a good condition on the soffit of the beam. Besides that, it was found that the period taken to reach the P7 until failure was very long. However the bonding between CFS and soffit of RC beam shows a very strong connection. In addition, CFS can be used effectively in order to provide an active protection to reinforced concrete structures by wrapping on the critical part which is on tensile part and bonding with the suitable epoxy. This material can help to prolong the lifespan of reinforced structures.

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