Analysis Improvements of Acoustic Emission Data in Evaluation of Concrete Beam

Shahiron Shahidan[1*], N.Muhamad Bunnori[2], N. Md Nor[3], M.Abd Rahim[4],S. R.Abdullah[1], S. S.Mohd Zuki[1]

[1]Faculty of Civil and Environmental Engineering, UniversitiTunHussienOnn Malaysia, Parit Raja 86400, BatuPahat, Johor, Malaysia.

[2]School of Civil Engineering, UniversitiSains Malaysia (USM), 14300 NibongTebal, Pulau Pinang, Malaysia.

[3]Faculty of Civil Engineering, UniversitiTeknologi MARA, 13500 PermatangPauh, Pulau Pinang, Malaysia.

[4]Department of Building Engineering, School of Environmental Engineering, UniversitiMalaysia Perlis, 02600 Arau, Perlis, Malaysia

E-mail :[1]shahiron@uthm.edu.my,

Keyword : Acoustic emission, Felicity ratio, Calm ratio, Reinforced concrete

Abstract: Structural health monitoring (SHM) is known as an assessment on damage detection in structural engineering. Nowadays, the application of SHMhas been widely used especially on the continuous real time monitoring system with minimum labour involvement. One of the most excellent tools in SHM for real time monitoring system is an Acoustic Emission (AE). AE waves are high frequency stress wave generated by rapid release of energy from localised sources within a material, such as crack initiation and growth. High sensitivity to crack growth, the ability to locate source, passive nature and the possibility to perform real time monitoring are some of the attractive features of AE technique. In spite of these advantages, challenges still exist in using AE technique for monitoring applications especially in analysing recorded AE data as large volume of data are usually generated during monitoring.In this research works, AE parameter, which are Signal Strength and Absolute Energy were selected to be used in determination of damage quantifications by means of Felicity and Calm. Laboratory experimental work was performed on a beam size 150x250x1900mm with concrete gred40. The beams were tested under cyclic loading with four points bending. In conclusion, AE data parameters analyses were prove to be reliable in determining the damage classification in concrete structure in accordance with the real observations during increased loading cycle.

Introduction:

Concrete infrastructure has been facing several damage mechanism and deterioration during its life time due to factor s such as excessive loading and harsh environmental exposure which cause concrete spalling and scalling, corrosion as well as reducing the load carrying capacity of the structures.The process of damage mechanism in concrete structure will induce the interaction of duration between long term services and short term services [1-5].These interaction times of theprocess affect the condition of structural and its integrity.

One of the most efficient tools in SHM for real time monitoring system is an Acoustic emission (AE).This technique is a powerful tool for evaluating any structural system as it enables to detect crack formation and growth without damaging the structures. It is based on the phenomenon whereby high frequency waves are generated from rapid release of energy in the material such as from initiating and growing cracks [3-6]. Therefore, this research focuses on AE technique for the evaluation of the damage mechanism on concrete structure.

The investigation incorporates the cyclic loading test (CLT) and AE technique on the sample beams. From both tests, the relationship between absolute energy and signal strength material were obtained for determination of damage mechanism level of s structures. The significant contribution of the findings can be used to assess structural integrity and performance in the concrete structures.These methods have been extensively utilized in AE technique for numerous applications but there is little research on the relationships between absolute energy and signal strength parameter for damage mechanisms level. The significance of this evaluation is key for structural integrity and performance and the combination of the existing and new development method will provide more confidence as a benchmark for evaluation system in reinforced concrete (RC) structures.

AE Analysis Method

Felicity Ratio

The felicity ratio is defined as :

$$\boldsymbol{FR} = \frac{\boldsymbol{P_{AE}}}{\boldsymbol{P_{1st}}} \quad (1)$$

Where P_{AE} is stress at which AE activity starts to generate (load at onset of significant AE during reloading), and P_{1st} is the maximum stress (maximum load during the previous loading history).

According to the felicity ratio value, the Kaiser effect is strongly present when the value is equal or greater than 1.0 while the structure is stable and it becomes unstable when the value is less than 1.0 [5-8].This value is not fixed depending on the material and specimens but most of the researchers used 0.5 as the level for damage identification in RC structures [6-9].

Calm Ratio

The ratio is defined as the total hits during unloading over total hits during loading [5,6]. The previous researches have further explored on the cumulative signal strength parameter in calm ratio and the result is promising due to the damage identifications [9]. Therefore, this study has selected absolute energy parameter and substituted it into calm ratio analysis method. Cumulative signal strength (CSS) and Cumulative absolute energy (CABSE) are substituted for the total number of hits as shown in the Eq 2 and 3[10];

$$Calm\ Ratio_{\ Signal\ strength} = \frac{CSS\ during\ unloading}{CSS\ during\ Loading} \quad (2)$$

$$Calm\ Ratio_{Absolute\ Energy} = \frac{CABSE\ during\ unloading}{CABSE\ during\ Loading} \quad (3)$$

Furthermore, damage classification based on AE activity can also be determined by using the calm and felicity ratio. These two ratio are recommended by the previous researches to determine the collaboration between failure mechanism and AE hit signal [7,8]. Fig 1 presents the damage quantification with a combination of Calm and Felicity ratio. This standard chart was presented by [5] to classify the damage mechanism into 3 levels; minor, intermediate and heavy damage.

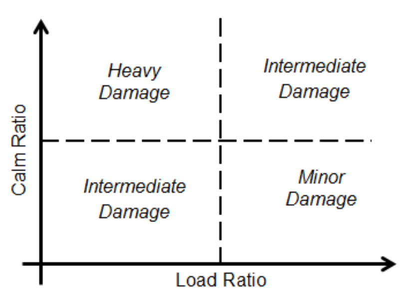


Fig.1; Damage quantification Calm and Felicity ratio by [10]

Laboratory Work

ARC beam specimens was designed and builtbased on a British Standard (BS 8110) with cross section of 150x 250x1900mm and had a compressive strength of 40MPa.The beam was reinforced with high strength steel bar and cured for 28days to gain uniform strength. The beam was placed on the steel support with neoprene pad to reduce the acoustic noise during the four point s cyclic load test. Fig 2 shows the illustration of the experimental set up.

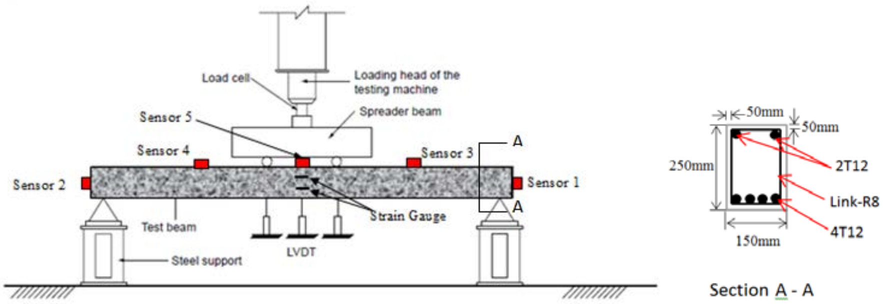


Fig 2 Experimental set up

The patterns of the CLT system loading is compressed at least three Load Set (LS) with the various load levels. The maximum test loading is recommended to be at least 85% of ultimate load. Whereas, the first loading set should not exceed 50% of the total load test (service load level) and the minimum holding load also should be at least 10 % of total load test [10]. The three load sets is illustrated in Fig3. The specimens were monitored using a Physical Acoustic Corporation (PAC) system, and AEwin software. The AE sensor type R6I (40-100kHz) was mounted on the top of beams location using viscous coupling agent. The sensitivity of the AE sensor installation was verified using the Hsu-Nielsen source method and the threshold setting was45dB to avoid detecting any noise from the surrounding area [9].

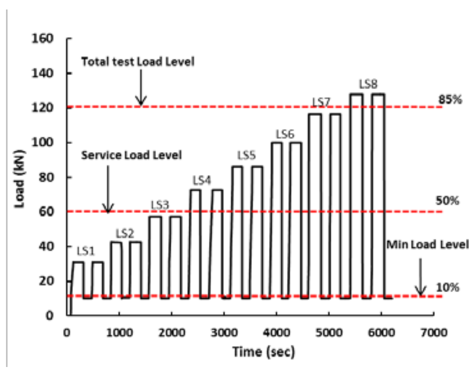
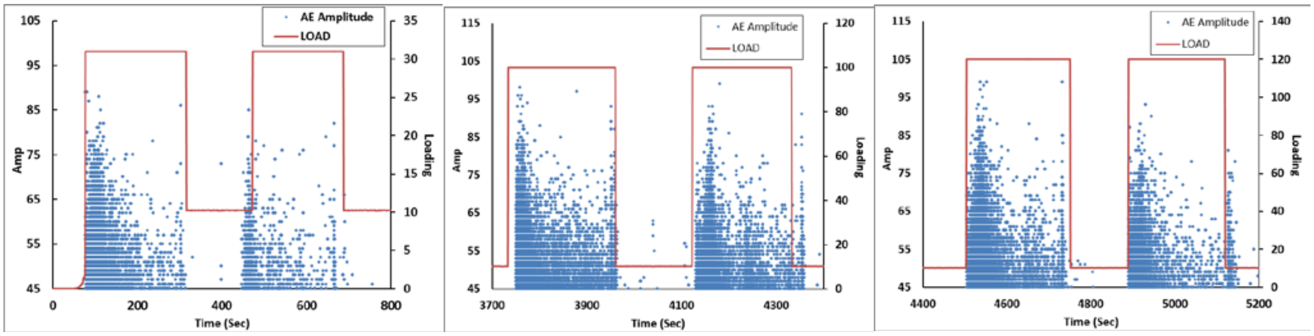


Fig 3 Loading Profile of CLT

Result and Discussion

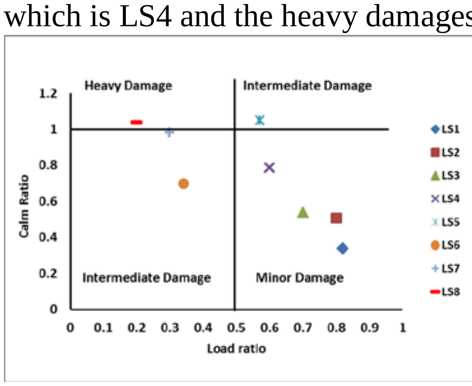
Fig 4 presents the general view of AE activity response for 3 stage of loading (Initial, Service and Total Load Level) by plotting AE amplitude over time with the superposition of load set variation. These two plots were related each other and the primary features show that; AE activities increased when the load sets increased especially during the first cycle as compared to the second cycle. The correlations between AE activities andthe CLT method are good indicators for the damage level from the initial load set until the final load set point. Nevertheless, these calibrations between loading and unloading for CLT method can be quantified by AE parameter analysis. Detailed analysis on this method will be further explained in the next section.



(c) Initial Load Level (a) Service Load Level (b) Total Load Level

Fig 4 Typical AE activity responses to CLT

The combination of two ratios parameter Signal Strength and Absolute Energy will be able to provide more information for the assessment on RC structure. These evaluation criteria were developed by Japanese Society of Nondestructive Inspection (JSNDI) [7,8]. Fig 5 and Fig 6 are the standard charts for damage classification on concrete structure obtained from the experiment. This evaluation is based on the load set with three types of classification; minor damage, intermediate damage and severe damage. In this chart, it is very important to define the appropriate threshold setting for Felicity ratio and Calm ratio. The common threshold setting is 1.0 for Calm ratio and 0.5 for Felicity ratio. Based on the previous researches, these ratios are selected according to the material and type of structure [7,8,9]. Fig 5 and Fig 6 show the positions of Load Set (LS) into a damage classification chart. These two charts calibrate with signal strength (Fig 5) and absolute energy (Fig 6) parameters. From the general observation, these two charts are useable to designate the level of damage from LS1 to LS8. From the chart in Fig 5, LS1, LS2, LS3 and LS4 are classified as minor damage and LS5 and LS6 are categorized as intermediate damage and the rest are classified as heavy damage. The chart patterns in Fig 6 are insignificantly different compared to the previous chart inFig 5. The differences are encountered in LS4 and LS7, whereas, LS4 is classified as intermediate damage and heavy damage for LS7. From this analysis, it is proven that, the intermediate damage started at the service load level which is LS4 and the heavy damages were classified in LS7.



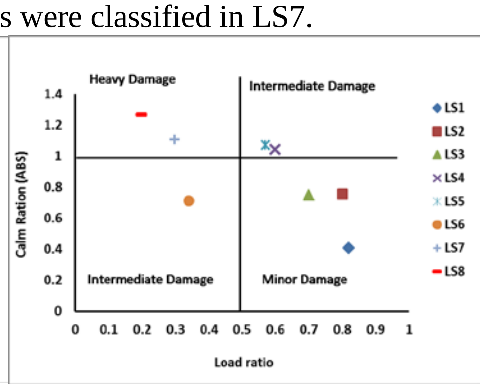


Fig 5Standard Chart for signal strength

Fig 6Standard Chart for Absolute Energy

Hence, due to the safety conditions and structural integrity in concrete structure, these changes in Fig 6 are acceptable and more efficient in determining the level of damage in concrete structure and this result analysis is compatible with the visual observation as presented in the Fig 7. From these figures, the beams specimens clearly indicated the damage process by increasing CLT method. During LS1 to LS3, the beam specimens are classified as a minor damage. When the CLT method increases to service load level, which is LS4–LS5, the beam exhibits the intermediate damage. Eventually, the beam is classified as severe damage when loading is increased up to LS8.

(c) Initial Load Level (b) Service Load Level (a) Total Load Level

Fig 7Visual observation in the laboratory work

Conclusion

The existing AE evaluation method such as Felicity and Calm Ratio is well researched but it requires improvement for precise result analysis.The parameter of absolute energy obtained from the AE evaluation method is very useful to determine the level of damage ranging from minor to heavy damage in RC structures.

Acknowledgments: The Author acknowledge to USM(PRGS Grant), UTHM and other research members.

References:

[1] Md Nor, N., A. Ibrahim, N. Muhamad Bunnori, H. M. Saman, S. N. Mat Saliah and S. Shahidan "Diagnostic of fatigue damage severity on reinforced concrete beam using acoustic emission technique." Engineering Failure Analysis(In Press Corrected Proof).

[2] Shahidan, S., R. Pulin, N. Muhamad Bunnori and K. M. Holford (2013). "Damage classification in reinforced concrete beam by acoustic emission signal analysis."Construction and Building Materials**45**(0): 78-86.

[3] Shahidan, S., R. Pullin, K. M. Holford, B. N. Muhamad and N. Nor (2013)."Quantitative evaluation of the relationship between tensile crack and shear movement in concrete beams."Advance Material Research Journal**626**: 355-359.

[4] Shahidan, S., N. M. Bunnori, N. MdNor and S. R. Basri (2012). Health index evaluation on acoustic emission signal for concrete structure by intensity analysis method. 403-408: 3729-3733.

[5] Behnia, A., Chai, H. K., & Shiotani, T. (2014). Advanced structural health monitoring of concrete structures with the aid of acoustic emission. *Construction and Building Materials*, *65*, 282–302. doi:10.1016/j.conbuildmat.2014.04.103.

[6] Nair, A. and C. S. Cai (2009). "Damage detection of concrete structures using acoustic emission." Key Engineering Materials**400-402**: 101-106.

[7] Kocur, G. K. and T. Vogel (2010). "Classification of the damage condition of preloaded reinforced concrete slabs using parameter-based acoustic emission analysis." Construction and Building Materials**24**(12): 2332-2338

[8] Miller, R. K. and E. v. K. Hill (2005). Nondestructive Testing Handbook "Acoustic Emission Testing" **Vol 6:** 3rd Edition.American society for Nondestructive testing 450ISBN1-57117-106-1

[9] Liu, Z. (2007). Evaluation of Reinforced Concrete Beams Using Cyclic Load Test, Acoustic Emission and Acousto-Ultrasonics. Department Of Civil Engineering. South Carolina, university of South Carolina. **Doctor of Philosphy:** 1-220.

[10] ASTM-E976 (2011). E976 -11. Standard Guide for Determining the Reproducibility of Acoustic Emission Sensor Response. United State, American Society of Testing Material