Acoustic emission characteristic for different thicknesses of RC slabs

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Abstract. Acoustic emission (AE) has been widely used for monitoring of the structure performance. However, identification of structure’s characteristic is still limited assess. Hence, this paper presents the characteristic of AE of different thicknesses of reinforced concrete (RC) slabs. Two different thicknesses of grade C25/30 RC slabs which are 125 mm and 175 mm were prepared and designated as S125 and S175, respectively. The slabs were designed based on Eurocode 2 with the size of 500 mm width x 1000 mm length were tested under three-point loading in conjunction with the AE monitoring. The maximum loads of the slabs were identified. The acoustic signal strength was analyzed and discussed. It is found that the maximum load of the RC slabs is increased as the thickness of the slab increases. Moreover, the signal strength of S175 is greater than the S125. Hence, this study is beneficial to provide factual data on the maximum load and AE characteristic of different thicknesses of slab.

1. Introduction

Reinforced concrete (RC) slab progressively develops several failure mechanisms when it is subjected to loadings. The crack propagation of the structural members is initiated by the yielding of reinforcement and concrete which later reduce the service life of a structure. Thus, early damage assessment could extend the service life of the structures. It can be done by assessing the damage using non-destructive testing (NDT). One of the effective NDTs is acoustic emission (AE) technique. It can be used to assess the behavior of structural member upon loadings. AE technique employs the transient elastic waves during any crack propagation event and monitors the structure behavior at real time [1].

The application, monitoring and analyses related to AE technique has been reviewed by many researchers [2–7]. From the AE technique, there are two parameters can be utilised to assess the behaviour of the structures, namely AE mode and transient mode (signal waveform). The investigation related to transient mode such as the effect of AE wave velocity with distance of sensors has been performed by Md Nor et al. [4]. They found that the wave velocity, threshold level and distance of sensor are close related to the arrival time of wave in a structure. Analysis based on AE parameter such as signal strength has been extensively investigated by many researchers worldwide. For instance, Abdul Hakeem et al. [5] studied a simple analysis based on signal strength of steel fibre reinforced concrete (SFRC) beam strengthened with carbon fibre reinforced polymer (CFRP) and found that the signal strength increases as the load applied to the beam increases. A specific investigation on correlation between AE signal strength, damage mode and load for pre-cracked RC beam retrofitted with CFRP has
been investigated by Soffian Noor and Noorsuhada [6]. It was found that the pre-cracked RC beam retrofitted with CFRP produced higher AE signal strength compared to control beam. Moreover, five crack modes were identified for control beam and six crack modes were identified for retrofitted beam. Carpinteri et al. [7] stated that the analysis based on the AE signal strength is close related with the sensor voltage, resolution and time. From the review, it is found that the comprehensive AE signal strength related to different thicknesses of RC slab is still limited assess.

Hence, this study is to investigate the AE characteristic such as signal strength, cumulative signal strength and its hits of RC slabs. Two different thicknesses of RC slabs with the same size of wire mesh were prepared and tested.

2. Experimental Programme

2.1. Preparation of materials and RC slabs
Two (2) RC slabs with two different thicknesses which are 125 mm and 175 mm were casted. The slabs were designed in accordance to Eurocode 2 [8] of proposed size of 500 mm width and 1000 mm length. Figure 1 shows the plan view and cross-sectional view (side view) of the designed slab for 125 mm to 175 mm thick. All dimensions in the details were measured in mm. The wire mesh (BRC – British Reinforcement Company) type A7 of 485 MPa strength was used for all slabs. The slabs with thickness of 125 mm and 175 mm were designated as S125 and S175, respectively. The reinforcement for the short span of both slabs was T10- 100 mm c/c and long span was T10 – 400 mm c/c. The concrete was designed from cement, fine aggregate and coarse aggregate with proportion of 1: 0.5: 1.59: 3.16, respectively. Water cement ratio of 0.5 and the maximum coarse aggregate of 20 mm were used in the mix concrete design.

![Figure 1. Details of the RC slabs (Dimensions in mm).](image-url)
2.2. Test set up and AE monitoring
Three-point loading with constant load rate of 0.02 kN/s was applied to the slab concurrent with AE monitoring as shown in Figure 2. The three-point loading was performed using Universal Testing Machine (UTM) which was applied monotonically to the slab to failure. For the acoustic emission monitoring, the preamplifier with gain of 34 dB was used. Four sensors type VS75-V were fixed onto the beam surface as shown in Figure 2 and designated as CH5, CH6, CH7 and CH8. The sensitivity between sensor and the slab surface were calibrated using pencil lead fracture (PLF). The threshold level of 40 dB was used throughout the AE monitoring, which similar threshold as used by Md Nor et al. [9].

![Set up of the slabs a) S125 b) S175.](image)

3. Results and Discussion
3.1. Maximum load of the RC slabs
Figure 3 shows the load with respect to deflection for RC slabs with thickness 125 mm (S125) and 175 mm (S175), respectively. It is found that the maximum load for slab S125 is 40.02 kN and for slab S175 is 51.60 kN. It indicates that the maximum load for S175 is higher than that of S125 with the percentage different of 29%. It means that the thickness of slab plays an important role for the determination of its ultimate load. It has been enhanced by Joohari and Mohd Amin [10] through their investigation that the increase of slab thickness had increased the maximum load applied to the slab.

![Load versus deflection for slab S125 and S175.](image)
3.2. Acoustic emission characteristics - signal strength

The acoustic emission characteristic as well as the signal strength is important to determine the integrity of the slab. According to Physical Acoustic Corporation [11], signal strength is defined as the integral of the rectified voltage signal over the duration of the AE waveform packet. It is referred to the energy amount released by the material or structure [12]. In this study, the signal strength with respect to time for all slabs at each sensor were observed and presented in Figures 4 and 5. The highest value of the signal strength for each sensor was then identified. For the highest signal strength, the value at CH5, CH6, CH7 and CH8 for slab S125 is 339 nVs, 1250 nVs, 691 nVs and 1930 nVs, respectively. Meanwhile, for slab S175, the highest signal strength is found to be 4890 nVs, 1950 nVs, 6100 nVs and 1160 nVs for CH5, CH6, CH7 and CH8, respectively. From these values, it can be observed that the slab S175 produced the highest signal strength compared to slab S125. In this scenario, it might be due to the size of the slab, where thicker slab produced the highest value of signal strength compared to thinner slab.

The highest signal collected by sensors for each slab represents the occurrence of internal crack in the slab. Md Nor et al. [13] stated that high of the signal strength is generally related with damage development in a structure. In this study, the high signal strength was occurred prior to the appearance of the first crack in the slab. As stated by Xu [14], the rapid increased of AE activities prior to appearance of crack indicates the development of internal microcracking in the material. It has been enhanced by Md Nor et al. [15] that AE is capable of predicting the occurrence forthcoming crack in the structure. The prediction of the crack can be made earlier than detection by visual observation [12] since the AE is very sensitive to detection of early onset of crack growth in RC structure [13].

![Figure 4. Acoustic signal strength with respect to time for S125 obtained from a) CH5 b) CH6 c) CH7 and d) CH8.](image-url)
the value of 2788. However, for slab S175, CH8 produced the highest number of hits compared to other channels with the highest number of hits of 166 numbers. The identification of number of hits is vital in order to understand the behaviour of the crack activity in the slab. At the same time, the location of the sensor and the formation of crack in the slab were also play an important matter in the production of AE hits. The collection of the signal strength and the number of hits is depending on the location of the sensor and the formation of the AE source in the slab. Xu [14] stated that it is related to the AE amplitude and duration of the signal. Generally, when the slab subjected to loading, the crack was developed at the bottom of the slab as shown in Figure 7. As the AE source forms owing to formation of crack, the AE wave produced and then captured by the sensors which fixed on the beam surface.

![Figure 5](image1.png)  
**Figure 5.** Acoustic signal strength with respect to time for S175 obtained from a) CH5 b) CH6 c) CH7 and d) CH8.

![Figure 6](image2.png)  
**Figure 6.** No of hits for each channel for slab a) S125 b) S175.
3.3. Acoustic emission characteristics - cumulative signal strength
The cumulative signal strength with respect to time is presented in Figures 8 and 9 for all sensors. The highest cumulative signal strength for S125 was CH8 with the value of 112004 as presented in Figure 10a. Meanwhile for S175, highest cumulative signal strength was CH7 with the value of 163905 as shown in Figure 10b. It is due to the accumulation of damage in the slab induced the formation of high AE activities in the slab. Similar to those stated by Abdul Hakeem et al. [5] that the high value of cumulative signal strength is closely related to the generation of the crack when the specimen is subjected to loading. Under load control, the cumulative signal strength is normally related to the illustration of damage in a structure and depends on the load rate applied during testing [13].

![Formation of the crack](image)

**Figure 7.** Typical crack pattern of the slab subjected to loading.

![Cumulative signal strength for slab S125](image)

**Figure 8.** Cumulative signal strength for slab S125.
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Figure 9. Cumulative signal strength for slab S175.

Figure 10. Maximum value for the cumulative signal strength at each channel for slab a) S125 b) S175.

4. Conclusion
In a nutshell, the ultimate load of the slab is close related to its thickness, where the higher the thickness would present the higher the strength of the slab. For analysis of signal strength with respect to time, thicker slab of S175 produced the higher value of AE signal strength compared to S125. It is found that the cumulative signal strength for S175 is greater than S125. This is due to the cumulative signal strength is close related to the illustration of damage in the slab. This study is basically investigated the behaviour of the slabs using AE characteristics. The study will go on with identification of hierarchical order of crack classification in the RC slabs, which is significantly vital for determination generic integrity of the slabs.

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