Kontribusi Fisika Indonesia
Vol. 12 No. 1, Januari 2001

The Evaluation of Crack Propagation in the Reinforced Concrete by Acoustic Emission

Titin Kathrina
P3FT - LIPI, PUSPIPTEK,
Serpong, Tangerang 15314.
e-mail: tikana@link.net.id

Abstract
Acoustic emission (AE) a non-destructive testing technique that is specially used to detect active cracks. This technique was employed to evaluate crack propagation in the reinforced concrete specimens during static loading in the four-point bend test. Cracks were detected by an array of AE sensors which were fixed on the surface of a specimen. AE signals from crack activities were then recorded and analysed by the AE computerised system. The AE results from crack activities during static loading were classified into three stages of crack mechanisms. In the first stage, the AE sources were expected to appear from micro and macro cracks in the presence of pores, voids, mortar, sand, etc. in the concrete part. In the second stage the steel bars were deformed elastically. Here AE sources were attributed to continuously macro cracking in the concrete part and slip between steel reinforcing bar and concrete. In the third stage, when the steel bars were deformed plastically, AE sources were generated by large crack in both longitudinal and shear cracks due to high level of applied loading. This experimental work showed a very sensitive AE technique to detect crack growing in the reinforced concrete structure.

Keywords: *Acoustic emission, Crack propagation, The reinforced concrete*

Abstrak
Acoustic emission (AE) adalah teknik non-destructive testing (NDT) yang digunakan khusus untuk menguji retak aktif. Teknik ini telah digunakan untuk mempelajari penjalaran keretakan pada beton bertulang selama uji statik pada four-point bend test. Keretakan diamati melalui sederetan sensor AE yang dilekatkan pada permukaan spesimen. Signal AE dari aktifitas keretakan direkam dan dianalisis dengan alat sistem AE. Hasil pengamatan selama uji statik diperoleh bahwa aktifitas keretakan dapat diklasifikasikan pada tiga tahap mekanisme keretakan. Pada tahap pertama signal AE diharapkan muncul dari keretakan mikro dan makro sebagai akibat adanya pori-pori, void, mortar, kersik, dll. Pada bagian beton pada tahap kedua terjadi deformasi elastis pada baja tulangan. Pada tahap ini sumber-sumber AE berasal dari penjalaran keretakan pada beton dan dari terjadinya slip antara beton dengan baja tulang. Sedangkan pada tahap ketiga ketika baja tulangan mengalami deformasi plastis signal AE dihasilkan dari keretakan yang besar pada keretakan longitudinal dan geser akibat pembebanan yang tinggi. Eksperimen ini menunjukkan bahwa teknik AE sangat sensitif untuk mendeteksi penjalaran keretakan pada beton bertulang.

Kata kunci : *Emisi akustik, Perambatan keretakan, Beton bertulang*

1. Introduction

In the area of civil engineering, the deterioration and cracking of the reinforced concrete structure due to fatigue or other mechanical damage has become a significant problem. Therefore, the development of diagnostic non-destructive evaluation (NDE) techniques to evaluate the degradation of concrete structures is one of the most important issues for an effective maintenance program.

Acoustic emission is one of the NDE techniques that could give critical information on interior failure. This technique is the only effective NDE technique for monitoring crack activity during mechanical loading, especially in a large structure. The advantage of this technique is mainly due to the high sensitivity of the AE system to detect crack activities in the very early stage of cracking. Crack propagation can be revealed in a linear, planar or three dimension image location in a real time[1)]. This technique, generally, can be applied for several purposes, such as; investigation of the behaviour of materials (e.g. rupture, yielding, fatigue, fracture corrosion, creep, welding, etc.), or monitoring structures, (e.g. leak or crack detection in pressure vessel, pipelines, bridge, tanks, reactor vessels, offshore)[1)].

Since AE is very sensitive for the initiation and growth of cracks in concrete, it has been used in both concrete specimens and structures[2,3)], but with only a few publications for the reinforced concrete[4-6)]. The previous work reported the application of AE to monitor the propagation of crack in two dimension image[7]. This paper describes the AE analyses to evaluate crack propagation in the same material during static loading in the four points bend test to analyse cracking mechanism in the reinforced concrete beam. This may give some contribution for the civil engineer to learn more the cracking behaviour in the reinforced concrete structure under mechanical loading.

2. Acoustic Emission

Acoustic emission technique is specially used for detecting active crack in a material under mechanical stress. Acoustic emission is defined as a transient elastic wave, which is generated by the rapid release energy from localised sources within a material. In metal, acoustic emissions are caused by dislocation movement, twinning, crack initiation, crack propagation, plastic deformation, etc. Whereas in concrete acoustic emission is primarily due to cracking processes and slip between concrete and steel reinforcement[2]. This wave propagate through the material, and their arrival at the surface can be detected by piezoelectric transducers (AE sensor) fixed on the surface of component under inspection, which in turn generates electrical signals. The signals, after being amplified and filtered, are usually handled as digital data and can be displayed on PC.

The signal resulting from a single acoustic emission burst will be similar to that shown in Figure-1, where in the ideal case the relationship between voltage, *V*, and time, *t*, for such signal, tend to a decaying sinusoid[1] :

$$V = V_p \sin(2\pi f t)\exp(-t/\tau) \qquad (1)$$

where f is a resonant frequency of the transducer, τ is the decay time and V_p is the peak voltage.

There are a number of different ways in which acoustic emission signals may be evaluated, i.e.; ring-down counting, event counting, signal duration, rise time, peak amplitude, frequency analysis, energy analysis, defect location, and wave-form analysis[1]. Ring-down count is the simplest method to obtain an indication of AE activity which is defined as counting the number of amplified pulses that exceed an arbitrary threshold voltage, V_t. The signal in Figure-1 would correspond to six ringdown counts. In the AE applications, ringdown count is known as ‘count’. It is sometimes convenient to record a count of unity for a single AE burst rather than the multiple count obtained by ringdown count. This is known as event counting. Waveform and frequency parameters have been less widely examined, but they too carry information about the emission source.

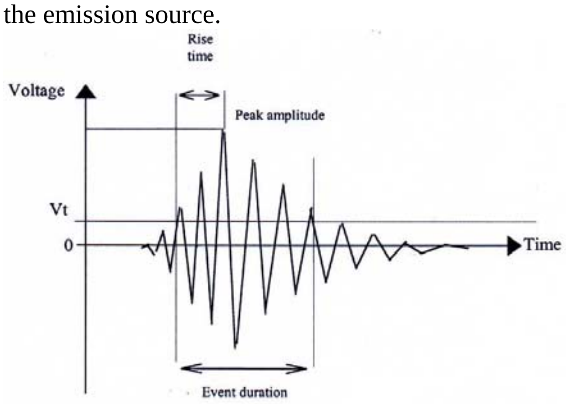


Figure 1. The amplified signal from piezoelectric transducer resulting from a single acoustic emission burst.

The main advantage of AE technique is that, under continuous monitoring, AE signals may be recorded as they occur and from any location in the body. The major disadvantage is that special high skill is needed for the operator to interpret the information from the structure and to relate it objectively to possible sources. By correlating the AE results to mechanical parameters, one can obtain the characteristics of damage growth, e.g. due to pressure, force, creep, fatigue or static loading.

3. Experimental Procedure

The configuration of specimen and the arrangement of AE sensors for a four-point bend test set up are shown in Figure-2. Specimen, dimension of 240x25x15 cm, was prepared with the 5 steel reinforcing bar, diameter of 16 mm, encased in the rectangular concrete beam. Concrete cover (depth of reinforcing bar) is 30 mm. The specimens were subjected to continuous static loading, in the four-point bend test, using the MTS electro-hydraulic machine with the load rate of 1kN/mm.

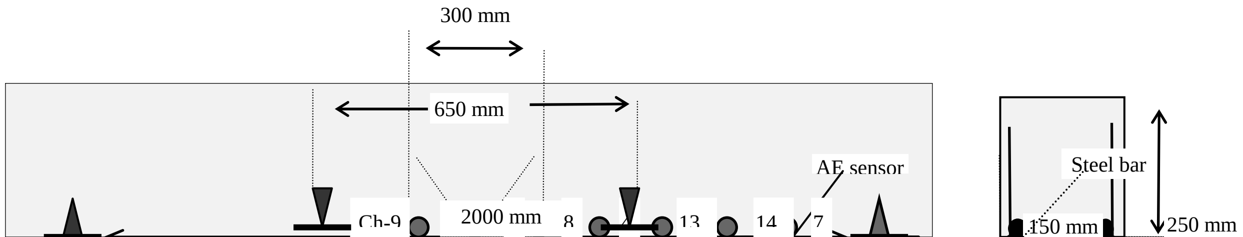


Figure 2. The four point bend test set-up for the steel reinforced concrete beam with 7 AE sensors arrangement attached on the front surface of specimen for channel-9,1,8,4,13,14 and 7, respectively.

Seven AE resonance sensors of 150kHz, frequency range of 100-200kHz, were attached on the front surface of the reinforced concrete specimen to perform five triangular locations. These sensors were arranged to cover the possibility of cracking in the centre and a half side of the beam that represented the whole condition of the beam. Each of sensors was connected to the 40dB preamplifier with a 100-200 kHz band-pass filter, which was then connected to each channel slot in the AE system. The grease couplant was first applied in between sensor and the specimen to avoid the air gap for the optimum acoustic emission transmission. The static load and beam deflection controllers were connected to the interface of AE system in order to record both of parameters at the same time with AE data acquisition.

The basic principle of AE data acquisition was as follows; during static loading, acoustic emission source from cracks was detected by AE sensor of which was amplified by 40dB preamplifier. AE signals were then processed and analysed by acoustic emission SPARTAN-2000 computerised monitoring system with a total system gain of 80 dB. A threshold of the AE data acquisition was set at 40 dB to avoid the AE source from noise (the unwanted source signal). The detected AE signals from crack propagation in the specimen were then displayed on PC, and hence the crack growing can be monitored continuously during static loading in a real time. The experimental work was carried out in about 2 hours continuously by recording the applied load, deflection and the acoustic emission activity from the cracks. The AE results were analysed by first post-filtered the numerous AE data from the unwanted signal. By plotting the AE parameters to the mechanical properties, the crack propagation can be evaluated by analysing the AE signal characteristic that may give some information about the behaviour of cracking.

4. Results and Discussions

From six experimental works on the reinforced concrete specimens, AE showed very sensitive technique to detect crack propagation during static loading. Results of one of the experiment are presented as follows. By plotting the applied load and beam deflection versus loading time, shown in Figure-3, the load history could be divided into 3 stages; the first stage is in the load range of 0-30 kN, the second is in the range of 30-110 kN, and the third is above 110 kN.

In the first stage, cracking was expected due to the tensile micro and macro cracks in the concrete part. Since the applied load was increased, at a certain level, the load pressure was transferred to the steel reinforcing bar. It is occurred in a second stage. At this stage, the steel reinforcing bars were deformed elastically and cracks were continuously propagated in a concrete part. At higher load, above yield point, the steel bar could not support the applied load. At this load level the steel bar was begin to deform plastically and cracks in the specimen continued growing rapidly. It was occurred in the third stage.

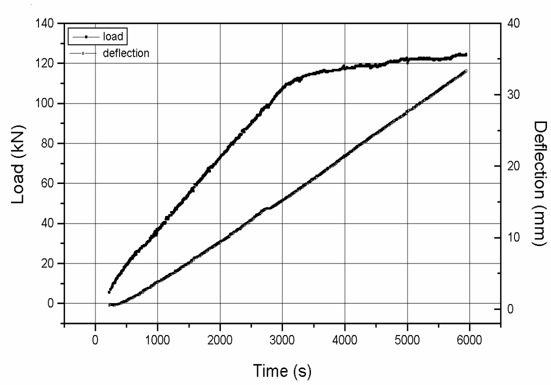


Figure 3: Plots of the applied load and beam deflections versus loading time in a four point bend test.

The AE results during static loading were presented by plotting the AE parameters (counts and peak amplitude) versus the applied load recorded from all of sensors, Figures 4 and 6. Data were first post-filtered to remove some of AE signal of which was generated from the unwanted source or noise.

The previous report explained that cracking was initiated at the bottom centre of the beam, which was followed by the main cracks growing upward, known as longitudinal crack[7]. In the increased of applied load, diagonal crack as a shear crack in between a support and load point were then propagated sometime later at the right side of the beam. Smaller crack lines were also growing upward in between longitudinal and shear crack location. According to Figure-2, channel-9,1,8 and 4 were mainly responsible to detect longitudinal cracks, whereas channel-13,14 and 7 were mainly for shear cracks.

According to the crack mechanism stages above and the previous report, the AE characteristic during loading may be represented by analysing the amplitude - load history during the test for all of channels, which were arranged according to the configuration in Figure-2. In the first stage, 0-30kN, the AE activities indicating the growing of longitudinal cracks which were expected to be generated from the micro and macro cracking between pores, grains, mortar, sand, etc. in the concrete part at the centre of the beam. This was detected mainly by the first four channel in Figure-4, i.e. channel-9,1,8 and 4. Whereas another three channels, 13,14 and 7, detected small number of AE counts as they were far from the crack source.

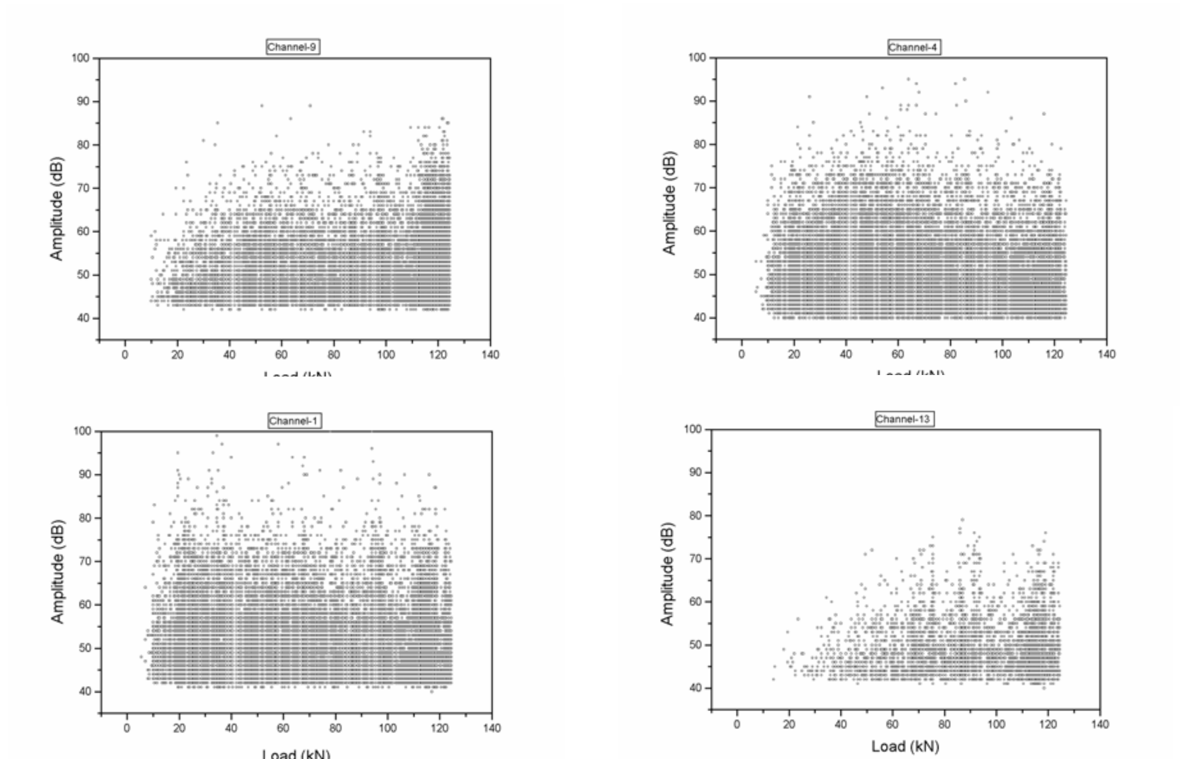
In the second stage, 30-110 kN, the first four channel showed the longitudinal crack growing steadily and tent to be weaker at the applied load close to yield point (100 kN). At this stage, the AE source was expected to be generated mainly from the continuous growing of the longitudinal cracks and from other smaller parallel crack lines in concrete part in between longitudinal and shear crack location. Slips between the steel reinforcing bars and concrete may also occurred to generate AE sources. Channel-13,14 and 7 which were responsible to detect shear crack showing the crack growing sometime later than longitudinal crack.

At the third stage, above 110 kN, the AE activity was increased rapidly. This indication was shown in all of channel. The AE sources were expected due to the rapid increased of longitudinal and shear cracks growing resulting in the rapid increased of AE counts.

This experimental work showed that the AE system was a very sensitive monitoring technique to detect crack propagation in the reinforced concrete structures.

5. Conclusion

Acoustic emission was found to be a very sensitive NDE technique for monitoring crack activity in the reinforced concrete beam during static bending test. Cracking mechanism was divided in three stages; the first stage was occurred in the concrete part only, the second stage was taken place in the elastic deformation phase of the steel reinforcing bar, and the third stage was in its plastic deformation phase. In the first stage AE source was expected due to micro and macro cracks in the presence of pores, voids, sand, mortar, etc. in the concrete part. In the second stage, the AE source was attributed to continuous crack growing in the concrete part and slip between the steel bars and concrete part. Whereas in the third stage, AE source was also expected due to rapid growing of longitudinal and shear cracks in very high applied load.



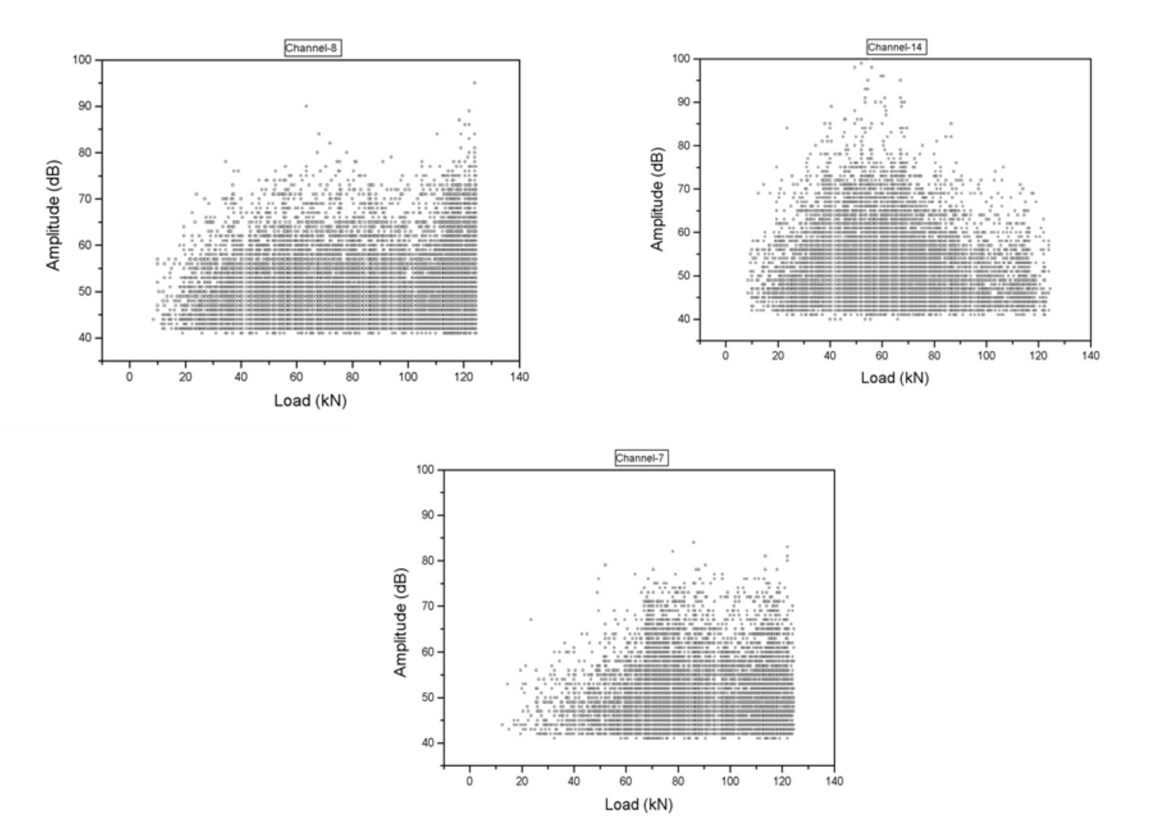


Figure 4. Plots of amplitude versus load for all of sensors arranged in Figure-2.

Acknowledgement:

I would like to express my sincere gratitude to the President of the Korean Research Institute of Standards and Science for the provision of the laboratory facilities during postdoctoral program. Also to my colleagues Dr. N.Kwon and Mr. Philip Park for their help in preparing specimens and mechanical test.

References

1. R.K.Miller and P.McIntire, NDT Handbook, vol. 5, ASNT, 1987, pp.326-345.
2. V.M.Malhotra and N.J.Carino, *CRC Handbook on non-destructive testing of concrete*, Boston, 1995, p.317-333.
3. K.Matsuyama, T.Fujiwara, A.Ishibashi and M.Ohtsu, *Field application of acoustic emission for the diagnosis of structural deterioration of concrete*, J.Acoustic emission, v.11, n.4, 1993, p.S65-S73.
4. S.Yuyama, T.Okamoto, M.Shigeishi and M.Ohtsu, *Quantitative evaluation and visualization of cracking process in reinforced concrete by a moment tensor analysis of acoustic emission*, Mater. Eva., v.53, n.6, 1995, p.751-756.
5. S. Yuyama, T. Okamoto, S. Nagataki, *Acoustic emission evaluation of structural integrity in repaired reinforced concrete beams*, Material Eva., v.52, n.1, 1992, p.86-90.
6. S.Yuyama, T.Okamoto, M.Shigeishi, and M.Ohtsu, *Acoustic emission generated in corners of reinforced concrete rigid frame under cyclic loading*, Material Eva., v.53, n.3, 1995, p.409-412.
7. T.Kathrina, *Acoustic emission monitoring of crack activity in the reinforced concrete beams*, Proceeding Seminar HFI, Serpong, 2000.