Acoustic Emission Analysis method for solving problems of damage mechanisms in concrete structures

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Résumé:

L'Analyse d'Emission Acoustique (AEA) est une méthode non destructive qui a été utilisée pour détecter les mécanismes d'endommagement dans différentes applications. L'utilisation de cette technique dans le diagnostic des défaillances des matériaux a augmenté au cours des dernières années. Dans le cas de structures en béton, elle est basée sur la détection de l'énergie libérée due à l'apparition d'événements de fissure. La détection de cette énergie libérée permet de détecter les fissures qui se développent dans les structures en béton avec une certaine fiabilité, comme cela a été étudié dans [1].

En raison de la complexité du mécanisme d'endommagement du béton, les caractéristiques de propagation des ondes dans ces structures ont généralement un motif très compliqué. Feng et Yi [2] ont présenté une méthode permettant d'analyser les caractéristiques d'atténuation de l'amplitude dans le domaine temporel et les caractéristiques d'accumulation du spectre marginal dans le domaine fréquentiel. Ils ont utilisé la transformée de Hilbert-Huang pour étudier quantitativement les caractéristiques de propagation d'une onde d'émission acoustique dans des structures en béton. Selon cette étude, le choix d'une fréquence de signal appropriée au cours du processus expérimental revêt une importance capitale pour l'obtention du coefficient d'atténuation des matériaux en béton afin d'améliorer le rapport signal sur bruit.

Dans ce travail, la modélisation par éléments finis de la propagation de l'onde d'émission acoustique est réalisée dans le logiciel Abaqus. Afin d'identifier les modes de dégradation de la structure en béton, nous avons extrait les caractéristiques de fréquence de crête des signaux d'émission acoustique. Cette méthode permet d'étudier quantitativement les caractéristiques de propagation des ondes d'émission acoustique dans les structures en béton.

Abstract:

Acoustic Emission Analysis (AEA) is a non-destructive method that has been utilized to detect damage mechanisms in different applications. The use of this technique in materials failure diagnosis has increased over the last years. In the case of concrete structures, it is based on detection of the released energy due to the occurrence of crack events. Sensing this released energy enable to detect cracks that develop inside concrete structures with some reliability as was studied in [1].
Due to the complexity of damage mechanism of concrete, the wave propagation characteristics in these structures have usually a very complicated pattern. Feng and Yi [2] have presented a method enabling to perform the analysis of attenuation characteristics of the amplitude in time domain and accumulation characteristics of the marginal spectrum in frequency domain. They have used the Hilbert-Huang transform to study quantitatively the propagation characteristics of acoustic emission wave in concrete structures. According to this study, the selection of suitable signal frequency during the experimental process has an important significance for obtaining the attenuation coefficient of concrete materials in order to improve the signal-to-noise ratio.
In this work, finite element modelling of the propagation of acoustic emission wave is performed under Abaqus software package. In order to identify the damage modes of the concrete structure, we've extracted the peak frequency characteristics of the acoustic emission signals. It was found that this method can investigate quantitatively the acoustic emission wave propagation characteristic in concrete structures.

Keywords: Acoustic Emission Analysis, damage mechanisms, concrete structures, cracks, finite element modeling.

1 Introduction

Concrete is a widely used in civil engineering, and concrete structures naturally face many challenging conditions such as chemical corrosion, frost, carbonization fire, etc. [3,4,5]. The damage to concrete structures under load is mainly caused by the generation, expansion, and fracture of cracks. This resulting harm may exacerbate the stress, weaken the integrity, impermeability, reduce the strength, and stability of the concrete structures. Therefore, it is imperative to precisely locate and measure the damage in the concrete structures and evaluate the mechanical properties of the damaged material accordingly.
During the last decades we have Acoustic Emission Analysis (AEA) signals are widely used in order to create a nondestructive and continuous structural health monitoring system [6-12]. AE signals are generated by the localized internal energy releasing during damage to the sample. When the specimen is subjected to internal or external stress, strain energy is released and spreads within the material in the form of elastic wave, which causes vibration on the surface of the specimen. When the vibration spreads to the AE sensors coupled on the specimen, the elastic deformation produced in the chip generates electric charges that appear at the surface and renders an electric field that can be detected. The vibration on specimen surface is therefore converted into electrical signals, and the signals are then amplified, processed, and displayed on the appropriate instrument. The analysis of the AE signals permits the cracks to be characterized, and then the material condition to be assessed [13,14], and prevents large-scale failure [15]. Moreover, it is possible to monitor the damage evolution on the structure in service [8,10,11,13,16-23], and it has been effectively used in measuring the deterioration of concrete structures [24,25].

Extensive efforts have been devoted to studying the AE features of concrete structures. Grosse and al. [12] deduced that AE became obvious when many microcracks were produced in the concrete and the tendency could be quantitatively evaluated based on the rate process theory. Dong and al. [26] experiment with concrete specimens to study the relationship between AE events and the stress of concrete, and consequently established the damage constitutive models of concrete under uniaxial compression. Ji and al. [27] described the characteristic function of the AE activity of concrete during loading process. They expressed the relationship between damage variables and AE wave parameters, and derived the damage development equation and the constitutive equation, both expressed in AE parameters. Heap and Lavallée [28] analyzed the variation of AE energy of concrete treated at different temperatures in the compression test. Fan and al. [29] investigated the dynamic performance of concrete structures by studying the characteristics of dynamic axial tensile AE tests of concrete under different initial static load and different initial damage. while a monitoring technique, AE has been widely used to assess deterioration of materials and evaluate the wellbeing of diverse systems, such as in detecting and locating fatigue cracks in bridges [20,21,30-31], monitoring the stability of tunnel linings [32,33], and checking concrete beams and slabs [34]. It was concluded that the concrete materials showed different AE modes at different stages of fracture, and the AE parameters characteristically reflected the stage of concrete damage. The damage of concrete could be evaluated by the characteristic AE parameters on account of significant correlation existed among the AE signals and the fracture process of concrete [35].

The damage modality is unforeseeable and accordingly any alteration of the AE signal due to propagation and attenuation cannot be known a priori. This can induce an effect whereby the AE signal reaches the transducer with low amplitude and the system does not identify the signal because it is corrupted by noise. Propagation can attenuate the signal under the trigger level causing signal loss, whereas the occurrence of multiple AE events can reason the loss or partial signal acquisition due to the unpredictability of the acquisition time period. In order to decrease the probability of losing or partial acquisition due to the unpredictability of the transducer that firstly detects the AE signal and to reduce the quantity of acquired data in continuous monitoring [16], suggest the multi-triggered acquisition modality. It is executed in hardware via the Logic Flat Amplifier and Trigger (L-FAT) generator block. When acquired the AE signals, the relationship with the damage characteristics to the structure needs specify [36].

This paper proposes to evaluate the damage to concrete material by using AE signals technology on the basis of the finites elements method law (FEM). The FEM law defines the relationship between the attenuation of the wave and the frequency of earthquake events recognized in a region during a pre-established time interval. The advantage of the proposed method is that it furnishes the criterion to establish the healthy state of the structure in concrete under uniaxial compression state. The preliminary results achieved are related to cubic specimens without any kind of concrete reinforcement. The solution proposed does not take into consideration the effect of the shape, size and reinforcement of the specimen. Moreover, different kinds of concrete material and applied stress such as bending or shear, will be analyzed in future works. This document is organized as follows: in Section 1, this part is devoted to information on the modality of damage in the concrete structure and the specificities of non-destructive technology for their detection; In Section 2, information about the Sample and Phased Array modelling then Excitation and Reception Protocol; In Section 3, the numerical results are presented and analyzed for observed the development of cracks and the evolution of damage inside concrete in addition to the correspondence between the critical AE signals selected on the basis of Abaqus software and specimen damage is synthetized; finally, in Section 4 the conclusions are drawn.

2 Materials and modelling methods

In the simplest cases, the elastic wave equation could have an analytical solution. But, to model wave propagation for more complicated structures and at high frequencies such as in ultrasonic waves, the analysis becomes more difficult. This is why approximate solutions as provided by numerical solutions should be searched for in that case. In structural mechanics and acoustics fields, use is often made of the finite element method as a basic modeling approach. In this paper, modeling was carried out based on the finite element method by using Abaqus software. The ultrasonic array probe parameters, the shape and the size of the inspected part and the materiel of the sample were defined as input data. Plain strain hypothesis was assumed and adequate boundary conditions were applied. The duration of calculation was scaled in order to avoid reflections from the boundaries.

2.1 Sample and Modelling Acoustic Emission waves

A 3-D structure simulation model using Abaqus software is created. This has the form of a concrete beam made. A cracking defect was inserted in the middle of this Cuboid. The flaw was modelled as a vacuum in the surface of materiel. Description of the modeled structural geometry, material characteristics, size depth and type of the defect in the sample are presented in tables 1 and 2.

Table 1. Materiel properties and structure dimensions

Materiel	Young's Modulus (GPa)	Poisson's ratio	Dimensions (mm^3)
Concrete 16/20	29	0.16	0.10 x 0.50 x 0.10

Table 2. Crack characteristics

	Defect size (mm^2)	Depth (mm)
Surface defect	0.025 x 0.004	0.01

In this study, a concrete beam has been modeled, see figure 1. The excitation time signal F(t) at in the coordinates point (-14.78, -8.75, 50.10^{-3}) in the structure has the form of an oscillating pulse centered on the work frequency. Its form is given by equation (1).

$$F(t) = e^{-at^2} \sin(2\pi ft) \quad (1)$$

Where f=1.5MHz is the central frequency, t the time and a the amplitude parameter. The length L must be 0.2 mm and the height up to the exciter is l = 0.05 mm.

This kind of modeling (figure 1) carries design problems, ie. the boundary conditions "beam embedding", which have been set for numerical reasons, induce reflected waves. To avoid the reflections of the waves in the conditions at the limits of embedding, one chooses to make our computation with the condition on the time of excitation which must be lower than the time of reflections; equation (2).

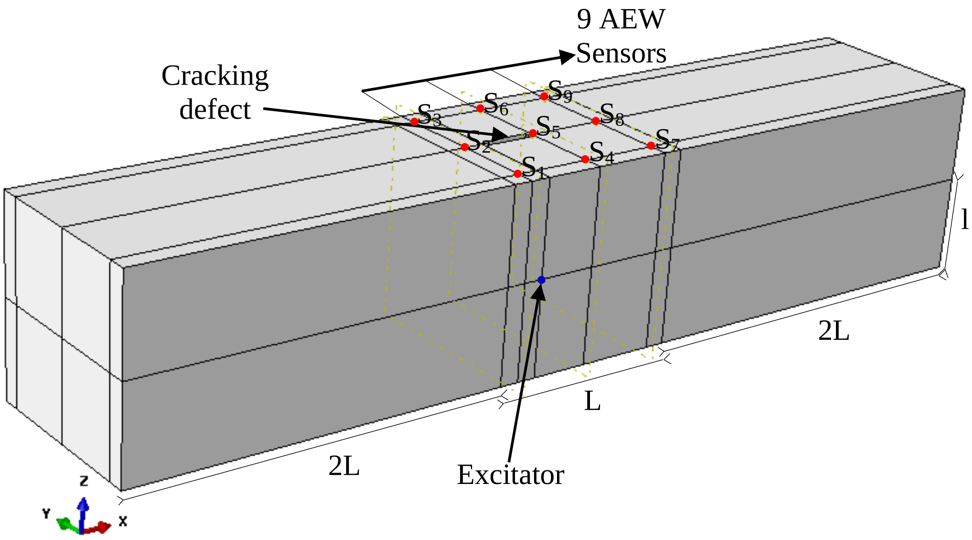

Figure 1. Designing specifics of problem model.

$$\Delta t_{excitation} \leq \Delta t_{reflection} = \frac{L}{c} \quad (2)$$

With: L the nearest length to have the reflection, (the length where the embedding condition), and c the velocity of the compression wave since it is larger than that of shear (c_s<c_l).

2.2 Excitation and Reception Protocol

One of the main advantages of the AE based technology is its ability to accurately characterize the state of structures integrity without degrading them. In this work where an AE system consisting of 10 linear elements is considered, the configuration of the inspection probe shown in figure is assumed to use an element as an exciter, while the response of the system is measured by the 9 elements which play the role of sensors. Other configurations are possible by changing the number and location of excitator and sensors. In the following, only the previous pattern made is investigated. To detect the presence of cracking, an indicator signal is defined as the difference between the system response in the model where the cracking defect was inserted and that one provided by a defect free model.

2.3 Additional crack depths

To assess the effect of cracking depth two additional models with a cracking defect inserted in the upper surface of the structure, were considered. The cracking size was kept fixed and the cracking depth is indicated in table 3.

Table 3. Crack characteristics in the additional models

Defect	Cracking	Cracking
Defect size (mm)	0.025 x 0.004	0.025 x 0.004
Depth (mm)	0.01	0.03

3 Results and discussion

3.1 Modelling results

The systems that uses the acoustic emission technique are assumed to be linear, so they comply with the principal of superposition. In our case, the actual system's input is the excitation function (1). Also, for the reason of the system's linearity, the response of the system can be regarded to be the sum of each individual responses. Considering the probe configuration mentioned above, the individual response envelope of the sensor 2 taken separately is plotted in figure 2. The response consists of the reflected signal by the defect following the initiated excitation element. It can be noticed that the intensity of received signals depends on the location of the excitator compared to sensor elements.
Figure. 2 shows also the AE signal in which specific characteristic parameters are highlighted such as the maximum amplitude A, and the hits. These parameters are used to characterize the fracture generating the AE signals and to assess the damage in the concrete sample.

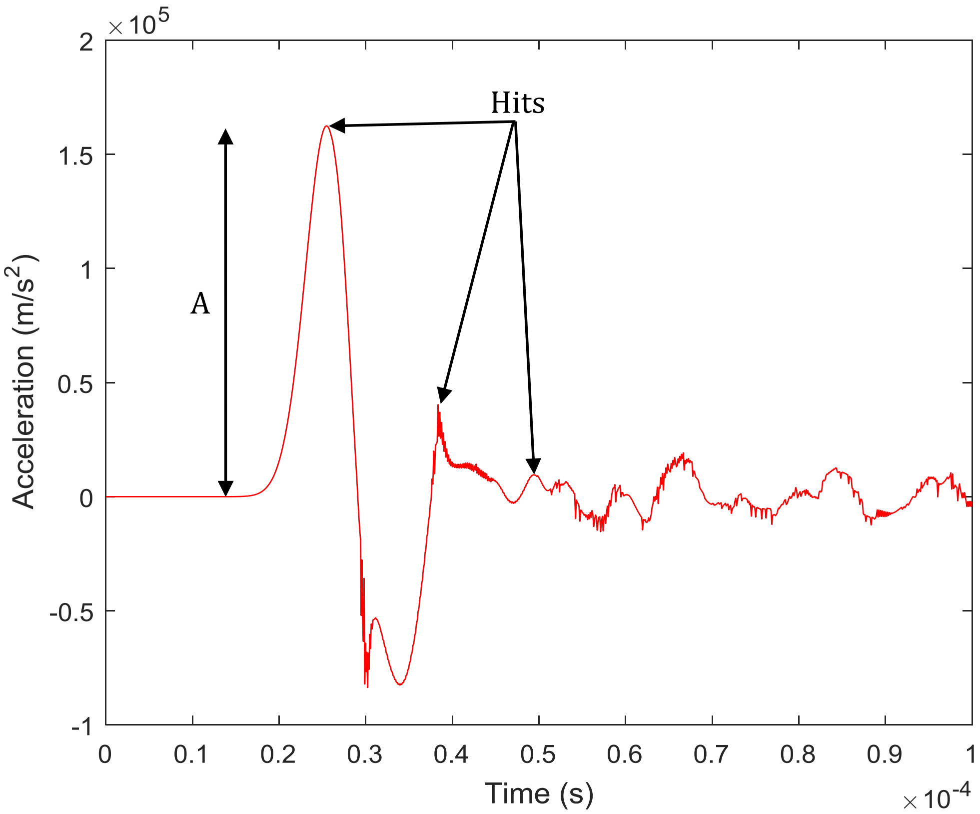

Figure 2. Received acceleration signal, that represent the defect echo, at sensor 2.

3.2 Effect of sensor position and crack depth

By comparing the signals received in each sensor, it could be concluded that the position of the sensor influences both the time of receiving the signal and the signal amplitude. More the position of the sensor is far from the excitation area, more the received signal amplitude is small. This is due to geometric dispersion of waves. This remark this enables the AEA elements to be enough closer to the defect area. To study the influence of the defect depth on the system's response, two different depth of

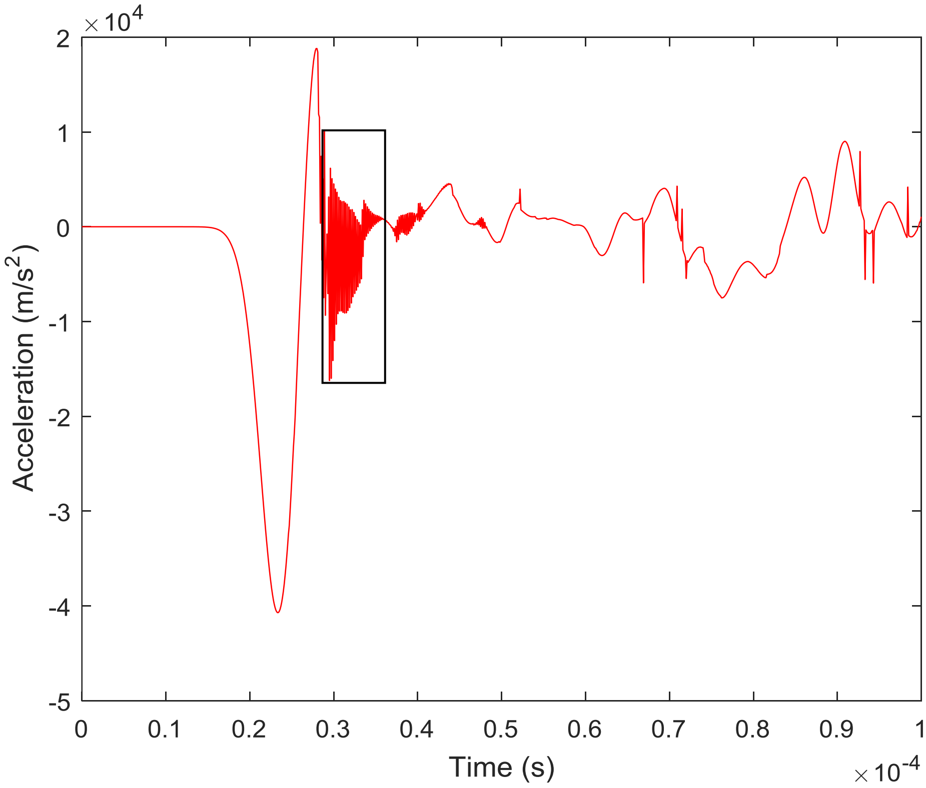

Figure 3. Received signal at sensor 6 (crack depth 0.01).

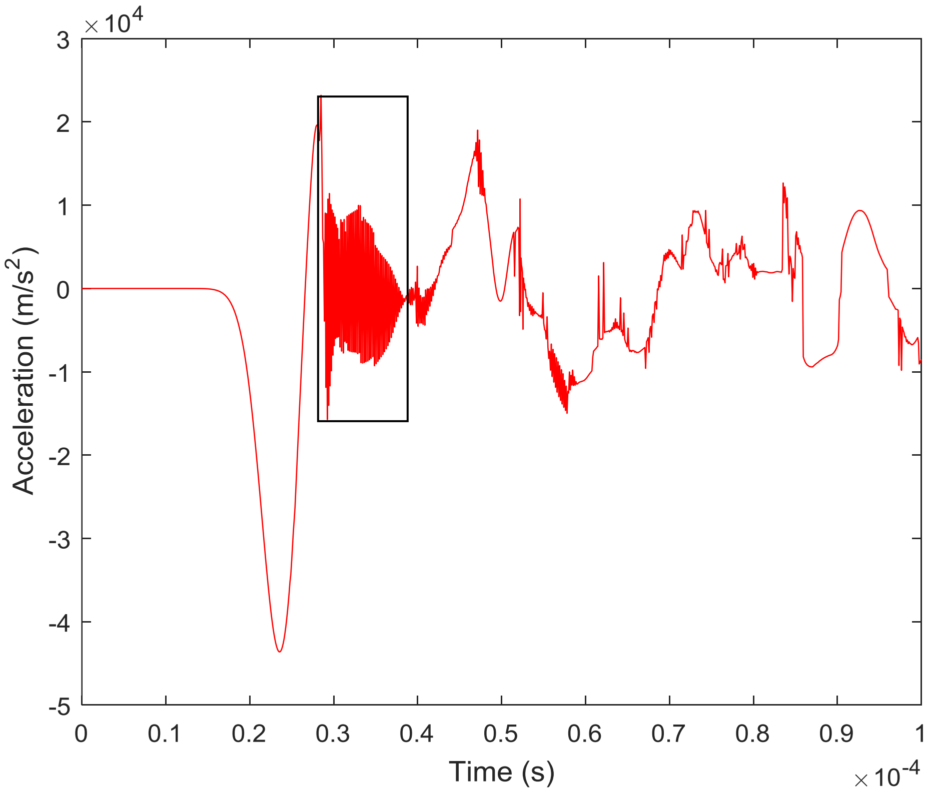

Figure 4. Received signal at sensor 6 (crack depth 0.03).

the cracking defect were considered.
Figures 4,5 present successively the received signals in the case where the cracking defect at the depth of 0.01 mm and 0.03 mm in the concrete beam. It can be seen that the cracking defect depth influences largely the intensity of the received signal and that the amplitude of the signal increase rapidly with defect depth.

4 Conclusions

This paper proposes a nondestructive technique for the damage evaluation of concrete structure. The technique is based on the Acoustic Emission analysis (AEA) signal. A 3-D approximation of wave propagation taking place in a concrete beam was assumed in order to study detection of cracking by Acoustic Emission (AE) signal. Different models were created for the purpose of simulating this linear system. These contained a cracking defect inserted in the upper surface of the concrete cuboid. A numerical solution of the problem was found using the finite element method. The numerical simulation results obtained from the AE modelling showed that a linear array consisting of 10 elements with a central frequency at 1.5MHz could provide enhanced examination of the concrete beam.
The influence of the cracking defect depth on the reflected signal received was analyzed, as well as the influence of the sensor position. The results of simulations showed that each sensor captures information depending on the distance separating the sensor from the defect and once this distance changes, the influence of factors (the depth of the defect in particular) changes also. Moreover, different shape, size and concrete type will be considered in a future work in order to correlate the parameter estimated by using the AE with the healthy state of the structure.

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