More information on acoustic emission

Acoustic emission signals are usually amplified first by a preamplifier and then by a main amplifier. They are filtered using a band-pass filter. A typical sensor (or transducer) transforms elastic vibrations of 10^{-9} mm amplitude into electrical signals of 10^{-6} V amplitude using piezoelectric element, such as lead zirconate titanate. The sensors must have a high signal-to-noise (S/N) ratio and a flat frequency response over a broad range. In concrete, acoustic emission events can be detected using an amplifier with 60 to 100dB of gain. The optimal frequency range in concrete is known to be from several kHz to a few hundred kHz.

In the 1950s, a German researcher, J. Kaiser, observed that metals, stressed up to a specified value and then unloaded, will only start to generate acoustic emissions once the stresses become greater than the original specified stress. This phenomenon, called the **Kaiser effect**, is a powerful tool to establish the maximum stress that a metal or a structure has been exposed to. Unfortunately, it seems that concrete does not show a Kaiser effect similar to metals.

An acoustic emission event in concrete is analogous to an earthquake. A seismologist wants to determine the magnitude and the location of the earthquake, so a set of sensors is placed on the surface of the earth to record the time when the wave hit the sensor. With this set of data it is possible, by triangulation for example, to determine the location of the earthquake. Similarly, the arrival time of the acoustic emission waveform at a sensor depends on the distance between the source and the sensor. Therefore, differences in arrival times at various sensors lead to a system of algebraic equations giving the source location. The process of the equations for homogeneous media is well-established, but it becomes complex when the material is heterogeneous at various levels.

Frequency domain analysis (**spectral analysis**) and time domain analysis (**moment tensor analysis**) are the two fundamental approaches used to infer the location, geometry, and propagation of the crack that originated the acoustic emission event. In spectral analysis, Fast Fourier Transform analyzes the frequency components of acoustic emission waves. This method takes into account the frequency response of the receiver transducer and the variation of wave attenuation as a function of frequency. The main disadvantage for in-situ applications is the presence of noise, which may alias the signal.

In moment tensor analysis, a model of the crack motion is created by assuming that a crack at point y is nucleated. Vector **n** normal to the crack surface and the displacement discontinuity vector **b**(**y**,t) between the two faces of the crack define the crack kinematics, which can be elegantly represented by a moment tensor m_{pq} defined as $m_{pq}=C_{pqkl}b_k n_l$, where C_{pqkl} are elastic constants. A mode I tensile crack* develops when the vectors **b** and **n** are parallel. Mode II or mode III shear cracks* develop when the vectors **b** and **n** are orthogonal. Physically, the moment tensor represent the angular dependence of P-wave and S-wave emitted by the source. As a result, AE waveform **u**(**x**,t) at observation point **x** due to crack vector **b**(**y**,t) on crack surface F is given by:

$$u_i(\mathbf{x},t) = \int_F G_{ip,q}(\mathbf{x},\mathbf{y},t) m_{pq} * S(t)\, dS \qquad (1)$$

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* See the three modes of crack propagation in figure 12-25 (Chapter 12).

where $G_{ip,q}$ is the spatial derivative of Green's function (transfer function of the displacement at point **x** and time t due to an impulse force applied at **y**), S(t) is the source-time function, and * indicates the convolution integral.
It is possible to recover the source function S(t) by deconvolution analysis [solving the integral Eq. (1)]. Thus, the effect of crack kinetics is readily recovered if the moment tensor components are known. Another advantage of using moment tensor analysis is that it can be used to determine the percentage of tensile, shear, and mixed mode cracks that occurs in an acoustic emission event. Ohtsu [1] developed a moment tensor inversion procedure that uses only the P-wave amplitude with full-space Green's function of homogeneous and isotropic material. With only two parameters per AE events (P-wave arrival time and amplitude), his code gave good results compared to experimental results concerning the location, kinetics and kinematics of crack propagation in a pull-out test of an anchor bolt. His measurements confirmed that the tensile cracks propagated radially from the anchorage to the reaction support, while shear cracks were only observed near the anchorage. Crack orientations of AE events due to tensile motion are approximately vertical to the final failure surface.

[1] M. OHTSU, AE observation in the pull-out test process of shallow hook anchors. *Proc. of JSCE* **11**, 177-86, 1989.