Available online at www.sciencedirect.com
ScienceDirect
Engineering Fracture Mechanics 74 (2007) 273–289
Engineering Fracture Mechanics
www.elsevier.com/locate/engfracmech

Structural damage diagnosis and life-time assessment by acoustic emission monitoring

A. Carpinteri *, G. Lacidogna, N. Pugno

Department of Structural Engineering and Geotechnics, Politecnico di Torino, Corso Duca Degli Abruzzi 24, 10129 Torino, Italy

Available online 20 March 2006

Abstract

The acoustic emission technique is applied to identify defects and damage in reinforced concrete structures and masonry buildings. By means of this technique, a particular methodology has been put forward for crack propagation monitoring and damage assessment, in structural elements under service conditions. This technique permits to estimate the amount of energy released during fracture propagation and to obtain information on the criticality of the ongoing process. In addition, based on fracture mechanics concepts, a fractal or multiscale methodology is proposed to predict the damage evolution and the time to structural collapse.

Keywords: Acoustic emission monitoring; Structural assessment; Damage mechanics; Crack growth; Life prediction

1. Introduction

The evaluation of safety and reliability for reinforced concrete structures, like bridges and viaducts or masonry historical buildings, represents a complex task at the cutting edge of technological research. Due to these reasons, the diagnosis and monitoring techniques are assuming an increasing importance in the evaluation of structural conditions and reliability. Among these methods, the non-destructive methodology based on acoustic emission (AE) proves to be very effective [1].

This method of damage detection, that now is attracting considerable attention, was employed at the beginning of the 1960s for the inspection of pressure vessels in USA. After this starting stage, the level of research interest became so high that international AE congresses were held all over the World. In response to this high level of research activity, AE has been investigated increasingly as a diagnostic tool for existing concrete structures [2].

Earlier in the history of AE, major efforts were directed to probing the fundamentals of AE phenomena and their behavior during deformation and fracture of metallic materials. It started in Germany with the research work on metals carried out by Kaiser [3], although AE on rock was already known in mining technology. With

* Corresponding author. Tel.: +39 011 564 4850; fax: +39 011 564 4899.
E-mail address: alberto.carpinteri@polito.it (A. Carpinteri).

0013-7944/$ - see front matter
doi:10.1016/j.engfracmech.2006.01.036

regard to the basis of AE research in concrete, the early scientific papers were published in the 1960s. Particularly interesting are the contributions by Rüsch [4], L'Hermite [5] and Robinson [6]. They discussed the relation between fracture process and volumetric change in the concrete under uniaxial compression. The most important applications of AE to structural concrete elements started in the late 1970s, when the original technology developed for metals was modified to suit heterogeneous materials [7,8]. At present, the AE technique is sometimes applied to concrete or reinforced concrete structures.

Another main field for AE research is actually the signal source location. This methodology is applied in order to determine the defects position and their orientation in the material. Among the first researchers who studied this methodology we find Shah and Li [9]. They applied the AE source location to identify the fracture process zone for cementitious materials, mainly subject to strain-softening loads. In this field, Ohtsu [2] carried out further studies, again performed at the laboratory scale. This studies concern the AE source location in bending tests of reinforced concrete beams. Two failure modes, bending failure and diagonal shear failure, are clearly identified from 3-D maps of source location.

Some later applications of AE technique to construction monitoring are described in Carpinteri and Lacidogna [10–12] where the AE monitoring is applied to forecast the damage evolution in reinforced concrete and in historical masonry buildings. In these papers, the stability evaluation of the structures is performed connecting the damage evolution, estimable by the dating and systematic survey, with the cumulative distribution of AE events in time. Since cracking is a multiscale phenomenon, recently AE data have been interpreted by statistical and fractal theories [13] like that proposed by Carpinteri and Pugno [14–16] for fragmentation and comminution phenomena.

2. Fundamentals of AE technique

Acoustic emission is represented by the class of phenomena whereby transient elastic waves are generated by the rapid release of energy from localized sources within a material. All materials produce AE during both the generation and propagation of cracks. The elastic waves move through the solid surface, where they are detected by sensors. These sensors are transducers that convert the mechanical waves into electrical signals. In this way, information about the existence and location of possible damage sources is obtained. This is similar to seismicity, where seismic waves reach the station placed on the earth surface [17,18]. Therefore, among the structural non-destructive tests, the AE monitoring technique is the only one able to detect a damage process at the same time when it occurs.

The AE method, which is called Ring-Down Counting or Event-Counting, considers the number of waves beyond a certain threshold level (measured in Volt) and is widely used for defect analysis [19,20]. As a first approximation, in fact, the cumulative number of counts N can be compared with the amount of energy released during the loading process, assuming that both quantities increase with the extent of damage (Fig. 1).

By means of this technique, we have analysed the evolution of cracks and estimated the released strain energy during their propagation in structural members. In particular, masonry historical buildings and reinforced concrete structures have been investigated.

3. Damage diagnosis of masonry buildings

Two masonry buildings have been monitored. The first one, called "Casa Capello" (Fig. 2), is located in the historical area of Rivoli, and was constructed upon pre-existing ruins, dating back to the XIV Century. This building has recently been object of complex interventions of functional extension and restoration. The AE methodology has been applied on certain walls of the building, in order to evaluate the status of the cracks that spread out after the collapse of a breast-wall [10]. In particular, the monitoring has involved two cracks which appeared inside the internal surface of the sustaining structure, at the ground floor level. Crack no. 1, monitored for about 900 h, has developed on a masonry wall reinforced with an external concrete surface. Crack no. 2 has been identified in a part of a wall, entirely built by bricks, and monitored for about 800 h.

Two transducers have been used to detect the AE released by the cracks. They were applied approximately 3 cm far from the top of cracks, to minimize signal attenuation. The dates of the first application of the transducers and their final removal, for the crack no. 1, are represented in Fig. 3. The graph, obtained by the mon-