Nondestructive Monitoring in RC Elements

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Contributor: Giuseppe Lacidogna, Marco Domaneschi, Gianni Niccolini

The structural and damage assessment of a **reinforced concrete (RC)** beam subjected to a **four-point bending laboratory test** is presented. Different **nondestructive testing** (NDT) techniques have been used with **distributed fiber optic sensors (FOS)** and **acoustic emission (AE) sensors**. The recorded AE activity results in good agreement with FOS strain measurements. At different loading steps, **digital image correlation (DIC)** analysis was also conducted.

Keywords: reinforced concrete ; four-point bending test ; structural health monitoring ; nondestructive testing techniques ; fiber optic sensors ; acoustic emission monitoring ; digital image correlation

1. Scope of research

During their service life structural elements can experience variable and increasing demand conditions (e.g., traffic increase in transportation infrastructures). They are also exposed to environmental effects, that can also degrade their capacity and affect their performance. In particular, reinforced concrete (RC) components can develop cracks due to tensile conditions that are normally absorbed by steel reinforcements. However, cracking can lead to the exposure of the steel bars to the aggression of external agents, such as chlorides, triggering corrosion and strength losses. In this incremental risk scenario for existing infrastructures, the role of structural health monitoring (SHM) becomes crucial in order to detect unusual behaviors and damage [1][2][3].

1.1. Fiber optic sensors review

The use of fiber optic sensors (FOSs) for SHM is proposed in several research works, including the seminal one that dates to 1990 by Glossop et al. [4]. FOSs can be used in aggressive environments, they show geometric adaptability, independence from electrical and magnetic field interference, and high resolution [5]. These characteristics make them excellent for implementation in the civil engineering field to detect anomalies and cracks in static conditions, while, in dynamic conditions, they can also be used to assess modal parameters [6][7][8].

1.2. Acoustic emission sensors review

Acoustic emission (AE) sensors have been widely used to detect early-stage damage before it results in failure. One of the earliest applications of AE was related to monitoring rotating machinery in the late 1960s. A comprehensive and critical review on the field of application of AE to condition monitoring and diagnostics of different mechanical components can be found in Mba and Rao (2006) [9]. Behnia et al. [10] present a comprehensive review of the acoustic emission (AE) technique for its applications in concrete structure health monitoring. Methods of AE are also developed for large structures in field application, e.g., for walls, bridge decks and reinforced concrete multi-story buildings (Carpinteri et al., 2007, 2011; McLaskey et al., 2010; Shiotani et al., 2009) [11][12][13][14].

Although AE sensors are normally developed using piezoelectric technology, there are many examples where optical fibers have been introduced as an alternative to piezoelectric sensors (e.g., Liang et al., 2009 [15]). However, there are a few applications where AE sensors are implemented in addition to distributed FOS sensors for strain detection, in order to integrate the monitoring and damage detection results obtained separately from the two systems. A representative example is one by Li et al. [16], where the results of an experimental investigation on corrosion monitoring of a steel reinforced mortar block through combined acoustic emission and fiber Bragg grating strain measurement are presented. Ansari [17] provided a short review of long gage interferometric and acoustic sensors with representative examples on the implementation of serially multiplexed long gage interferometric sensors and multiplexing of optical fiber acoustic emission sensors. Moving to composite fiber/epoxy materials, Park et al. [18] present an application for micro-failure evaluation using embedded fiber-optic sensors and acoustic emission piezoelectric sensors.

1.3. Combination of FOS and AE sensors

Detection of crack-induced AEs by a piezoelectric (PZT) sensor network focuses on individual cracks and displacements providing a very detailed damage description, but it suffers from limited detection range due to high attenuation of ultrasonic waves. Vice versa, global sensors act as a fully distributed sensor network to be interrogated at any point along the fiber length or integrating the response along the FOS length so as to cover a larger area. The disadvantage of global damage detection systems is their poor damage location capability. Therefore, the concurrent application of local and global methods combines damage detection possibilities and advantages of both systems.

Verstrynge et al. [19] applied a global FOS setup for AE-based damage detection in concrete elements. This line-integrating technique did not allow AE source location—carried out in that experiment through concurrent application of PZT transducers—but it has the potential for AE detection in large structures of interest to civil engineering.

2. Present research outline for an integrated SHM system

AE-based local damage detection through a PZT sensor network is coupled with a FOS setup for global strain mapping. FOSs act as a distributed sensor network to be interrogated at different points along the fiber length. Local and global methods are herein coupled through a digital image correlation (DIC)-based strain localization covering an intermediate-sized area. Hence, DIC-based strain data is herein used to reduce uncertainty on the FOS-based strain field description.

The integrated SHM system has been implemented in an RC beam specimen in laboratory subjected to a four-point loading test to monitor the state of cracking in terms of initiation and the thickness propagation. The outcomes of the integrated AE and FOS monitoring systems are confirmed by comparison with the final crack pattern. At different loading steps, digital image correlation (DIC) analysis was also conducted in specific areas of the beam specimen to reconstruct the strain field. A numerical model has also been prepared to investigate the mechanical behavior of the beam up to collapse. The analysis has been focused on both the global behavior in terms of force-displacement response, and also the local characterization of cracks. A satisfactory match between the numerical outcomes and the monitoring data has been observed.

3. Results and conclusions

The integrated use of different nondestructive testing techniques as proposed in this paper is a reasonable and reliable SHM strategy for damage detection and localization in RC elements. This study confirms how the integrated use of different nondestructive testing techniques can be useful for specific civil engineering applications, e.g., for large-sized structural elements where visual inspection is not always possible and accurate. Thus, the simultaneous use of nondestructive testing techniques such as acoustic emission, embedded fiber optic sensors, and digital image correlation, possibly aided by visual inspection, seems to be a step toward the realization of a reliable real-time structural alert system.

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