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A framework for the damage evaluation of acoustic emission signals through Hilbert–Huang transform

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ABSTRACT

The acoustic emission (AE) is a powerful and potential nondestructive testing method for structural monitoring in civil engineering. Here, we show how systematic investigation of crack phenomena based on AE data can be significantly improved by the use of advanced signal processing techniques. Such data are a fundamental source of information that can be used as the basis for evaluating the status of the material, thereby paving the way for a new frontier of innovation made by data-enabled analytics. In this article, we propose a framework based on the Hilbert–Huang Transform for the evaluation of material damages that (i) facilitates the systematic employment of both established and promising analysis criteria, and (ii) provides unsupervised tools to achieve an accurate classification of the fracture type, the discrimination between longitudinal (*P*-) and traversal (*S*-) waves related to an AE event. The experimental validation shows promising results for a reliable assessment of the health status through the monitoring of civil infrastructures.

1. Introduction

The behavior of heterogeneous materials, such as concrete, under compression load is a complex process involving different phenomena and it is governed by the nucleation and the growth of defects and damages. As the number of defects increases, a non-linear response related to a change of the mechanical parameters (e.g. nominal strength), and eventually irreversible processes leading to material collapse take place [1]. The failure mechanism is strongly dependent on different aspects, the evolution of the cracking patterns during the loading process, the shape and size of the specimens, and the type of applied stress [2].

Due to the release of localized internal energy, acoustic emission (AE) data [3] have been widely used for Structural Health Monitoring (SHM) [4–8] and adopted as a mean of identifying defects in pipelines [9] and composite materials [10].

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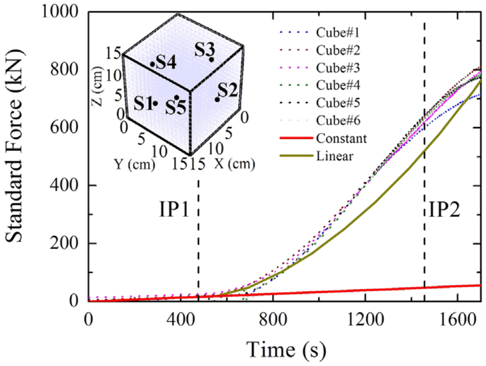

Fig. 1. Experimental load-vs-time diagrams (dotted lines) for the samples under test, and simulation results considering either constant (red line) and time-varying Young modulus for the specimen (gold line). Inset: position of the piezoelectric transducers for testing purposes. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

This approach is beneficial to characterize the cracks, enabling an early assessment of both material condition [11] and possible large-scale failure. Such monitoring method helps to manage the structures safely and economically. The analysis of AE data has significant advantages as compared to other nondestructive testing (NDT) techniques, such as ultrasound [12] and x-rays [13,14]. The key one is that the development of cracks can be studied on site directly and the retrieved information can be used to reveal the existence of different types of deformation [15].

From an experimental point of view, the AE signals related to the elastic waves resulting from damage events are recorded by piezoelectric transducers, which are commonly placed on the outer surfaces of the specimen [16], which convert the elastic waves to electrical signals. However, recent findings [17] have pointed out how disturbances (e.g. scattering attenuation due to damage accumulation, viscous damping, inhomogeneity of concrete, internal sample structure defects, etc.) can give rise to misleading data if they are not well accounted and minimized [18]. In order to avoid that, suitable computing environments including superior denoising performance and accurate algorithms for the efficient estimation of AE parameters have to be realized and tested [19].

Here, we have developed a processing framework to provide advanced analysis tools required to build the next-generation of SHM systems. It comprises an algorithm to perform sensor transfer function removal (TFR) adjusting the influence of the acquisition system, and an unsupervised tool based on the Hilbert–Huang Transform (HHT) [20,21] that enhances the Signal to Noise Ratio (SNR) [22] and permits both a better quantification [23–25] of AE parameters (for example the estimation of the propagating speed) and the damage location by using the Multilateration (MLT) algorithm [26]. The proposed tool is tested on experimental data measured by a multi-sensor Acquisition System (AS) [27].

The paper is organized as follows. Section 2 provides information about the acquisition system and the experimental setup. Section 3 describes the proposed framework. Sections 4 and 5 present results and discussions. Finally, in Section 6 the conclusions are provided.

2. Experimental setup

The AE measurements have pointed out that elastic energy due to a crack formation is characterized by modes with frequency in preferential bands [28] that, for cementitious materials, are in the range of kHz [16]. In concrete, for the characterization of AE data, standardization is currently being attempted [29], meaning to propose a well established type of sensors and measurement procedures. With this regards, we have already developed a multi-triggered acquisition system that takes into account emerging standards and enables both high sampling frequencies and reduced storage requirements [27,30], as detailed below.

The experimental setup consists of:

- One hydraulic press with a closed loop governing system with 3000 kN and accuracy class 0.5%, connected to the AS to record the load–displacement diagram;
- Five AE transducers, R15α, with a peak sensitivity of 69 V/(m/s), resonant frequency 150 kHz, and directionality ± 1.5 dB [22,31];
- The Logic Flat Amplifier Trigger generator (L-FAT) [27];
- Two Data acquisition boards (DAQ) NI-6110 with four input channels, 12 bit resolution, and sampling frequency $f_{AS}=5$ Msample/s ± 1154 sample/s. A channel (Ch) is associated to each transducer;
- A self-implemented processing framework.

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