

## A near and far-field monitoring technique for damage detection in concrete structures

Costas Providakis<sup>\*1</sup>, K. Stefanaki<sup>1</sup>, M. Voutetaki<sup>1</sup>, J. Tsompanakis<sup>2</sup>  
and M. Stavroulaki<sup>1</sup>

<sup>1</sup>*Applied Mechanics Lab, School of Architectural Engineering, Technical University of Crete, GR-73100 Chania, Greece*

<sup>2</sup>*School of Environmental Engineering Technical University of Crete, GR-73100 Chania, Greece*

*(Received April 12, 2014, Revised May 4, 2014, Accepted May 8, 2014)*

**Abstract.** Real-time near and far-field monitoring of concrete structural components gives enough information on the time and condition at which damage occurs, thereby facilitating damage detection while in the same time evaluate the cause of the damage. This paper experimentally investigates an integrated monitoring technique for near and far-field damage detection in concrete structures based on simultaneous use of electromechanical admittance technique in combination with guided wave propagation. The proposed sensing system does not measure the electromechanical admittance itself but detect time variations in output voltages of the response signal obtained across the electrodes of piezoelectric transducers bonded on surfaces of concrete structures. The damage identification is based on the spectral estimation MUSIC algorithm. Experimental results show the efficiency and performance of the proposed measuring technique.

**Keywords:** electromechanical admittance; guided waves; concrete beam structures; PZT patches; chirp signal; fourier transform

### 1. Introduction

The structural integrity of the civil infrastructure is very important for the safety, productivity and quality of life of the society. This integrity is often a concern due to the aging of the infrastructure, the occurrence of earthquakes, exposure to wind loading and ocean waves, soil movement, excessive loading and temperature excursions. Thus, there is need for real-time monitoring damage in a non-destructive way, so that timely repair or retirement of structures takes place.

Damage sensing (i.e., structural health monitoring) is valuable for concrete structures for the purpose of hazard mitigation. Health of concrete structures is mainly monitored by recording and measuring propagation of stress waves through them. The occurrence of damage generates changes of stress waves which carry important information of the nature and extent of damage. This allows for a reduction of the cost of maintenance and inspection tasks leading to a more

---

\*Corresponding author, Professor, E-mail: [cprov@mred.tuc.gr](mailto:cprov@mred.tuc.gr)

economical condition-based maintenance strategy that is capable of prompt condition assessment of critical civil facilities.

Many traditional global or local experimental structural health monitoring (SHM) and damage detection methods have been proposed in the past and have been used in a variety of concrete structures such as C-scan, X-rays, radar techniques, etc (Cruz *et al.* 2010, Fan and Qiao 2011, Brownjohn *et al.* 2011). While these techniques provide useful information for the decision makers, however, they require bulky equipments, they are extremely time-consuming and most of them request that the vicinity of the damage is known a priori.

One of the promising active sensing approaches which utilizes piezoelectric (PZT) transducers as actuators/sensors, the electromechanical admittance, or its inverse impedance, the so-called EMA technique, has received growing attention in recent years for in-situ health monitoring due to its distinct advantages (Annamdas and Soh 2010, Kumar *et al.* 2012, Yun *et al.* 2011). EMA response is derived from the dynamic interaction between PZT transducers and the host structure. EMA is typically applied using an electrical impedance analyser which scans a predefined frequency range in the order of tens to hundreds of kHz. The main advantage of EMA technique is its capability to detect local (near-field) damages, even in complex structures. However, unfortunately, taking into account that since steady-state response, which is needed for admittance measurements, is limited to a small region close to the admittance transducer one may conclude that EMA can detect damages only locally. In contrast, when guided stress wave (Raghavan and Cesnik 2007) is propagated along the length of any structural component then the boundary of the components allow a long range "guidance" achieving far-field monitoring capabilities.

In the present paper, the proposed damage detection technique does not use any measurement of the electromechanical admittance itself. The conventional admittance sensing technique is replaced here by acquiring output voltage variations generated across a simple circuit connected to the PZT transducer. To combine the advantages of EMA and GW techniques an integrated multi-mode sensing technique is proposed, referred as EMA-GW technique (Providakis *et al.* 2012) that detects changes in the admittance spectrum of a PZT transducer in the range of a predefined frequency band as generated by: a) continuous locally inspected admittance signatures, and b) simultaneously detected changes in admittance signatures from guided wave disturbances originated from a second PZT patch which acts as a guided wave transmitter.

The main advantage of the proposed approach is that the combined EMA-GW technique incorporating synchronous admittance-based and guided wave propagation measurements retains the benefits of both techniques allowing effective near-field damage detection and in the same time increased sensing capabilities for wider regions. The combine use of the two techniques has been also investigated by other researchers over the last decade (Georgiutiu *et al.* 2004, Wait *et al.* 2005, Park *et al.* 2006, Zagrai *et al.* 2010, An and Sohn 2011, Park *et al.* 2012, An *et al.* 2012, Zhu and Rizzo 2012, Dürager *et al.* 2012), however, the applicability of those techniques has not yet been tested or demonstrated in details for concrete structures. For instance, in the monitoring technique presented in the recent work of Zhu and Rizzo (2012), an integrated experimental monitoring procedure was demonstrated dealing only with Lamb wave propagation in steel structures.

To detect damage in a concrete structure, it is necessary to develop a damage identification methodology that can extract the quantitative information of any damage state affecting the performance of the structure. The damage identification using electromechanical admittance measurements is a complicated procedure since it is embedded in high-level noise. Therefore, to have a reliable data analysis tool capable of analyzing damage in concrete structures with low























