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Application of low-profile piezoceramic transducers for health monitoring of concrete structures

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ABSTRACT

Using piezoceramic patches bonded on concrete beams to perform structural health monitoring is investigated in this paper. To evaluate the performance of piezoceramic sensors and ultrasonic wave methods, two series of tests were carried out on $100 \times 100 \times 500\,mm^3$ concrete prisms. In the first series of tests, the influence of the frequency of the input signal on the waveforms was investigated and the optimum frequency to generate ultrasonic waves was evaluated. From the velocity of Rayleigh waves and longitudinal waves, the dynamic modulus of elasticity and dynamic Poisson's ratio of the concrete were obtained. In the second series, the effect of uniaxial compressive stress and the resulting internal cracking of the concrete on the amplitude of the waveforms received by piezoceramic sensors was investigated. It is shown that differences in amplitude between two wave packets are sensitive to the cracking process of concrete with externally applied loads. The results confirm that piezoceramic sensors and corresponding ultrasonic waves methods have the potential to monitor cracking and the long-term deterioration of concrete structures.

1. Introduction

Most infrastructure construction is made of concrete and reinforced concrete, and it is generally a very expensive national investment. Concrete structures have a long service life compared to other mechanical, electrical and electronic commercial products. Further, like all construction materials, concrete structures also age and deteriorate with time, the deterioration of concrete and reinforced concrete can arise from a number of sources such as aging of the material, exposure to aggressive environmental conditions, excessive use, overloading, insufficient maintenance and lack of proper inspection methods and repair strategies. All these factors lead to a progressive degradation of the structure as internal and external damages develop and progress to adversely affect its safety and structural integrity.

The development and implementation of damage detection strategies, and the continuous health assessment of concrete structures then become a matter of utmost importance. A wide variety of very effective classical non-destructive methods of inspection and monitoring the serviceability performance of concrete structures have been used in the past and reported in literature [1–8]. However, many of these methods are often cumbersome, and suffer from many practical difficulties. On the other hand, smart materials/sensors, such as fibre optic sensors, piezoelectric materials and magnetostrictive sensors, offer a more integrated structural health monitoring system which can provide continuous and on-line techniques to detect the location and extent of damages in concrete structures. Piezoelectric ceramics have the advantage that they can work as both transmitter and receiver of ultrasonic waves. They have been made available as small plates of different thickness, and can be cut to sensors of arbitrary geometry. Wang et al. [9] bonded PZT sensors on steel reinforcing bars to detect the debonding process between the rebar and concrete. They found that the amplitude of the received signals increased in a linearly proportional manner to the debonding size of the steel rebar from concrete. They have also used PZFlex software to simulate the response of the sensor as parameters in RC structures such as crack width, debond size and rebar position changed [10]. The feasibility of damage detection by non-destructive techniques through an array of piezotransducers bonded to the surface of a concrete block has also been reported [11]. Saafi and Sayyah [12] have developed an active damage interrogation method to detect and localize debonding between repaired concrete and fibre reinforced polymer (FRP) sheets with an array of PZT transducers bonded to the FRP. Song et al. [13] used embedded PZT patches along with the wavelet packet analysis method to detect the onset and severity of cracks in concrete structure. Fibre optic sensors can also be used as

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ultrasonic sensors in laboratory tests. Chen and Ansari [14] reported a fibre optic distributed pulse-echo system to monitor defects in concrete structures. Betz et al. [15] reported that optic fibre Bragg grating sensors had the ability to sense ultrasonic Lamb waves.

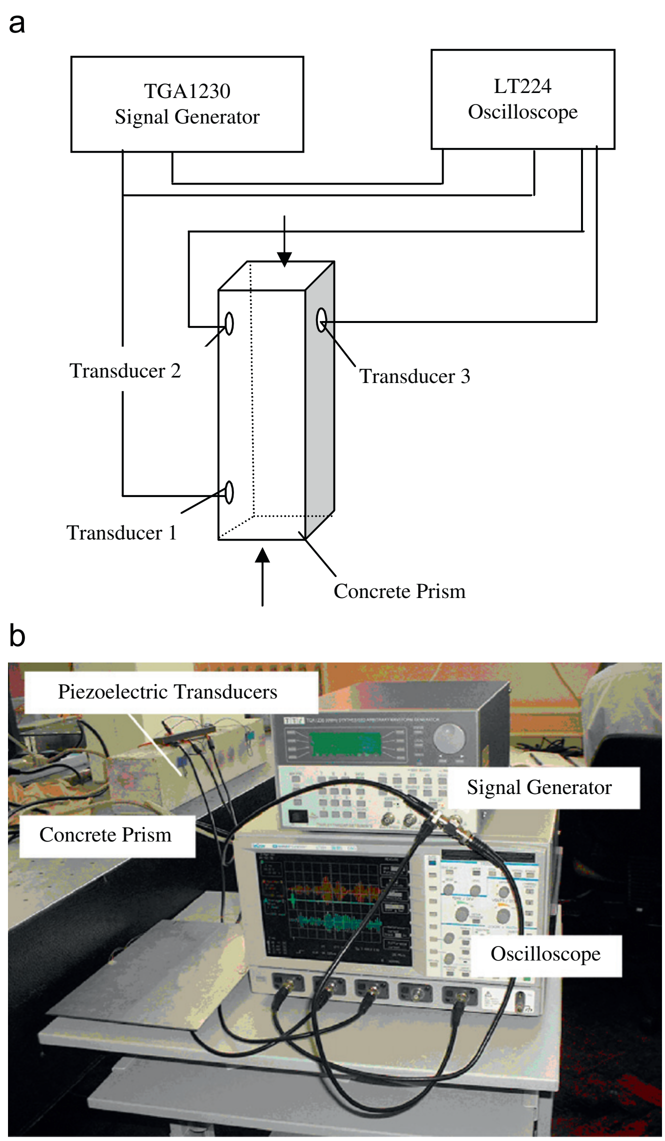

Fig. 1. The test system: (a) schematic diagram and (b) photograph of the measurement system.

This paper concerns the use of piezoelectric ceramic sensors and ultrasonic wave method to monitor the dynamic elastic constants of concrete and cracks as part of the SHM system of concrete structures. Two series of tests are reported. In the first series, the Poisson's ratio and dynamic modulus of concrete were evaluated using PZT sensors and analysing the resulting waveforms. All concrete structures crack during their service life, and therefore, in the second series of tests, the effect of internal cracking under uniaxial loads of concrete prisms on the amplitude of the waveforms was investigated. A major objective of this study is to show that the proposed ultrasonic waves method is a feasible non-destructive test to determine the dynamic elastic constants of concrete, and monitor the degradation of concrete as it cracks under external loading. The main advantage of the use of these techniques is that it can transform concrete structures into active, intelligent systems capable of assessing their own structural serviceability.

2. Initial experimental analysis

2.1. Materials and specimens

The tests reported here were carried out on $100 \times 100 \times 500\,mm^3$ concrete prisms. The concrete was designed for a compressive strength of 90 MPa. The mix proportions of the concrete were cement:water:sand:coarse aggregate = 1:0.4:2.019:3.433, all by mass. The maximum size of coarse aggregate was limited to 15 mm. All test specimens were cured in water for 28 days; they were then placed in ambient drying conditions.

2.2. Experimental set-up

The size of piezoceramic patches was 10 mm in diameter × 1 mm thick. They were bonded on to the surface of specimen as shown in Fig. 1 using a well-tested adhesive for strain gauges after the surface was smoothed over with the sand paper. After about 24 h, lines were soldered onto the two surface electrodes of piezoceramic patches. They were located at 100 mm from the ends of the prism. In Fig. 1, piezoceramic transducer 1 works as the transmitter, while transducers 2 and 3 work as the receiver. The signal generator, the oscilloscope and piezoceramic transducers were all connected using coaxial shielding cables. The oscilloscope was triggered to sample the data by a synchronization signal generated by the signal generator, which coincided with the excitation pulse. In order to improve the signal-to-noise ratio, 1000 repetition averaging was performed. The maximum sampling rate of the oscilloscope was about 200 MS/s. Using the cursor, the time at any point on the waveform can be measured

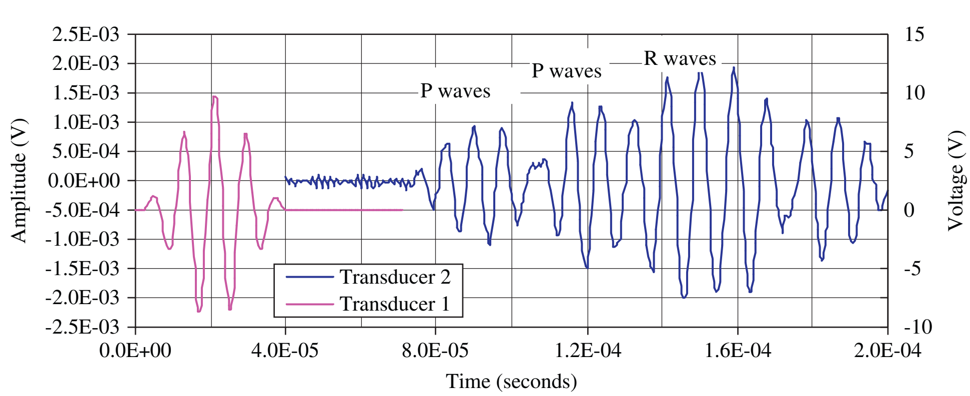

Fig. 2. Waveform received by piezoelectric transducer 2 (120 kHz).