Detecting micro-cracks

PR Armitage of Theta Technologies and CD Wright from the College of Engineering, Mathematics and Physical Sciences at the University of Exeter, discuss a new instrument and method to detect early stage micro-cracking in concrete by measurement of acoustic harmonic generation.

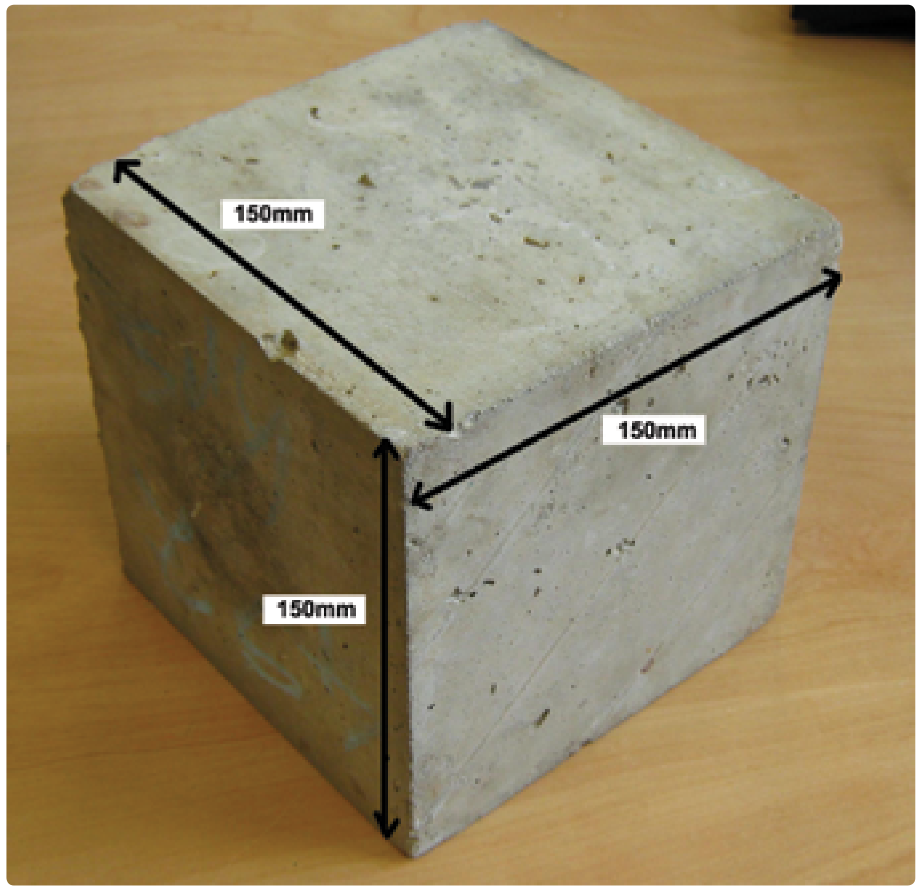


Figure 1: Standard concrete test cube.

The ultrasonic testing of the early stages of damage in concrete structures has posed many problems. Conventional methods such as pitch catch examine the acoustic pulse delay and amplitude change as it passes through or over a concrete structure. However, though such changes are minimal until the concrete has been stressed to approximately 80% of its maximum compressive strength, the concrete's tensile strength is significantly weakened at much lower values.

The pulse echo method is of limited use as the aggregates cause scattering and multiple reflections. Impact echo method has proved useful for the detection of large near surface cracks and defects but does not detect micro-cracks. Similarly, impact resonance will only give an indication of the latter stages of damage.

Detecting early-stage damage

The authors have conducted an experiment that compares conventional testing methods to a new ultrasonic technique, based on non-linear acoustics, that will detect early-stage damage in concrete, particularly micro-cracking that occurs at levels below 40% maximum applied compressive strength.

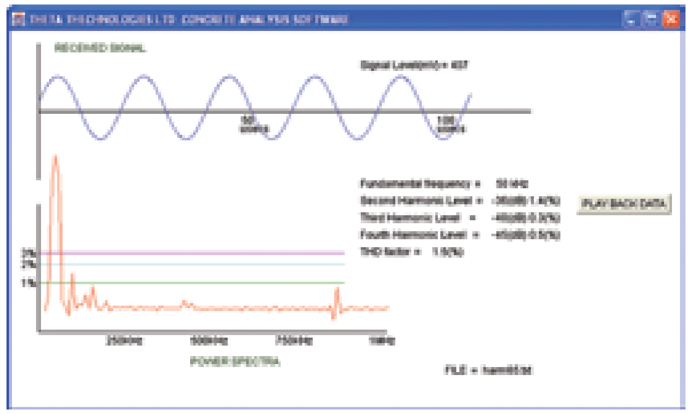
Figure 1 shows a photograph of the concrete test block used in this experiment. It consists of a 150 × 150 × 150mm cube cured for 28 days in water at 20°C, then air dried for a further 37 days, before testing. The concrete used 20mm granite aggregate with no admixtures or reinforcements.

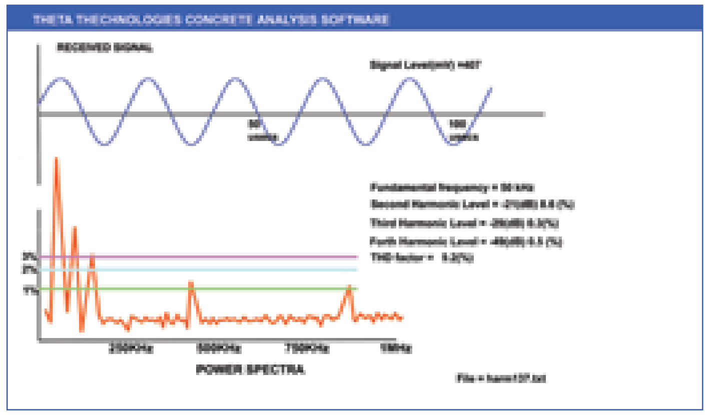
Currently the most common non-destructive method to test for damage in concrete is pulse velocity. This method measures the time of flight of an acoustic pulse as it traverses through or over the surface of a concrete structure. Other ultrasonic testing methods include measuring the amplitude attenuation of an acoustic pulse and the resonance spectra generated by a pulse or impact.

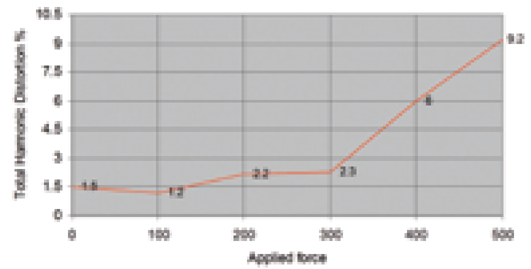
All these methods have great difficulty in detecting early stage damage in concrete. The pulse velocity method is insensitive to the degree of damage until nearly 80% of the concrete's maximum compressive strength. Recently, various ultrasonic testing methods have been investigated that examine the mechanical stress-strain non-linearity that occurs during the failure process. Of particular relevance is the method of non-linear elastic wave spectroscopy.

Figure 2: Testing the cube (front view).

Figure 3: Testing the cube (side view).







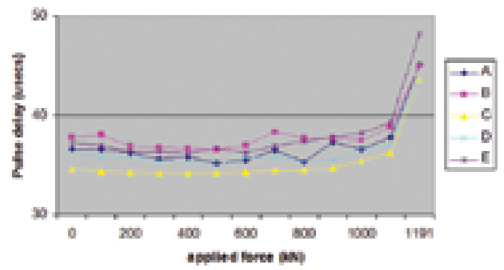


Figure 4 top left: Initial undamaged state, Maverick1000 instrument receiver located in centre (at centre position).

Figure 5 top right: Recorded after 500kN force applied.

Figure 6 far left: THD measurement of Maverick1000.

Figure 7 left: Pulse velocity method detects only after 90% of failure load.

Figure 8 below: The Maverick1000 instrument.

> **"This experiment has shown that it is possible to detect early stage damage in concrete using the Maverick1000 as a non-linear acoustic measurement instrument."**

From the authors' experiments this technique has been shown to be capable of detecting early-stage damage in concrete typically below 40% maximum compressive strength. The experiments were performed using a Maverick1000, which is the first instrument designed specifically to provide non-linear acoustic testing of concrete.

Figures 2 and 3 show the Maverick1000 being used to test the concrete cube. The transmitter transducer is coupled to the rear cube surface using petroleum jelly and for this experiment supported in a holder at the face centre.

Figure 2 shows the front view of the cube, the receiver transducer is held in position by hand. Five locations were tested. The transducer is also coupled by petroleum jelly. The cube is systematically crushed by applying a series of loads to the top surface and measurements taken at each stage.

Test measurements were first made to the cube in its initial undamaged state. The cube was then subjected to a load of 100kN, removed and test measurements recorded at the five locations. The cube was then further loaded in 100kN steps until failure at 1191kN. At each step a series of recordings were made. In addition to the non-linear measurements, industry standard instruments were used to measure the pulse wave velocities and impact resonance at each of these test locations (see Figures 4–5).

In all tests the received signal is plotted in blue and the frequency spectrum for this signal is plotted in red. At this undamaged state, the only large peak is that of the fundamental transmitted wave at 50kHz, which is normal.

Figure 6 shows that at 200kN (17% of failure load) a total harmonic distortion factor (THD) of 2.2% was recorded and at 500kN (42% of failure load) a THD factor of 9.2% was recorded. This indicates that as the load increases the Maverick1000 can clearly detect change in the very early stages of damage.

Figure 7, in contrast, shows that when using the pulse velocity method, it can be clearly seen that only after 1100kN (around 90% of failure load) is any significant change to the pulse delay observed.

Early stage detection possible

This experiment has shown that it is possible to detect early stage damage in concrete using the Maverick1000 as a non-linear acoustic measurement instrument. Of particular importance is its ability to detect the very early stages of damage. Conventional methods are unable to measure to this same level of sensitivity. This research has led to a greater understanding of how and at which point the applied loading of concrete leads to the formation of micro-cracks. ●