Laboratory measurements and discrete element method calculations of acoustic emission in concrete beams during fracture

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Fracture is one of the most important and challenging issues in concrete materials. A deep understanding of the damage process (crack creation and development) is necessary for safety reasons. Especially, the early prediction of micro-cracks with non-destructive methods is important, nowadays. In this article, the acoustic emission (AE) technique was employed, which is common and effective [1]. First, the experimental analysis was made for three concrete beams (40x40x160 mm^3) with a notch (4x7 mm^2) in the middle part. Support spacing was chosen as 120 mm. All beams were made of a concrete mix consisting: CEM I 42.5R (450 kg/m^3), water (177 kg/m^3), sand 0-2 (675 kg/m^3) and gravel 2-8 (675 kg/m^3). The bending test was carried out on Zwick/Roell Z10 universal testing machine. The elastic waves caused by cracking concrete were sensed using four piezoelectric transducers, arranged in a 2x2 grid. They were located on both sides (left and right) from the notch in the distance of 50 mm, at 10 mm and 30 mm in height (on the front side of the beam). Data acquisition was carried out using the AMSY-6 system (Vallen Systeme GmbH). The loading was performed with a constant displacement rate of 0.05 mm/min (quasi-static conditions). The AE signals were recorded during whole tests, up to the final damage of the beams.

In parallel with laboratory tests, the numerical model was created. The discrete element method (DEM) was used since it directly simulates the material meso-structure. Thus it is suitable for comprehensive studies of mechanisms of the initiation, growth, and formation of localized zones, cracks, and fractures at the mesoscale [2]. It easily represents discontinuities caused by fracturing or fragmentation. The open-source code YADE [3] was employed for calculations. Three samples were created, based on the real geometry (from the photo). Due to calculation time, the numerical study was limited to the 2D problems only (one layer of grain). The concrete was simulated as 4 phase material, consist aggregate, interfacial transition zone (ITZ) around them, air voids and cement matrix [3]. The cement matrix was filled specimen in 97% (thus microporosity was equal to 3% as in the experiment). The air voids were simulated as empty spaces. The aggregates were composed of spherical elements with cohesion, which can break in contrast to the last calculations, where they were simulated as non-breakable clumps. The shape and position of the aggregate were taken directly from photos of laboratory beams. The numerical parameters were calibrated on uniaxial compression and tension [3]. Each specimen contained more than 30'000 elements (with a coordination number of about 7). The elastic wave was recorded during the test in the same places as in the experiments.

The force-deflection (and CMOD) curves were compared, and good agreement was found between laboratory tests and numerical calculations. Also, the shape of the final crack (determined experimentally by the digital image correlation technique) was similar in both cases. The results obtained on all transducers were also compared directly with laboratory tests, with good agreement. The non-destructive AE method has shown to be a good tool for early-stage damage detection. Moreover, the DEM method shows a great ability to successfully model the elastic wave during the fracture process. In future work, the 3D calculations on real geometry are planned.

References

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