ANALYSES OF SIZE EFFECT IN CONCRETE AT MESO-SCALE DURING SPLITTING TENSION TEST USING DEM

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1. Introduction

The size effect is a fundamental phenomenon in concrete materials. It denotes that both the nominal structural strength and material ductility (ratio between the energy consumed during the loading process after and before the stress-strain peak) always decrease with increasing element size under tension [1]. Thus, concrete becomes ductile on a small scale and perfectly brittle on a sufficiently large scale. Two size effects are of a major importance: energetic (or deterministic) and statistical (or stochastic) one. In spite of the ample experimental evidence, the physically based size effect is not taken into account in practical design rules of engineering structures, assuring a specified safety factor with respect to the failure load. Instead, a purely empirical approach is sometimes considered in building codes which is doomed to yield an incorrect formula since physical foundations are lacking.

The objective of the present paper is to analyze numerically a quasi-static size effect in concrete at the meso-level during differing failure mechanisms (varying from quasi-brittle to very brittle with the snap-back instability) observed in quasi-static splitting tension tests for different specimen diameters.

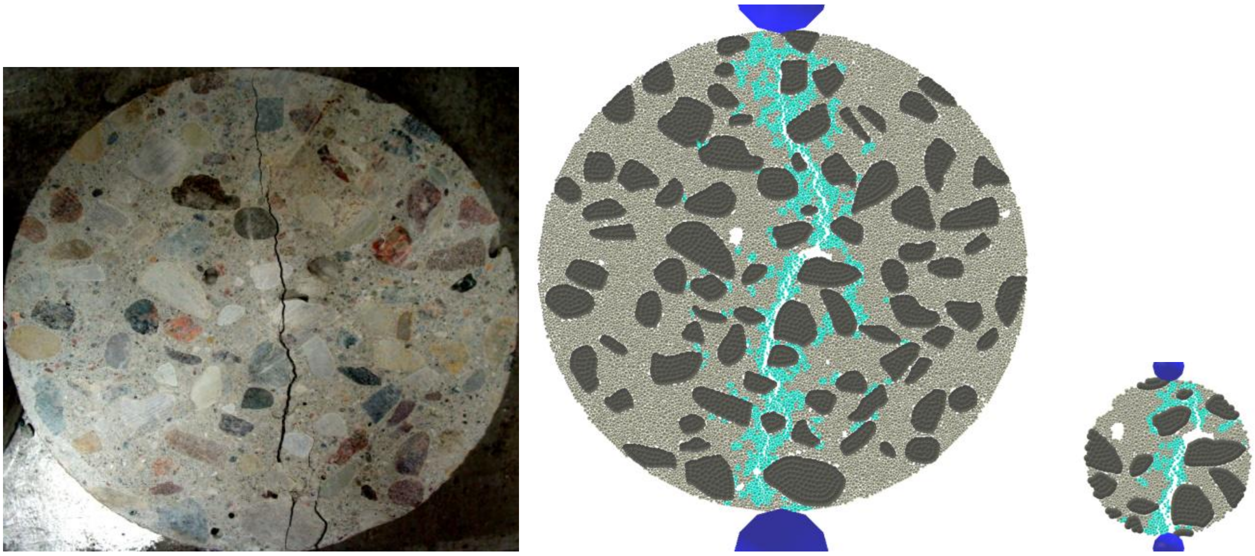
2. Experiments

Own experiments on splitting tension were carried out with concrete specimens of the diameter D=74, 100, 150, 192 and 250 mm under the CMOD-control. The strength and ductility decreased with increasing specimen diameter. For large specimen diameters D>100 mm, a clear snap-back instability occurred. Advanced x-ray micro-tomography system Skyscan 117 was used to determine concrete meso-structure [2].

3. Simulations with Discrete Element Method (DEM)

The calculations were performed with the three-dimensional spherical discrete element model YADE, which was developed at University of Grenoble [3]. This 3D spherical discrete element method takes advantage of the so-called soft-particle approach (i.e. the model allows for particle deformation which is modelled as an overlap of particles). During the simulations, particles may overlap that can be interpreted as a local contact deformation. A linear normal contact model in compression was used. The interaction force vector representing the action between two spherical discrete elements in contact was decomposed into a normal and tangential vector, respectively. The normal forces acting on spheres were modelled by an elastic law with cohesion. Concrete was depicted as a four-phase composite material including aggregate, cement matrix, interfacial transitional zones (ITZs) and macro-voids [4]-[6]. The realistic description of the meso-structure with the presence of ITZs was necessary to faithfully reproduce the crack shape in concrete. The DEM calculations were performed with the concrete specimens of the different diameter used in experiments(Fig.1). ITZs were simulated for the sake of simplicity as contacts between aggregate and cement matrix grains. Thus they had not the physical width in contrast to experiments. The detailed calibration procedure was based on preliminary uniaxial compression laboratory tests.

The process of micro- and macro-cracking was studied in detail for various failure modes including the snap-back. The macroscopic stress-CMOD curves and shapes of cracks were directly compared with the test outcomes. In addition, the evolution of contact forces, crack displacements, number of broken contacts were analysed at the aggregate level. Internal energies were carefully studied in specimens of the different diameter with various failure modes. A satisfactory agreement between with experiments was obtained. The experimental size effect was realistically reproduced in numerical calculations at the aggregate level, i.e. the concrete strength and ductility decreased with increasing concrete specimen diameter. The decreasing strength reached an asymptote with increasing specimen diameter.



a) b) c)

Figure 1: Fracture in concrete specimen in splitting tensile test in a) experiment and DEM calculations with 2 different specimen diameters: b) D=0.15 m and c) D=0.05 m (black colour indicates aggregates, grey colour represents cement matrix, white colour shows macro-pores, cyan colour denotes area with broken contacts and blue colour shows supports

The relatively more contacts were broken before the peak load for the larger concrete specimen than for the smaller one (by 25%) and after the peak load for the smaller specimen than for the larger one (by 25%). Thus, during the snap-back behaviour relatively less contacts were damaged than during the quasi-brittle behaviour. The strong micro-cracking process mainly started in the smaller specimen slightly before the peak load and in the larger specimen clearly before the peak load (that contributed to the lower strength).

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4. References

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