SIMULATION OF FRACTURE PROCESS IN CONCRETE ELEMENTS WITH STEEL FIBRES USING DISCRETE LATTICE MODEL

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1. Introduction

The fibre reinforced concrete is commonly used for industrial floors. The determination of its strength and ductility is of a major importance for the design of floors. This paper deals with simulations of a fracture process in concrete including steel fibres with our novel discrete lattice model [1], [2]. Concrete is described at a meso-scale as a four-phase material composed of aggregate, cement matrix, interfacial zones and steel fibres. The elements are stochastically distributed in the form of a lattice mesh using a Delaunay's construction scheme. The calculations are carried out for concrete specimens including steel fibres subject to uniaxial extension and three point bending.

2. Discrete lattice model

Our lattice model [1], [2] differs from classical lattice beam models [3] composed of beams connected by non-flexible nodes in that it consists of rods with flexible nodes subject to longitudinal deformability and rigid body rotation. Thus, shearing, bending and torsion are represented by a change of the angle between rod elements connected by angular springs. This quasi-static model is of a kinematic type. The calculations of element displacements are carried out on the basis of the consideration of successive geometrical changes of rods due to translation, rotation and normal and bending deformation. Thus, the global stiffness matrix is not built and the calculation method had a purely explicit character. Owing to that, the computation time is significantly reduced. In addition, torsion in three-dimensional simulations is included. Each rod element is removed from the lattice if the local critical tensile strain is exceeded. The lattice elements possess a longitudinal stiffness k_l (controls the changes of the element length), bending stiffness k_b (controls the changes of the angle between elements) and torsional stiffness k_t (controls the changes of the torsional angle between elements). The quasi-brittle material is discretized in the form of a 3D tetrahedral grid or a 2D triangular grid including lines. The distribution of elements is assumed to be completely random using a Delaunay's construction scheme. First, a tetrahedral grid of nodes is created in the material with the side dimensions g. Then each node is randomly displaced by a 3D vector of the magnitude s. Then each edge in the Delaunay mesh connecting those nodes forms a lattice rod. The model needs 2 parameters to randomly distribute elements in the lattice. The material heterogeneity is implemented by projecting it on the lattice and corresponding properties are assigned to relevant lattice elements with steel fibres distributed in the whole specimen. The material parameters have been determined empirically to match the experimental results at the macro-scale with the numerical ones on the basis of a uniaxial tension and compression test [2].

3. Numerical results

Figure 1 presents results with plane concrete specimens composed of 200000 rod elements subject to uniaxial extension (Fig.1A) and three-point bending (Fig.1B). The average rod length was g=1 mm (the rod length changed between 0.3 mm and 2 mm). One assumed following material parameters for the cement matrix, aggregate and bond: k_b/k_l =0.6 (with k_l=20), local ε_{min}=0.2%

(cement matrix), k_b/k =0.6 (with k_l=60), local ε_{min}=0.133% (aggregate), k_b/k_l =0.6 (with k_l=14), local ε_{min}=0.05% (bond) and k_b/k_l=1 (with k_l=160), local ε_{min}=3% (steel fibres). The aggregate density was assumed to be 25%. The mean aggregate diameter was d_{50}=3.5 mm (the aggregate diameter changed between 2 mm and 16 mm). Five simulations were performed. The steel fibres content was 0%, 2% and 5% respectively (with respect to the total amount of rods). The moduli of elasticity were: 60 GPa (aggregate), 20 GPa (matrix), 14 GPa (bond) and 160 GPa (fibres), respectively. The interface had, thus, the lowest strength.

A)

a)　　　　　　　　　　　　　　　　　　　b)
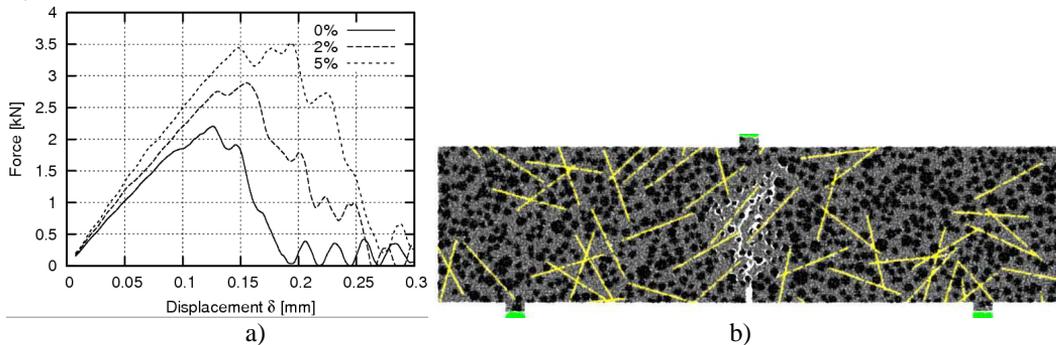
B)
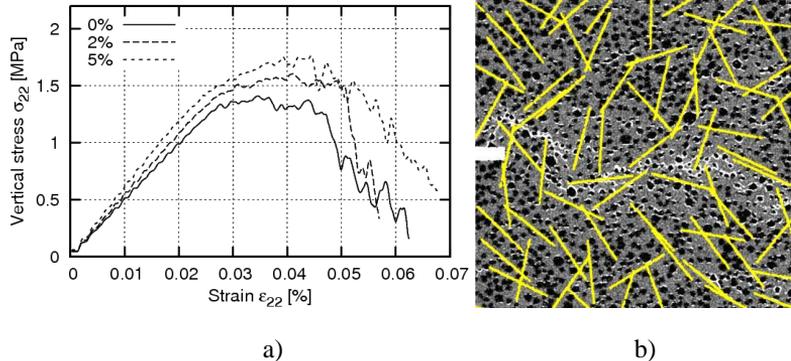
a)　　　　　　　　　　　　　　　　　b)

Figure 1: Notched concrete specimens with a different steel fibre amount subject to uniaxial extension (A) (a) vertical normal stress versus vertical normal strain, b) crack propagation) and three-point bending (B) (vertical force versus vertical displacement, b) crack propagation)

The results show that the presence of fibres increases both the strength and ductility of concrete elements due to a longer propagation way of cracks.

4. References

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