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Preface

# Discrete modeling of concrete materials and structures

The computational modeling of concrete has proven to be an elusive task. Over the past several decades, many researchers have tried to simulate concrete within the classical hypotheses of continuum mechanics but with limited success. One main reason for such difficulty is that concrete behavior depends strongly on its heterogeneous character, which affects damage localization, and cracking even under service loads. These phenomena are always associated with displacement discontinuity that clearly violates the continuum hypothesis.

This has motivated the formulation of discrete models that are the subject of this special issue. Discrete models are characterized by the definition of the displacement field only at a finite number of points and by governing algebraic equations, as opposed to partial differential equations typical of continuum mechanics, traducing the classical concepts of equilibrium and deformation compatibility. In addition, discrete models employ vectorial, as opposed to tensorial, stress versus strain relationships to describe the constitutive behavior.

Discrete models, in the form of either lattice or particle models, have been quite successful in simulating concrete material heterogeneity as well as damage localization and fracture. Such success has been reported at various international conferences, including the First International Conference on Particle-based Methods (Particles 2009) held in Barcelona, Spain, in November 2009 and a two-session mini-symposium within the 7th International Conference on Fracture of Concrete and Concrete Structures (FraMCoS 7) held on Jeju Island, Korea, in May 2010. The majority of the authors of this special issue presented research within at least one the aforementioned events. Those original contributions have been extended to form the papers featured hereafter.

The special issue collects eleven papers covering a wide variety of concrete mechanics phenomena spanning several length scales, from the scale of cement particles to that of reinforced concrete structural members. At the finest scale considered, Slowik and Ju model plastic cement paste subjected to drying. By simulating the interactions of micron-sized cement particles suspended in water, the authors were able to predict the development of negative capillary pressure and the associated shrinkage that eventually leads to cracking.

Several of the paper contributions involve micro- or meso-scale models of cement-based composites, in which aggregate or fiber inclusions are explicitly modeled. Crack initiation is investigated by Asahina et al., where the 3D computational representation is obtained directly from tomographic images of microconcrete specimens. The various phases (spherical glass particles, mortar matrix, matrix/particle interface) are discretized at the sub-millimeter scale by means of a Rigid-Body-Spring Network. As done in several other works presented here, Delaunay/Voronoi dual tessellations are an integral part of the discretization process. Man and van Mier use a three-dimensional beam-lattice model to investigate the distribution of damage and size effect of concrete specimens loaded in flexure. Actual aggregate shapes within the concrete are acquired through X-ray microtomography and discretized by the lattice model. Kunieda et al. introduce short-fiber reinforcement within a lattice model, with the objective of simulating the diffuse damage and localization delay that is typical of strain-hardening cementitious composites. From this discrete representation of individual fibers, the model simulates the effects of fiber distribution nonuniformity on composite performance.

In a two-part study, Cusatis et al. present the formulation, calibration, and validation of the Lattice Discrete Particle Model (LDPM). By modeling each coarse aggregate as a rigid particle, this comprehensive model is able to simulate the most important failure behaviors of concrete, from tensile fracturing, characterized by strain-softening, to high confinement compression, exhibiting strain hardening plastic deformations. Donzé et al. present an equally comprehensive particle model, in which particle size is a user-defined quantity for the purpose of discretization. Attention is given to concrete triaxial behavior and the results confirm earlier experimental evidence suggesting that under high confinement cracks appear in planes orthogonal to the main direction of compressive loading.

Several of the paper contributions apply Rigid-Body-Spring Models at the concrete macroscale, at which there is no explicit consideration of material structure. Appropriate constitutive equations describe the mechanical interaction of the polyhedral Voronoi cells, which are considered to be rigid and connected through nonlinear springs. Kim and Lim formulate a new constitutive equation that, by combining plasticity and damage mechanics, allows for the simulation of concrete fracture dynamics and rate effect. Grassl and Davies study the effects of corrosion on the pullout resistance of reinforcing steel bars, which are discretized in three dimensions. A plasticity-based model for the bar–concrete interface couples bar slip with radial pressure and, therefore, crack development. In the work of Nakamura et al., pressures generated by the expansion of corrosion products cause radial cracking about the reinforcing steel. The effects of penetration of the corrosion products into the discrete crack network are investigated. In contrast to most continuum-based approaches that have been applied to this problem, the RBSM simulations reproduce well the anisotropy of the mechanical response typically observed in experiments. The special issue is completed by an application of the

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RBSM framework to a practical structural situation: analyses of deep reinforced concrete beams and their behavior at failure. Reinforcing steel is represented by series of one-dimensional line elements within the RBSM. The results agree well with experimental measurements and suggest that out-of-plane deformations of the beams are a source of size effect.

The wide variety of subjects presented in this special issue demonstrates the potential of discrete models as effective tools for the computational analysis of concrete and reinforced concrete at failure as well as under service conditions. They are a viable alternative to classical continuum-based approaches.

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Gianluca Cusatis
*Department of Civil and Environmental Engineering,*
*McCormick School of Engineering and Applied Science,*
*Northwestern University,*
*Evanston, IL 60208, USA*
*E-mail address:* g-cusatis@northwestern.edu

Hikaru Nakamura
*Department of Civil Engineering,*
*Graduate School of Engineering,*
*Nagoya University,*
*Nagoya City 464-8603, Japan*
*E-mail address:* hikaru@nagoya-u.jp