Discrete and smeared approaches in computational fracture mechanics

René de Borst

University of Sheffield, Department of Civil and Structural Engineering, Sheffield S1 3JD, UK

The first attempts to simulate fracture numerically date back to the late 1960s, when the discrete and smeared crack models were introduced. In the discrete crack approach fracture initiation and propagation is modelled by changing the topology of the domain and cracks have a clearly defined width. This approach is physically intuitive, but requires tracking of each individual crack, including the concomitant topological changes of the domain. Different from this approach, smeared or diffuse methods for simulating fracture distribute the crack over a finite width, and the kinematic quantities of the discrete approach, namely the crack opening and crack sliding, are replaced by crack strains. While this can be computationally advantageous, in particular for three-dimensional simulations, it retains certain drawbacks which are less straightforward to resolve, such as the proper incorporation of traction-relative displacement relations as occur in cohesive-zone models, and dealing with flow and mass transport in cracks when considering multi-physics problems.

Over the years, strong opinions have been expressed regarding both approaches. In this presentation, we will discuss discrete and smeared crack models in a historical perspective and will attempt to dispel some misunderstandings. We will start at the origins of the discrete and smeared approaches to fracture, and discuss the improvements which have been applied to both methods in order to make them more versatile and more closely simulates the underlying physical processes. For discrete crack models an important step was the introduction of re-meshing, which enabled the approach to become mesh-objective in the sense that the crack path became independent from the underlying finite element discretisation. The extended finite element method can be viewed as an intelligent form of re-meshing, although it suffers from the disadvantage that the total number of degrees of freedom remains constant, thus limiting the mesh densification that is desirable around crack tips.

A fundamental problem with smeared approaches turned out to be that strain softening is introduced in the continuum to represent the degrading processes around the crack tips. Nonlocal and gradient approaches have been proposed successfully to remedy the severe mesh sensitivity that results from the introduction of strain softening, but some open issues persist such as the determination of the additional material parameters and the additional boundary conditions.

Recently, new discretisation methods, such as isogeometric analysis, and a new diffuse formulation, the phase-field approach, have been proposed. The final part of the lecture will examine the possibilities and limitations of these technologies for accurately and efficiently simulating fracture, including extensions to cohesive fracture and fracture in fluid-saturated porous media, and relations to preceding approaches like gradient-enhanced damage models.