Abstract

Characterization of material response and failure under different type of loadings is an essential step in any engineering design. In the present investigation, structures (made of ceramics and concrete) subjected to extreme (high-velocity impact and earthquake) loadings are studied. Under extreme loading, the structural response involves various complex mechanisms such as large deformation, formation and coalescence of a multitude of cracks leading to fragmentation and material separation. The major difficulty associated with modelling these physical processes is that the field variables become discontinuous across the crack and the computational domain loses its continuum nature. Smoothed Particle Hydrodynamics (SPH), a particle-based method, is better equipped to deal with such specific problems, which are otherwise difficult to capture in conventional mesh-based approaches. The aim of the current thesis is to address the issues related to stability and modelling evolving cracks in SPH framework, and develop a robust computational framework for simulating problems in structural mechanics. Two application areas are considered viz. response of ceramic target subjected to impact loading, and failure of concrete gravity dam under earthquake.

Tensile instability, often observed in SPH, is a numerical artefact that manifests itself by unphysical clustering or separation of particles. A stable SPH formulation is proposed in this study by continuously modifying the shape of the kernel function (by changing the knot position) to alleviate the conditions associated with tensile instability without using any artificial penalty parameter, and compromising with the accuracy and efficiency of the solution. The efficacy of the proposed model, when tested through some benchmark elastic-dynamic problems, yields promising results to extend its application further to plasticity and fluid dynamics problems.

The constitutive material models available to represent ceramics failure in the literature differ from one another depending on the material parameters, exponents and constants used in the model. In the present study, two different types of material models viz. phenomenological material models (JH1, JH2) and micro-mechanics based models (Deshpande and Evans model) are explored to capture the response of ceramics under high-velocity impact. Efficiency and limitations of various material models are discussed.

The concrete gravity dams need to be designed against damage/fracture under dynamic loads as any failure will result in untold human tragedy and huge economic losses. The fracture in concrete is a complex phenomenon involving several factors, including the material strength, type of loading, and strain rates. The capability of the current SPH framework is explored to study fracture in gravity dam under earthquake excitation. The numerical predictions are compared with the experimental observations of a scaled dam section in a shake table testing under dynamic loading.

Keywords: *Smoothed particle hydrodynamics (SPH), Phenomenological and micromechanics based material models, Tensile instability, Ceramic composites, Crack modelling, Cohesive zone based damage model for concrete, Shake table testing, and Seismic analysis*