CONTINUUM/DISCRETE REPRESENTATIONS OF FRACTURING SOLIDS

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Many industrial and scientific problems are characterized by a transformation from a continuum to a discontinuum state. For example, material separation and progressive failure phenomena can be found in applications such as concrete structural failure, food technology processes, high speed machining, rock blasting operations and fracture of ceramic or other quasi-brittle materials under high velocity impact. The problems are initially represented by a small number of continuous regions (often a single entity) prior to the deformation process. During the loading phase, the bodies are progressively damaged and modelling of the subsequent fragmentation may result in possibly three to four orders of magnitude more bodies by the end of the simulation. The overall system response is governed firstly by appropriate constitutive mechanisms which control the material separation process followed by description of the inter-element interaction forces which can be short-ranged, such as mechanical contact, and/or medium-ranged, such as attraction forces in liquid bridges, which control the subsequent motion of particles.

There is currently considerable research interest in the solution of this class of problems and strategies range from continuum based approaches, such as decohesive zone models, to discontinuum driven formulations, such as discrete discontinuous analysis (DDA) methods. For problems in which interest is restricted to relatively small deformations, the use of continuum based methods may be suitable, but for situations involving large geometric changes, such as the modelling of particle flow behaviour post-fracture, there are compelling advantages in employing combined finite/discrete element solution strategies. Such an approach not only provides a more appropriate description of the physical processes involved, but also often renders the constitutive material modeling more tractable.

Some current issues related to the computational treatment of problems involving plastic flows resulting in evolving geometries and continuum to discrete transitions brought about by multi-fracturing behaviour are addressed in the presentation. Particular consideration is given to the introduction of discrete fractures within an initial continuum formulation and the following essential issues are addressed.

- **Contact detection and element interaction:**

For the detection of potential contact between large numbers of discrete bodies, as arises under multi-fracturing conditions, a spatial search algorithm based on space-cell subdivision and incorporating a tree data storage structure possesses significant computational advantages [1]. Solution procedures generally involve representing each geometric entity (element) by an axis-aligned bounding box, which is extended by a buffer zone, and locating for each box a list of neighboring boxes that may potentially interact with it. Options for this operation include Spatial Digital Tree methods with complexity O (N Log N) or “Hashing” approaches which display O (N) complexity. In the second phase, each potentially contacting pair is locally resolved on the basis of their kinematic relationship employing the actual geometric entities involved.

- **Material failure criteria; continuum-discrete transition**

In order to predict the localized continuum-discrete transition associated with the formation of a macroscopic crack, appropriate material failure indicators have to be adopted. Due to the complex interaction between various phenomena that precede failure the formulation of such criteria is not trivial. Recent comparative analyses suggest that damage-based measures are more reliable in predicting the correct site of fracture initiation [2] and the use of fracture criteria based on total damage work offers considerable promise, due to the high gradient exhibited by the indicator near the critical failure zone. In the context of numerical simulations of fracturing materials, it is crucial that the fracture criterion accurately predicts the failure initiation site otherwise spurious fractures may appear [2]. Although the standard Lemaitre [3] model can predict damage growth with reasonable accuracy over simple strain paths, increasing deviations from experimental results may be expected as strain paths become more complex. One attempt to remedy this problem is by inclusion of crack closure effects in the material behaviour. It is experimentally observed that cracks that open in tension resulting in loss of load carrying area and stiffness may partially close and increase the load bearing area and stiffness under subsequent compression. The model proposed by Ladevèze [4] and Lemaitre [5] takes into account the effect of partial crack closure in isotropically damaged materials.

- **Element technology for nearly incompressible materials**

A fundamental requirement in the present context is that the finite elements employed must be able to represent the wide range of phenomena encountered in multi-fracturing solids; for example, complex frictional contact, crack initiation and propagation, including the essential adaptive mesh refinement that accompanies such procedures. In addition, the element should be able to model the incompressible nature of the plastic flow that characterizes ductile materials. Due to their inherent simplicity, together with mesh generation issues, the use of simplex tetrahedral elements is advantageous, however the tendency of the solution to lock prohibits their use. One effective solution to this problem is offered by the F-bar-Patch element [1], which is based on a multiplicative deviatoric/volumetric split in conjunction with the replacement of the compatible deformation gradient with an assumed modified counterpart.

- **Parallel computational strategies**

For the solution of industrial scale problems, parallel processing becomes an obvious option for significantly increasing existing computational capabilities. The necessity of frequent introduction of new physical cracks and/or adaptive remeshing at both local and global levels to represent material failure makes parallel implementation more difficult and challenging than for conventional finite element problems. For the current situation involving both finite and discrete elements, a dynamic domain decomposition strategy is adopted since domain re-partitioning has to be frequently undertaken due to the highly dynamic evolution of the problem configuration [1]. The principal issues which are addressed include: (i) Dynamic domain re-partitioning, based on a graph representation, (ii) Dynamic parallelisation of the global search procedure and (iii) Dynamic load re-balancing based on a (relative) cost model for the computational effort associated with each discrete object.

- **Applications**

The applicability of the methodology developed is illustrated through several practical examples related to the simulation of high velocity impact problems, mineral extraction and processing operations, high speed machining processes, etc. For the solution of industrial scale problems, the benefits of parallel processing techniques are emphasised.

References

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