Objective numerical evaluation of cracking in quasi-brittle materials via adaptive mesh and formulation refinement

G.B. Barbat[1*], M. Cervera[1], H. Venghaus[1], C.A. Moreira[1] and M. Chiumenti[1]

[1] International Center for Numerical Methods in Engineering (CIMNE), Technical University of Catalonia – BarcelonaTECH, Edificio C1, Campus Norte, Jordi Girona 1-3, 08034 Barcelona, Spain
gabriel.barbat@upc.edu

The numerical analysis of localized structural failure using the standard displacement-based finite element (FE) formulation from solid mechanics has shown to produce results spuriously dependent on the mesh employed to perform the calculation. Crack trajectories and failure mechanisms computed with this approach present the critical issue of being spuriously dependent on the orientation of the FE mesh used to evaluate the problem.

In the past, this aspect has been resolved by the authors via the employment of a mixed strain/displacement finite element formulation to perform the nonlinear solid mechanics analysis. This method guarantees the local convergence of the problem, allowing to produce mesh bias objective calculations [1-2].

For the efficient analysis of quasi-brittle fracture, the present work proposes adoption of an Adaptive Formulation Refinement (AFR) scheme [3]. This approach allows to start the simulation using the standard displacement-based FE formulation, and to adaptively activate the mixed FE method only in the areas where the crack develops while the standard formulation is maintained in the rest of the structure. This enables to introduce very significant savings in computational cost while maintaining the accuracy and mesh objectivity in the calculation of the crack path provided by the mixed FE.

The AFR method is combined with the adoption of an Adaptive Mesh Refinement (AMR) strategy to further increase the efficiency of the computations [3]. With the proposed octree-based AMR scheme it is possible to adaptively refine the mesh only in certain areas of the domain. This allows to initiate the analysis with an initially relatively coarse mesh and to introduce its refinement only where the cracks develop. With this strategy it is possible to reproduce the phenomenon of cracking with the sufficient accuracy while preserving a reasonable computational cost of the simulation.

The nonlinear behavior of the material is reproduced through the adoption of local isotropic and orthotropic damage models. Within the proposed framework, the local format of the problem of fracture is preserved, without inserting regularizing terms in the variational form. Neither are gradient or higher order terms introduced in the constitutive law.

The accuracy and cost efficiency of the proposed framework is examined through an extensive set of numerical simulations of benchmark problems as well as experiments. Computations show that the combination of the AFR and AMR strategies allows to produce mesh objective results in terms of crack trajectories, collapse mechanisms, load capacity and nonlinear response. Experimental results are reproduced with precision in 2D and 3D.

The comparative assessment of the proposed AFR scheme with corresponding computations using the standard FE formulation only is performed, showing the superior performance of the AFR approach in terms of result quality. Computational efficiency of the methodology is examined as well, showing its ability to produce very significant savings in computational cost while allowing to provide mesh bias objective results.

References

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