Analysis of Dynamic Crack Propagation using Powell-Sabin B-Splines

Lin Chen*, **Bin Li**† **and René de Borst***

* Department of Civil and Structural Engineering
University of Sheffield
S1 3JD, Sheffield, UK
e-mail: lin.chen@sheffield.ac.uk; r.deborst@sheffield.ac.uk

† Sibley School of Mechanical and Aerospace Engineering
Cornell University
NY 14853, Ithaca, USA
e-mail: bl736@cornell.edu

ABSTRACT

The analysis of dynamic crack propagation remains a challenging problem due to crack initiation, unstable propagation, branching, multiple crack interaction, coalescence and merging. To well understand these phenomena, numerical models, which for instance utilise cohesive crack models and phase field models, have been introduced in attempts to model crack nucleation, tortuous crack paths and micro-cracking in front of a main crack. With dense meshes arbitrary crack paths can be captured fairly well [1]. The accurate calculation of the stress at the crack tip is a most important issue in the analysis of dynamic fracture [1]. However, standard finite elements do not produce smooth stress field due to the $\mathcal{C}^0$ inter-element continuity [2]. The stresses are often inaccurate around crack tips unless extremely fine discretisations are used, and can therefore not be used readily in criteria for crack initiation and crack propagation. This tends to be even worse when using the extended finite element method. For this reason, stresses are often averaged over finite domains, encompassing several elements. Also, stress fields can be improved when enriching stress fields with higher-order terms, while crack tracking algorithms can also help to better simulate complex dynamic crack patterns, such as crack branching. More recently, isogeometric analysis has also been introduced in the context of crack propagation analysis [2]. However, isogeometric analysis has some limitations to insert cracks at arbitrary locations as the initial mesh must be aligned closely with the final crack path *a priori* [2]. Another disadvantage is that the higher-order continuity of basis functions breaks down near crack tips and only $\mathcal{C}^0$-continuity remains.

Herein we exploit Powell-Sabin B-splines for cohesive crack modelling [1]. Powell-Sabin B-splines are based on triangles. Direct crack insertion in the physical domain is possible due to the flexibility of triangles. Upon crack insertion, there may be elements with an unsuitable aspect ratio. Remeshing the domain around the crack tip is then required, which can be carried out fairly easy for triangular elements. After remeshing, new Powell-Sabin B-spline functions are computed on the new triangles. The state vectors (displacement, velocity and acceleration) must also be transferred to provide initial values for the next time step. This is done by a novel methodology based on a least-squares fit. To preserve the energy during the transfer, the energy is taken as a constraint in the mapping. The versatility and accuracy of the approach to simulate dynamic crack propagation are assessed in two case studies, featuring mode-I and mixed-mode crack propagation.

REFERENCES

[1] Chen L, de Borst R. Cohesive fracture analysis using Powell-Sabin B-splines. *Int. J. Num. Meth. Engng. Int. J. Numer. Anal. Methods Geomech*, (2019) **43**(2): 625-640.

[2] Chen, L., Verhoosel, C. V., & de Borst, R. . Discrete fracture analysis using locally refined T-splines. *Int. J. Numer. Methods Eng.*, (2018) **116**(2): 117-140.