A non-smooth extrinsic cohesive zone model including contact and friction

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Cohesive zone models are a particularly high-fidelity way to model fracture propagation, although this accuracy comes at the cost of requiring high degrees of spatial and temporal refinement, which in turn means substantial computational demands. Cohesive zone models come in two basic flavours, intrinsic and extrinsic. Intrinsic models feature an initial elastic behaviour with crack opening, while extrinsic models are initially rigid. The extrinsic model family is universally recognised to be superior in dynamics due to its absence of spurious artificial compliance, but this comes at the cost of generally being more difficult to implement.

However, in instances of complex loading that cause cohesive zones to unload and then reload, this artificial compliance (and its associated numerical difficulties) can return, due to the elastic behaviour assumed in many models. As such, we aim to completely eliminate the pathologies of artificial compliance by eliminating the unload-reload elasticity from the formulation.

Due to the initial rigidity present in extrinsic cohesive zone models, using tools widely adopted in rigid-body mechanics is natural. We make use of non-smooth mechanics, a standard approach in rigid body and contact mechanics, to properly formulate an extrinsic mode I cohesive zone model that eliminates unload-reload elasticity, and also includes contact non-interpenetration within the formulation. After the construction of an implicit time-stepping schema, the discrete-in-time-and-space form of this model in dynamics can be written as a linear complementarity problem (LCP), which we are able to prove is well-posed and algorithmically dissipative (and symplectic in the absence of impacts), and is very efficient numerically [1]. We assign (and demonstrate) a physical meaning to this well-posedness, namely the absence of "solution jumps" given a sufficiently small time-step. We further demonstrate that a system that is ill-posed (exhibiting a solution jump) in quasi-statics becomes well-posed in dynamics, thus demonstrating the regularising effect of dynamics, even for slow loading rates.

Taking inspiration from classical non-smooth treatments of contact with friction [2], we extend our model to mixed mode I – mode II fracture, and we are also able to include the effects of friction within the model. We are once again able to write the problem as an LCP, for which we can exploit efficient numerical methods. As the problem is substantially more elaborate, we are only able to demonstrate a proof of the existence of the solution, but we are still able to show that the algorithm is dissipative numerically.

We are able to treat certain examples of academic interest from the literature [3], in some cases with orders-of-magnitude larger time-steps than comparable methods, by combining our monolithic LCP solver with the finite element method.

Finally, we highlight some potential future directions to extend the method, notably the extension to a fully mixed mode I – mode II – mode III model, and the possibility of capturing multiphysical effects using non-smooth mechanics techniques.

References

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