# Application of a generic path-following to phase-field fracture

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The phase-field approach to fracture has emerged as a powerful tool to simulate the nucleation and growth of cracks in a structure. In the past two decades, it has been extensively applied to fracture problems as it captures crack initiation, propagation, and interaction without explicitly tracking the crack path.

One of the most popular algorithms to solve phase-field problems is alternate minimization. However, it can suffer from slow convergence, especially when dealing with unstable crack propagation. Moreover, force-controlled loading often leads to unstable crack propagation and the lack of equilibrium solution after the crack propagation, preventing their use.

Path-following methods offer a promising solution to those limitations, enabling the tracking of unstable crack propagation while preserving the equilibrium during the whole loading (Rastiello et al., 2022). Based on various control strategies, these methods also improve the solver stability. Singh et al. (2016) and May et al. (2016) proposed path-following approaches specifically tailored to the resolution scheme of Miehe et al. (2010) based on crack surface and fracture dissipation. Additionally, Wu (2018) adapted the nodal displacement control (Borst, 1987) and the fracture surface control (Singh et al., 2016) to the alternate minimization. Nevertheless, the first approach is problem-dependent, and the second approach may fail under force loading (Rastiello et al., 2022).

This work proposes a generic path-following method applicable to various fracture problems, regardless of geometry, boundary conditions, or fracture model complexity, by leveraging the maximum strain increment control (Chen & Schreyer, 1990). This method is model-independent, as it relies solely on the displacement field, and problem-independent, it does not rely on a specific choice of control DOF.

After presenting the modified alternate minimization solver, we demonstrate its effectiveness through simulations of crack propagation in the SENT test. The results are compared to a semi-analytical solution based on LEFM and to the alternate minimization solution. Notably, the classic alternate minimization fails to capture the snap-back (instability under displacement control) observed in the semi-analytical method. The proposed approach correctly captures this phenomenon, which converges towards the semi-analytical solution. Then, this method is also applied to the simulation of Compact Tension (CT) experiments, in which the selection of numerical boundary conditions at the pinhole significantly influences the fracture behavior (Triclot et al., 2023). The proposed solver renders the application of force boundary conditions possible, better representing the experimental conditions.

## References


Borst, R. de. (1987). Computation of post-bifurcation and post-failure behavior of strain-softening solids. *Computers & Structures*, *25*(2), 211–224. https://doi.org/10.1016/0045-7949(87)90144-1

Chen, Z., & Schreyer, H. L. (1990). A numerical solution scheme for softening problems involving total strain control. *Computers & Structures*, *37*(6), 1043–1050. https://doi.org/10.1016/0045-7949(90)90016-U

May, S., Vignollet, J., & Borst, R. de. (2016). A new arc-length control method based on the rates of the internal and the dissipated energy. *Engineering Computations*, *33*(1), 100–115. https://doi.org/10.1108/EC-02-2015-0044

Miehe, C., Hofacker, M., & Welschinger, F. (2010). A phase field model for rate-independent crack propagation: Robust algorithmic implementation based on operator splits. *Computer Methods in Applied Mechanics and Engineering*, *199*(45), 2765–2778. https://doi.org/10.1016/j.cma.2010.04.011

Rastiello, G., Oliveira, H. L., & Millard, A. (2022). Path-following methods for unstable structural responses induced by strain softening: A critical review. *Comptes Rendus. Mécanique*, *350*, 205–236. https://doi.org/10.5802/crmeca.112

Singh, N., Verhoosel, C. V., Borst, R. de, & Brummelen, E. H. van. (2016). A fracture-controlled path-following technique for phase-field modeling of brittle fracture. *Finite Elements in Analysis and Design*, *113*, 14–29. https://doi.org/10.1016/j.finel.2015.12.005

Triclot, J., Corre, T., Gravouil, A., & Lazarus, V. (2023). Key role of boundary conditions for the 2D modeling of crack propagation in linear elastic compact tension tests. *Engineering Fracture Mechanics*, *277*, 109012. https://doi.org/10.1016/j.engfracmech.2022.109012

Wu, J.-Y. (2018). Robust numerical implementation of non-standard phase-field damage models for failure in solids. *Computer Methods in Applied Mechanics and Engineering*, *340*, 767–797. https://doi.org/10.1016/j.cma.2018.06.007