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An enriched phase-field method for the efficient simulation of fracture processes, part 1: phase-field approximation

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Complex crack processes like crack initiation, branching and coalescence can be simulated quite elegantly with the phase-field method for fracture [1]. The criterion for crack propagation is contained within the partial differential equation and with the help of its solution, the scalar phase-field $\phi(\mathbf{x})$, the crack can be reproduced. Therefore, the evaluation of the criterion for crack propagation and the tracking of the crack geometry do not have to be addressed separately.

One drawback, however, is the high computational effort necessary to approximate $\phi(\mathbf{x})$. In between the phases (broken and intact) it interpolates using a function with exponential characteristics. The slope of this function and therefore the width of the regularized crack depends on the internal length parameter l, chosen to be small in comparison to the structural geometry. With a polynomial ansatz function extremely fine meshes are necessary to be able to reproduce $\phi(\mathbf{x})$ and its gradients correctly.

Borrowing the concept from the extended finite element method (XFEM) [2], an exponential ansatz mimicking the continuum solution of the phase-field equation in 1D is introduced. Embedding a standard polynomial ansatz into an exponential function enables an improved approximation of the optimal solution for $\phi(\mathbf{x})$ even with coarse meshes. Still the crack is allowed to develop freely.

The phase-field degrees of freedom themselves attain a level set type quality. This can be useful in further calculations, especially when it comes to the displacement approximation, which also requires special attention due to its high gradients across the crack.

This extended phase-field method is able to reduce computational effort significantly and is still able to produce accurate solutions which is shown by its application to common crack simulations from literature. Special attention is given to its stabilisation, which enables the differentiation at the phase field peak, and to the integration.

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