The efficient simulation of fracture processes in concrete with an extended phase-field method

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The simulative prediction of the behaviour of thin-walled carbon-reinforced concrete structures under different load conditions can significantly help evaluate new designs regarding their robustness. The focus here is the investigation of cracks, their initiation and propagation in the concrete matrix at the mesoscale level. Especially phenomena like branching and coalescence can result in intricate crack patterns for which the discrete reproduction within the finite element (FE) method is rather difficult. Thus, the phase-field method is applied, where cracks are represented in a smeared manner with an order parameter. However, the accurate representation of the phase-field, the displacement field and their respective gradients requires very fine FE-meshes, leading to a high computational effort. Therefore, an adjustment of the ansatz space for both the phase-field and the displacement field is employed, to enable the utilisation of much coarser meshes.

For the phase-field, a quadratic Lagrangian ansatz is embedded into a function resembling the analytical phase-field solution in one dimension for a fully broken bar. With this transformation, the reproduction of the phase-field profile within one finite element is made possible. For the displacement field, very steep gradients across the crack are expected. Their reproduction is enabled with an enrichment of the ansatz, derived directly from the phase-field solution.

Special care has to be taken with the integration since a standard Gaussian approach is not suitable for the non-polynomial ansatz. Furthermore, the crack is still allowed to develop freely, so the crack path is not known a priori. That is why the integration scheme must be impartial to any crack geometry.

The extended phase-field method can reduce computational effort significantly due to the reduced number of elements and is still able to produce accurate solutions.