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Modelling of dynamic fracture by Phase Field and Finite Fracture Mechanics

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Fracture is the physical process through which an initially pristine and continuous structural domain undergoes changes in its mechanical configuration due to the development of an internal discontinuity over time. Macroscopically, this phenomenon manifests as a worsening in the structural performance of the affected components that eventually leads to a total collapse. Therefore, the proper understanding of the involved physics is essential for ensuring structural integrity. On the other hand, the inherent dynamism that arises from the evolution over time of fracturing systems suggests that the dynamic aspects of fracture should not be lightly neglected. In this context, the present thesis delves into the modelling of dynamic fracture by exploiting two different but complementary approaches: the Phase Field fracture model and the Finite Fracture Mechanics failure criterion. The former provides a highly-detailed and theoretically robust description of fracture that allows the development of a solid core understanding of the involved physics, albeit at a considerably high computational cost. In contrast, the latter failure criterion provides less detailed but cost effective predictions that align with experimental evidence, rendering it a useful tool for preliminary stages of structural design. As such, the present work provides a multi-perspective insight into the modelling of dynamic fracture.

The first thematic block is devoted to the Phase Field fracture model, which is introduced and developed following a bottom-up approach. Firstly, the framework is contextualized by describing the pioneer variational revisit of brittle fracture and its ensuing regularization that led to the original Phase Field fracture model. Thereafter, the generalized formulation of the Phase Field fracture model in a quasi-static context is introduced, and the main existent modelling options are briefly described. The ability of the approach to accurately reproduce crack growth under multi-axial stress states is then tested through a case study on the crack onset from circular holes under quasi-static biaxial loadings, in which reasonable agreement is shown with Dugdale's Cohesive Zone Model when the No-Tension strain energy decomposition and the AT1 Phase Field model are used. With these learnings present, the Phase Field fracture model is subsequently developed in a dynamic context by virtue of Hamilton's principle and variational inequalities. In addition to the theoretical deriva-

tion of the governing principles, the main technical aspects concerning its numerical implementation with an explicit time integrator are also covered. Subsequently, the inherent ability of the Phase Field fracture model to reproduce complex crack patterns is exploited to study the post-punching fragmentation of biaxially pre-strained glass panes, depicting the effect of the pre-straining intensity and biaxiality on the resultant crack patterns. Eventually, the already introduced quasi-static and dynamic Phase Field fracture models are juxtaposed under unstable crack growth conditions, revealing that: (i) inertial effects are not negligible for such conditions, even under quasi-static loadings; (ii) the representativeness of the resulting crack paths is undermined if the actual diffusion of mechanical information is overlooked; and (iii) the irreversibility condition of fracture is significantly weakened if crack growth is not modelled progressively.

The second thematic block instead covers the Finite Fracture Mechanics failure criterion, once again following a bottom-up approach. Hence, the well-established quasi-static formulation is first introduced and then particularized to two different case studies. The first one involves the size-effect of failure when stemming from a spherical void embedded in a uniaxially tensioned infinite domain. This setup leads to relatively simple failure conditions, and available experimental results show reasonable agreement with the Finite Fracture Mechanics predictions. More complex failure conditions are instead obtained by retrieving the case study on the crack onset from circular holes under biaxial loadings, where the resultant Finite Fracture Mechanics predictions are found to agree with those of Dugdale's Cohesive Zone Model. Once the specific aspects of the criterion are understood in a quasi-static setup, its formulation is then extended to include sudden loadings. To that end, the basic requirements of proper dynamic failure criteria are first drawn, and then the existent approaches are put to the test. To address the identified shortcomings of the previously proposed criteria, a pre-emptive proposal for the dynamic Finite Fracture Mechanics is put forward, implemented, and compared with relevant sets of experiments. Despite the limited amount of experimental data, the proposed formulation shows promising capabilities for predicting the loading rate effect in the onset of cracks.