Development of a coupled Discrete Element Method (DEM) and Phase-Field Modeling (PFM) and application to fracture phenomena in granular materials

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Significant progresses have ben made in the last decades for the modeling and simulations of non linear behavior of granular materials. For instance advanced continuum models have been proposed in the literature to account for complex phenomena such as volumetric plastic dilatancy, non local effects, etc.. In essential, such phenomena result from discrete nature of granular materials, the collective motion of particles and/or their strong mechanical interactions including frictional contact. Details of these interactions are more documented by full-field numerical simulations largely based on the use of Discrete Element Method. In spite of the powerful nature of DEM simulations, few researches have been devoted to the predictions of fracture nucleation and growth in granular media. One of the main reasons, is that the fracture of granular materials under external loads is a complex mechanical process due to their specific characteristics. In particular, contact conditions, which vary with material properties and with the geometric features, are still difficult to model accurately. The aim of this thesis is to take advantage of recent variational approaches on fracture which provide suitable tools for the mathematical modeling and predictive numerical simulation of fracture processes in quasi brittle materials. The proposed methodology will consist in coupling DEM tools with the so-called Phase-Field Method (based on the above-mentioned variational approach).

In a first part of the thesis, a phase-field variable will be introduced to account for the surface of each particle, and the contact force can be formulated using the phase-field distribution. Then, taking full advantage of the existing algorithms and developing new ones based on the existing DEM theory, a numerical simulation program for the flow and fracture of granular materials will be developed. A detailed energetic characterization of the fracture process (elastic and dissipated energy) will be systematically provided. Moreover, a validation of the developed tools will be performed by confronting the predictions from numerical simulations with experimental available databases (mechanical responses, imaging, etc.). Finally, an important and last part of the thesis will be devoted to a large benchmarking on various engineering structures.

Keywords : Discrete Element Method, Phase field model, Granular materials, Fracture phénomena.

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