2020_37: New rock mechanics models for excavation, mining and geohazards

Supervisors: Dr Emilio Martínez Pañeda (e.martinez-paneda@imperial.ac.uk); Professor Catherine O'Sullivan. Dept. of Civil and Environmental Engineering. Imperial College London. Professor. Norman Fleck FRS FREng. Engineering Department. University of Cambridge

Department: Civil and Environmental Engineering

The project aims to develop a new generation of physically-based models for rock fracture, with applications in mining, excavation and prediction of geohazards.

The civil and mining engineering industries have many energy-intensive processes that involve fragmenting rocks. Mining accounts for up to 6% of world energy consumption, with rock comminution (grinding, crushing and cutting) being responsible for half of this vast energy expenditure. Rock excavation, either through mechanical drilling or by blasting, constitutes the largest source of energy consumption in a wide range of civil engineering applications, from tunnels to buildings. The emergence of low-energy techniques for rock fracture could have a major impact on sustainability and global warming, and is necessary because of economic competitiveness, tougher environmental regulations, and continuously growing global energy demand.

Major improvements in rock comminution procedures are hindered by the lack of understanding of the mechanics of micro-cracks and their overall response to applied loading. Because of the large scales involved, deformation and failure in rock engineering have been traditionally modelled through empirical approaches. However, these phenomenological models require extensive calibration and have a regime of applicability that is limited to scenarios resembling the calibration schemes. Predictive modelling requires an explicit connection with the underlying microstructure.

The essential ingredients necessary to develop physically-based models that will significantly shift the knowledge frontier are now available. First, recent major advances in high resolution measuring techniques – particularly, micro X-ray computerised tomography (μCT) and Digital Volume Correlation (DVC) – provide a direct connection to the microstructure and enable cracking pattern characterisation. Secondly, relevant features of the microstructure can be incorporated into large-scale simulations as a result of larger computational resources and the development of robust numerical methods to capture crack fragmentation.

The project will combine theoretical, experimental and numerical endeavours. On the theoretical side, a new microstructurally-informed framework will be developed, capable of delivering predictions from macro and micro nominal material properties, as opposed to empirical parameters. The aim is to build upon the success of the "micromechanics revolution" that has significantly enhanced our understanding and modelling of metals and ceramics. Experimental observations will be critical in identifying the micromechanisms dominating micro-crack growth and coalescence. This will be achieved using 3D DIC and μCT-based DVC. On the numerical side, the model will be implemented in a finite element setting and comparisons will be conducted with experiments and discrete element method (DEM) simulations. The model will be employed to identify crack patterns that will allow designing low-energy comminution procedures. Not only will loading criteria be established for minimizing friction but also crack branching will tailor the mineral size as produced by each process. By giving insight into the mechanisms at play, the project will benefit the understanding and modelling of other geological applications, such as hydraulic fracture and earthquake rupture.

The PhD project will be co-supervised by Dr Emilio Martínez-Pañeda (fracture, material modelling), Prof. Catherine O'Sullivan (geomechanics, μCT, DEM) and Prof. Norman Fleck FRS FREng (micromechanics), in an interdisciplinary endeavour that crosses the boundaries of solid mechanics, geology and materials science.