Abstract

Cemented Granular Materials are ubiquitous in nature and are often artificially produced. Their behaviour is driven by phenomena occurring at the scale of individual grains and cement bonds. They have been widely studied and characterised over the years. However, the relationship between the two scales has lacked a systematic description and is rarely acknowledged in the models portraying their behaviour. This dissertation contributes to the development of a methodological framework for cemented granular materials, which relates the behaviour of individual grains to their collective response observed at the engineering scale. This is accomplished by developing a combination of analytical, experimental and numerical approaches.

Analytically, a novel constitutive model for cemented granular materials is developed, which adopts measurable internal variables describing the evolution of key grain-scale processes. This thermomechanically consistent model can successfully predict stress-strain responses as well as the onset and development of localisation patterns in triaxial specimens for a wide range of pressure regimes. Furthermore, in this approach, constitutive parameters are directly quantifiable and therefore have a precise physical meaning. The part in the model that refers to the grains originates from the framework of Breakage Mechanics (Einav, 2007a,b); this thesis supplements to this granular element an account for the role of dilation and porosity. The extended framework is then adopted to build a second, enhanced model for cemented granular materials, which broadens its predictive capabilities to an even wider range of confinements.

Experimentally, a testing program is carried out that focuses on measuring the evolution of grains and cement scale structures consistent with the internal variables of the analytical models. X-ray computed tomography is adopted to extract images of specimens of cemented granular materials at a resolution sufficient to discern individual grains and cement bonds. A toolset is developed to characterise, for the first time, both grains and cement bridges in the specimen and measure their individual evolution during triaxial loading tests. Using this image analysis toolset, statistically representative measures of the occurring grain scale processes are established, which enables the quantitative study of their correlations.

Numerically, boundary value problems are solved using the finite element method that bridge experimental observations to analytical predictions, and vice versa, while accounting for the effects of strain localisation. An assessment is made with the numerical model of the effect of misaligned boundaries and statistical variations of constitutive properties within the triaxial samples on their response at both the micro- and macro- scales. At the micro-scale the corresponding numerical results can be compared with the experimental counterparts as a result of the image analysis toolset developed.

The acknowledgement of grain-scale behaviour within this methodological framework allows for a realistic validation of the constitutive models not only at the scale of the specimen response and its localisation features, but also at the scale of individual grains. This is pivotal in a number of open engineering problems where the localised evolution of the micro-structure dictates the observed response (*e.g.*, compartmentalisation of hydrocarbon reservoirs due to localised permeability reduction).