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LINKS BETWEEN PHENOMENOLOGICAL AND MICROMECHANICAL SOIL BEHAVIOUR

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The majority of constitutive models, that are used nowadays to describe the behaviour of granular materials such as sands are continuum models based on phenomenological approaches. In order to describe some of the phenomena occurring on the macroscopic scale, e.g. an abrupt change of stiffness due to a load reversal, these constitutive models use phenomenological state variables (e.g. back stress in elasto-plasticity [6] or the intergranular strain concept for hypoplasticity [7]) which often lack a clear physical meaning. The mechanisms that control the macroscopic behaviour and, as such, different phenomena, that can be observed on the continuum scale, must be sought at the grain-scale with the interactions of individual particles playing the key-role.

The most common approach to investigate the effect of the interplay of particles on the continuum behaviour of granular materials is the discrete element method. Using this approach, numerous studies have been conducted focused on particle interactions and several links between the micromechanical behaviour and macroscopic observations have been proposed [4, 9]. Although the macroscopic results from these discrete element simulations match experimental observations, these approaches encounter problems when it comes down to represent the complexity of real granular materials; one example being the restriction of shapes: the majority of the approaches can only use convex shapes whereas natural grains are mostly far from being convex. This in turn influences the geometrical contact description as one grain can touch another one on multiple contact points in natural materials. Furthermore, a threshold area of a real contact remains unclear.

Laboratory testing using optical methods can give valuable insight into the micromechanical origins of the behaviour of granular materials. Although experiments on soils produce only geometrical outputs, as they cannot access inter-particle forces yet, they don't suffer any assumptions in contrary to the numerical simulations. In the past, either post-mortem thin sections of the specimens of natural materials were used to characterize the structure [8] or experiments on artificial materials (e.g. 2D rods) were carried out with the structure being evaluated from photos taken during the experiments [3].

X-Ray μ-computed tomography (CT) allows for a 3D imaging of soil samples in various loading conditions [2] and thus will be the tool used in this study. However, if a mechanically representative specimen, in terms of the macroscopic behaviour, is to be tested, the resolution of the final images is limited due to a required minimum number of particles in the specimen [1]. In order to extract information on the structure of the granular material, different image analysis approaches can be used and their accuracy should be evaluated with respect to the limited resolution.

Independent of the approaches used to access the grain-scale, different entities can be used to describe the structure, e.g. particle-based, contact-based and void-based orientations. As it remains ambiguous which of these entities play the key-role in controlling the macroscopic behaviour, the influence of their evolution has to be investigated individually and possibly combined. In order to describe the evolution of the different structural variables, fabric tensors of various kinds and orders [5] are commonly used.

In the first part of the presented study, the ability as well as the accuracy of different approaches to extract fabric descriptors, i.e. in this case particle- and contact-based entities, from 3D images is assessed and enhancements are proposed and validated. Artificial as well as high resolution images coming from x-ray nano-CT serve as the basis of this analysis which shows that the standard approaches strongly suffer in accuracy and often introduce huge artefacts.

Real experiments carried out on natural sands will be described and analysed in the second part of this study. During a macroscopic loading the sand specimens were scanned using a laboratory x-ray scanner in order to assess the grain-scale behaviour in-situ and link it with the macroscopic observations. The individual fabric entities were extracted from the 3D images at different steps of the loading and captured using fabric tensors. The evolution of various fabric tensors, defined using different variables and different orders, is then assessed and linked to the evolution of the macroscopic stresses and strains. Furthermore, the evolution of the microstructure can be linked to the evolution of the phenomenological variables, e.g. the intergranular strain for hypoplasticity for changes in loading direction, leading to a possible micromechanical enhancement of these concepts.

Establishing a link between micromechanical variables, such as the fabric tensors describing the stucture, and the macromechanical observations cannot only enhance our understanding of different phenomena occurring on the continuum scale, but also enable an incorporation of these effects into phenomenological approaches in a more straight-forward and reliable way.

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