Behaviour of rockfill geostructures by experimental approach and discrete element modelling

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This PhD thesis subject proposes to deal with mechanical behavior of coarse granular media and it is included in a broader topic, namely the mechanical behavior of civil engineering structures built with rockfill (dikes, dams, retaining walls, railway structures). Rockfill media are coarse media composed of quarry rock debris or crushed rock fragments with a characteristic size from few cm to one meter. The construction technics, for dams, rudimentary at the beginning, have been enhanced upon time, and have taken a significant development from the 20th century. Their design is still principally empirical, even if new models attempted to take into account principal features of this material (Frossard et al. 2012 and Ovalle et al. 2014).

These materials have the particularity of exhibiting grain breakage under the structural loads, which distinguishes them from other materials. A rockfill structure is submitted to a range of loads and stresses that can lead to important grain breakage, which has a high influence on the macroscopic mechanical behavior of the material, and can lead to considerable, and sometimes dangerous, settlements. These settlements appear in the whole lifespan of the structures, owing to changes in total or effective stress state (construction, filling, climatic changes, heavy rains).

In the last decade, several high rockfill dams (where the impermeability is ensured by a concrete mask on their upstream face), have experienced the rupture of their concrete face at the first filling, showing the limits of empirical approaches and current knowledge.

To design correctly these structures, the prediction of the type and amplitude of deformations is of great importance: the prevention of settlements is crucial to ensure the imperviousness and stability of these structures. It is then necessary to better understand and evaluate multi-scale mechanisms that play a crucial role in the rockfill behavior under large stresses, under dry or unsaturated conditions, and upon time.

Methodology and tools

Experimental work is still needed to complete the actual knowledge on rockfill and particularly about multi-scale mechanisms influencing rockfill compressibility on controlled environmental conditions.

The objectives of this thesis is to improve the design of these structures allowing the tracking of potential stress and settlements evolutions (in real time), due to long time ageing processes or triggered by sudden changes in the environmental conditions (heavy rains, intense heats).

This thesis proposes a main experimental challenge: the development of smart rocks, unbreakable and simple shaped self-sufficient grains (artificial rocks with edges of 4-5 cm) able to measure their position, forces on their faces and the local hygrometry, so that they can evaluate the stress tensor, heterogeneities, and sudden changes into a granular media under varying environmental conditions. Few prototypes will be dipped into a large scale laboratory test composed of rockfill submitted to compression. The knowledge of real force network is actually an important data to evaluate how the stress redistributes into the granular media along with the potential breakages of the material. Quasi-static tests (with stress superior to 2 MPa) can be planned in large scale oedometric tests in our laboratory, with controlled hygrometry.

The knowledge of the order of magnitude of stress redistribution and their impact on the granular media could be of great importance for detection of sudden changes in the media that may eventually lead to significant settlements or even the collapse of the whole structure. These smart sensors will help the better understanding of the preferential trigger mechanisms of breakages and reorganizations into the media.

Another challenge for this thesis will be to simulate the laboratory experiences with the use of the discrete element method. For more than twenty years, the emergence of discrete element methods have been giving force distribution in granular media, allowing visualizing force chains crossing the samples and other shielded zones poorly loaded.

These methods are very efficient but suffer from the lack of comparison at the local scale with experimental works: even if experiences -rarely enough- exist for that material size, they only give information at the boundaries of the sample. The numerical simulations will be performed with an opensource platform (LMGC90, developed by the Laboratory of Civil Engineering in Montpellier) which uses the Contact Dynamics approach developed by Jean and Moreau (1992). This platform is usually used to perform simulations on rigid bodies. A thesis, conducted in our laboratory (F. Nader's thesis, defensed in 2017), has enabled the development of 3D grain breakage model with rigid bodies. Using rigid bodies allows to have access to the contact forces between the different bodies, but not inside them. Introducing deformable bodies (non breakable) in the media will enable to have access accurately to the stress tensor of the material and could represent a step forward in the understanding of breakage in granular media. In a second step, deformable bodies with zone cohesive models could be used to describe breakage and would represent a key contribution in the granular material community as deformable bodies are still less used.

Coupling experiments and modelling could help a better understanding of the mechanisms involved when rockfill are submitted to loading, and enable developing accurate models for the grains' breakage, so that prediction could be done concerning the triggering of reorganization and settlements.

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