Numerical study of the effect of the boundary conditions in DEM modelling on the mechanical behavior of a cemented granular media: application to biocalcified sand

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Résumé

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1 Introduction

Microbially induced calcite precipitation (MICP) is a recent technique used to reinforce soil, structures and materials. It uses bacteria to precipitate calcite in a medium to improve its strength by creating bonds between the grains. It has been shown that only a small percentage of calcite is needed to considerably increase the strength of sand (1), and that the mechanical properties of the materials depend on the micromechanical properties of the contact (2).

In order to predict the mechanical behaviour of this cemented sand, a first numerical model has been developed (3) using the open-source code Yade (4) based on the discrete elements method (DEM). In particular, the goal was to simulate a triaxial test on biocalcified sand, using micromechanical parameters determined by experiments (5). This first numerical model allows to describe, with good accuracy, the macroscopic response of lightly cemented samples when the volume fraction of calcite is lower than 4%. However, the peak stress was generally underestimated with the numerical model, whereas the dilatancy of the sample was overestimated for higher volume fraction of calcite. The three main limitations identified in this model were the low average numerical coordination number, the use of rigid boundary conditions and a parallelepipedic sample, whereas triaxial test are performed with cylindrical samples with a high average coordination number surrounded by an elastic membrane.

2 Numerical model

*Intervenant

To tackle these limitations, a numerical development has been done to model cylindrical samples with a flexible membrane. The membrane model uses a topological object called α-shape (6), which extends the notion of convex hull to non-convex envelopes (7). To compare indicators between samples with different boundary conditions, a method to compute the internal values of porosity and volumetric strain have been developed with the use of Voronoi cells. Cemented interactions are assigned in the initial state to match the experimental coordination number. Simulated triaxial compression with such model shows a significant increase of the strength compared to uncemented sand, and the post-peak response is much more fragile, as expected for cemented sand.

The model is used to study the effect of the boundary conditions on the mechanical behavior of a cemented granular media. Triaxial tests are simulated under three different confining pressures, three different density (loose, intermediate and dense), different geometries (cylindrical and parallelepipedal) and different boundary conditions (rigid walls and membrane). Overall, these simulations showed good stress-strain reproduction with almost no differences between different boundary conditions. The main difference is observed for the volumetric strain, which is reduced by around 40% for membrane boundary condition in comparison to rigid wall. The 3D shapes of the samples and the associated strain fields produce results much closer to those observed experimentally with the membrane. More specifically, it has been shown that the friction angle on the piston used for the test has a great impact on the final shape of the samples, going from barrel deformation to lateral displacement of the sample with a shear band. The initial geometry of the specimen was found to have little influence on the numerical macroscopic response.

Finally, a comparison with triaxial experiment performed under X-Ray microtomography is being carried out to quantify our ability to predict the macroscopic behavior of biocemented sand.

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