MODELLING SATURATED SOIL COLUMN COLLAPSE WITH 2-PHASE 2-POINT MATERIAL POINT METHOD

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1. Introduction

The collapse of soil columns is commonly employed in geotechnical modelling to study the rheology of complex natural mixtures, as well as to calibrate major parameters controlling free surface earthfall behavior and potentially correlated debris-flows.

Despite many experimental and computational works formerly carried out, the scientific literature still lacks experiences with 2-phase models. Capturing solid grains and pore fluid interactions and their evolution along time is challenging. This issue is investigated numerically in this study by means of the Material Point Method (MPM). The potentialities of a recently proposed 2-phase 2-point formulation [1], implemented in the software Anura3D (www.anura3d.eu), are investigated.

This formulation assumes that the saturated porous medium consists of a superposition of two independent continuum, and it is governed by the momentum balance and mass balance equations of the two phases, together with the constitutive laws. The drag force determines the interaction between the phases. The solid skeleton and the liquid phase are represented separately by two sets of Lagrangian MPs: solid material points (SMPs) and liquid material points (LMPs). While SMPs move attached to the solid skeleton, LMPs follow the liquid motion, both carrying properties of respective phases. The behaviour of the continuum can vary from dry porous media to pure fluid; moreover fluidization and sedimentation processes can be simulated. The latter lead to extreme changes in flow regime and high volumetric strain rates depending on concentration ratio gradients of the two phases.

2. Results

This groundbreaking formulation is tested in the present work, focusing on two main aspects: the drag force expression, and the phase transition from solid to liquid state.

The drag force vector, incorporates two terms (see Eq. 1): a first "viscous" term, linearly proportional to the relative velocity between the phases through the material permeability, and a second term depending on the squared of the relative velocity vector, introduced by [2], to correctly account for turbulent flow. The drag expression resembles the formulation proposed by Ergun, after studies on fluidized beds, including two empirical constants (A, B) from the same work [3].

$$\boldsymbol{f}^d = \frac{{n_L}^2 \mu_L}{\kappa_L}(\boldsymbol{v}_L - \boldsymbol{v}_S) + \beta {n_L}^3 \rho_L |\boldsymbol{v}_L - \boldsymbol{v}_S| (\boldsymbol{v}_L - \boldsymbol{v}_S) \tag{1}$$

Where n_L = porosity, μ_L = liquid dynamic viscosity, ρ_L = liquid density, $\boldsymbol{v}_L$ = liquid velocity, $\boldsymbol{v}_S$ = solid velocity, β = non-Darcy flow coefficient depending on κ_L = intrinsic permeability as follows

$$\beta = B/\sqrt{\kappa_L A {n_L}^3}\ , \kappa_L = \frac{D^2}{A}{n_L}^3/(1-n_L)^2 \tag{2}$$

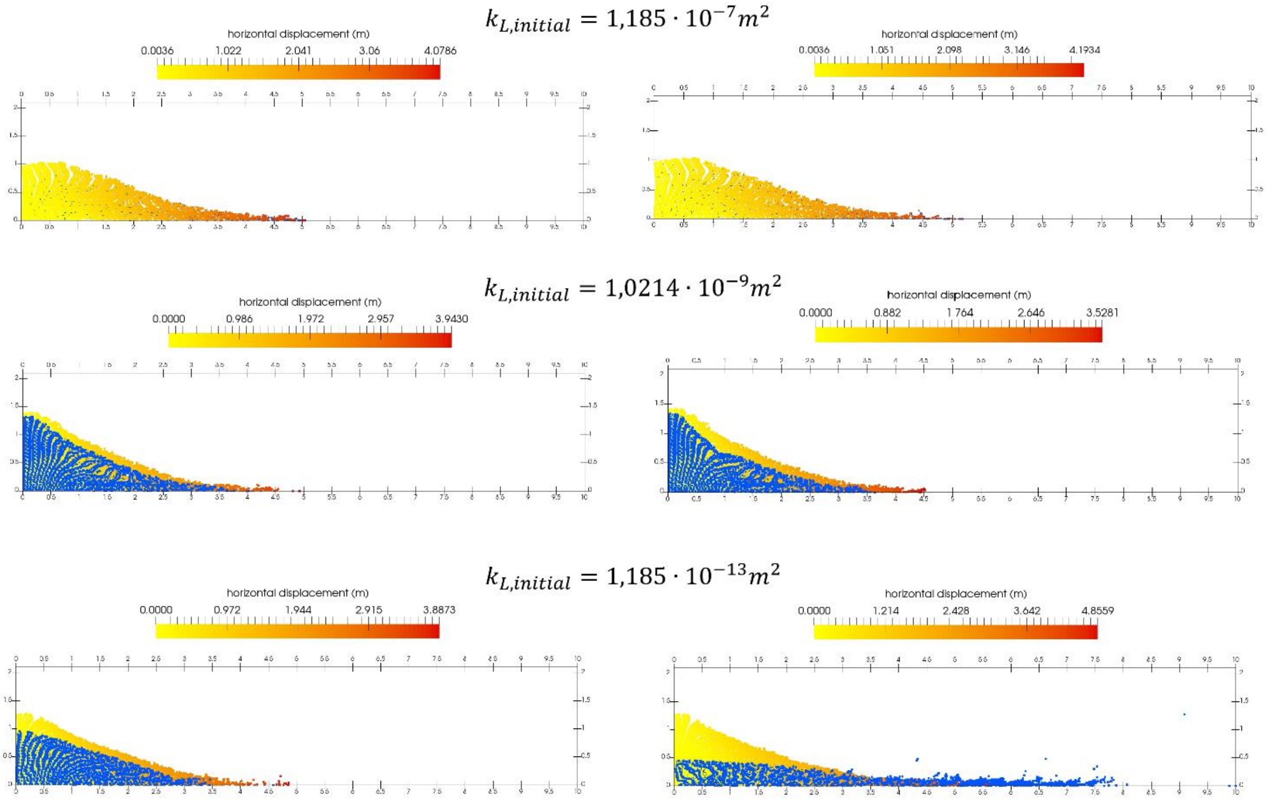
A=150 and B =1.75 are empirical constants, D = effective grain size diameter.

Since the influence of the soil intrinsic permeability, calculated and updated at every time step with a Kozeny-Karman formula, plays a fundamental role in the drag force computation, a parametrical study has been performed on columns with three different values of initial intrinsic permeability (Fig. 1), depending on grain effective diameter variations, since initial porosity is constant for all the cases.

Another series of tests was undertaken for each column, with drag force including or neglecting the non-linear term, to make comparisons in terms of viscous or kinetic forces predominance, during the run out (Fig. 1). Analyzing the propagation of the front, the formation of a granular front appears in coarse materials if both linear and quadratic terms of the drag force are included. In contrast, a liquid front is observed if only the linear term is used. Concurrently, particle recirculation seems to develop in a portion close to the front and at the contact with the column base.

As previously mentioned, a special attention was given to the liquefaction process, thanks to an assigned value of maximum porosity, separating solid and fluid states; it essentially corresponds to the moment of complete particles detachment, which fluctuates in the fluid, loosing all the resistance and cohesion properties, with consequent effective stress state annulment.

In conclusion, this numerical work on saturated soil columns collapse, draws attention to the need of further research to correctly evaluate stress states in both phases, and to understand the correlation between fluid flow and solid stress transmission. A key issue to correctly describe these problems is the definition of the interaction term (drag force in eq. 1) between the two phases.


$k_{L,initial} = 1{,}185 \cdot 10^{-7} m^2$

$k_{L,initial} = 1{,}0214 \cdot 10^{-9} m^2$

$k_{L,initial} = 1{,}185 \cdot 10^{-13} m^2$

Figure 1. Location of LMPs (blue dots) and horizontal displacements for SMPs at time t=2,5 s for columns with 3 different initial intrinsic permeabilities. Left set performed with linear and quadratic terms of drag force, right set performed only with linear term.

3. References

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[3] Ergun, S. & Orning, A.A. (1952). Fluid Flow Through Packed Columns, *C. E. P.*, **48,** 89-94.