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Critical state theory: The key to effective pressure in subaquatic granular flows

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The incompressible Navier-Stokes Equations have become a popular method for the simulation of granular flows. This has been made possible by modelling the viscosity of the granular material as a pressure depended term [1]. However, we have to keep in mind, that granular material is only affected by the effective pressure, which is the total pressure reduced by the pore pressure.

The concept of effective pressure is well known since the pioneering work of Terzaghi [2]. However, within the framework of incompressible Navier-Stokes Equations it is not straight forward to distinguish between effective pressure and pore pressure. For subaerial granular flows, this is not a big issue, as pore pressure is negligible small. However, pore pressure in subaquatic granular flows can be substantial and a proper decomposition of total pressure is imperative.

A simple approach, assuming that pore pressure is hydrostatic has for example been presented by Savage et al. [3]. However, excess (positive and negative) pore pressure and all its consequences can not be modelled with this approach. A more complex but undeniably more powerful approach has been presented in the form of mixture theory and critical state theory by various researchers [4,5]. Critical state theory introduces an additional equation, allowing to determine the effective pressure and its dynamic evolution, depending on packing density, pore-pressure and permeability. Moreover, mixture theory introduces a variable grain-pore ratio, leading to a quasi-compressible flow model.

We apply both approaches to subaerial and subaquatic granular flows, using customized OpenFOAM [6] solvers. While both approaches perform equally well under subaerial conditions, the critical state theory shows substantial advantages for subaquatic cases. We validate simulations with respective experiments and highlight the importance of excess pore pressure.

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