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Interaction forces caused by relative movement in a continuum mechanical model for suffusion

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Dam failures and landslides can be caused by erosional processes. Suffusion, a special type of internal erosion (Yang et al., 2019), is the initial stage of a backward erosion process (van Beek, 2015) which may lead to creeping degradation of the dam's stability and in the end to catastrophic outcomes like the Brumadinho tailings dam collapse in Brazil 2019 (Silva Rotta et al., 2020). Currently, there are no field-scale models that can predict the time scale of the process and the area of collapse. Only empirical criteria (Chang et al., 2013) can be used to determine whether a soil is erosionally stable or unstable (Fell et al., 2015). New projects could be planned following these criteria. However, some existing earthworks may not meet these criteria and a reliable risk evaluation is not possible. Moreover, for economic reasons, modelling the whole process and, in consequence, predicting the duration of erosion processes may lead to more cost-effective constructions.
To model suffusion at the field scale, the authors are currently researching a continuum mechanical approach. The total soil is modelled with three phases: grain skeleton, water and particles which can be eroded or deposited. These three phases can move independently, and their motion is described by balance equations and constitutive laws. Analog to the effects of suffusion, these laws include the weakening of the soil mechanically. The detachment of particles increases water conductivity, while particle agglomerations impede flow in certain areas, resulting in an increase of seepage forces on the grain skeleton. In a further development of existing approaches by Vardoulakis (2004), the particle diameter is introduced as a parameter. If the particles are very fine and their volume fraction is relatively small, their movement is dominated by advective transport. Consequently, the particles move simultaneously with the water phase. If the particle size is above a certain diameter, friction between particles and water becomes dominant and causes relative motion between these constituents. Additionally, the interaction between the particles and the pore channel of the grain skeleton arises significantly. (e.g., Bear et al., 1987; Schaufler et al., 2012)
A new model based on the Theory of Porous Media (TPM) (Bowen, 1976) represents the mechanical aspects of particle transport through the pore space. Resistivities are defined to represent the interaction forces between the three soil constituents. Observing a special case, the interaction between the soil skeleton and the pore fluid represents the Darcy velocity. The drag force caused by the interaction between particles and pore fluid is also known, but it is typically used for sedimentation and not in combination with the Darcy equation. Additionally, there is an interaction between the particles and the soil skeleton, which has not yet been applied to continuum mechanical models.
Analytical and numerical findings show that the movement of the fluid and particle phases within the pore space can be represented in a continuum mechanical model. The results are plausible for both laminar and non-laminar flow, as well as for different particle concentrations.

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Primary authors: BUSCHER, Solveig (University Duisburg-Essen); Prof. PERAU, Eugen (University Duisburg-Essen)

Presenter: BUSCHER, Solveig (University Duisburg-Essen)

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