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Geomechanical modelling of sinkhole development using Distinct Elements with application to the Dead Sea

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A new approach of geomechanical modelling of sinkhole formation is proposed by using a 2D Distinct Element Method (DEM) code (PFC2D_V5). In this, a slowly growing set of void spaces in the subsurface creates a mechanical feedback loop between material failure and bulk porosity increase. In consequence, the overburden fails at a certain stage of the void space growth and creates a sinkhole. The collapse process, structural features and sinkhole morphologies hereby depend on the geometrical and mechanical properties of the subsurface.

Detailed simulated compression tests enable one to define material parameters such as deformability and tensile/shear strength parameters that agree to realistic bulk values from literature and laboratory measurements. Tracking of several geodetic and geophysical parameters has been implemented in the code, such that surface subsidence, stresses, strains, porosity, seismic velocities and micro seismic events can be recorded/calculated for different stages of the void space development.

We apply the new approach to the problem of sinkhole development at the Dead Sea shoreline, where thousands of sinkholes have formed in the last few decades. Firstly we define DEM materials that possess expected bulk properties of three geo-materials present at the Dead Sea sinkhole sites: (1) low-strength lacustrine mud, (2) middle-strength alluvial sediments and (3) higher-strength Holocene salt deposits. For each material we then simulate a void space growth on several random particle assemblies. At different stages of the sinkhole formation process we receive different structural features: In the pre-collapse stage, a large-scale subsidence occurs with highest amplitudes in the centre of the projected set of voids for all material strengths. In the collapse stage, for weak material of type (1), a funnel like structure forms and leads to material transport from top to bottom. For stronger materials of type (2), cracks from bottom to top may propagate and material compounds may fail as blocky assemblies. This leads, in a final post-collapse stage to deep surface fractures and rotated blocks for alluvial sediments and cone-shaped depressions for the lacustrine mud. The salt material does not fail until the cavity has grown close to the surface, hence providing a high stability.

Secondly we used the approach to investigate the more realistic setting of alluvial layers above cohesive mud for the specific case study at Ghor Al-Haditha, Jordan. This setting leads to a remarkable detachment effect at the interface between both material types. Due to this, a deeper situated void space leads to larger material removal at the layer interface. In addition to the overall subsidence structures we looked at expected seismic velocities of the subrosion horizon and acoustic emissions before and during a simulated collapse.