Geophysical Research Abstracts
Vol. 21, EGU2019-13808, 2019
EGU General Assembly 2019

Geomechanical modelling of sinkhole cluster and large-scale depression formation by using Distinct Elements

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A 2D Distinct Element Method (DEM) code (PFC2D_V5) is used to simulate the evolution of subsidence-related karst landforms, such as single and clustered sinkholes, and associated larger-scale depressions (uvalas, poljes). Subsurface material in the DEM model is removed by a feedback loop to produce an array of cavities; this simulates a network of subsurface groundwater conduits growing by chemical/mechanical erosion. The growth of the cavity array is coupled mechanically to the surroundings such that cavities can grow also in part by material failure at their margins, which in the limit can produce individual collapse sinkholes. Two end-member growth scenarios of the cavity array and their impact on surface subsidence were examined in the models: (1) cavity growth at the same level and at the same individual growth rate; (2) cavity growth at progressively deepening levels with varying individual growth rates. These growth scenarios are characterised by differing stress patterns in the subrosion zone and its overburden, which are in turn an important factor for the formation of sinkholes and uvala-like depressions. For growth scenario (1), a stable compression arch is established around the cavity array, hindering sinkhole collapse into individual cavities and favouring block-wise subsidence across the whole cavity array. In contrast, for growth scenario (2), the stress system is more heterogeneous, such that local stress concentrations exist around individual cavities. Consequently, sinkhole collapses into individual cavities occurs by shear or tensile failure of the overburden, and these sinkholes lie within a larger scale depression linked to the cavity array as a whole. The results from models with growth scenario (2) are in close agreement with observations from a karst area on the eastern shore of the Dead Sea, which show that the initial appearance of individual sinkholes (or of sinkhole clusters) is followed by development of a surrounding larger-scale depression (uvala).