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Geological and numerical modelling of sinkholes induced by instability of man-made underground caves

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An increasing number of areas in southern Italy are being interested by sinkholes related to the presence of artificial cavities, and in particular of underground quarries. Aimed at defining the most proper criteria for the study of such phenomena, the case of Cutrofiano (Apulia, SE Italy) is here presented as an example. This territory is well known for the underground quarrying activity of soft calcarenitic rocks that caused in the last decades widespread phenomena of subsidence at the surface, with extensive damages and problems to the main communication routes in the area. A very complex and intricate network of subterranean galleries is present underground, for a total development on the order of several tens of kilometres. The Gravina Calcarenite Formation, that is the object of the underground quarries, consists of whitish calcarenite with an upper greenish clayey-sandy interval rich in fossils. This formation is overlain by grey sandy clays (Subapennine Clays) grading upward to fossil-rich sands (Brindisi Sands). In recent years, clay mining has been resumed at the ground surface, following to the opening of a cement factory, and resulting in the realization of wide open quarries. The local sedimentary sequence is closed by terraced calcarenite deposits rich in ostreids, holding a phreatic groundwater body and overlain by a shallow soil cover. The results of detailed geological, geomorphological and geomechanical surveys, supported by laboratory tests, show that in the Cutrofiano area the thickness of the stratigraphical succession, the depth of the underground galleries, the structural conditions of the rock mass, and the failure mechanisms observed within the quarries are variable. The geological model reconstructed represents the base for the numerical simulations, which are aimed at defining the eventual mechanisms of rock failure, up to the formation of the sinkhole. In particular, two different geological settings have been considered: the first is representative of those areas close to the town that does not show the clay-sandy interval, and has the galleries at an average depth of 10m; the second, which typically characterizes the sectors some kilometres farther south, shows, on the other hand, the presence of the clay-sandy interval and has galleries at depth variable from 15 to 45m. Starting from these geological settings, numerical analyses have been developed by using the finite element method to investigate the stress-strain evolution of the rock mass surrounding the galleries due to long-term degradation of the rock properties induced by weathering and water infiltration. The results obtained from the numerical simulations point out that a strong degradation of the calcarenite around the galleries may be responsible initially of local failures and, later on, of unstable conditions of the rock mass overlying the gallery.