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Landslide hazard assessment, stability analysis modelling and mitigation measures applied to the archaeological area the ancient Stabiae (Gulf of Naples, Italy)

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The paper reports the development of a landslide hazard and risk assessment, based on geomorphological and geotechnical approaches, carried out in the archaeological area of the Hill of Varano (ancient Stabiae, Naples). The archeological site of Varano Hill is a complex of three Roman villas (1^{st} century A.D.) completely buried by the volcanic eruption of Vesuvius in 79 A.D. The villas are located over a large terrace, near the border of a slope with average angle $>45^{\circ}$. The slope is formed by parallel-bedded pyroclastic and alluvial terrains that overlay coherent or semi-coherent tuffs of the Campanian Ignimbrite (33,000 y. B.P.) that constitute the local bedrock of the area. The slope, characterized by high relief energy, has been involved by historical landsliding since the Roman period (1^{st} century A.D.). In fact, typical Roman drainage systems and slope reinforcements are still working along the perimeter of the terrace to prevent slope instability. The dimension and the typology of the works suggest that failure depths can be estimated in few meters (2-5 m.) before the urbanization of the area, while field surveys carried out since 2001 have stressed a landslide activity mainly involving 1-2 m of soil. Over 30 landslides have occurred in the area since 1931. Landslides can be classified mainly as debris-earth flows and, subordinately, rotational slides that develop along the upper border of the terrace. The instability process has a retrogressive activity, evidenced, near the edge of the slope, by tension cracks, on the floor, and wall fracturing of the archaeological buildings. The

ancient large Roman reinforcement structures let us assume that historical instability could be roto-translational slides with estimated failure depth of 2-3 m. Recent slope instability processes are mainly represented by earth-debris flows, with modest volumes of weathered soil and depth of sliding surfaces generally < 1.5 m. The main landslide-triggering factor can be envisaged in heavy rainfall with intensity of 80-100 mm, duration of 12-24 hours, and estimated return time variable from 5 years, from 1930 to 1980, to 2 years from 1980 to date. The increase of slope instability is likely due to abrupt change in land use around the area, where greenhouse cultivation has progressively substituted open agricultural practices. This has caused a change of the hydrological pattern, with an increase of runoff. In addition, some modifications of geomorphological conditions at the toe of the slope have also occurred in time. The numerical modelling analysis of the more susceptible areas of the slope, have been carried out with PLAXIS ® code finite elements. The FEM analysis has produced two main results. The possibility of assessing the stability past condition (through a back analysis procedure) and the estimation of present stability conditions by assuming different hydraulic conditions within the investigated slope. The back analysis has allowed to calibrate the geotechnical parameters of soils derived by laboratory tests. The analysis, performed along the sections of *Villa del Pastore* and *Villa Arianna* shows that instability develops for saturated conditions of soils whereas potential failure depths are $>$10m following a typical roto-translational shape. For both areas the plasticity indicators show a tensile stress that is mostly acting in the crown area at ca. 10 m from the scarp; this results as a typical retrogressive activity of instability processes. The results of the analysis implemented for *Villa Arianna* have been confirmed by very recent earth-debris flow occurred in Sept. 2003 and Dec. 2004, that affected part of the Roman cisterns. Observations on landslide typology, failure surface and mobilized volumes, fit substantially with the assumed model, following a different type of kinematical pattern with respect to events developed in the last decades. Finally, this study is the result of a multi-disciplinary approach applied to Earth Science disciplines and represent a first step for a rigorous landslide risk analysis and sustainable and effective mitigation measures applied to preservation and conservation of the Roman Villas of Stabiae.