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Multiphysics Laboratory Tests for Modelling Gravity-Driven Instabilities at Slope Scale

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Abstract

Ischia Island (Italy) experienced slope instabilities during the Holocene that occurred at different scales, from shallow mass movements up to large rock and debris avalanches. These events were strictly related to volcano-tectonic activity and the presence of a well-developed hydrothermal system and mobilized significant volumes of greenish alkali-trachytic tuffs (Mt. Epomeo Green Tuff, MEGT). Ongoing gravity-induced slope deformations in the Mt. Nuovo region also involve the MEGT over an area of 1.2 km2. In order to constrain geometry and mechanism of this phenomenon, and to highlight possible interactions between the thermo-baric field of the hydrothermal system and stress-strain conditions related to the Mt. Nuovo slope deformations, laboratory tests were carried out to assess and characterize the mechanical behaviour of the MEGT. Physical properties of the MEGT were first measured, including porosity, permeability, and elastic wave velocity. Mechanical characterization was then performed using a combination of uniaxial, tensile, and triaxial experiments on as-collected samples and samples thermally stressed in the laboratory. The obtained results reveal MEGT to have a high porosity and permeability, and that it deforms in a compactant (i.e. ductile) manner at very low confining pressure (i.e. depth). The triaxial tests allow us to derive failure envelopes for MEGT under dry and water-saturated conditions, defining the range of stress conditions for failure.

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Keywords: Slope stability; landslides; hydrothermal system; mechanical behaviour; numerical modelling

1. Introduction

Flank instabilities represent the most common indirect geo-hazard related to volcanic activities. Destabilization is usually produced by a combination of predisposing and triggering factors. Although magma emplacement or

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earthquake shaking are the most common triggers able to produce external transient forcing that could interact with inner pressures or accelerate deformations [1, 2], hydrothermal systems may also play a significant role, influencing slope stability in two ways: i) alteration can weaken or strengthen the materials involved as function of PT conditions and the chemical composition of fluids [3] and ii) transiently increasing the stress field within the slope [4, 5, 6]. Such collapses can in turn trigger subsequent hazardous events in a sort of "domino effect" leading to the occurrence of explosive eruptions, triggered by the sudden decompression of shallow magma reservoirs or hydrothermal systems [7, 8] or, in the case of marine volcanoes, destructive tsunami waves [9]. The case study of a gravity-induced slope deformation affecting the edge of Ischia resurgent caldera is presented here; to account for a well-constrained mechanical behavior of the involved lithologies, in view of future multiphysics numerical modelling, a suite of mechanical laboratory tests was carried out.

2. Geological Framework

Ischia Island represents the westernmost part of Phlegrean Volcanic District (Southern Italy) and hosts several Holocene slope instabilities that occurred at different scales, from shallow landslides triggered by meteo-climatic events, up to massive rock slope failures such as large rock and debris avalanches related to the volcano-tectonic dynamics of an asymmetric resurgent caldera. Such landslides and slope deformations generally involved trachytic pyroclastic flow deposits named Mt. Epomeo Green Tuff (MEGT) [10], emplaced during an intense explosive eruption dated 55 ka [11]. This asymmetric resurgence, controlled and driven by the intrusion of a shallow magmatic body, strongly modified the geological evolution of the island producing a stable hydrothermal system and influencing the local seismicity, as well as the gravitational processes of the steep resurgent block [12]. Recent studies pointed out the presence of significant recent slope failures and ongoing slope-scale deformations on the island of Ischia (e.g. [13, 14]) that could be related to internal forces of the volcanic system. These gravitational phenomena consist of large-scale mass movements including lahars, debris flows and large debris avalanches whose volumes ranged between 0.5 and 1.5 km^3 [14, and references therein]. Ongoing deformations still involve part of the western edge of the resurgent block located in the Mt. Nuovo area. This area, prone to failure, could mobilize a volume of about 180-190 million cubic meters [14] that could cover the town of Forio (Fig. 1). Importantly, Ischia Island also hosts a stable hydrothermal system [15] characterized by high heat flow (200-400 mW/m^2) and several thermal springs and gas vents (i.e. fumaroles) with surface temperatures up to 100°C. The internal circulation of this hydrothermal system could interact with the slope-system thereby modifying the thermo-baric and stress-strain field. This could, in turn, negatively affect the mechanical behaviour of the rock mass [16, 17] through material degradation [3, 18, 19, 20, 21] and therefore jeopardize the stability of the rock mass (e.g. [4, 5]).

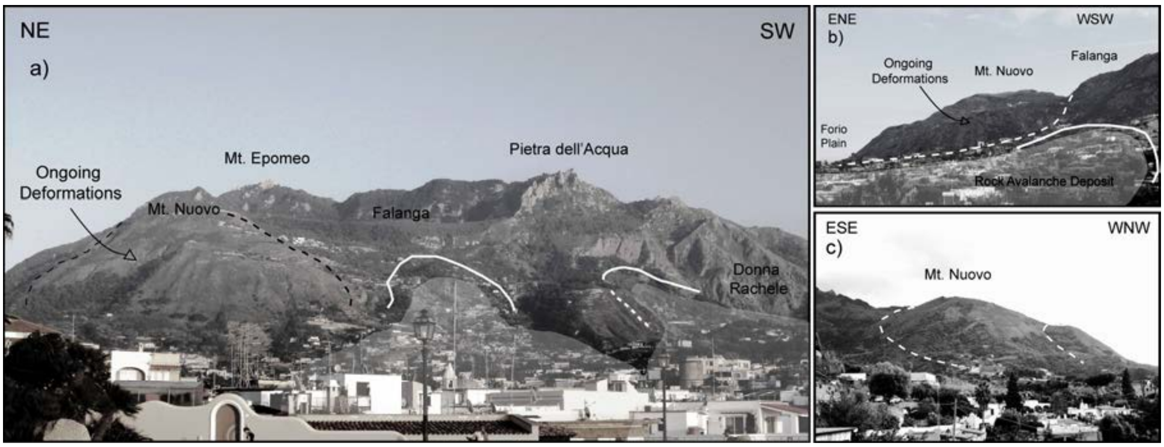

Fig. 1. (a) Panoramic view of the Mt. Epomeo relief from the Forio plain; the Mt. Nuovo area, involved in the ongoing gravitational deformation is clearly visible on the left side of the picture; (b) NW-SE view of the deformed block and of the apical zone of one of the documented rock avalanches [14]; (c) ESE-WNW view of ongoing deformation with secondary landslide terrace and counterslopes.