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# Landslides induced by the 2017 Lesvos (North Eastern Aegean Sea) earthquake and engineering measures for landslide disaster mitigation

E. Skourtsos[1], S. Lozios[1], K. Soukis[1], B. Antoniou[1], E. Andreadakis[1], S. Mavroulis[1], Ch. Filis[1], N.-I. Spyrou[1], I. Lialiaris[1], V. Alexoudi[1], N. Voulgaris[1], E. Lekkas[1]

(1) National and Kapodistrian University of Athens, Department of Geology and Geoenvironment, Panepistimiopolis Zografou, 15784, Athens, Greece, eskourt@geol.uoa.gr

## Introduction

Landslides induced by the 2017 Lesvos Earthquake (North Aegean Sea, Greece) are presented along with their controlling factors and the engineering measures for landslide disaster mitigation. All presented data were derived from the research program applied in the earthquake-affected areas of southeastern Lesvos Island and conducted by the authors.

## The 2017 June 12 Mw 6.3 Lesvos earthquake

On June 12, 2017 (12:28 GMT) an Mw 6.3 earthquake struck Lesvos Island (Northeastern Aegean, Greece) with focal depth of about 13 km and epicenter located offshore Plomari town (southeastern Lesvos). The main shock was generated by the rupture of the northern margin of the offshore Lesvos basin located between Lesvos Island in the north, Chios Island in the south and İzmir bay in the east (Papadimitriou et al. 2018). As regards the geodynamic setting, the North Aegean constitutes an extensional zone south of the North Anatolian dextral strike-slip fault zone and north of the Hellenic Trench (e.g. Le Pichon and Angelier, 1981). The small scale uplift of the Aegean area enables Anatolia to move with increasing velocity towards WSW resulting in the formation of the İzmir bay and the offshore Lesvos basin, which is bounded by E-W striking normal faults (Mascle and Martin 1990).

## Earthquake environmental effects

Among the impact on public health (1 casualty and 15 injured people) and on the built environment (structural and non-structural damage in buildings), the earthquake also generated secondary environmental effects comprising mainly slope movements, ground cracks and a small-scale tsunami (Lekkas et al., 2017, Mavroulis et al., 2018). Slope movements were observed in several sites of the affected area resulting in partial damage to the road network including cracks and craters in the asphalt pavement and deformation of road protection barriers as boulders bounced across the roads, damage to adjacent building structures and related facilities and temporary or permanent traffic disruption (Mavroulis et al., 2018).

## Factors controlling the earthquake-induced landslides

The observed slope movements are mainly attributed to pre-existing instability conditions formed in geotechnically unstable areas and landslide zones, presence of active faults forming intense relief with high and abrupt slopes and scarps, as well as suitable geometry of beds and discontinuities dipping towards the free face of slopes. Moreover, the eastern part of Lesvos Island is characterized by an arid to semi-humid climate, which is accompanied by relatively large surplus of water during the winter period (Karras, 1973). On the other hand, the western part of Lesvos Island is characterized by semi-arid climate with a small surplus of water during the winter period and high potential of evapotranspiration. The prevailing winds are northern and the southern winds follow. The distinction of the island into different climatic types reveals the difference in the occurrence of landslide phenomena between the two parts, with the eastern part having more landslide phenomena that the western one.

## Local geological and morphological setting and types of the observed earthquake-induced slope movements

The research team conducted a detailed mapping of the sites affected by the earthquake-induced slope movements by combining not only the classical geological and geotechnical mapping but also modern and innovative mapping techniques including Unmanned Aerial Vehicles (UAV).

The observed slope movements were classified into:

- Wedge detachments, planar slides, toppling failures or movements due to combination of these slope movements attributed to the synergy of bedding, schistosity and fractures.
- Rotational landslides and failures of the soil, of the weathering mantle and of the surficial parts of the loose rockmass of the schists and pyroclastic rocks.

Slope movements were observed in the Agios Isidoros, Akrassi and Mesotopos areas and along Plomari – Melinta – Palaiochori road network.

Agios Isidoros and Plomari – Melinta – Palaiochori areas are composed of alpine formations including blueschists and marbles of Carboniferous age. These series also comprise carbonaceous metaconglomerates and large masses of greenschists. The affected areas are characterized by intense morphological slopes and morphological discontinuities, which locally are equal to or larger than 100 %, while the majority of the affected areas are characterized by slopes varying mainly from 51 to 100% and secondarily from 11 to 50 %. During the 2017 earthquake, rockfalls, planar slides and wedge failures occurred in Agios Isidoros and Plomari – Melinta – Palaiochori areas.

Akrassi area is located east of the homonymous village and along the road network leading from Akrassi to Plomari. This area comprises Neogene ignimbrites lain unconformably over marbles, schists and ophiolites. Ignimbrites are composed of massive sheets with strong cohesion with flat surface overlying eroded surfaces of alpine formations. This area is characterized by intense morphology and slopes varying mainly from 51 to 100 % and secondarily from 11 to 50 %. During the 2017 earthquake, the generated slope movements in Akrassi included rockfalls and landslides.

Mesotopos area is located east of the main provincial road leading from Agra to Mesotopos. Ii is comprised by lava layers and pyroclastic rocks. During the 2017 earthquake, rockfalls were generated and affected the part of the aforementioned road.

## Proposed engineering measures for the landslide disaster mitigation

The proposed engineering measures for the landslide disaster mitigation include the following:

- Removal of hanging, unstable and isolated rock blocks or of the loose rockmass
- Cleaning of the landslide materials accumulated behind retaining walls in order to create space for future slope movements and accumulation of mobilized material.
- Construction of concrete retaining walls along the base of natural or artificial slopes
- Simple and quick construction of gabion walls with flexibility to withstand foundation movement and with space behind them in order to receive and safely sustain loads of mobilized material
- Support and reinforcement anchors along with fastening of wire meshes over slopes with highly fractured, brecciated and loose rockmass
- Construction of concrete retaining walls along with landslides and rockfalls protection fenches on their top
- Excavation of horizontal benches into slope face for protection from rockfalls and the reduction of tensional forces in the surface rock and of surface erosion rates
- Construction of dynamic rockfall barriers
- Combinations of systems often provide the most effective solutions

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