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Landslide monitoring based on an Integrated Monitoring System (IMS) using a combination of geodetic, geotechnical, and meteorological monitoring technics: a case study from Maia (Santa Maria Island, Azores)

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Landslides are the most frequent type of natural hazard in the Azores Archipelago and are responsible for significant socio-economic consequences and nearly 40 casualties in the last three decades. Landslide monitoring is a mandatory step in landslide risk mitigation. Various techniques, such as remote sensing, geotechnics, geodetics, geophysics, and hydrologic, can be employed for monitoring landslides. These methods allow the collection of crucial data regarding landslide conditions, including the location of failure surfaces, areal extent, landslide kinematics, and hydrogeometeorological parameters.

In March 2010, a landslide triggered by rainfall, covering an area of approximately 18.500 m^2, caused several damages on roads, houses and problems related with water and energy supply on Maia (Santa Maria Island). Since then, an Integrated Monitoring System (IMS) was designed and implemented to assess the kinematic behaviour and geometry of the unstable mass. This system incorporates a combination geodetic (total station), geotechnical (inclinometer), and meteorological monitoring technics. The IMS data is transmitted to the Centre for Information and Seismovolcanic Surveillance of the Azores (CIVISA), responsible for the permanent system management and data analysis. Periodic bulletins are issued by this entity, along with the dissemination of warnings and alerts to the Azores Regional Government.

The results of the geodetic network demonstrates a heterogeneous spatial deformation pattern in the unstable mass. The planimetric displacement and the subsidence pattern in the upstream sector of the road in the central part of the landslide, may be associated with the concave morphology of the terrain. This setting promotes the accumulation of water through surface runoff, that increase the effective load and shear stress in this sector. It is also worth noting that downstream of the road, both planimetric and altimetric displacements increase with proximity to the shoreline, with maximum accumulated displacement since 2012 of 0.054 m and 0.012 m, respectively. This observation is justified by the erosive action of the sea at the toe of the landslide, which enhances greater deformation of the destabilized mass in this sector.

Since the beginning of inclinometric monitoring in October 2017, the maximum cumulative displacement of the landslide at depth is 18.5 mm and 21.5 mm at depths of 7.0 m and 1.0 m in boreholes FSM1 and FSM2, respectively. Results obtained from the inclinometric monitoring network allowed the recognition of the rupture surface of the landslide between depths of 18.0 m and 18.5 m in borehole FSM1 and between depths of 15.5 m and 16.0 m in borehole FSM2. In general, the deformation velocity along the vertical profile of the terrain is uniform in borehole FSM1 and tends to decrease with depth in borehole FSM2. The behaviour of the kinematics of the landslide at depth is strongly determined by the higher or lower soil water content, as indicated by variations in the velocity of the displacement.