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Rockfall Analysis and Protection Measures Recommendations at Eptahori Village, Epirus, Greece

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This paper deals with a rockfall analysis in the northern steep slope at Eptahori Village, Epirus, Greece, which exhibits extended rockfall instabilities along its face, placing the village at the base of the slope at high risk. Along the examined slope, numerus older rockfall events were recorded. These rockfalls were caused by toppling of overhanging sandstone blocks formed by large tension cracks that were generated due to the erosion of the weak siltstone layers. The geological setting of the study area consists of molassic formations of "Eptahori" and "Pentalofo" units and more particularly by thick sandstone beds ("Pentalofos" unit) on the upper part of the slope, underlied by thin siltstone layers ("Eptahori" unit), which continues to the base of the slope. The structure of the rock mass is blocky, developed by bedding orientation NW – SE, dipping to the slope, which consists the main joint set of the rock mass as well by sub-vertical joints with orientation NNW – SSE within the thick sandstone layers (Figure 1). These joints act as tension cracks along the slope due to the loss of support of the eroded material. These joints are widened due to the high rate of atmospheric precipitation that enters these open discontinuities of the rock mass and to the temperature changes, creating significant unstable blocks along the slope.

Figure 1. (a) Face log of the slope to SW, (b) Major planes of the rock mass in Schmidt projection, (c) Resulting point cloud from LiDAR scanning

The objective of this paper is to assess the engineering geological model of the rockfall events, to evaluate the degree of rockfall hazard along the face of the slope and finally propose the protection structures along the slope. A detailed field survey of the geological and engineering geological conditions was executed during July – August 2018 along with field measurements. Moreover, terrestrial laser scanning (Light Detection and Ranging – LiDAR) (Fig. 1c) as well as Unmanned Aerial Vehicle (UAV) flights above the study area were made. According to the resulting images and the generated point clouds, the slope morphology and block structures were precisely determined. The unstable zones were also detected and volume measurements of hanging blocks were carried out so as to develop the engineering geological model of the slope and evaluate the behavior of the formations prior to rockfall.

Rockfall analysis were conducted by developing rockfall trajectory simulation models using RAMMS: Rockfall (RApid Mass Movement Simulation), which stands out to be a usefull and advanced modelling software in simulation of rockfall trajectories in three dimensions. According to these models, all the potential rockfall trajectories along the face of the slope were examined and the trajectories evaluated with high risk were analyzed, estimating the worst-case scenario of rockfall along the slope. Moreover, the parameters of motions of rocks were determined by the simulation results. The resulting model parameters were calibrated according to restitution coefficients in order to improve simulation results. The simulation model was developed by an accurate and detailed Digital Surface Model (DEM) of the terrain of the slope created by the high resolution resulting point cloud data set of LiDAR scanning. The input parameters of the model concerning the type of terrain and vegetation at the slope as well the best-fit simulation of rock bodies were determined in accordance with detailed field observation data (Fig. 2).

a) b)

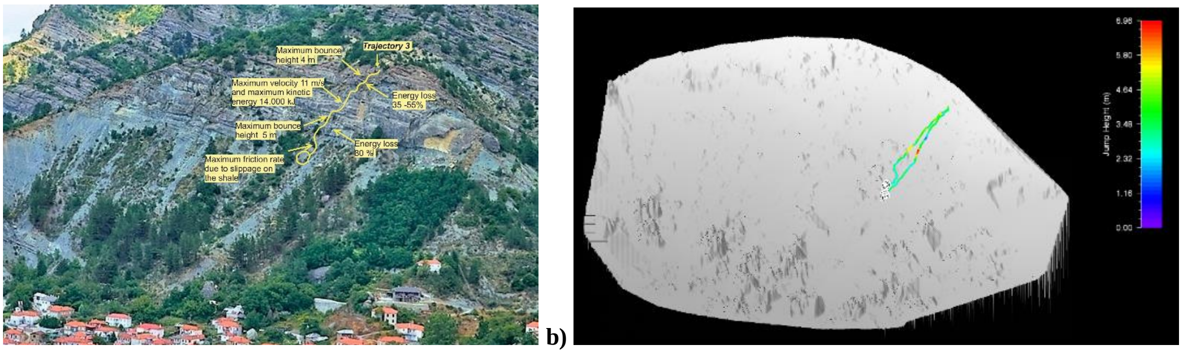

Figure 2. Simulation model of potential rockfall trajectory along the slope (a) displaying parameters of motion of rock, (b) in RAMMS: Rockfall.

According to the rockfall simulation model, the blocks develop an average jump height of 3 to 4 m with a local maximum of 8 m during bouncing at sandstone benches, where the velocity of the rocks range from 5 to 8 m/s reaching a maximum of 15 m/s. During their motion, the rocks develop high kinetic energy rates (8.000 – 12.000 kJ), which are reduced, as indicated by the values of the restitution coefficients, when sliding on the shale layers of the base of the slope. During this contact, friction forces are developed and provoke the absorption of high amount of kinetic energy. The trajectories are hence stopped at the base of the slope or continue with reduced velocity towards the toe of the slope, placing the residential zone at high risk. The rockfall potential along the slope was assessed as medium to high hazard degree, based on the rock mass quality, the volume of blocks, the history of older rockfalls, the steepness of the slope and the presence of unstable blocks.

A series of protection measures – both active and passive – are proposed in order to reduce the hazard to the lowest possible level. Active structures aim to decrease the probability of failure by surface drainage of the slope by construction of drainage ditches and protection measures (e.g. sprayed polymer coatings) from the erosion of the siltstone members. Passive protection structures are strongly proposed as effective measures in order to retain falling blocks and absorb impact energy (Fig. 3). In particular, the measures proposed are:

- Dynamic rockfall barriers (or flexible catch fences) constructed in two lines at the toe of the slope, up to a height of 3 m and energy absorption capacity of up to 10,000 kJ for the first line and a height of up to 2 m and energy absorption capacity of up to 8,500 kJ for the second line. Of course, these very high energies concern the worst-case scenario of the analysis.
- Ditches (rock traps) constructed in front of barriers 2 to 5 m wide with depth up to 1 m filled with soil material for the absorption of average energy of 10,000 kJ.

Figure 3. Recommended construction sites of dynamic rockfall barriers and ditches at the toe of the slope.

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