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Impulse waves generated by rock falls: Run-up assessment along a lakeshore (Lake Lucerne, Central Switzerland)

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The inoperative Obermatt quarry is an up to 160 m high rock face located directly at the lakeside of Lake Lucerne in Central Switzerland. Geologically the study site is situated in the Helvetic nappes and at its base consists of siliceous limestone (Kieselkalk Formation). The upper part of the quarry can be characterized by alternating limestone and weak marly layers (Drusbergschichten).
Several major rock fall events in the past are documented causing two human casualties in the 1960's, as a consequence of the failure of rock masses in the range of approximately 70'000 m3 and 100'000 m3. The most recent rock falls, occurring in 2007, involved volumes in the range of 10'000 - 20'000 m3. All events generated impulse waves with different heights in the lake, directly in the slope line of the instable rock face. The 1-2 m high waves reached the community of Weggis at the opposite lakeside at 3.5 km distance, causing large damage to infrastructure along the entire lake shoreline.

The object of this study was to assess the structural predisposition of potential rock slope instabilities that menace to fail, plunge into the lake and induce impulse waves. The wave propagation and its variability across the lake and along the vulnerable lakeshore were studied. As a consequence from the hazard assessment several monitoring systems and structural measures in the source as well as the potentially affected areas across the lake were evaluated.

Due to the difficult access to the steep slope, structural and stability analyses have been carried out based on a High Resolution Digital Elevation Model (HRDEM) point cloud derived from terrestrial and airborne laser scanners. Besides detailed investigations of probable triggering factors of previous rock falls, potential instable rock masses where investigated by fieldwork (rappelling) and extensive image analysis of the scar area.

By compilation of field observations and structural data, unstable volumes ranging from 4'000 m3 to 309'000 m3 were distinguished. They were verified by structural analysis on the laser scanning point clouds and the failure mechanisms were calculated using the Sloping Local Base Level (SLBL) method and by geometrical criteria's. Eight potential instable volumes and three different failure mechanisms were detected, from which four scenarios where deduced based on different factor of safety calculations as well as geological/geomorphological considerations.

Wave heights, wave run-up and wave overtopping were calculated according to the VAW manual "Landslide generated impulse waves in reservoirs" for selected scenarios. The underlying equations had been empirically deduced from physical scale modeling. The calculation procedure was calibrated for the mentioned 2007 rock fall event by comparing the computed results with eyewitness accounts in order to increase its validity.

For two scenarios the wave height and run-up volume per lakeshore meter were calculated. The maximum wave height amounts to more than 7 m. Through detailed field work the geometry of the infrastructure was mapped. In a next step the wave broadening was analyzed and compared with previous events. Finally through a wave propagation map it was possible to identify impact intensities along the lake shoreline for each scenario.