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Subsurface deformation measurements during a fast shallow landslide triggered by rainfall

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A forested area in Ruedlingen, northern Switzerland, was selected to investigate the geotechnical and hydrological response of a steep slope prior to a rainfall induced failure. Artificial rainfall was applied according to a pre-planned schedule and parameters such as pore water pressure, volumetric water content, horizontal soil pressure, temperature, piezometric water level and subsurface deformations were monitored. The latter were determined from four deformation probes that were developed in the Institute for Geotechnical Engineering, ETHZ. Strain gauges have been attached at a regular spacing along a long, slender, flexible plate to enable measurements of bending strain to be made at different points along it. The strain gauges were connected as "half bridges" to minimize the temperature effects. A biaxial inclinometer was also installed on the top of the plate, 20 cm above the soil surface, to measure the tilt above ground level, providing more boundary conditions to determine the deformed shape of the probe. The probe is installed vertically inside the soil, while the lowest part is grouted into the stiffer layer under the topsoil, and is assumed to be stable and without any rotation. Bending strains and the inclination at the top of the probe are sampled at a frequency of 100 Hz. These are input into an algorithm to determine a polynomial relationship of deformations and rotations with depth, so that the initiation of slow movements and propagation of failure during fast soil mass movements can be examined.

A 4-camera arrangement was used for the image acquisition to monitor surface movements using photogrammetric analyses. Approximately 250 white ping-pong balls were attached to the ground and used as target points. Using a network simulation tool that was developed in-house, an a priori point positioning accuracy of the ping-pong balls was estimated to be $\pm$ 10.3 mm along the horizontal direction and $\pm$ 3.5 mm in the vertical direction. The cameras operated at a data acquisition rate of circa 8 frames per second (fps). Image measurements were made using the Least Squares image matching method, which was implemented in another in-house developed software package (BAAP) to compute 3D coordinates of the balls.

Two sprinkling experiments were conducted in Ruedlingen, in autumn 2008 and spring 2009, the second of which resulted in mobilising about 130 m3 of debris. In the second sprinkling experiment, the area of interest was moved ca. 5 metres up the slope. In order to make the targets more discernable on the image space, the ping-pong balls were replaced with approximately 80 white tennis balls. A posteriori point positioning accuracy obtained from bundle adjustment in the first sprinkling experiment was $\pm$ 16.5 mm along the horizontal direction and $\pm$ 3.4 mm along the vertical direction. For the second experiment, these values were $\pm$ 11.0 mm and $\pm$ 4.3 mm for the horizontal and vertical directions, respectively.

The results of subsurface deformation during this shallow landslide event are presented and compared with surface movements determined from photogrammetric measurements.