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Hydrologic behavior of a steep forested slope prone to shallow landsliding

Matteo Berti and Alessandro Simoni

Dipartimento di Scienze Biologiche, Geologiche e Ambientali, Università di Bologna, Via Zamboni 67, 40127 – Bologna (ITALY). matteo.berti@unibo.it

Over the past ten years, the frequency of debris flows in the Northern Apennines of Italy has significantly increased. Gravitational movements in the area are dominated by slow-moving landslides involving fine-grained soils and, to a lesser extent, by shallow slips in weathered arenaceous rocks. During the past 5 years, at least 20 debris flow events were triggered by exceptional rainfall events. Although no fatalities of injuries resulted from these landslides, the appearance of this new danger generated great concern among local communities. The Civil Protection Agency of the Emilia-Romagna region therefore decided to produce a debris flow susceptibility map to target high-risk zones and to help local authorities in emergency planning. This task, however, is particularly difficult due to the lack of historical data required to apply heuristic or statistical methods. In this context we installed a monitoring system on a representative slope in order to investigate the hydrologic response to rainfall and to support the choice of a suitable deterministic model.

The selected slope is close to the village of Porretta Terme (Province of Bologna, Italy) at an elevation of 510 m asl. The slope has an inclination of about 30° and consists of a thin soil cover (0.5-1 thickness) lying over a fractured arenaceous bedrock. The soil is a well-graded sand with silt, gravel, cobbles, and weathered rock blocks. The slope is densely vegetated with grass, shrubs and mature trees. Part of the slope failed on the 30th November 2008 after a rainfall of 140 mm in 24 hours. A shallow slide of the soil mantle rapidly mobilized into debris flow leaving the bedrock exposed in the source area. The monitoring system is located on an unfailed slope close to the initiation area. The system consists of three stations aligned along the maximum slope at a distance of 15-20 m. Each station is equipped with: i) an open-standpipe piezometer installed near the soil-rock interface (1 m deep); ii) three tensiometers installed in the soil cover at different depths (0.2, 0.5 and 0.8 m); iii) three soil moisture capacitance sensors installed beside the tensiometer probes. The uphill station also includes an ultrasonic sensor for measuring snow depth and a barometric/temperature sensor. A tipping-bucket rain gage is installed in an area free of tree vegetation located 50 m further uphill. All the data are recorded every 10 minutes and stored on site.

The monitoring system was installed in September 2012 and the first two years of data provide a consistent picture of slope hydrology. During all the dry season (from June to September) the sandy soil is essentially dry with strong negative pore pressures (less than -80 kPa). Occasional summer rainfall causes the infiltration of water into the unsaturated soil but the soil never approaches the saturation, nor groundwater is accumulated at the soil-rock interface. With the start of the wet season (around October) the soil water content progressively increases and the pore pressure rises to values detectable by the tensiometers (higher than 80 kPa). The soil, however, remains generally unsaturated with negative pore pressures in the order of -20/-30 kPa. Full saturation is temporarily reached in response to intense rainfall events. Rainfall water induce fast, transient pore pressure increases in the soil mantle and moves vertically toward the soil-rock interface, eventually leading to the development of a transient perched water table during the heaviest rainfall events. The thickness of the perched water table is clearly related to rainfall intensity (very intense rainfall may saturate up to 80% of the soil profile) while the contribution of lateral flow is less evident probably because it is dominated by macropores or because because bedrock fractures favour deeper circulation.