Experimental analysis of seasonal processes in shallow landslide in a snowy region through downscaled observations

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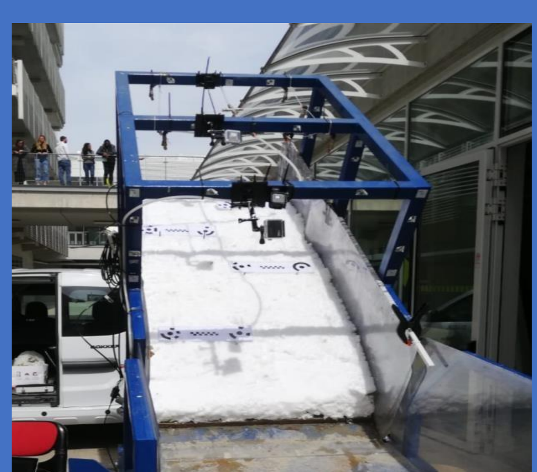
1 SHALLOW LANDSLIDES

Mountain areas exhibit seasonal behaviour with high rainfall intensity events during summer, snow depositing during winter and snow melting in spring.

Several studies were carried out with the aim to deeply investigate the rainfall-induced shallow landslide (Zhang et al. 2014; Ivanov et al., 2021). However, the role of snow melt remains a challenge. That leads this research to focus on how snow layer might influence the stability and the occurrence of slope failure.



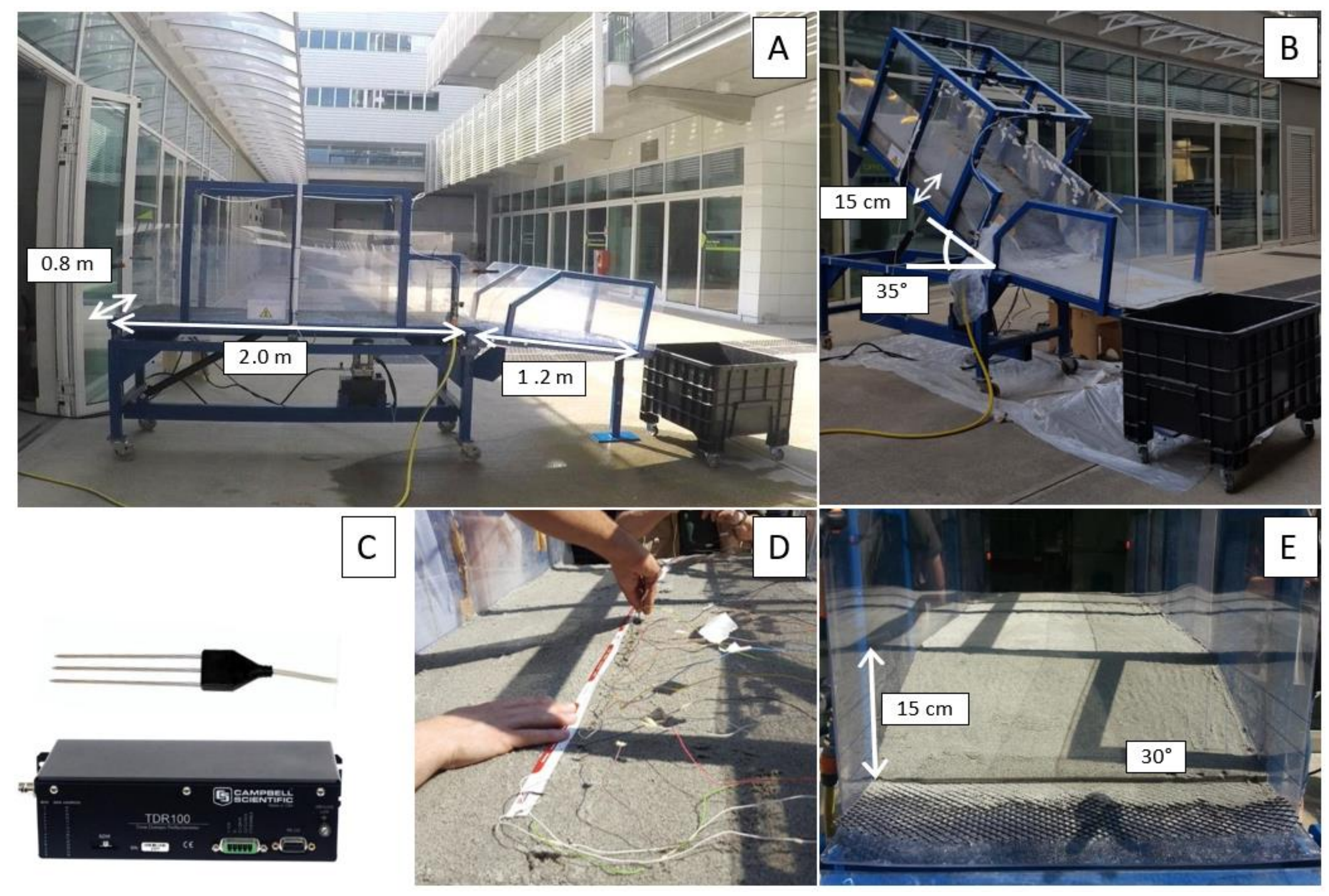
Some authors experienced that during the snow melting period, the permeability of the upper strata of the soil became less permeable due to the increment of the load, reducing the infiltration rate and increasing the runoff process (Osawa et al., 2017). Water reached the downstream slopes by filtration and infiltration increasing the pore water pressure to saturation and getting closer to the limit state of soil on a steep slope (Hinds et al., 2021).

2 METHODS

According to the work in situ done by Hinds et al., 2021 , laboratory experiments have been carried out with the objective of simulating a slope covered by snow on a landslide simulator. In this way many variables have been controlled in the experimental analysis to verify the effects of snow melt under winter, spring and summer conditions.

A multidisciplinary approach has been exploited in order to best investigate the phenomenon from a wider point of view; photogrammetry, geophysical and geological approaches (Ivanov et al., 2020) were used to reach a more accurate interpretation of the dynamic of melting and water circulation.

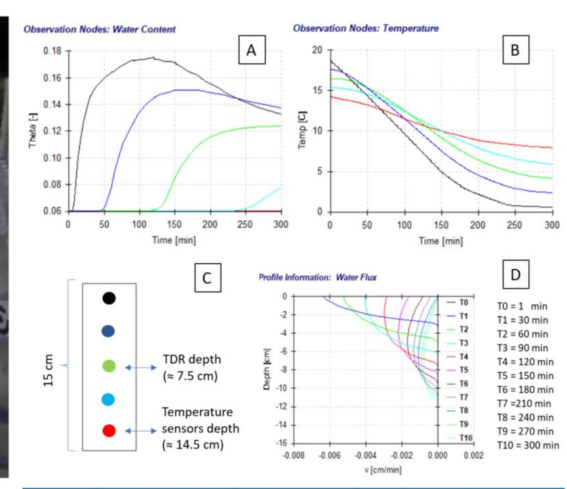
The results derived from the monitoring on the downscaled landslide have been compared with the ones obtained from the software **HYDRUS 1D** to verify if the numerical solutions fit the downscaled physical processes.

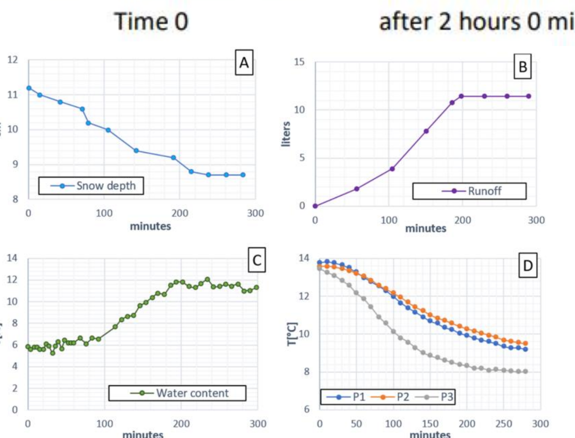


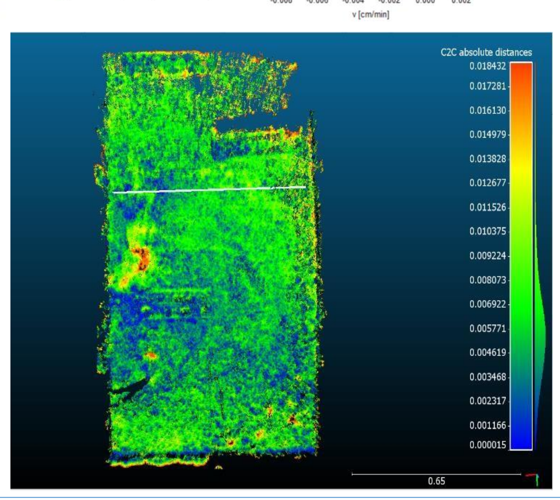
A: Simulator geometry without soil and in horizontal position. **B**: Simulator inclined of 35° with a soil layer of 15 cm positioned on the slab; **C**: TDR probe; **D**: electrodes array for the geo-resistivity survey; **E**: soil foot frontal view

3 EXPERIMENT 1 – WINTER CONDITONS

Time 0 | after 2 hours 0 min 0 sec. | after 3 hours 58 min 0 sec.



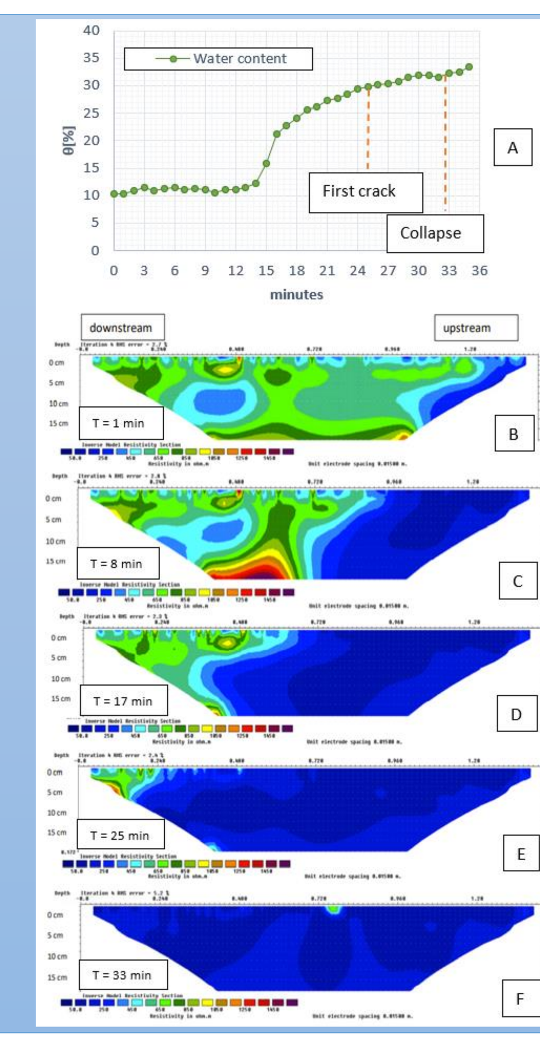




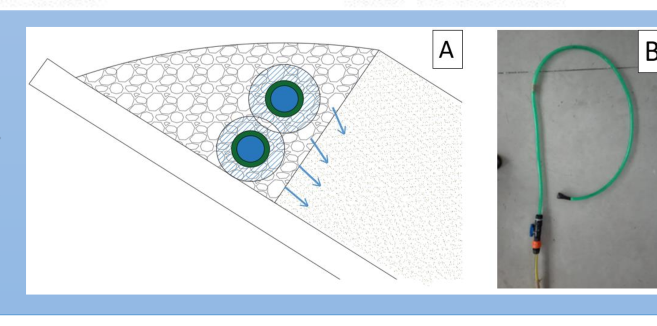
A: Snow depth evolution recorded by observation; **B**: cumulated runoff water gathered inside the bawl along the experiment; **C**: volumetric water content **D**: temperature registered by the three sensors placed along the landslide simulator.

4 EXPERIMENT 2 – SPRING/SUMMER CONDITONS

Time 0 | after 31 minutes | after 42 minutes

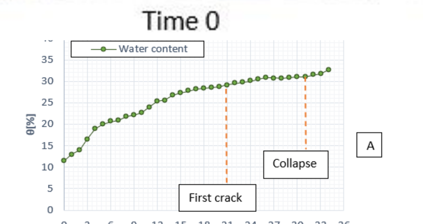


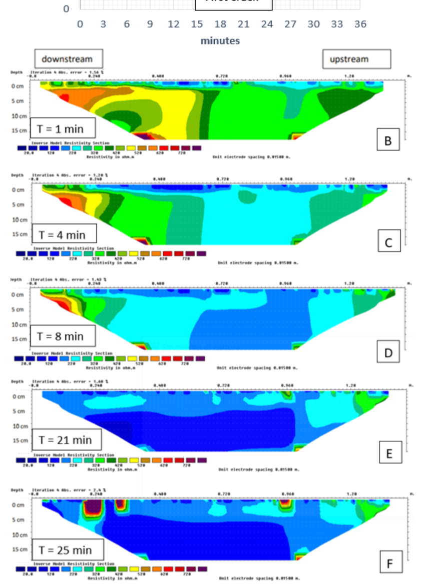
Considering seasonal cycles, this experiment started with the initial water content equal to the final water condition of Experiment 1. Water was provided by a self-built drain placed upstream the soil layer.



5 EXPERIMENT 3 – AUTUMN CONDITONS

Time 0 | after 23 minutes | after 34 minutes

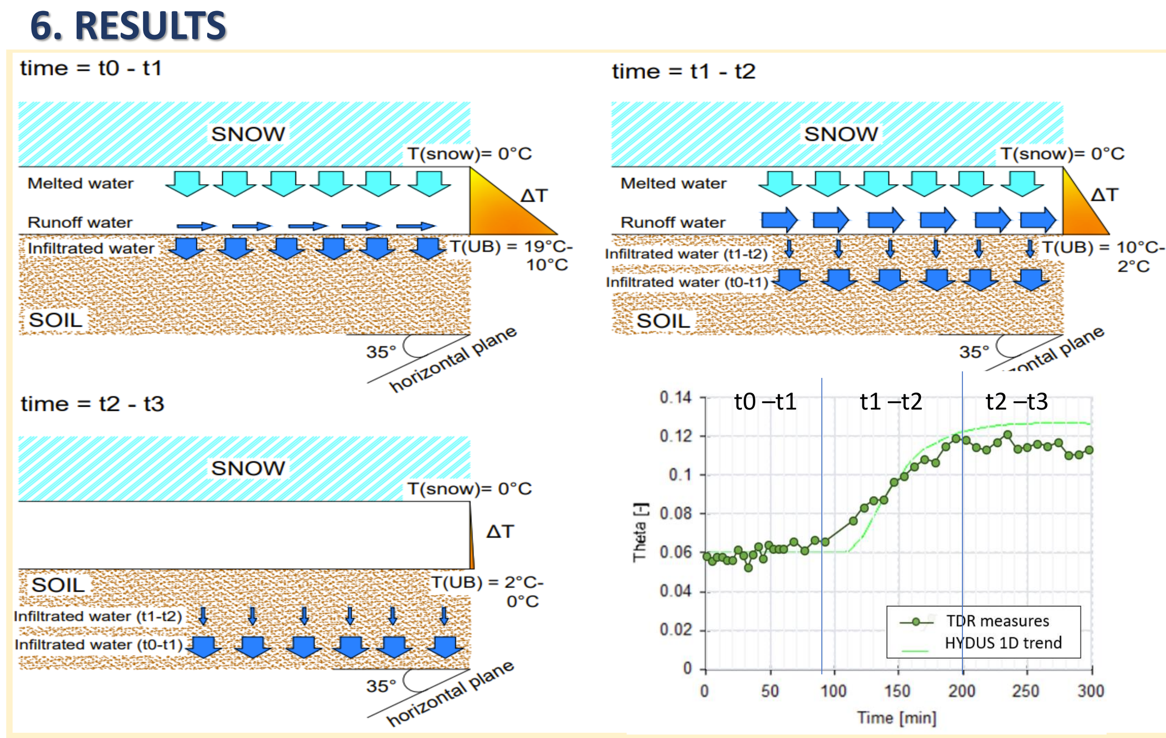




This test was useful to compare the role of water due to snowmelt (experiments 1 and 2) with rainfall condition. The same initial water content (11 %) of Experiment 2 was settled. Moreover, the same water intake of the previous simulation was applied, in fact, it had been converted the discharge of 1.7 l/s, provided upstream by the drain, into a rainfall intensity of 72 mm/h.

After 21 minutes, it was possible to notice the presence of the first crack, which was located in the upper part of the soil (Fig. 11E). The blue zone in the lower left part, registered the accumulation of water close to the foot which collected the infiltrated rain flowed till this point by gravity.

6. RESULTS

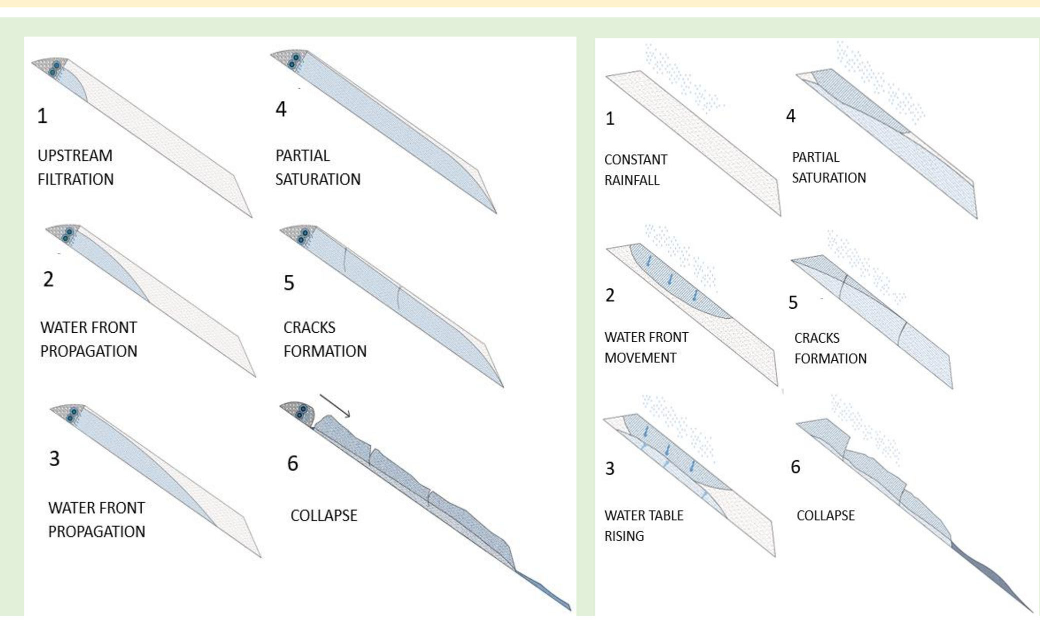


1) t_0 = 1 min, T_{UB} = 19 ° C; t_1 = 100 min, T_{UB} = 10 ° C: the snow melted due to the remarkable thermal gradient between the two layers, there was more infiltration than runoff. Conspicuous water percentage infiltrated and part of it ran off among the inter-layer, the thermal gradient between soil and snow began to decrease.

2) t_1 = 100 min, T_{UB} = 10 ° C; t_2 = 200 min, T_{UB} = 2 ° C: snow continued to melt due to the residual temperature gradient, but lower ground temperatures favoured more runoff than infiltration. The water barely infiltrated, soil temperature decreased but it remained high enough to melt snow, leading to most of the water to runoff on the surface rather than infiltrate.

3) t_2 = 200 min, T_{UB} = 2 ° C; t_3 = 300 min, T_{UB} = 0 ° C: the thermal gradient between the two layers was almost erased, the snow in the interlayer no longer melted, there was a stationary phase, in which no runoff or infiltration occurred. Without new income from upper BC, water just migrated downward the soil layer. The thermal gradient between snow and ground was cancelled out, the ground no longer transmitted heat to the snowpack, making sure that it no longer melted. A stationary situation was reached.

The transverse water circulation of Experiment 2 brought to a very fast slip involving all the soil portions simultaneously. On the contrary, the Experiment 3 conditions brought to a slower collapse mechanism with differential movements of the portion involved. Therefore, different seasonal conditions can lead to different failure mechanism, which directly affect the phenomena hazard level.



CONCLUSIONS

- Through this careful experimental analysis, it can be seen that the direct interaction between snow and ground does not favour the infiltration of a large amount of water.
- The protective role of snow lies in keeping the first film of soil at 0 degrees and loading the soil by decreasing its infiltrative capacity; this no longer occurs when the water, melted by the snow, flows downstream and begins to infiltrate into uncovered and warmer soils.
- the runoff water supplied by the melting, flowing through channels and concave morphologies, can concentrate in some areas no longer covered by the snow layer. Without thermal or overload barriers, the water pours into the ground. Therefore, a potential susceptible area can be the victim of different filtering and infiltrative contributions from upstream, saturating quickly and collapsing. For these reason, ground temperature and snowpack presence become significant parameters for a proper definition of the triggering thresholds in a snowy region.

FUTURE WORKS

- Analysis of the effect of the depth of snow layer in the downscaled experiments.
- Experiments with different weather conditions.
- mathematical model to evaluate the behaviour of water and snow considering the equation of fluids in porous media based on *porepy* (Keilegavlen et al., 2021).

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