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S-wave velocity as an indicator of solid-liquid transition in clay

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Clayey landslides, which are widely spread all over the world, pose specific problems to territorial planners, owing to dramatic variations in kinematics. Indeed, the analysis of landslide movements in a clay-rich area like the Trièves plateau (French Western Alps) indicates that slow slope movements can suddenly accelerate or fluidize as a result of heavy and/or long-lasting rainfalls or loading. Previous rheometric tests performed on the Trièves clay revealed a thixotropic behavior of the clay with a highly pronounced viscosity bifurcation at a yield stress τc. Below that stress, the material behaves like a solid, while it abruptly starts flowing when this yield stress is reached.

This solid-liquid transition was investigated by measuring the variations of the shear wave velocity (Vs) in the Trièves clay during rheometric tests and flume tests. First, rheometric parallel-plate tests were performed at 3 different clay water contents (52%, 66% and 78%). Oscillatory stress tests were conducted during the experiments, allowing the shear modulus and Vs to be measured as a function of the shear stress level. Results revealed a dramatic Vs change at the same yield stress as for the viscosity bifurcation. When the stress is lower than the yield stress, Vs regularly increases with time up to a limit value. As soon as the yield stress is reached, Vs abruptly decreases to reach values of a few m/s in the fluidized clay.

In order to investigate at a larger scale (approximately 1 m) the evolution of the shear wave velocity during the clay fluidization, flume tests were performed for two clay water contents (57 % and 68%). These experiments consist in progressively tilting a flume filled with a saturated clay layer (35cm wide, 60cm long and 10cm deep) until reaching the fluidization at a given slope. The Rayleigh wave velocity (VR), which is related to Vs, was continuously monitored using a piezometric source and 4 vertical component accelerometers placed at the surface of the clay layer. The Rayleigh wave propagation was reconstructed by cross correlating the source signal (50-700 Hz sweep) and the 4 recorded signals. The clay mass motion was measured, using 3 height sensors (vertical displacement) and a digital camera to follow the displacement of three superficial markers (colored pins). The tilt angle, which increased by 1 degree per minute, was given by an inclinometer placed on the flume. Signals were generated every 30 seconds. Results showed no variation of VR during the flume tilting. Just before that the mass moved at a critical angle, a rapid decrease in VR (between 4 and 7%) was observed on all the signals, evidencing a change in Vs at the base of the layer.

Both experiments showed that Vs could be a valuable good indicator for rheological changes in clay. The seismic measurements during flume tests are in agreement with passive seismic monitoring results at the Pont Bourquin landslide (Switzerland), where a drop of 7% in VR was measured 4 days before a earth-slide earth-flow in 2010, which mobilized about 4,500 m3 of clay material.