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Velocity profiles and plug zones in a free surface viscoplastic flow : experimental study and comparison to shallow flow models

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Rheological studies concerning natural muddy debris flows have shown that these materials can be modelled as non-Newtonian viscoplastic fluids. These complex flows are generally represented using models based on a depth-integrated approach (Shallow Water) that take into account closure terms depending on the shape of the velocity profile. But to date, there is poor knowledge about the shape of velocity profiles and the position of the interface between sheared and unsheared regions (plug) in these flows, especially in the vicinity of the front. In this research, the internal dynamics of a free-surface viscoplastic flow down an inclined channel is investigated and compared to the predictions of a Shallow Water model based on the lubrication approximation.

Experiments are conducted in an inclined channel whose bottom is constituted by an upward-moving conveyor belt with controlled velocity, which allows generating and observing gravity-driven stationary surges in the laboratory frame. Carbopol microgel has been used as a homogeneous and transparent viscoplastic fluid. High-resolution measurements of velocity field is performed through optical velocimetry techniques both in the uniform zone and within the front zone where flow thickness is variable and where recirculation takes place. Specific analyses have been developed to determine the position of the plug within the surge. Flow height is accessible through image processing and ultrasonic sensors.

Sufficiently far from the front, experimental results are shown to be in good agreement with theoretical predictions regarding the velocity profiles and the flow height evolution. In the vicinity of the front, however, analysis of measured velocity profiles shows an evolution of the plug different from that predicted by lubrication approximation. Accordingly, the free surface shape also deviates from the predictions of the classical Shallow Water model. These results highlight the necessity to take into account higher-order corrective terms in Shallow Water models in order to better account for the internal dynamics of the fluid layer.