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Theoretical study of debris flow – structure interactions using a SPH-based numerical model

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The understanding and quantification of debris flow – structure interactions in terms of modification of the incident flow and impact force applied to the obstacle are of paramount importance for the conception and design of structural countermeasures. However, to date, only a limited number of studies has been carried out on that subject, with the consequence that the design of check-dams and other countermeasures against debris-flows, remains essentially empirical and widely depends upon the experience accumulated for several decades by field engineers.

The general goal of the study presented is to characterize the influence of the protection structure on the flow and for instance to quantify the flow energy loss, but also to characterize the impact force applied to the protection structure : its evolution versus time, quantification of the peak intensity of the strength and distribution of this latter on the face of the structure submitted to the debris-flow impact.

In that aim, we have developed a theoretical study of the flow – structure interactions based upon a new numerical model (Lachamp 2003). This model is based upon the SPH (smoothed particles hydrodynamics) numerical method. SPH is a particular method of treatment of fluid mechanics equations (Monaghan 1994) : particles used in the method are not physical, they must be considered as a mean of representation of a fluid having some rheological characteristics given by an apparent viscosity. This apparent viscosity makes it possible to deal with different types of fluids. In the present study, we have considered some viscoplastic fluid with a Herschel-Bulkley type rheological behaviour suitable for viscous debris-flows (Coussot 1992), but other types of rheology have been successfully tested (Lachamp et al. 2002). After some specific treatment of the fluid – channel bed interaction (Monaghan 1989), SPH is suitable for the computation of highly transitory free surface flows of complex fluids in complex geometries. Thus, it is suitable for the treatment of debris-flow waves – structure interactions. A 2D vertical model is presented in the present paper but its extension to full 3D presents no major theoretical problem. It requires however large computation capacities.

In the present paper, we present first the main features of the SPH model. SPH simulations are compared to theoretical velocity profiles of steady free surface flows of viscoplastic fluids. Several simulations of steady flow – obstacle interactions are presented. Results are analysed in terms of reduction of the flow velocity and increase of the pressure and flow depth in the vicinity of the obstacle versus the obstacle height.

Several simulations of transitory flow – obstacle interactions are presented. Results are systematically compared to reference flows (same conditions but without obstacle). The influence of the obstacle on both flow depth and momentum is analysed. The evolution of the dynamic pressure applied to the obstacle versus time is established. Values of the peak intensity of the pressure are given and compared to those of the reference flow. Finally, the distribution of the peak pressure on the upstream face of the obstacle is presented.

Considering theoretical results are of great interest but still need to be confirmed, the numerical approach will be completed shortly by some experimental analysis whose goal is to analyse the modification of the flow during the short time of impact and in the vicinity of the structure (using image analysis techniques) and to record the dynamic pressure applied to the structure by the transitory free surface flow of some viscoplastic fluid (use of small pressure cells). In the future, we also intend to analyse observations of real field structures damaged by debris flows.

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