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MPM simulations of the impact of fast landslides on retaining dams

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Abstract. Possible protection systems against flow-like landslides are earth dams built to stop or deviate the flow. The evaluation of impact forces on the structures is still based on oversimplified empirical approaches, which may lead to a very conservative design, with high costs and environmental impact. Numerical methods able to capture the essential features of the phenomenon can offer a valuable tool to support the design of protection measures. This paper shows the potentialities of the Material Point Method (MPM) in this field. A dry granular flow, modelled with the Mohr-Coulomb model is considered. The landslide is placed in front of the barrier with a prescribed velocity and the impact forces on the slanted face is monitored with time.

Keywords: MPM, fast landslides, protection dams.

1 Introduction

Landslides of the flow-type, such as rock or debris avalanches, and debris flows, are among the most dangerous natural hazards worldwide. To reduce the associated risk, defense structures such as earth dam can be used to stop, deviate or slow down the flow. The design of these structures requires the knowledge of the impact forces, which are customarily estimated with empirical approaches. These simplified methods have a high level of uncertainties that sometimes lead to very conservative design of the structures with a significant environmental impact. Numerical models can support the design of these structures, thus leading to a more efficient implementation of the risk mitigation measures. In this paper, we analyze the potentialities of the Material Point Method (MPM) in this field.

MPM is a continuum particle-based method specifically developed for large deformations of history dependent materials. It simulates large displacements by Lagrangian points moving through an Eulerian grid. A 3D MPM code (Anura3D) featuring a specific algorithm to model soil-structure interaction and frictional sliding is applied in this study. The software has been recently validated in a number of geomechanical problems see e.g. [2–4] and references therein.

In this paper, the propagation phase of the landslide is disregarded and we focus on the impact forces generated on a slated rigid structure by placing the dry soil mass, with an initial prescribed velocity, in front of the barrier.

2 Numerical model

The mass is initially positioned in front of the barrier with a prescribed velocity v_0 varying between 4 and 32m/s. The flow is 3.0m thick and 15.0m long. The model is 0.2m wide. The numerical results are normalized with respect to the model width. The obstacle is 6m-high and all the boundaries, as well as the structure face, are assumed to be smooth. Different inclinations of the barrier face (β) are considered. The mesh is refined in the proximity of the obstacle. 20 MPs are initially placed inside each active element (yellow color in Fig. 1). The structure is assumed to be rigid, i.e. the MPs do not move and the nodal velocity is zero (thus the MPs do not move and the nodal velocities are set to zero).

The behavior of the soil is modelled with a linear elastic perfectly plastic model with Mohr-Coulomb failure criterion. The reference parameters are summarized in Table 1.

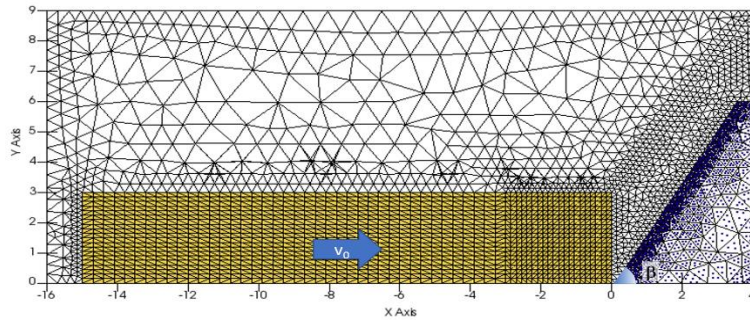


Fig. 1. Geometry and discretization of the numerical model

Table 1. Material constitutive parameters

Parameter	Symbol	Value
Solid density [kg/m ³]	ρ_s	2650
Porosity [-]	n	0.45
Friction angle [°]	φ	33
Young modulus [kPa]	E	58000
Poisson ratio [-]	ν	0.2

3 Results

During the impact, the material climbs the wall decelerating and it exerts a pressure on the surface, which has a horizontal and a vertical component (Fig. 2a). To properly design these structures, both these components are important and they are considered

separately in the following. Both the impact force components (F_x , F_y) increase with time up to a peak value, at slightly different instants (Fig. 2b).

Decreasing the structure face inclination β , the horizontal force decreases, while the reduction of maximum vertical force is less significant. The horizontal force is significantly lower than the case of $\beta=90^\circ$, moreover F_{max} varies non-linearly with v_0 .

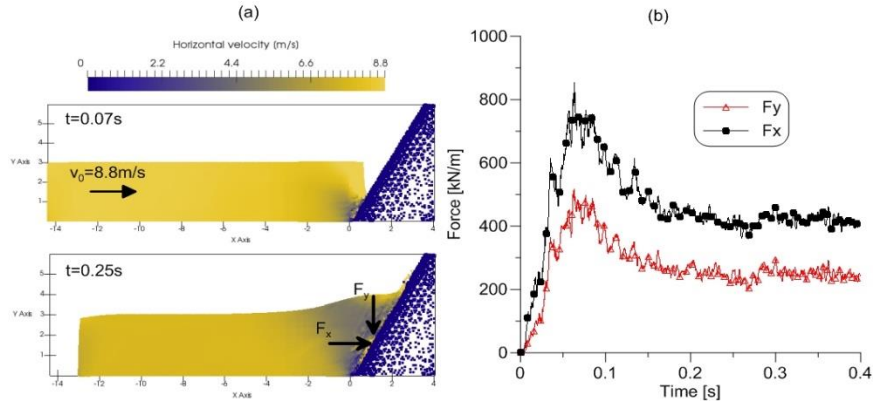


Fig. 2. (a) Horizontal velocity of the landslide impacting the structure at different instants. (b) horizontal and vertical forces on the structure face along time. ($\beta=60^\circ$, $v_0=8.8m/s$)

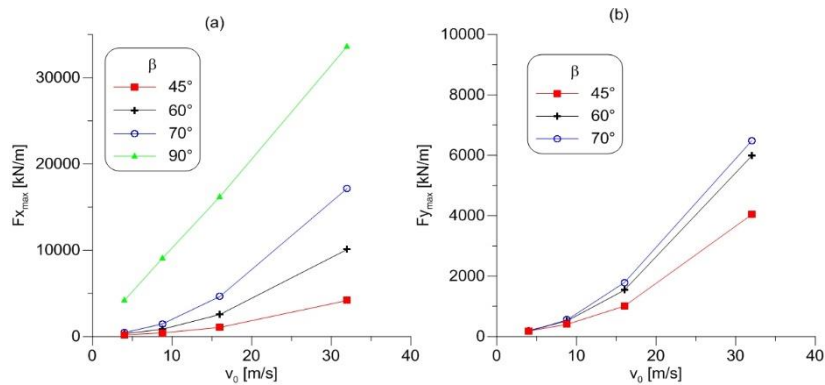


Fig. 3. Maximum horizontal (a) and vertical (b) force on the structure for different impact velocities and face inclinations.

Slanted structures can be built with compacted granular materials or with the use of geosynthetics, to improve soil strength and reduce the dimensions of the dam by using steeper faces. An important parameter for the design of the geogrids applied in earth reinforced walls (ERW) is the horizontal force at the level of a potential sliding plane between the soil and the geogrid. Moreover, the global stability of the dam must be considered. Several procedures have been proposed for the design of these structures in static conditions [1], but their design under impact loading is not yet supported by a comprehensive scientific literature.

The structure face is divided in 6 parts and the evolution of the force exerted by the landslide at the level of each grid is monitored (Fig. 4a). This may be of interest for the definition of the reinforcement length in ERW.

The impact force reaches its maximum at a different time for each considered grid, thus the pressure distribution assumed for the global stability of the structure could be inaccurate to study the internal stability of the wall. The maximum impact forces for each strip is shown in fig. 4b where it should be noted that the maximum force increases non-linearly with depth.

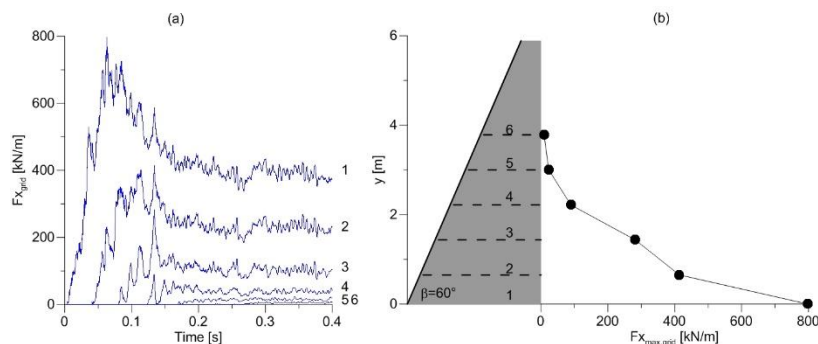


Fig. 4. (a) Evolution of the horizontal force at the level of each grid with time. (b) Maximum horizontal force at the level of each grid.

4 Conclusions

This paper presents some preliminary analyses that show the potentialities of the MPM in simulating the impact of flow-like landslides on ERW. This is relevant for the global and internal stability of these structures, for which a comprehensive scientific literature of design under dynamic loading is still missing.

Future developments of the research will investigate the internal stability of these barriers and the impact of soil-water mixtures.

References

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