A Lagrangian finite element approach for the numerical simulation of landslide runouts

Massimiliano Cremonesi[a *], Francesco Ferri[b] and Umberto Perego[c]

Department of Civil and Environmental Engineering, Politecnico di Milano, Italy

[a]massimiliano.cremonesi@polimi.it, [b]francesco.ferri@polimi.it, [c]umberto.perego@polimi.it

* corresponding author

Keywords: landslide simulation, Lagrangian finite element approach, slip boundary conditions

Landslides are extreme natural phenomena frequently occurring in our country and causing casualties and extensive damage to residential structures, infrastructures and to the historical and cultural heritage.

The numerical simulation of these events requires capabilities for tracking evolving interfaces and free surfaces, accounting for the mixing of different constituents, for complex constitutive behaviors, extremely large deformations and possible multi-physics processes.

Recently, several scientific contributions have treated landslides as viscous fluids in motion (see e.g. [1]), an approach that has opened the way to new applications of computational methods conceived for the simulation of fluid problems. While in the case of fluids most approaches are developed in an Eulerian framework, in the case of landslides, the complex constitutive behavior of the soil and the rapidly evolving free surface are more appropriately modeled with a Lagrangian approach. The PFEM (Particle Finite Element Method) [2] is an innovative Lagrangian numerical method, particularly suited to the solution of problems with interactions between fluids and structures.

In the PFEM, the Navier-Stokes equations, governing the motion of fluids and structures, are approximated using a material formulation (Lagrangian) in which the mesh nodes move together with material particles. For this reason, in order to emphasize the material description of motion, the nodes are named 'particles'. All the physical properties such as density, viscosity, velocity, position, and other variables such as temperature, are assigned to the particles and are transported during the motion of the mesh nodes. The problem of elements distortion due to the large deformations of the moving fluid, is solved with a very efficient and continuous mesh re-triangulation based on the Delaunay technique [2,3,4] and driven by a fast and effective geometric distortion criterion.

A non-Newtonian constitutive law has been introduced to describe the behavior of the granular material, which is assumed to be incompressible in the landslide running out regime. The deviatoric stress is related to the deviatoric strain rate $\dot{\gamma}$ through an apparent viscosity $\hat{\mu}$ defined as:

$$\hat{\mu} = 2\mu + \frac{p\tan(\varphi)}{|\dot{\gamma}|}\left(1 - e^{-n|\dot{\gamma}|}\right)$$

where p is the pressure field, φ is the friction angle and n is a regularization parameter.

To better describe the interaction between the moving landslide and the slope substrate, slip boundary conditions have been introduced. The velocity component along the slope u_t^{slip} is written as:

$$u_t^{slip} = \beta(\tau_{nt} - \tau_0)$$

where τ_{nt} is the tangential stress, τ_0 represents a stress threshold, below which no slip can occur, and β a parameter, having the dimensions of a length over a viscosity, defining the amount of slip. This condition states that the slip is resisted by a tangential force proportional to the relative velocity. For $\beta = 0$ the no-slip boundary condition is recovered, while $\beta \rightarrow \infty$ represents the stress free boundary condition.

The proposed approach has been validated against experimental tests, showing a good agreement with the expected results. In Fig. 1 an example of a tridimensional simulation of a landslide along a slope is presented.

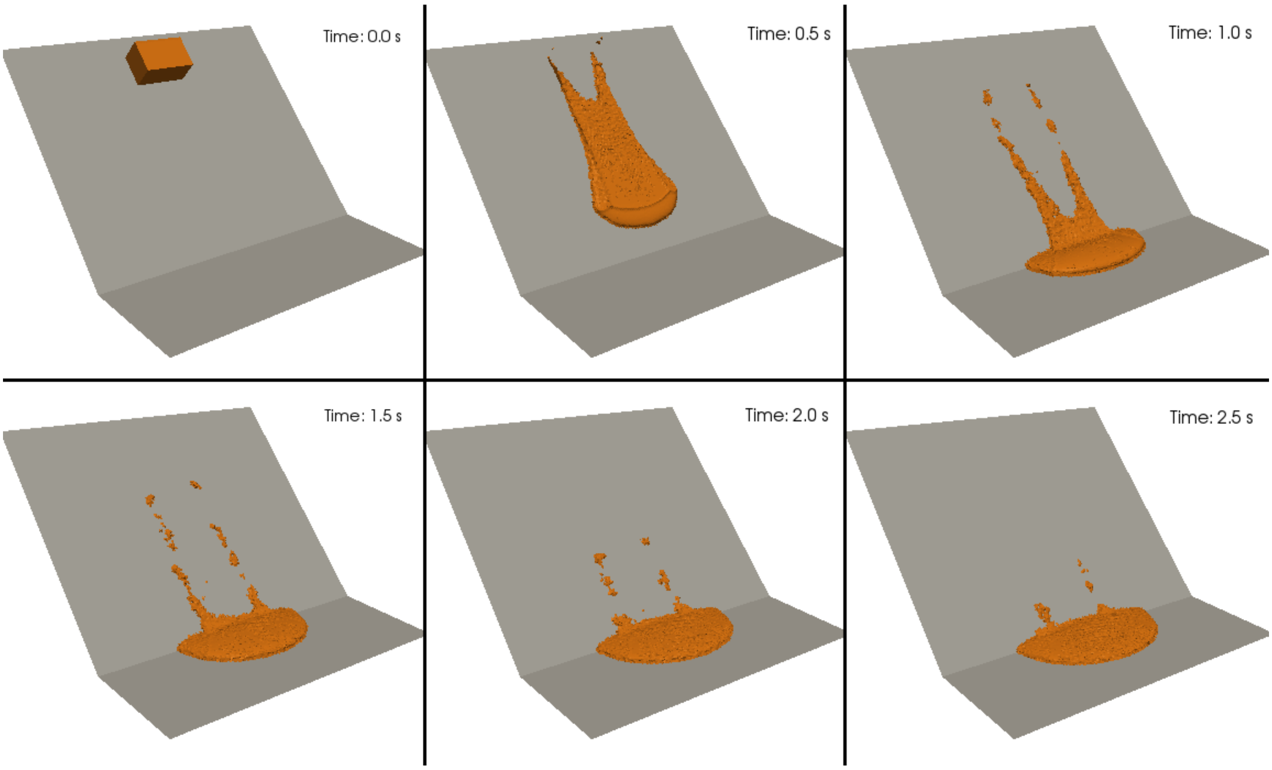

Figure 1: Propagation of a landslide on a slope: snapshots at different time istants.

References

[1] M. Quecedo, M. Pastor and M.I. Herreros, Numerical modelling of impulse wave generated by fast landslides, *International journal for numerical Method in Engineering*, 59(12), pp.1633-1656, (2004).

[2] E. Oñate, S.R. Idelsohn, F. del Pin and R. Aubry. The Particle Finite Element Method. An Overview. *International Journal Computational Method*, 1(2), pp. 267-307, (2004).

[3] M Cremonesi, A. Frangi, A. and U. Perego, A Lagrangian finite element approach for the analysis of fluid-structure interaction problems. *International journal for numerical Method in Engineering* 84:pp 610-630 (2010).

[4] M.Cremonesi, A. Frangi, U. Perego, A Lagrangian finite element approach for the simulation of water-waves induced by landslides, *Computers &.Structures*, 89(11-12), pp. 1086-103, (2011).