Towards robust landslide simulations from initiation to post-failure using the Smoothed Particle Hydrodynamics

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論 文 名　：　Towards robust landslide simulations from initiation to post-failure using the Smoothed Particle Hydrodynamics
(Smoothed Particle Hydrodynamics による斜面崩壊の発生から崩壊後までの堅牢なシミュレーションに向けた基礎研究)

区　　分　：甲

論　文　内　容　の　要　旨

The primary objective of this Ph.D. thesis is to show some advancements towards numerical simulations of landslides with the Smoothed Particle Hydrodynamics (SPH) method, from initiation to post-failure behavior. Specifically, the author developed two different techniques that might be applied depending on the initiation process of the landslide: a soil-water strong coupling formulation, when the landslide is initiated by the increase of pore water pressure; and a multi-physics approach when the primary instability source are external forces such as earthquakes.

The soil-water strong coupling formulation is based on the full set of Biot's equations, and the stress is updated in a hypoelastic-plastic manner. The scheme presented is called one point-two phases, where SPH particles represent the soil skeleton, while the water quantities are embedded into the SPH soil particles. Then, the incompressibility of the soil grains and pore water are enforced in the governing equations leading to a pressure Poisson equation, hence, this method is classified as an incompressible SPH method (ISPH). The greatest novelty of this method is the implicit time integration of the drag force, which decreases the constraint on time increments for soils with low permeability. Within this work, several numerical tests verify and validate the proposed method. In particular, the method is capable of simulating both drained and undrained conditions in the triaxial compression test using the modified Cam-Clay constitutive model. Lastly, the author demonstrates the robustness of the method in simulating a realistic landslide problem with the Selborne experiment.

As for the second approach, the author proposes to treat the landslide as a multi-physics problem, where its stable part is solved with Solid Mechanics, while the flowing part with Fluid Dynamics. The method consists of a highly accurate total Lagrangian SPH (TLSPH) formulation for the Solid Mechanics part with finite strain elastoplasticity for the stress update. Then, through a simple rupture criterion, ruptured particles change their physical status to a fluid phase with non-Newtonian fluid rheology in a fully implicit SPH method. In addition, the author proposes a newly developed solid-solid contact algorithm that considers both normal impact forces and friction. Finally, solving the Aso landslide problem, the method successfully simulates the initiation and post-failure behavior of the landslide as a natural consequence of the earthquake.

This work is divided into seven chapters as follows.

Chapter 1 is dedicated to explaining the motivation of this research, detailing the state-of-art in this topic and showing the outline of the Ph.D. thesis.

Chapter 2 summarizes the basics of the SPH method. First, it starts showing the several forms for the SPH approximations of generic functions and its spatial derivatives. Then, it introduces the ISPH projection method. Lastly, it presents a conventional approach to adapt the SPH method for Solid Mechanics problems with porous materials.

Chapter 3 presents a novel ISPH scheme to simulate saturated soils. A strong coupling technique models the interaction between soil and water phases in which the SPH particles represent the soil skeleton, while the water quantities are carried by such particles (also called one point-two phases scheme). This chapter also includes the newly developed implicit update of the drag force and several numerical tests such as the Selborne experiment

Chapter 4 is devoted to presenting TLSPH used for the stable part of the landslide, which eliminates the inaccuracies generated by uneven particle distribution. In addition to the presentation of the method, the author includes three main contributions: 1) the development of a Mathematically consistent solid-solid contact algorithm, 2) the introduction of a finite strain elastoplastic constitutive model with the logarithmic strain, and 3) the adaptation of a simple rupture criteria to initiate discontinuities during the simulation.

Chapter 5 presents a procedure to adapt the ISPH framework from chapter 2 to a fully implicit formulation, giving rise to the implicit ISPH (IISPH). In special, the Laplacian of velocity is calculated with an equation capable of conserving the angular momentum, which increases the overall accuracy. As a backdrop, it becomes necessary to solve a linear equation with three times the number of particles in the predictor step. Finally, the author uses the cross-model to model the Bingham plastic non-Newtonian rheology of the landslide mass.

Chapter 6 is devoted to concluding the multi-physics approach for simulating landslides coupling the TLSPH with the IISPH. Here, all soil mass starts as a solid body under the TLSPH numerical framework. Then, defining a fluidized particle as one that exceeds a threshold on plastic deformation, such fluidized particles become the fluid phase of the landslide, which are treated as a non-Newtonian fluid in the IISPH framework. Hence, the author regards this approach as solving a multi-physics phase-change problem.

The thesis concludes in Chapter 7, summarizing all chapters and presenting future works related to this topic.