学　位　論　文　内　容　の　要　旨
DISSERTATION ABSTRACT

博士の専攻分野の名称　　博士（工学）　　氏名　Ahmed Mohamed Abdelrazek Ibrahim

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Modeling and Analysis of Geo-disaster Problems Using the SPH Method
(SPH 法を用いた自然災害のモデリングと数値解析)

Geologic disaster is one of several types of adverse geologic conditions capable of causing damage or loss of property and life. It includes earthquakes, landslides, debris flow, soil liquefaction, rock falls, avalanches, tsunamis, and flooding. These disasters may be induced by natural factors and human activities, and can cause damage in infrastructures, property and lose of human life. Every year, millions of people all over the world experience the effects of geologic disasters. Hence, it is in a major importance to establish effective prediction methods for such events appear to be helpful. This study treats the destruction of recent geo-disasters in the world and basic characteristics of large deformation in those disasters. Based on a review of studies on large deformation simulation and its current limitations, a novel mesh-free particle method called Smoothed Particle Hydrodynamics is introduced, and its advantages and disadvantages are detailed. The basic concept of the SPH method and its innovation are also summarized here.

Our main target is to develop 2D (two-dimensional) and 3D (three-dimensional) models on the basis of the Smoothed Particle Hydrodynamics (SPH) method to simulate various phenomena in the science of computational fluid dynamic. The SPH method is a mesh-free Lagrangian method. It does not require Eulerian grids and deals with a number of particles in a Lagrangian framework.

We developed a Two-dimensional SPH model to simulate free surface flow problems, and we used it to simulate two benchmark tests, (collapse of a water column with a rigid obstacle, and dam break on a wet bed). The simulation results were compared with experimental data and the solutions of Moving Particles Semi-implicate method. The comparison shows a good agreement and states that our SPH model could capture the water free surface shape precisely, (Abdelrazek et al., 2014, JSCE Ser. B1, Vol.70 No. (4), pp. I_67-I_72). The model is then extended to be Three- dimensional and used to solve the same two benchmark tests. We get good results in terms of particles spreading and the shape of the free surface.

A novel non-Newtonian three-dimensional SPH model was developed to simulate real snow avalanches mechanisms. The snow was considered as a Bingham fluid and the snow viscosity was calculated based on the Bingham constitutive model, on the basis of Coulomb's failure criterion. An equivalent Newtonian viscosity is calculated to express the Bingham viscosity into Navier-Stokes equations. Model validation was performed by simulating the movement of an unsteady mudflow released from a reservoir of a finite size onto a steep channel (Komatina & Jovanovic 1997, Journal of hydraulic research). The results show a good agreement between our models and the experimental

results, indicating that this numerical method can be used for practical simulation of non- Newtonian fluid. A small scale snow avalanche experiment with different types of obstacles was simulated using the present refined SPH model. Numerical results showed that, in the most cases, good agreements were found by the means of leading-edge position and the travel length, (Abdelrazek et al., 2014, River Flow 2014 & JSCE, Ser. A2, Vol. 70, No.2, pp. I_681-I_690).

The elastic–perfectly plastic model has been implemented in the SPH to develop three-dimensional SPH model to simulate the gravity granular flow past different types of obstacles. The model was validated by the experiment on the collapse of a 3D axisymmetric column of sand. A good agreement was observed between the numerical and experimental observations. Granular flows past different types of obstacle, (A group of stake rows with different spacing, circular cylinders, forward-facing and rearward-facing pyramids (tetrahedral) wedge) have been numerically simulated using the SPH model. The computational results were compared with the experimental data, and two numerical methods to check the capabilities of the proposed model. The numerical results in the first case in terms of the final granular deposition shapes, spreading of the particles and the position of the leading edge is found to be in good agreements with the experimental results. Although the efficiency factor from the experimental results in all cases is slightly greater than the calculated from the SPH results, the error is less than 1 %. Simulations of granular free-surface flows around a circular cylinder and tetrahedral obstacle show that the present SPH model can capture and describe the formation of the bow shock, normal shock, oblique shock around the obstacle. It also succeeded in describing the protected area as observed in the experiments, the hydraulic avalanche model solution, and the Savage and Hutter theory solution. This study suggests that the proposed refined SPH could be a powerful tool for solving problems with granular materials subjected to large deformation, and could be used to design real avalanche defenses (Abdelrazek et al., 2015, JSCE Ser. B1, Vol.71, No.4, pp. I_199-I_204 & Abdelrazek et al., 2015, Journal of Glaciology, submitted).

An application of the smoothed particle hydrodynamics (SPH) to simulation of soil–water interaction is presented in order to simulate the soil scour and erosion behind the seawall had occurred during the overflow (return flow). In this calculation, water is modeled as a viscous fluid with week compressibility and soil is modeled as an elastic–perfectly plastic material. The Mohr–Coulomb failure criterion is applied to describe the stress states of soil in the plastic flow regime. The interaction between soil and water was done by adding the seepage force and pore water pressure terms to the momentum equation. The Louvain erosional dam break experiment which induces a surge leading to erosions of the soil, (Fraccarollo and Chapart, 2002), was used to validate our model. The results were compared with experimental data and showed a good agreement between the simulation and experimental results. Finally, the model applied to simulate the return flow scouring experiment done by Yamamoto (2011). It was confirmed that the SPH method can express soil erosion and scouring. However, its analysis result is good from a qualitative perspective, but not so good from quantitative one.