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Simulation of sediment-related disaster and long-term landform process using Depth-Integrated Particle Method

Takashi Matsushima[a]*

[a] *University of Tsukuba, Tsukuba, Japan*
* tmatsu@kz.tsukuba.ac.jp

Abstract

Depth-Integrated Particle Method (DIPM) is an efficient numerical method suitable for simulating sediment-related disaster such as slope failure and subsequent debris flow/mudflow running through complicated topography (Hoang et al. 2009, Nakata and Matsushima 2014, Zhang and Matsushima 2016, 2018, Edris and Matsushima 2019). The method deals with the flowing mass as a collection of soil columns, and the equation of motion of such soil columns is solved as 2D discrete 'particles' moving along with the surface terrain. The particles are subjected to bottom shear friction calculated by modified Manning's formula with a yield stress and particle-wise interaction based on their hydraulic gradient. Accordingly, the material parameters governing the flow behavior are only two: the Manning's coefficient, *n*, and the critical deposition angle, θ_{cr} related to the yield stress. Also, from the viewpoint of numerical method, it is quite similar to Discrete Element Method with very soft particles whose computational characteristics has been well established.

In the present study, Atami mudflow occurred on July 1st, 2021 was analyzed as a recent case study. The topography of analyzing domain of about 2300m by 2300m was extracted from Digital map 5m (elevation) published by Geospatial Information Authority of Japan (GSI). According to the publishment record, the data was taken in 2009, which means that a check dam built in 1999 between the slope failure location and the densely populated area is reflected in the data, but the landfill soil at the failure site, that was constructed after 2009, is not. The initial slope failure location and the sliding mass volume of about 56,000m^3 were determined from the information in the Emergency report of GSI (2021). Manning's coefficient was set to 0.1 based on the previous studies (Nakata and Matsushima 2014, Edris and Matsushima 2019), which corresponds to the typical value of natural waterway with irregular bottom surface (see e.g., Chow 1959). A series of simulations were carried out by changing the critical deposition angle, θ_{cr} from 0.0 to 15.0(deg.) as it is unknown and sensitively affected by the soil type and the water contents. Comparing the disaster observation and the simulation results (Fig.1), we found the followings:
(1) In the cases that $\theta_{cr} \geq 12$(deg.) the mudflow does not reach the densely populated area, while it reaches the seacoast when $\theta_{cr} \leq 10.0$(deg.). This is consistent with the observation that the average slope angle in the valley is about 11(deg.) in GSI report (2021).
(2) The maximum flow velocity is about 6.0 to 8.0 (m/s) when it reaches the densely populated area in case that $\theta_{cr} = 7.5$(deg.), which is in accordance with a SNS video taken at around Aizome bridge.
(3) It is observed that the check dam captured about 6,000 to 7,000m^3 mass (Emergency report by Asia air survey co. ltd., 2021). However, that was not reproduced in the simulation because of the limitation of elevation data.

It should be noted that the above simulations do not consider the erosion of the valley bottom soil due to the mudflow. In order to incorporate such erosion/ sedimentation process in DIPM, a soil transport model of suspended load was implemented based on Lane-Kalinske (1941) model with Garcia and Parker (1991) empirical model for dimensionless sediment entrainment rate (Matsushima 2015). In addition, the model was extended to a multi grainsize model (Fig.2). To demonstrate the performance of the model, some simple examples of erosion and sedimentation in a uniform slope were simulated (Fig.3). In the simulation, water particles are regularly put on the center of the slope, and they erode the material on the slope surface and sedimented in the downstream flat plane forming a alluvial fan-like landform. This model can be used not only for a single debris flow / mudflow simulation but also a long-term simulation of fluvial landform process.

Keywords: Atami Mudflow, Depth Integrated Particle Method, Long-Term Landform Process

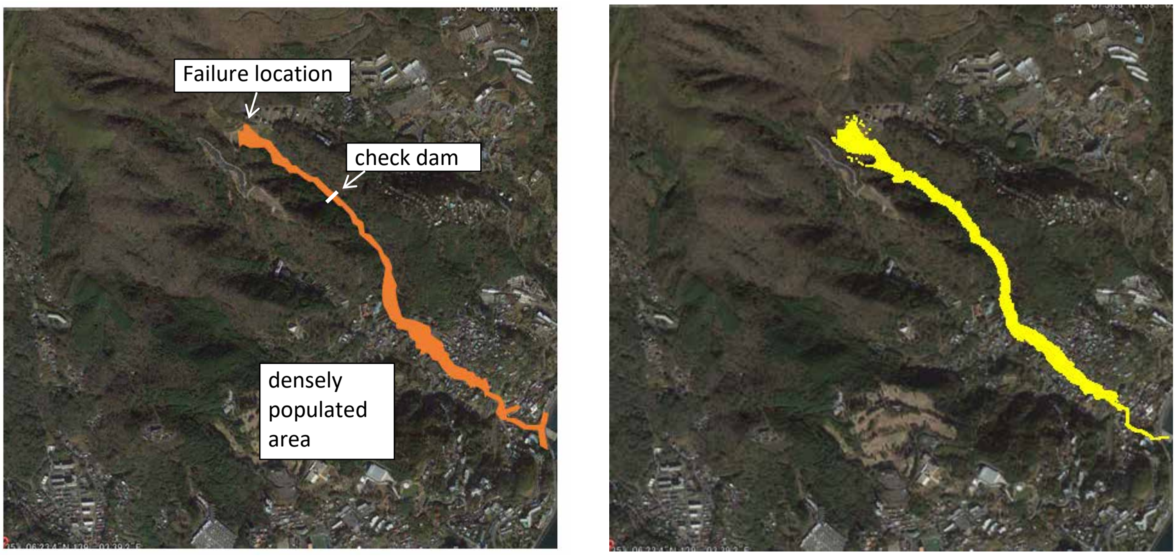
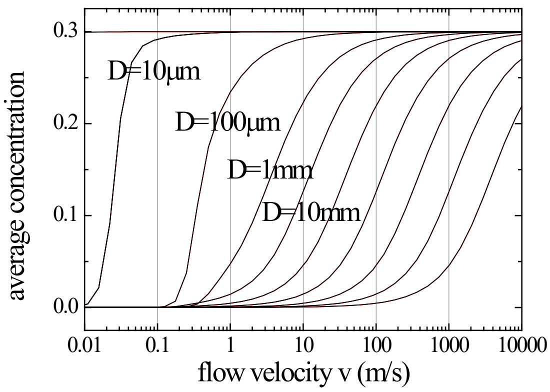


Fig. 1. Observed affected area (left, GSI 2021) and simulation result (right, $n = 0.1,\ \theta_{cr} = 8.0\text{deg.}$)



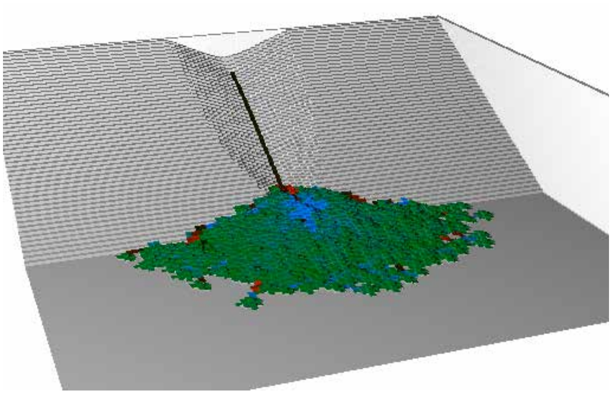


Fig. 2. multi grainsize model for the suspended load. Fig. 3 Final alluvial fan-like landform.

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