

SEDIMENT MODEL FOR LANDSLIDE TSUNAMIS USING SMOOTHED PARTICLE HYDRODYNAMICS

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INTRODUCTION

Tsunamis can sometimes be generated by soil mass movement such as slide, slump, and sector collapse. The well-known recent events such “landslide tsunami” include Papua New Guinea tsunami in 1998, Sulawesi tsunami and Krakatau tsunami in 2018. In order to estimate how severely landslide tsunamis affect buildings and infrastructures in coastal areas, it is necessary to analyse both landslide and tsunami accurately. Many studies have been done by experiments (Wiegel, 1995; Iwasaki, 1982), empirical prediction laws (Fritz et al., 2004; Watts et al., 2005), and analytical approach (Dienkulova et al., 2010; Romano et al., 2020). Numerical models have been also developed such as the Kinematic Landslide (KLS) model (Satake, 2001) and the two-layer model (Imamura and Imteaz, 1995). The numerical models need to be further improved to obtain more accurate results. Smoothed Particle Hydrodynamics (SPH) is a particle method which was originally developed in astrophysics (Gingold and Monaghan, 1977; Lucy, 1977). Because of the Lagrangian scheme, SPH is capable of simulating multi-physics and large deformation problems. Thus, SPH is expected to be suitable for landslide tsunami simulation. This work focuses on submarine landslide tsunami and presents the implementation of the soil yield criterion for submarine landslide in SPH.

OVERVIEW OF SPH

DualSPHysics (Crespo et al., 2015), one of the open-source solvers of SPH, was used in this work. The governing equations of SPH are the Navier-Stokes (NS) equations in the following Lagrangian form:

$$\frac{d\mathbf{u}}{dt} = -\frac{1}{\rho}\nabla P + \nu\nabla^2\mathbf{u} + \mathbf{F} \quad (1)$$

$$\frac{d\rho}{dt} + \rho\nabla\cdot\mathbf{u} = 0 \quad (2)$$

where \mathbf{u} is a velocity of a particle, ρ is density, P is pressure, ν is a kinematic viscosity, and \mathbf{F} is an external force, respectively. Pressure is obtained by the equation of state (Batchelor, 1974; Monaghan, 1994) as follows:

$$P = b \left[\left(\frac{\rho}{\rho_0} \right)^\gamma - 1 \right]; b = c_0^2 \rho_0 / \gamma \quad (3)$$

where ρ_0 is the reference density of fluid and c_0 is the speed of sound at the reference density, respectively. Generally, the reference density of fluid is 1000 kg/m^3 and γ is set at 7.

DualSPHysics has the non-Newtonian fluid model (Fourtakas and Rogers, 2016) called Hershel-Bulkeley-Papanastasiou (HBP) model. The constitutive law of the HBP model can be written by the shear stress tensor $\vec{\tau}$ and the shear rate tensor $\vec{\dot{\gamma}}$ as follows:

$$\vec{\tau} = \eta_{app}\vec{\dot{\gamma}}; \vec{\dot{\gamma}} = [\nabla\mathbf{u} + \nabla\mathbf{u}^T] \quad (4)$$

where η_{app} is the apparent viscosity given by

$$\eta_{app} = \mu|\dot{\gamma}|^{n-1} + \frac{\tau_y}{|\dot{\gamma}|} [1 - e^{-m|\dot{\gamma}|}] \quad (5)$$

In Equation (5), τ_y is yield stress, and m and n are index parameters, respectively.

TEST SIMULATION OF HBP MODEL

Underwater soil mass moves together with water. Therefore, soil mass can be modelled by non-Newtonian fluid. The HBP model in DualSPHysics was tested through the experiment conducted by Rzdakiewicz et al., (1997). The computational domain is described in Figure 1. The submerged sand is placed on a 1:1 slope. The provided value of sand property is density $\rho = 1950 \text{ kg/m}^3$ only. Other parameters such as yield strength and viscosity were carefully selected by parametric study. In the simulation, m was 100 and n was set at 2 since moving sand mass was assumed to be Bingham fluid. Figure 2 presents the particle snapshot at 0.8 s and Figure 3 compares the wave profile with the existing studies (Capone et al., 2010; Ikari et al., 2012), respectively. Sand mass represented by particles in red successfully collapsed on the slope in Figure 2. Fluid represented by blue particles formed the complicated shape on the free surface. The overall wave profile agreed well with the experimental results as shown in Figure 3. In the HBP model, the yield stress is generally adjusted as the non-Newtonian fluid movement can be physical behaviour. The critical problem is that the value might not always satisfy the range of typical soil property.

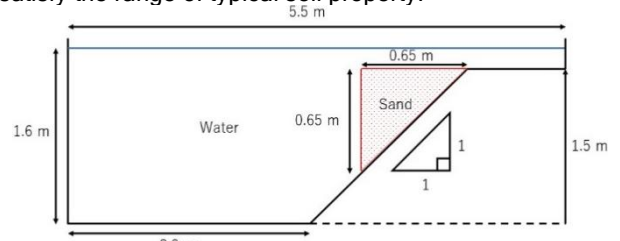


Figure 1 - Computational domain of submarine landslide

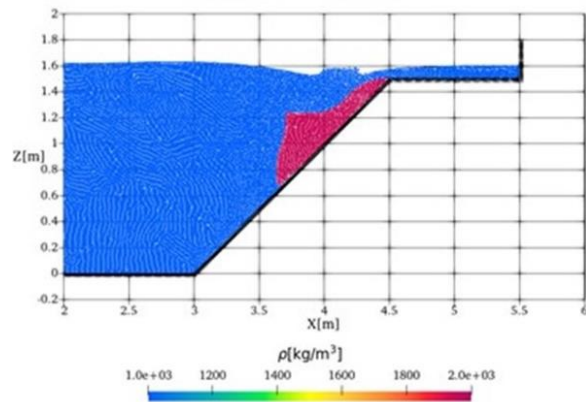


Figure 2 - Particle snapshot at 0.8 s

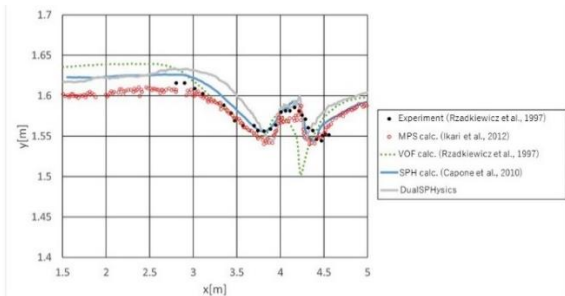


Figure 3 - Wave profile comparison

YIELD CRITERION IMPLEMENTATION

In order to develop the model based on soil mechanics, the following Coulomb yield criterion is newly introduced to DualSPHysics:

$$\tau = c + \sigma \tan \varphi \quad (6)$$

where c is cohesion, σ is normal stress, and φ is internal friction angle, respectively.

The source codes are updated so that the yield criterion can be selected instead of the existing HBP model. The algorithm is shown in Figure 4. In the main loop, the Coulomb criterion will be checked before interaction of moving soil mass is calculated.

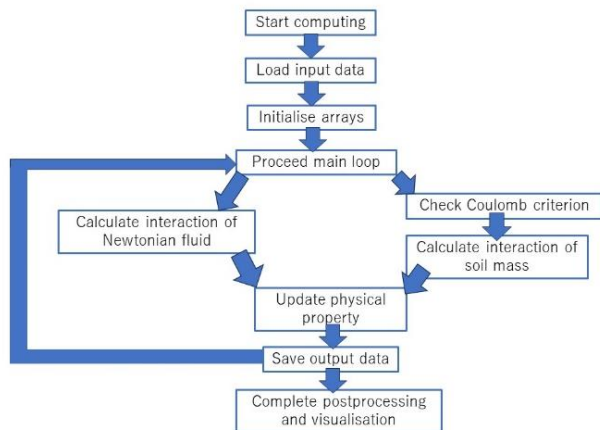


Figure 4 - Algorithm including the Coulomb criterion

The implemented sediment model is validated through the experiment conducted by Rzadkiewicz et al., (1997). Typical value is given to cohesion and internal friction angle which can be obtained by soil testing. The wave amplitude is compared with the experiment. The results are further analysed and discussed.

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