Amirkabir Journal of Civil Engineering

Amirkabir J. Civil Eng., 52(4) (2020) 247-250
DOI: 10.22060/ceej.2019.15114.5831

Numerical Simulation of Sub-Surface Landslide Waves Using an explicit three-step compressible SPH algorithm

S. E. Hosseini Mobara, R. Ghobadian*

Department Of Water Engineering, Razi University

ABSTRACT: The coastal waves that are produced by a landslide in the lake of reservoir dams can threaten the dam safety. Therefore, the exact recognition of hydraulic flow due to coastal waves has always been of interest to researchers. So far, extensive laboratory and numerical research have been conducted. In this research, a completely lagrangian numerical method which is based on particle and non-grid called the Smoothed Particle Hydrodynamic Method (SPH) was used to simulate coastal waves due to landslide. In the present study, a new three-step SPH algorithm based on the prediction and correction method was solved by governing equations. To validate the method, the laboratory data of the dam break problem on dry bed has been used. The results of this study approximated the analytical solution well, and the current model result was close to the analytical solution for the depth of flow in the break site. Also, the correlation coefficient of 0.9998, the mean absolute error of 0.5426 and the efficiency coefficient of the Nash-Sutcliff model 0.974 for the calculated parameters indicated that the model is accurately calibrated and the model can simulate the depth and discharge of water. Also, the results showed that the ability of the present model in the numerical simulation of sub-surface landslide wave in the production region and run-up region is high, and it stimulates the propagation region very well with an accuracy of 95%. With the comparison of measured and laboratory results, the correlation coefficient and the root mean square error were 0.95 and 0.0071 respectively, which indicates the high accuracy of the model in calculating the surface water profile due to subsurface landslide.

Review History:

Received: 10/10/2018
Revised: 12/25/2018
Accepted: 1/8/2019
Available Online: 1/8/2019

Keywords:

Wave simulation
Sub-surface landslide
Freeflow
Smoothed particle hydrodynamics method

1. INTRODUCTION

Fluid movement in open channels, water flow due to slipping or dam break, propagation and failure of the waves on the coast, shaking waves and coastal waves are important examples of free flows, which is difficult to simulate because of, high changes in the shape of the free surface of them so that it is difficult to apply the boundary condition for these flows. On the other hand, in numerical methods that use grid computing space to make their calculations, the production of the computational grid for such complex physics creates problems. For out coming to this problem in this research, landslide modeling is explored using an explicit three-step compressible SPH algorithm.

To validate the model that uses an explicit three-stage algorithm in the form of a Fortran code, the problem of dam break on the dry bed has been investigated. The model result was compared with the experimental data. Then, this method is used to simulate the landslide wave pattern and its results are compared with the results of a laboratory model.

2. METHODOLOGY

2.1. Smoothed Particle Hydrodynamics

To estimate the quantity of a parameter at a given point, it is assumed that the adjacent points, concerning an interpolation function, share a part in the estimation of the value of this parameter at the desired point [1]. Each characteristic of the particle *I*, which can be vector or scalar, is calculated directly from the corresponding characteristics of its neighboring particles and is calculated as follows:

$$\phi_i(r_i) = \sum_j m_j \frac{\phi_i(r_i)}{\rho_i(r_i)} W(|r_i - r_j|.h) \tag{1}$$

where φ is the desired quantity at r, $r = (x, y)$, and h is the length of the smoothing, and W is the interpolation function. m is the mass and ρ is the density of the particle, and i and j respectively refer to the main article and the neighboring particle. Gradients, divergences, and Laplacian are also defined in the form of SPH to obtain the governing equations in the form of SPH [2]. Viscosity, free surface conditions, solid boundaries, and time-step sizes were calculated and applied.

2.2. Three-step algorithm for a fluid solution using incompressible SPH method

In the first step of this algorithm, the momentum equation is solved with the application of volumetric forces, regardless of other forces, and average speed is obtained [3]. In the

*Corresponding author's email: rsghobadian@gmail.com

Copyrights for this article are retained by the author(s) with publishing rights granted to Amirkabir University Press. The content of this article is subject to the terms and conditions of the Creative Commons Attribution 4.0 International (CC-BY-NC 4.0) License. For more information, please visit https://www.creativecommons.org/licenses/by-nc/4.0/legalcode.

Table 1. Statistical comparison of wavefront for the Newtonian fluid calculated at the dam break site for the present numerical model with analytical values

Parameter	r[1]	MAE[2]	RMSE[3]	NSE[4]	RMSE[5]
amount	0.9998	0.0542	0.0003	0.974	0.168

[1] Correlation coefficient
[2] Mean Absolute Error
[3] Root Mean Squared Error
[4] Nash-Sutcliffe model efficiency coefficient
[5] Normalized Root Mean Squared Error

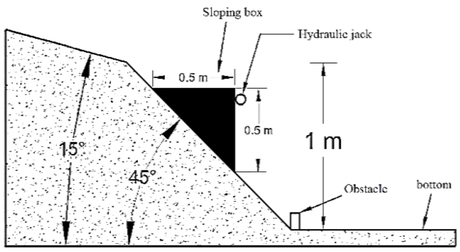

Fig. 1. Laboratory setup [4].

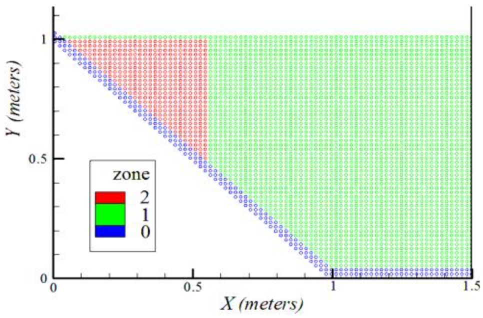

Fig. 2. The distribution of simulated particles at t=0 (zone 0=Wall, zone 1=Water, zone 2=Solid body)

second step, the average speeds calculated in the previous step are used to calculate the derivative to calculate shear stress divergence. These two steps are called the prediction phases, to calculate the change in the density generated by the continuity equation and to obtain a temporary density for the particle. The particle velocity field is recalculated to improve the density of the fluid to its original value. In the third step, which is the correction step of the algorithm, the pressure gradient in the momentum equation is merged with the continuity equation.

The stated algorithm is for each particle at any time, so it should be done for all particles to create the whole fluid flow for a time step. To simulate fluid motion at a specific time, this process continues to meet the desired time.

3. VALIDATION OF THE MODEL

Using the explicit three-phase algorithm in the form of Fortran code, the problem of dam failure has been investigated. Then the results are verified by numerical and experimental data.

In order to compare the wavefront for the Newtonian fluid calculated at the dam break site by the present numerical model with the analytical value, the statistical parameters of the following table calculated.

It is considered that the numerical model approximates the analytical solution well, and the results of the present model are close to the analytical solution[1] for the depth of flow in the dam break site, and the model has the ability to simulate the depth and flow discharge.

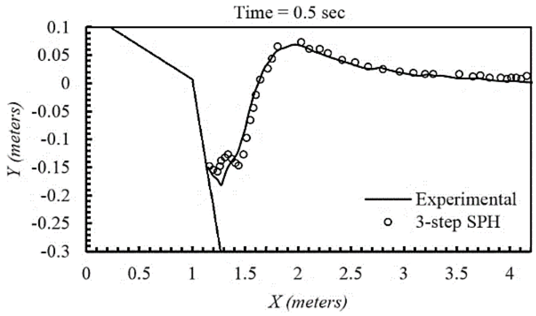

Fig. 3. Comparison between laboratory and numerical waveform profiles for submarine landslide

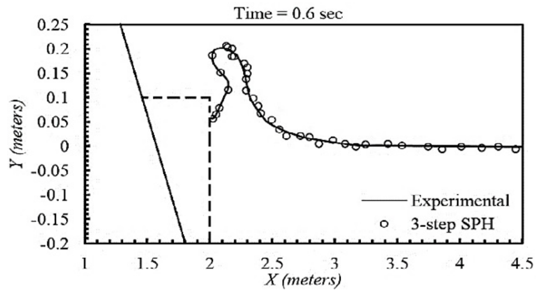

Fig. 4. Comparison between laboratory and numerical waveform profiles for aerial landslide

4. WAVES CAUSED BY SUB-SURFACE LANDSLIDE

The problem that is discussed in this paper is the problem geometry that Hinrich has used for landslide experimental studies [4].

Distribution of simulated particle in the sub-surface landslide is shown in Fig. 2, for t=0.

The first experiment is a Submarine Landslide with a water depth of one meter and the whole body is submerged at the start of the test. In the second experiment, the landslide occurs outside the surface of the water (Aerial landslide), with a water depth of 40 cm, and the whole body at the beginning of the experiment is above the surface of the water. "Figs. 3 and 4" shows an experimental wave profile with the calculated profile by the present numerical model.

Comparing the measured results with the laboratory, r values and RMSE for submersible landslide were 0.95 and

1

0.0071 respectively and for aerial landslide, were 0.91 and 0.0045, respectively. These results indicate the high accuracy of the model in calculating the surface water profile of the submerged landslide.

5. CONCLUSIONS

In this research, a completely lagrangian numerical method which is based on particle and non-grid, also is used to simulate coastal waves due to landslide. In the present study, a new three-step SPH algorithm based on the prediction and correction method is solved by governing equations. In order to validate the method, the laboratory data of the dam break problem on the dry bed has been used. The results of this study approximated the analytical solution well, and the current model is close to the analytical solution for the depth of flow in the break site. Also, the correlation coefficient of 0.9998, the mean absolute error of 0.5426 and the efficiency coefficient of the Nash-Sutcliff model 0.974 for the calculated parameters indicate that the model is accurately calibrated and the model has the ability to simulate the depth and discharge of water. In addition, the results showed that the ability of the present model in the numerical simulation of sub-surface landslide wave in the production region and run-up region is high, and it stimulates the propagation region very well with an accuracy of 95%.

REFERENCES

[1] R. A. Gingold, J. J. Monaghan, Smoothed particle hydrodynamics: theory and application to non-spherical stars, *Monthly Notices of the royal astronomical society*, Vol. 181, No. 3, pp. 375-389, 1977.

[2] F. Rouzbahani, K. Hejranfar, A truly incompressible smoothed particle hydrodynamics based on artificial compressibility method, *Computer Physics Communications*, vol. 210, pp. 10-28, 2016.

[3] S. Hosseini, M. Manzari, S. Hannani, A fully explicit three-step SPH algorithm for simulation of non-Newtonian fluid flow, *International Journal of Numerical Methods for Heat & Fluid Flow*, Vol.17, pp.715-735, 2007.

[4] P. Heinrich, Nonlinear water waves generated by submarine and aerial landslides, *Journal of Waterway, Port, Coastal, and Ocean Engineering*, vol. 118, pp. 249-266, 1992.

HOW TO CITE THIS ARTICLE

S.E. Hosseini Mobara, R. Ghobadian, Numerical Simulation of Sub-Surface Landslide Waves Using an explicit three-step compressible SPH algorithm, Amirkabir J. Civil Eng., 52(4) (2020) 247-250.

DOI: 10.22060/ceej.2019.15114.5831

This page intentionally left blank