Coastal Sediment Transport Study along Shoreline by using Smooth Particle Hydrodynamics

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Abstract. Sediment transport typically due to combination of gravity acting on the sediment, and/or the movement of the fluid in which the sediment is entrained. This paper gives an exposure simulation of three-dimensional (3D) sediment transports by using Smooth Particle Hydrodynamics (SPH) at coastal area. The SPH formulation from Monaghan constructed in the code is modified according to the desired model to be solved. The code is then computed by using single Graphics Processing Unit (GPU) with 14 cores multiprocessors. The behavior of sediment transport is investigated in this research based on Herschel-Bulkley-Papanastasiou (HBP) model. A constant sinewave of 0.5sin(0.5πt) is applied to the fluid domain to create sea wave effect that will cause sediment transport. The results show that the goal to get sediment transport is achieved and for the further study, the rate of erosion and accretion can be determined to give more meaningful and valuable to the result.

1. Introduction

Sediment transport is the one of the problems occur in coastal area which is can cause catastrophic failure to the building that build near to the coastal area. Some country builds power plants near the coastal area to extract natural resources such as natural gas. The study of sediment transport is important in order to make sure that the building is safe for several or long periods of time. The simulation of sediment transports are difficult to model by Eulerian approach (traditional mesh) as compared to Lagrangian based approach [1]. SPH was originally developed to study astrophysical problems [2, 3, 4] and has been widely used now a day to the engineering applications. Previously, the study of sediment transport by using SPH is more focused on two-dimensional (2D) as compared to 3D. Manenti et al. (2012) used 2D SPH simulation to model sediment flushing induced by a rapid water flow [5,6].

Besides that, Shi et al. (2017) also used 2D SPH model for sediment laden flows [7]. After that, the 2D multi-phase SPH model is improved to investigate scouring and erosion [8, 9]. In addition, Ghiatnallis et al. (2018) used an elastic-viscoplastic model [10] is combined to a multi-phase SPH formulation [11, 12] to model granular flows and non-cohesive sediment transport [13]. Furthermore, the 3D model of SPH is effectively used in numerical analysis study of Sarawak barrage river bed erosion and scouring [14-17]. Therefore, this paper attempts to avoid such boundaries with the aim of producing high-precision 3D simulation model of sea wave-sediment interaction with minimum computational effort.
2. SPH formulation

The SPH involves the computation of discretized fluid into a set of particles, each particle is referred to a nodal point in which physical quantities are computed as an interpolation of the values of the nearest particles. The integral approximation of any function \( A(\vec{r}) \) is

\[
A(\vec{r}) = \int A(\vec{r}') W(\vec{r} - \vec{r}', h) \, dr'
\]

(1)

In which \( h \) is the smoothing length and \( W(\vec{r} - \vec{r}', h) \) is the smoothing kernel or weighting function at particle \( a \) is given by:

\[
A(\vec{r}) = \sum_b m_b \frac{\rho_b}{\rho_a} W_{ab}
\]

(2)

In which \( m_a \) and \( \rho_a \) being the mass and the density associated to the neighboring particle \( b \), respectively. The term \( W_{ab} \) describes the weight function which is \( W_{ab} = W(\vec{r}_a - \vec{r}_b, h) \). There are several types of kernel definitions and for this research, the cubic spline kernel is selected and shown as follows:

\[
W(r, h) = a_d \begin{cases} 
1 - \frac{3}{2} q^2 + \frac{3}{4} q^3 & 0 \leq q \leq 1 \\
\frac{1}{4} (2 - q)^3 & 1 \leq q \leq 2 \\
0 & q \geq 2
\end{cases}
\]

(3)

In which \( a_d = \frac{1}{\pi h^3} \) in three-dimensional.

The momentum equation in SPH method is implemented to determine the acceleration of a particle \( a \) as the result of the particle interaction with particle \( b \):

\[
\frac{d\vec{v}_a}{dt} = - \sum_b m_b \left( \frac{P_b}{\rho_b} + \frac{P_a}{\rho_a} \right) \nabla_a W_{ab} + \vec{g}
\]

(4)

The detailed SPH formulation can be obtained in book [18].

3. Methodology

3.1. Modelling of Coastal Area

3.1.1. Coastal modelling by using Solidworks

The model is constructed in Solidworks based on the scanned topography from the drone as shown in Fig. 1.
3.1.2. SPH model

Fig 2 shown a SPH model for the numerical analysis whereby elements such as sediment, bridge, seawater and cliff are represented. The wave is generated by the wave paddle is 0.5sin(0.5πt) to mimic the real case study.

4. Results and Discussions

Fig 3 shown that the changes of coastal profile along the duration of 100s. The red circles are the area that can be noticed the movement of the sediment. The movement of sediment highly occurs at the region near to the building due to the wave erosion.
5. Conclusions
In this paper, 3D simulation of SPH is combined with the wave generation equation to simulate liquid-sediment for application to coastal area. This 3D simulation was shown effectively simulate the effect of sediment transport due to interaction of sea wave. This allows early precaution to be taken to avoid any failure to the building near to the coastal area. In the near future, the rate of erosion and accretion can be determined to give more valuable and meaningful data to the result.
6. References

[1] Müller M, Charypar D and Gross M 2003 Particle-Based Fluid Simulation for Interactive Applications Proceedings of the 2003 ACM SIGGRAPH/Eurographics symposium on Computer animation pp 154–9

[2] Gingold R A and Monaghan J J 1977 Smoothed particle hydrodynamics: theory and application to non-spherical stars Mon. Not. R. Astron. Soc. 181 375–89

[3] Lucy L B 1977 A Numerical Approach to The Testing of The Fission Hypothesis Astron. J. 82 1013–24

[4] M. Radzi, Nashruddin, M.N, Zawawi, M. H., Abas, Aizat, Azman, Aqil and Hassani, A, "Effect of free surface water level of Kenyir Dam on spillway structure using fluid-structure interaction (FSI) analysis," Applied Physics of Condensed Matter (Apcom 2019), vol. 2131, no. August, 2019.

[5] Manenti S, Sibilla S, Gallati M, Agate G and Guandalini R 2012 SPH Simulation of Sediment Flushing Induced by a Rapid Water Flow J. Hydraul. Eng. 138 272–84

[6] N. M. Zahari, Zawawi, M. H., Sidek, L. M., Mohamad, Daud, Itam, Zarina, Ramli, M. Z., Syamsir, Agusril, Abas, Aizat and Rashid, M., "Introduction of discrete phase model (DPM) in fluid flow: A review," in AIP Conference Proceedings 2030, 2018.

[7] Shi H, Yu X and Dalrymple R A 2017 Development of a two-phase SPH model for sediment laden flows Comput. Phys. Commun. 221 259–72

[8] Fourtakas G and Rogers B D 2016 Modelling multi-phase liquid-sediment scour and resuspension induced by rapid flows using Smoothed Particle Hydrodynamics (SPH) accelerated with a Graphics Processing Unit (GPU) Adv. Water Resour. 92 186–99

[9] Zubeldia E H, Fourtakas G, Rogers B D and Farias M M 2018 Multi-phase SPH model for simulation of erosion and scouring by means of the shields and Drucker–Prager criteria. Adv. Water Resour. 117 98–114

[10] Ulrich C, Leonardi M and Rung T 2013 Multi-physics SPH simulation of complex marine-engineering hydrodynamic problems Ocean Eng. 64 109–21

[11] Hu X Y and Adams N A 2006 A multi-phase SPH method for macroscopic and mesoscopic flows. J. Comput. Phys. 213 844–61

[12] Ghaitanellis A, Violeau D, Leroy A, Joly A and Ferrand M 2015 Application of the unified semi-analytical wall boundary conditions to multi-phase SPH 10th International SPHERIC Workshop, Parma, Italy

[13] Ghaitanellis A, Violeau D, Ferrand M, Abderrezak K E K, Leroy A and Joly A 2018 A SPH elastic-viscoplastic model for granular flows and bed-load transport Adv. Water Resour. 111 156–73

[14] Zainol M R R M A, Kamaruddin M A, Zawawi M H and Wahab K A 2017 Numerical analysis study of sarawak barrage river bed erosion and scouring by using Smooth Particle Hydrodynamic (SPH) IOP Conference Series: Materials Science and Engineering vol 267

[15] M. H. Zawawi, Saleha, A., Salwa, A., Hassan, N. H., Zahari, N. M., Ramli, M. Z. and Muda, Z. C., "A review: Fundamentals of computational fluid dynamics (CFD)," in Green Design and Manufacture: Advanced and Emerging Applications, 2018.

[16] A. Azman, Abas, Aizat, Zawawi, M. H., Rozainy M. A. Z., Mohd. Remy and Abustan, Ismail, "Numerical study of the effect of flow on bottom outlet of dam," Applied Physics of Condensed Matter (Apcom 2019), vol. 2131, no. July, p. 020090, 2019.

[17] M. H. Zawawi, Hazwani, Mohamad, Ghaizali, Mohd, Zhafran, Ahmad and Mazlan, Ahmad, "Vibration analysis due to frequent spilling over hollow buttress Chenderoh Dam sector gate spillway," in 2018 International Conference on Vibration, Sound and System Dynamics (ICVSSD 2018), 2019.

[18] Violeau D 2012 Fluid mechanics and the SPH method: Theory and applications (Oxford University Press)
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