PAPER • OPEN ACCESS

Two-phase SPH for sloshing simulation in prismatic tank

To cite this article: Andi Trimulyono *et al* 2021 *IOP Conf. Ser.: Mater. Sci. Eng.* **1034** 012058

Two-phase SPH for sloshing simulation in prismatic tank

Andi Trimulyono*, Deddy Chrismianto, Samuel, Muhammad Iqbal
Department of Naval Architecture, Faculty of Engineering, *Universitas Diponegoro*
Prof. Soedarto, S.H, Kampus Undip Tembalang, Semarang-50275, Indonesia
*Email: anditrimulyono@lecturer.undip.ac.id

Abstract. The sloshing phenomenon is one challenging event in fluid-structure interaction especially for the liquid carrier such as a ship. Sloshing can endanger ships when there is energetic sloshing with volatile liquid inside the tank. One of the LNG carriers is membrane type which the tank is prismatic. The study aims to reproduce long-duration sloshing using a prismatic tank. The particle method so-called smoothed particle hydrodynamics is used to deal with long-duration sloshing. To accommodate of experiment condition a two-phase SPH is used. To accelerate SPH computation, a GPU solver is used in this study. The hydrostatic pressure from SPH is compared with an analytic solution and dynamics pressure is compared with experimental data to validate the results. The result shows SPH has good accuracy for hydrostatic pressure and dynamics pressure shows a similar trend to experiment with spurious pressure. Finally, free surface deformation has a tendency similar to experiment with void of air trapped in the water that can capture by SPH.

Keywords: sloshing, two-phase SPH, prismatic tank, GPU

1. Introduction

Sloshing is one challenging event in fluid-structure interaction in marine engineering and ocean engineering field. A liquid carrier such as LNG ship is prominent to sloshing events caused by ocean waves during sea state conditions. One of LNG carrier is the membrane-type carrier that the shape of the tank is prismatic. Sloshing can endanger ship when it is energetic and violent that would lead to an explosion caused by the impact of volatile fluid such as LNG. Sloshing can lead to structural damage caused by the impact pressure of fluid with the sidewall tank. Because sloshing is dealing with free surface flow, particle methods have the advantage to apply to this problem. One of the particle methods is smoothed particle hydrodynamics (SPH). SPH was developed for free surface flow by Monaghan [1]. Since then there have been many application SPH for free surface flow in water wave and sloshing. Application SPH for water wave was carried out by Altomare et al. [2] for implementing active wave absorption in SPH and made verification with the analytic solution. Trimulyono et al. [3] were validated 2D water waves in large wave basin using SPH. Pringgana et al. [4] used SPH for modelling tsunami-induced bore with interaction coastal structure. It was showed SPH has good accuracy for water waves. Implementation SPH in sloshing demonstrated by Trimulyono et al. [5] to reproduce experimental validation for single-phase and two-phase SPH simulations using the prismatic tank in 2D and 3D. It shows SPH has good accuracy in static and dynamics pressure for two-phase. In addition, Trimulyono et al. [6] used a low pass filter to reduce pressure oscillation using 2D domain. Recently, Green and Peiró [7] were successful in reproducing sloshing in term of surface elevations, and force of the tank using a low fil ratio with long-duration sloshing. In the present study, sloshing in the prismatic tank was carried out using two-phase SPH. The present study was extended works of Trimulyono et al. [5]. The open-source SPH solver DualSPHysics version 4.2 was used to make a 2D sloshing simulation developed by Crespo et al. [8]. DualSPHysics has implemented general-purpose computing on graphics processing units (GPGPU) technology that speeds up SPH computation. In this study, GPU GTX Geforce 1080 ti was used in simulations. Only roll motion is used in the SPH simulation with a 50% filling ratio. One pressure sensor was used to validate the dynamics pressure in the SPH simulation. The analytic solution is utilized to validate hydrostatic pressure. Finally, the duration of the SPH simulation was the same as an experiment conducted and it was a long duration sloshing event.

2. Methodology

2.1 *Smoothed Particle Hydrodynamics (SPH)*

SPH is a Lagrangian meshless method that uses the interpolation approach to estimate the quantities of physical value and derivatives of a continuous field using discrete evaluation points. The main approach of the SPH method is based on integral interpolants and it is well explained in Liu and Liu [9]. Equation 1 shows the particle approximation in SPH, and equation 2 shows continuity equations. The Navier Stokes equations show in equation 3 where W is a kernel function, v is velocity, P is pressure, ρ density, and τ is a diffusive term.

$$\boldsymbol{A(r_a) \approx \sum_b A(r_b) W(r_a - r_b, h) \frac{m_b}{\rho_b}} \tag{1}$$

$$\boldsymbol{\frac{D\rho}{Dt} = -\rho \nabla v}, \tag{2}$$

$$\frac{Dv}{Dt} = -\frac{1}{\rho}\nabla P + \mathrm{g} + \tau, \tag{3}$$

$$\boldsymbol{\frac{Dr}{Dt} = v}, \tag{4}$$

Quintic kernel function [10] is used in this study. The momentum equation shows in equation 5 for the water-phase and equation 6 for air-phase. The delta-SPH (δ_Φ) is used in based on works of Molteni and Colagrossi [11]. The equation of state is shown in equation 7. For the detailed SPH implementation, the reader can refer to the DualSPHysics guideline.

$$\boldsymbol{\frac{dv_a}{dt} = -\sum_b m_b \left(\frac{P_{a+P_b}}{\rho_a \cdot \rho_b} + \Pi_{ab}\right) \nabla_a W_{ab} + \mathbf{g}}, \tag{5}$$

$$\frac{dv_a}{dt} = -\sum_b m_b \left(\frac{P_{a+P_b}}{\rho_a \cdot \rho_b} + \Pi_{ab}\right) \nabla_a W_{ab} - 2a\rho_a^2 \sum_b \frac{m_b}{\rho_b} \nabla_a W_{ab}, \tag{6}$$

$$\Pi_{ab} = \begin{cases} \frac{-\alpha \overline{c_{ab}} \mu_{ab}}{\overline{\rho_{ab}}} & v_{ab} \cdot r_{ab} < 0 \\ 0 & v_{ab} \cdot r_{ab} > 0 \end{cases}$$

$$\boldsymbol{P = b\left[\left(\frac{\rho}{\rho_0}\right)^\gamma - 1\right] + X - a\rho^2} \tag{7}$$

Figure 1 shows the schematic view of the prismatic tank. In this study, only two dimensions of the prismatic tank was used. It can be explained as in the sloshing experiment pressure sensor location in the mid of the tank using regular motion, as a result, the sloshing simulation is two dimensions. It will be different when irregular motion is applied. The breadth of the tank is 0.3 m, the height of the tank is 0.21 m, and the level water is 0.105 m. Only the pressure gauge located at the bottom was used to compare with the experiment. In the SPH simulation, we added 2 second in the tank movement to calm the fluid particles. The additional time was used to get static pressure and validation of static pressure was made with an analytic solution.

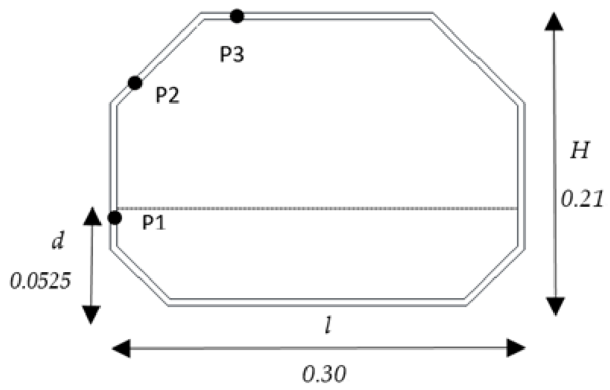

Figure 1. The schematic view of the pressure position in the tank.

2.2 Experiment and numerical condition

The experimental condition was based on works in Trimulyono *et al.* [5] which sloshing was conducted in three filling ratios and combination of motion. In the present study, roll motion is used to reproduce long-duration sloshing events based on experimental data. Because roll motion is also one of the dangerous motion in ship movement. **Figure 2** depicts the experiment condition of the 50% filing ratio of the tank. Roll motion means that it moves rotationally whose center of a movement is above the tank. In the experiment, a forced oscillation machine was used to move the tank into four degrees of freedom. For the detailed information of the experiment, the reader can refer to Trimulyono *et al.* [5].

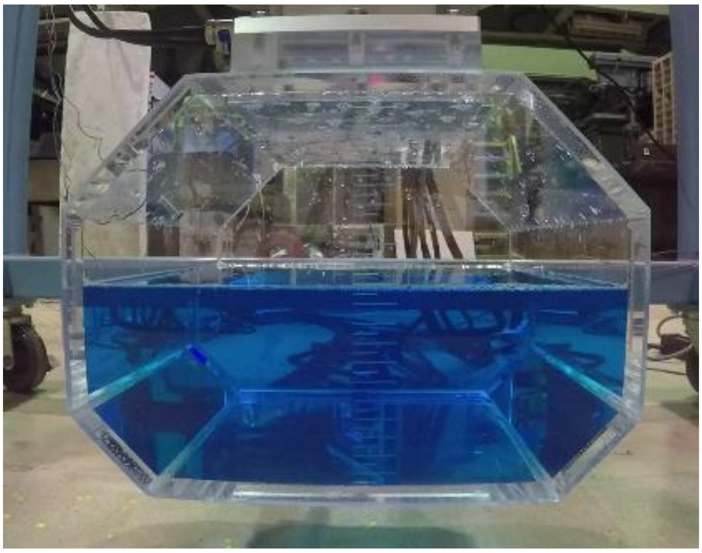

Figure 2. The experiment condition for sloshing.

Table 1 shows the parameter setup of the SPH simulation. In this study, we use the coefficient of smoothing length is 0.95 that was successfully reproduces sloshing simulation in the previous works for 2D simulation. Coefficient artificial viscosity 0.07 was used with initial particle distance

0.8 mm. 0.1 delta-SPH is used to suppress density fluctuation. The speed of sound was used 65 for the water phase and 478 is used for the air phase. These combination has proven from previous works to reproduce two-phase SPH simulation in 2D simulation. Mokos et al. [12] was mentioned in their works that is ratio speed of sound one of the important parameter to get appropriate accuracy for the pressure field. The simulation time is 70 second that was same as the experiment condition in sloshing experiment.

Tabel 1. Parameters setup

Parameters	
Kernel function	Wendland
Time step algorithm	Sympletic
Artificial viscosity coefficient	0.07
The speed of sound for water & air	65 & 478
Particle spacing (mm)	0.8
Coefh	0.95
CFL number	0.2
Delta-SPH (δϕ)	0.1
Simulation time (s)	70.0

3. Results and discussion

The SPH simulation has the advantage to handle large-deformation especially in violent flow or fluid-structure interaction, in this study a violent and long-duration sloshing was tried to reproduce using SPH. Figure 3 shows the hydrostatic pressure of two-phase SPH. The gradient color shows the blue color as minimum pressure for the air-phase in opposite red color shows for the maximum pressure. The difference of SPH results and the analytic solution is 1.45%, it shows SPH has good accuracy for capture hydrostatic pressure. The result depicts SPH accuracy for a static condition that is well capture and this condition is included air-phase in the simulation. The merit using SPH is free surface can easily capture without any special algorithm. The dynamics pressure was shown in **Figure 4**. It depicts pressure oscillation still occur although delta-SPH was used. Green and Peiró [7] were used double precision in their simulation and the smoother pressure field was captured, on the contrary, our simulation is using single precision.

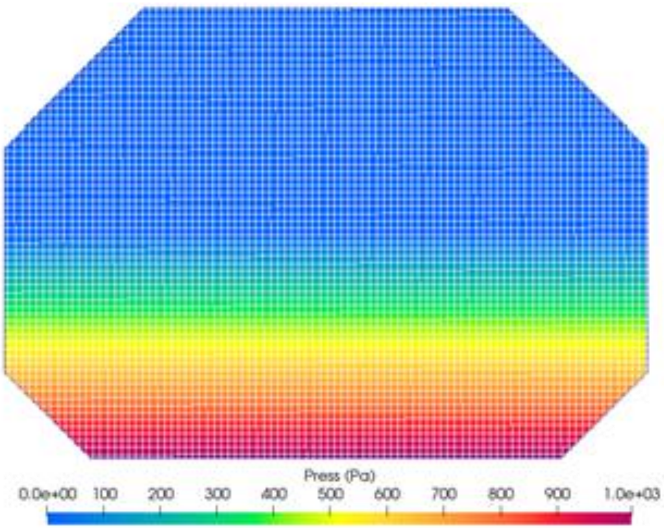

Figure 3. The hydrostatic pressure in the SPH simulation

doi:10.1088/1757-899X/1034/1/012058

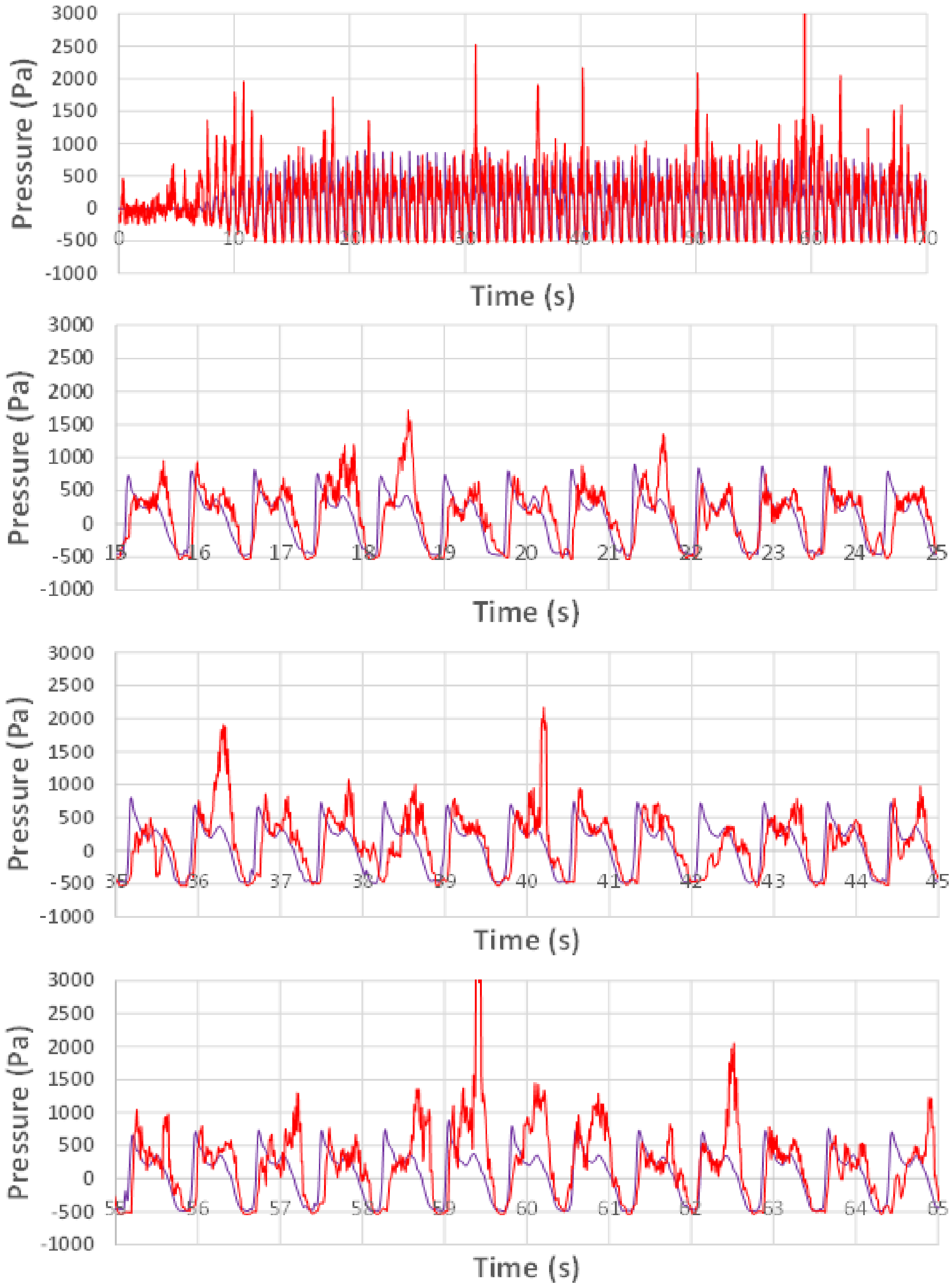

Figure 4. The dynamics pressure for filling ratio 50%

The comparison of free surface deformation was shown in **Figure 5**, the tendency of free surface deformation from SPH similar to experiment result. This is one of the advantages using particle method that large deformation of free surface well captures by SPH. The red color represents the air phase and the blue color is the water phase. **Figure 6** depicts the water-air mixture that created a void in the water phase. The phenomenon is well captured by SPH. The feature two-phase SPH is void caused by air trapped in water can easily capture that in the reality this phenomenon is essential especially for volatile fluid.

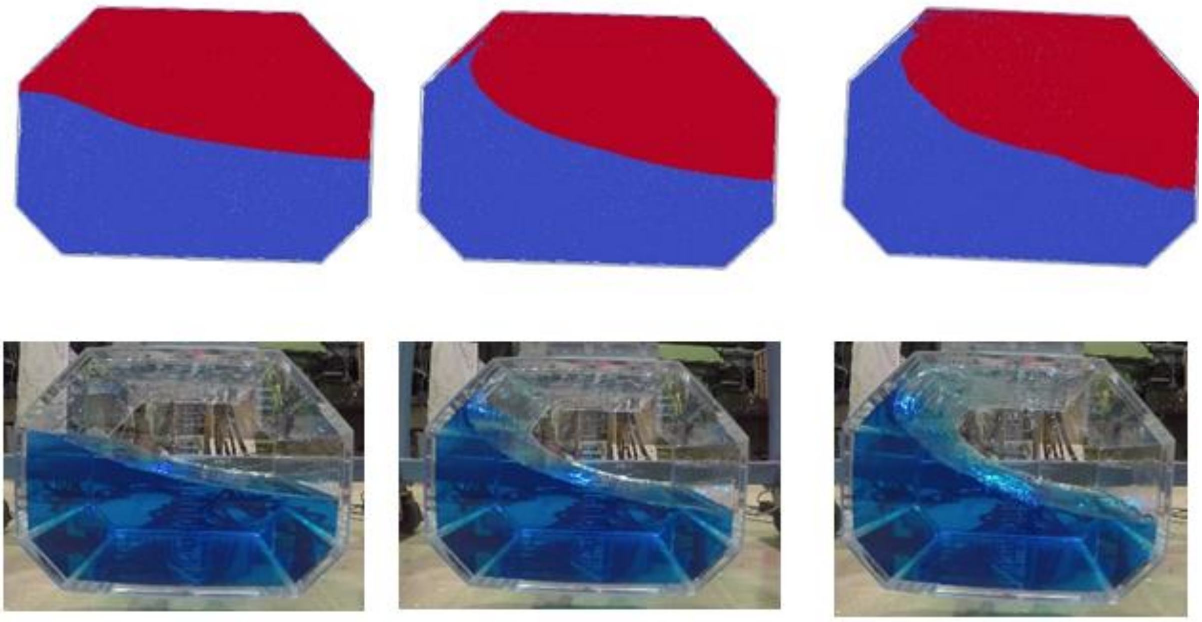

Figure 5. Comparison of free surface deformation

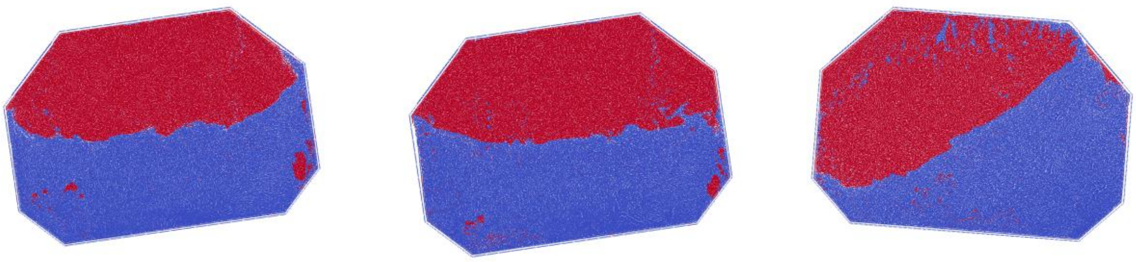

Figure 6. Two-phase SPH simulation with t= 46 s, 46.75 s, 47 s.

4. Conclusions

Two-phase SPH simulation was used for reproducing a sloshing event in the prismatic tank. The results revealed that SPH has a promising method to apply to marine engineering problems. Hydrostatic pressure has good accuracy compared to the analytic solution. While dynamic pressure shows a similar trend with experimental data although there is spurious pressure oscillation still exists. The free surface deformation tends to similar to the experiment and also the water-air mixture is well captured by SPH.

5. Acknowledgments

The authors wish to thank the laboratory of ship hydrodynamics, Department of Naval Architecture, *Universitas Diponegoro* for the computer resources.

6. References

[1] Monaghan JJ 1994 Simulating free surface flows with SPH *J Comput Phys* **110**(2) 399–406.
[2] Altomare C, Domínguez JM, Crespo AJC, González-Cao J, Suzuki T, Gómez-Gesteira M, et al.

2017 Long-crested wave generation and absorption for SPH-based DualSPHysics model *Coast Eng*. **127** 37–54.
[3] Trimulyono A, Hashimoto H and Kawamura K 2017 Experimental Validation of SPH for Wave Generation and Propagation in Large Wave Tank. In: *Proceedings of the Twenty-seventh International Ocean and Polar Engineering Conference* San Francisco, CA, USA, June 25-30
[4] Pringgana G, Cunningham LS, Rogers BD 2016 Modelling of tsunami-induced bore and structure interaction *Proceeding Inst Civ Eng Eng Comput Mech* **169** 109–25.
[5] Trimulyono A, Hashimoto H, Matsuda A 2019 Experimental validation of single- and two-phase smoothed particle hydrodynamics on sloshing in a prismatic tank *J Mar Sci Eng* **7**(8).
[6] Trimulyono A, Samuel, Iqbal M 2020 Sloshing Simulation of Single-Phase and Two-Phase SPH using DualSPHysics *Kapal Jurnal Ilmu Pengetahuan dan Teknologi Kelautan* **17**(2) 50–7.
[7] Green MD and Peiró J 2018 Long duration SPH simulations of sloshing in tanks with a low fill ratio and high stretching *Comput Fluids* **174** 179–99.
[8] Crespo AJC, Domínguez JM, Rogers BD, Gómez-Gesteira M, Longshaw S, Canelas R, et al 2015 DualSPHysics: Open-source parallel CFD solver based on Smoothed Particle Hydrodynamics (SPH) *Comput Phys Commun* **187**.
[9] Liu G-R, Liu MB 2003 Smoothed Particle Hydrodynamics: A Meshfree Particle Method World Scientific.
[10] Wendland H 1995 Piecewise polynomial, positive definite and compactly supported radial functions of minimal degree. Adv Comput Math **4**(1):389–96.
[11] Molteni D and Colagrossi A 2009 A simple procedure to improve the pressure evaluation in hydrodynamic context using the SPH. *Comput Phys Commun* **180**(6):861–72.
[12] Mokos A, Rogers BD, Stansby PK 2016 A multi-phase particle shifting algorithm for SPH simulations of violent hydrodynamics with a large number of particles. *J Hydraul Res* **1686**