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Judul Artikel : Investigation of Sloshing in the Prismatic Tank with Vertical and T-Shape Baffles

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Submitted	11 November 2021	Lampiran 1
Reviewer Comments	14 Februari 2022	Lampiran 2
Revise our Manuscript	7 Maret 2022	Lampiran 3
Accepted	12 April 2022	Lampiran 4
Final Manuscript	13 April 2022	Lampiran 5
Published	14 April 2022	Lampiran 6

Andi Trimulyono <anditrimulyono@live.undip.ac.id>

Submission for Journal Brodogradnja

Nastia Degiuli <Nastia.Degiuli@fsb.hr> Thu, Nov 11, 2021 at 9:28 PM
To: Andi Trimulyono <anditrimulyono@live.undip.ac.id>
Cc: Andrea Farkas <Andrea.Farkas@fsb.hr>, Ivana Martić <Ivana.Martic@fsb.hr>

Dear PhD Trimulyono,

Your manuscript entitled

"The investigation of sloshing in the prismatic tank with vertical and T-shape baffles", authors Andi Trimulyono, Haikal Atthariq, Deddy Chrismianto, Samuel Samuel

has been successfully submitted and is presently being given full consideration for publication in the journal Brodogradnja.

Please note that for all papers submitted after 31 December 2019 an Article Publishing Fee applies.

The APF amounts to 350 Euros and has to be paid after article/paper acceptance before publication (see Submission guides for authors).

Kind regards,

Nastia Degiuli

Editor in chief

[Quoted text hidden]

Andi Trimulyono <anditrimulyono@live.undip.ac.id>

Journal Brodogradnja

8 messages

Nastia Degiuli <Nastia.Degiuli@fsb.hr> Mon, Feb 14, 2022 at 3:35 PM
To: "anditrimulyono@live.undip.ac.id" <anditrimulyono@live.undip.ac.id>

Dear PhD Trimulyono,

Please find attached reviewer 1, reviewer 2, and reviewer 3 major comments regarding your submission entitled

The investigation of sloshing in the prismatic tank with vertical and T-shape baffles

Therefore, I invite you to respond to the reviewers' comments in detail and revise your manuscript by **7th March 2022**.

Professional English reading is required.

Kind regards,

Editor in chief

Nastia Degiuli

PhD Nastia Degiuli, Full Professor

University of Zagreb

Faculty of Mechanical Engineering and Naval Architecture

Department of Naval Architecture and Ocean Engineering

Head of Chair of Ship Hydrodynamics

Ivana Lucica 5

10000 Zagreb

CROATIA

Phone: +385 1 6168 269

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e-mail: nastia.degiuli@fsb.hr

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3 attachments

C-2021-1501-Brodogradnja-Paper-Review-Form-reviewer_1.pdf
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C-2021-1501-Brodogradnja-Paper-Review-Form-reviewer_2.pdf
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Andi Trimulyono <anditrimulyono@live.undip.ac.id> Mon, Feb 14, 2022 at 5:58 PM
To: Nastia Degiuli <nastia.degiuli@fsb.hr>

Thank you for your mail,
I will revise the manuscripts as reviewer comments and use professional English service

With best regards,
[Quoted text hidden]

Andi Trimulyono <anditrimulyono@live.undip.ac.id> Mon, Mar 7, 2022 at 9:48 AM
To: Nastia Degiuli <nastia.degiuli@fsb.hr>

Dear Prof. Nastia Degiuli
Editor in Chief
Journal Brodogradnja

We would like to thank you for giving us opportunities to submit and revised manuscript for Journal Brodogradnja.
We try our best to accommodate the reviewer comments, and hopefully, our manuscript can be published in Journal Brodogradnja.
With this email, I hereby send a cover letter and a revised manuscript.
We looking forward to hearing from you soon.

With best regards,
Andi Trimulyono

On Mon, Feb 14, 2022 at 3:35 PM Nastia Degiuli <Nastia.Degiuli@fsb.hr> wrote:
[Quoted text hidden]

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2 attachments

Author Responses to The Reviewers.docx
168K

Manuscript_Andi T_revised 07-03-22.docx
4540K

Nastia Degiuli <Nastia.Degiuli@fsb.hr> Tue, Mar 29, 2022 at 11:54 PM
To: "anditrimulyono@live.undip.ac.id" <anditrimulyono@live.undip.ac.id>

Dear PhD Trimulyono,

Please find below reviewer 2 comments regarding your revised submission entitled

The investigation of sloshing in the prismatic tank with vertical and T-shape baffles

Therefore, I invite you to respond to the reviewers' comments in detail and revise your manuscript by 12th **April 2022**.

Professional English reading is required. Please provide the certificate.

Kind regards,

Editor in chief

Nastia Degiuli

Reviewer 2

So I reviewed the paper and I don't have much to say on the results, they seem sound and free of bias.

However, I still find the reading flow very bad, you can see sections such as 3.3 and others having periods every 10-15 words.

If it goes through another round of reviews, I would recommend stressing that not only the English has to be correct, but the body has to read well and fluently.

[Quoted text hidden]

Andi Trimulyono <anditrimulyono@live.undip.ac.id> Wed, Mar 30, 2022 at 11:30 AM
To: Nastia Degiuli <nastia.degiuli@fsb.hr>

Thank you for your email. I will revise and resubmit it as soon as possible

With best regards,
Andi Trimulyono
[Quoted text hidden]

Andi Trimulyono <anditrimulyono@live.undip.ac.id> Thu, Apr 7, 2022 at 9:08 AM
To: Nastia Degiuli <nastia.degiuli@fsb.hr>

Dear Prof. Nastia Degiuli,

I hereby sent a revised manuscript with the title " Investigation of sloshing in the prismatic with vertical and T-shape baffles". We have used professional English reading Enago to fulfill reviewer comments and journal standards. Please find the attached file for a certificate from Enago. We look forward to hearing from you soon.

With best regards,
Andi Trimulyono

On Tue, Mar 29, 2022 at 11:54 PM Nastia Degiuli <Nastia.Degiuli@fsb.hr> wrote:
[Quoted text hidden]

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3 attachments

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Nastia Degiuli <Nastia.Degiuli@fsb.hr> Thu, Apr 7, 2022 at 12:23 PM
To: Andi Trimulyono <anditrimulyono@live.undip.ac.id>

Please upload it in Comet.

Poslano s mojeg iPhonea

> 07.04.2022., u 04:08, korisnik Andi Trimulyono <anditrimulyono@live.undip.ac.id> je napisao:
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Nastia Degiuli <Nastia.Degiuli@fsb.hr> Thu, Apr 7, 2022 at 12:47 PM
To: Andi Trimulyono <anditrimulyono@live.undip.ac.id>

Please ignore my previous email.

Poslano s mojeg iPhonea

> 07.04.2022., u 07:23, korisnik Nastia Degiuli <Nastia.Degiuli@fsb.hr> je napisao:
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Undip Email @live.undip.ac.id

Andi Trimulyono <anditrimulyono@live.undip.ac.id>

Journal Brodogradnja

5 messages

Nastia Degiuli <Nastia.Degiuli@fsb.hr> Tue, Apr 12, 2022 at 2:03 AM
To: "anditrimulyono@live.undip.ac.id" <anditrimulyono@live.undip.ac.id>

Dear PhD Trimulyono,

your paper

Title: "The investigation of sloshing in the prismatic tank with vertical and T-shape baffles"

Author(s): Andi Trimulyono, Haikal Atthariq, Deddy Chrismianto, Samuel Samuel

Paper id: 1501-2021

has successfully passed the peer review and has been accepted for publication. **Before we proceed with our standard publishing procedure you have to settle the publication fee in the amount of 350€. If the payment is done by the Author(s) as physical entity(ies), 25% VAT will be added to the price.**

Please provide the full information on the payer to the editorial office of journal Brodogradnja (brodogradnja@fsb.hr).

Full information on the payer (physical or legal entity):

Full name:	
Full postal address including postcode:	
VAT number:	

Kind regards,

Nastia Degiuli

Editor-in-Chief

Ivana Martić

Executive Editor

Andrea Farkas

Executive Editor

PhD Nastia Degiuli, Full Professor

University of Zagreb

Faculty of Mechanical Engineering and Naval Architecture

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10000 Zagreb

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Phone: +385 1 6168 269

Fax: +385 1 6156 940

e-mail: nastia.degiuli@fsb.hr

Andi Trimulyono <anditrimulyono@live.undip.ac.id> Tue, Apr 12, 2022 at 4:58 AM
To: Nastia Degiuli <nastia.degiuli@fsb.hr>

Thank you for the good news. The information for the payer is as follows:

Full name:	Dr. Andi Trimulyono
Full postal address including postcode:	Jl. Banjarsari Gg Tunjungsari No. 15, Semarang, postcode-50275, Indonesia
VAT number:	€ 437.50

With Best regards,
Andi Trimulyono
[Quoted text hidden]

Andi Trimulyono <anditrimulyono@live.undip.ac.id> Wed, Apr 13, 2022 at 9:34 AM
To: "Atthariq180699@gmail.com" <Atthariq180699@gmail.com>

[Quoted text hidden]

Andrea Farkas <Andrea.Farkas@fsb.hr>
To: "anditrimulyono@live.undip.ac.id" <anditrimulyono@live.undip.ac.id>
Cc: Nastia Degiuli <Nastia.Degiuli@fsb.hr>, Ivana Martić <Ivana.Martic@fsb.hr>

Wed, Apr 13, 2022 at 3:50 PM

Dear PhD Trimulyono,

Your paper entitled

investigation of sloshing in the prismatic tank with vertical AND T-shape baffles is accepted for publication in journal Brodogradnja.

However, it is important for authors and the journal to cite appropriate papers published earlier in Brodogradnja.

Just before publishing please consider some additional published papers in Brodogradnja if they are of possible interest for being cited in your paper, for example:

EXPLOITATION OF LIQUEFIED NATURAL GAS COLD ENERGY IN FLOATING STORAGE REGASIFICATION UNITS

By:

Naveiro, M **(Naveiro, Manuel) [1] ;** Gomez, MR **(Gomez, Manuel Romero) [2] ;** Fernandez, IA **(Fernandez, Ignacio Arias) [2] ;** Gomez, JR **(Gomez, Javier Romero) [2]**

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BRODOGRADNJA

Volume

72

Issue

4

Page

47-78

DOI

10.21278/brod72404

Published

DEC 2021

Indexed

2022-01-13

Document Type

Review

EVALUATION OF THE ADDED RESISTANCE AND SHIP MOTIONS COUPLED WITH SLOSHING USING POTENTIAL FLOW THEORY

By:

Martic, I (Martic, Ivana) [1] ; Degiuli, N (Degiuli, Nastia) [1] ; Catipovic, I (Catipovic, Ivan) [1]

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BRODOGRADNJA

Volume

67

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4

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109-122

DOI

10.21278/brod67408

Published

DEC 2016

Indexed

2017-02-22

Document Type

Article

An Overview of the Hydro-Structure Interactions During Sloshing Impacts in the Tanks of LNG Carriers

By:

Malenica, S (Malenica, Sime) ; Kwon, SH (Kwon, Sung Hon) [1]

BRODOGRADNJA

Volume

64

Issue

1

Page

22-30

Published

MAR 2013

Indexed

2013-03-01

Document Type

Article

Kindest regards from the editorial team,

Nastia Degiuli

Andrea Farkas

Ivana Martić

Andi Trimulyono <anditrimulyono@live.undip.ac.id> Wed, Apr 13, 2022 at 10:02 PM
To: Andrea Farkas <Andrea.Farkas@fsb.hr>
Cc: Nastia Degiuli <nastia.degiuli@fsb.hr>, Ivana Martić <Ivana.Martic@fsb.hr>

Dear editorial team
Journal Brodogradnja

Thank you for the information. I have considered two of the reference to be added to the manuscript.
The first Ref. in my opinion is not linear with the current study. I hope this is okay for the final version.

Best regards,
Andi Trimulyono
[Quoted text hidden]

Manuscript_Andi T_revised 06-04-2022.docx
4544K

Andi Trimulyono <anditrimulyono@live.undip.ac.id>

Journal Brodogradnja

3 messages

Andrea Farkas <Andrea.Farkas@fsb.hr> Thu, Apr 14, 2022 at 5:00 PM
To: "anditrimulyono@live.undip.ac.id" <anditrimulyono@live.undip.ac.id>
Cc: Nastia Degiuli <Nastia.Degiuli@fsb.hr>, Ivana Martić <Ivana.Martic@fsb.hr>

Dear Authors,

Your paper "**INVESTIGATION OF SLOSHING IN THE PRISMATIC TANK WITH VERTICAL AND T-SHAPE BAFFLES**" is now published in V 73 N 2 2022.

You may find it on the web

https://brodogradnja.fsb.hr/view-articles/

http://hrcak.srce.hr

Your paper DOI number is http://dx.doi.org/10.21278/brod73203 which you may check at http://www.doi.org/

The references are completed by appropriate DOI numbers as required by CrossRef.

Your paper has got the Universal Decimal Classification Code UDC 532.5:532.58:532.594 and is categorized as an Original scientific paper. Authors may check the UDC code and propose modifications.

It takes several months from publication to indexing by the Web of Sciences bibliographic database.

Please check whether everything is correct and let us know if there are any mistakes in formatting as soon as possible.

Thank you for your interest in the journal Brodogradnja.

Please recommend this journal to your research colleagues.

Hoping to hear from you in the next future.

Please confirm the receipt of this information.

Kind regards,

Professor Nastia Degiuli, Editor in Chief

PhD Andrea Farkas, Executive editor for database administration

PhD Ivana Martić, Executive editor for similarity checking

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2 attachments

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1409K

Andi Trimulyono <anditrimulyono@live.undip.ac.id> Thu, Apr 14, 2022 at 5:41 PM
To: samuelaritonang@lecturer.undip.ac.id, deddy.chrismianto@ft.undip.ac.id, Atthariq180699@gmail.com

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Andi Trimulyono <anditrimulyono@live.undip.ac.id> Thu, Apr 14, 2022 at 9:39 PM
To: Andrea Farkas <Andrea.Farkas@fsb.hr>
Cc: Nastia Degiuli <nastia.degiuli@fsb.hr>, Ivana Martić <Ivana.Martic@fsb.hr>

Thank you very much for your email. The manuscript is correct, thank you for the help during submission to publication.
Definitely, Brodogradnja will be on my list for publishing a paper in the near future.

Best regards,
Andi Trimulyono
[Quoted text hidden]

Brodogradnja/Shipbilding/Open access Volume vv Number n, 20yy

Andi Trimulyono
Haikal Atthariq
Deddy Chrismianto
Samuel Samuel

http://dx.doi.org/10.21278/brodvvnP (provided by the Editor) ISSN 0007-215X
eISSN 1845-5859

THE INVESTIGATION OF SLOSHING IN THE PRISMATIC TANK WITH VERTICAL AND T-SHAPE BAFFLES

UDC 629.5(05) Provided by the Author or by the Editor
Categorization suggested by the reviewers provided by the Editor

Summary

The capacity of liquid carrier LNG tanks has increased in recent years. One of type LNG carriers is membrane type. The tank shape is a prismatic tank. One of the natural phenomena in a liquid carrier is sloshing. One of the effective ways to mitigate sloshing is using a baffle. In the present study, sloshing in a prismatic tank was carried out with two filling ratios, i.e., 25% and 50%. Smoothed particle hydrodynamics (SPH) was used to overcome sloshing with a single vertical baffle, double vertical baffle, and T-shape baffle. The height of the baffle is 0.9. This value is ratio baffle height and water depth. The comparison is made for dynamic pressure with the experiment. It was found that SPH has acceptable accuracy both for dynamic pressure and hydrostatic pressure. A baffle significantly decreases the wave height. As a result, the dynamic pressure is decreased. Finally, the hydrodynamics force is slightly decreased due to baffle installation.

Key words: *Smoothed particle hydrodynamics; Sloshing; Vertical baffle; T-shape baffle; Dynamic Pressure; Wave height; Hydrodynamics force.*

1. Introduction

The capacity of liquid carrier LNG tanks has increased in recent years. One of the LNG carrier types is a membrane-type carrier. The shape of the membrane-type carrier is a prismatic tank. The prismatic tank has the merit that the shape was similar to the ship hull shape. Another advantage is the larger capacity. One of the natural phenomena in a liquid carrier is sloshing. Sloshing is defined as the movement of fluid inside the tank due to excitation force into the tank. One of the effective ways to mitigate sloshing is using a baffle. Sloshing is one of the nonlinear phenomena which are challenging to overcome in fluid dynamics. Many studies were carried out in both experiment and numerical analysis. Thanks to computer technology that was increasing drastically, the numerical method became popular. The present paper is carried out a numerical study of sloshing using smoothed particle hydrodynamics (SPH). SPH is one of the particle methods that are meshless and Lagrangian approach. Due to the meshless method, large deformation and nonlinear phenomena are easy to reproduce. In the present study, weakly compressible SPH (WCSPH) is used to reproduce sloshing in the prismatic tank.

SPH is firstly applied for the astrophysical problem [1]. Monaghan developed it for free surface flow for dam-break dan water waves case [2]. Moreover, SPH application becomes wider, such as structure interaction of the wave with breakwaters [3]. SPH was applied for long-distance water wave propagation in a large wave basin with experimental validation [4]. It shows SPH has good accuracy for free surface flow such as water waves. Furthermore, to reduce of reflection wave in the numerical wave tank (NWT), an active wave absorption was developed [5]. Later on, water waves simulation was carried out using open boundaries combined with active wave absorption [6]. Implementation of SPH for numerical wave tank with Incompressible SPH (ISPH) was done using GPU to reduce pressure noise in weakly compressible SPH(WCSPH) [7]. It was shown SPH has a promising result for water waves.

SPH application for violent flow sloshing in low filling ratio using obstacle in the rectangular tank was carried out in one-phase SPH [8]. Furthermore, one-phase and two-phase SPH was carried out in a prismatic tank with a low-pass filter technique to reduce pressure oscillation due to the nature of WCSPH [9]. Later on, one-phase and two-phase of low filling ratio of sloshing in the prismatic tank was studied in the three-dimension domain [10]. It showed SPH had a high computational cost for three-dimension computation. A study of sloshing with baffle had been done using elastic baffle to reduce sloshing in the rectangular tank [11]. The study of two-dimension sloshing was carried out with a T-shape baffle to reduce the sloshing effect in the RANS solver [12]. Coupled SPH with smoothed finite element method (SFEM) used to study sloshing in a rectangular tank with flexible vertical and T-shape baffle [13]. The long duration of sloshing using the rectangular tank in three-dimension has been studied with a combination of tanks such as the pill, spherical, and cylindrical shape tank [14]. Implementation of δ-SPH and particle shifting was used to tackle sloshing with flexible baffle and elastic wall of the rectangular tank [15]. The comparison study used Volume of Fluid (VOF), SPH, and Arbitrary Lagrangian-Eulerian to study Braking and Roll Responses of Partly Filled Tank Vehicles [16]. A single and double vertical baffle study was carried out with rectangular tanks [17].

The present paper is carried out of sloshing in a prismatic tank with single, double, and T-shape baffles. The baffle height was based on the work of a previous study, which is an effective baffle between 0.75 to 0.9 of the ratio of the baffle and water depth [17]. In this paper, the baffle height was chosen 0.9. One pressure sensor was used to verify the validity of SPH simulation based on experimental work [18]. There are two water height probes set to capture free surface deformation inside the tank. The oscillation motion of the tank is rolling with a filling ratio of 25% and 50%. An open-source SPH solver, DualSPHysics version 5.0 was used to simulate sloshing in the prismatic tank [19]. DualSPHysics has been implemented with General Purpose computing on Graphics processing units (GPGPU) [20]. It makes a million particles that can be handled using a single GPU.

Sloshing in the prismatic tank was done in one phase SPH. It was revealed that vertical baffle has a significant effect on reducing fluid movement. The fluid became calm, and hydrodynamics pressure was reduced due to the effect of the baffle. Finally, hydrodynamic force and moment were decreased.

.

2. Theoretical background and method

2.1 Experimental setup of sloshing and SPH simulation.

The experimental setup of sloshing in the prismatic tank showed in Figure 1. There was three pressure sensor used in the experiment; in this study, only one pressure sensor was used to validate against the SPH simulation. Because in this study, only two filling ratios were used, i.e., 25% filling rato and 50% filling ratio (see Figure 1). As a consequence, a pressure sensor is located at the bottom that uses for validation of SPH simulation. It can be explained because the filling ratio 25% pressure sensor position is near a free surface. It was a challenging case for reproducing of impact pressure caused by sloshing.

Moreover, the pressure sensor position in the filling ratio of 50% is at mid of water depth. The pressure sensor was set fix in the experiment. There are four cameras used in the experiment. Two are inside of the oscillation machine, and others are outside of the oscillation machine. The reader can refer to the detailed information of the sloshing experiment [18].

Figure 2 depicts the geometry of the prismatic tank for SPH simulation. Where L, H, l, and d are the length of the tank, the height of the tank, width of the tank, and water depth, respectively. The dimension of the tank is shown in Table 1. Figure 3 depicts a prismatic tank with three types of baffle shapes in the filling ratio of 25%. The height of all baffles is 0.9 of ratio baffle height and water depth. The position of the vertical baffle is in the mid of the tank. While The distance of the double vertical baffle is the width of the tank divided into three sections. The T-shape baffle was set in the mid. The width of the baffle is ¼l, where l width of the tank. The thickness of the baffle was set as 6.0 mm. d1 and d2 are water depth in filling ratio 25% dan 50%.

Figure 4. shows the displacement of a tank in the experiment for roll oscillation motion. The oscillation motion is regular. In this study, the tank's movement is directly imposed from the experiment (see Figure 4). This is one of the merits of SPH that the movement of the tank is as same as in the experiment. Roll motion is one of the dangerous motions in the seakeeping area. Sloshing can endanger a ship when there is energetic sloshing, especially when sloshing excitation frequency is near or identical with the natural frequency of the tank.

The amplitude of roll motion is 8.660. The sloshing excitation frequency is 1.04 Hz for 25% filling ratio and 1.30 Hz for filling ratio 50%. It shows the frequency of excitation close to the natural frequency of the prismatic tank [18].

Table 1. Principal dimension of prismatic tank

Dimension	(m)
L	0.38
l	0.30
H	0.21
d	0.0525 (25%) 0.1050 (50%)

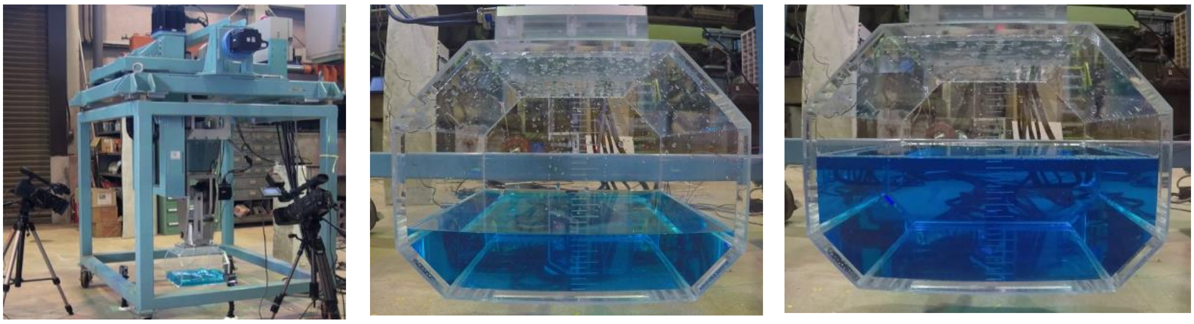


Fig. 1 Experimental condition of sloshing filling ratio 25% (a), condition of water depth with filling ratio 25% (b), and 50% (c).

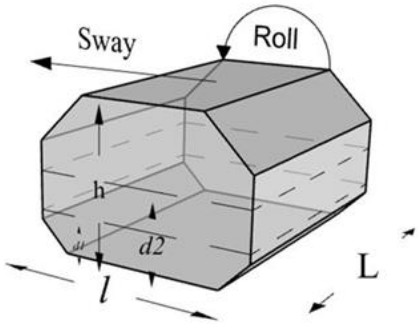


Fig. 2 The sketch of prismatic tank with principal dimension.

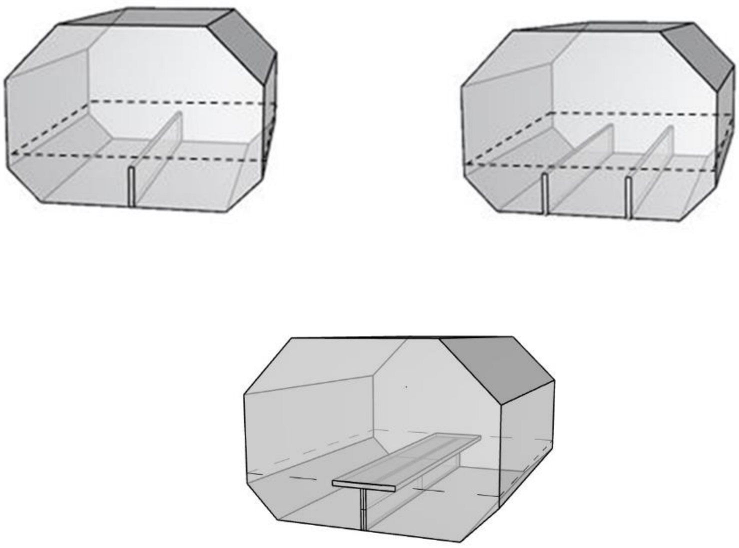


Fig. 3 The sketch of prismatic tank with single baffle (a) double baffle (b) and T-shapebaffle (c).

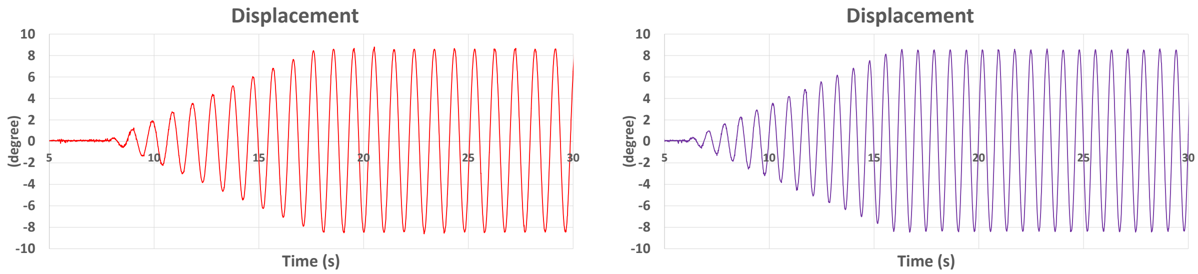


Figure 4. The displacement of the prismatic tank in SPH computation for filling ratio 25% (a) and 50% (b)

2.2 Smoothed particle hydrodynamics (SPH)

Smoothed particle hydrodynamics (SPH) was initially for the astrophysical field that is developed by Monaghan [1] and Lucy [21]. Later on, It was applied to the free surface problem for dam break and water waves on the beach [2]. SPH is a meshless and Lagrangian approach that uses an interpolation scheme to approximate physical values and derivatives of a continuous field by using discrete evaluation points. The evaluation points are identified as smoothed particles that contain mass, velocity, and position. The quantities are obtained as a weighted average from adjacent particles within the smoothing length, h, to reduce the range of contribution from the neighbor particles. The main features of the SPH method, which is based on integral interpolants, are described in detail [22,23].

Figure 5. shows the radius influence of particle *a* in the kernel function. Where contribution of particle inside the kernel is weighting using smoothing length. where $\boldsymbol{r_{ab}}$ is a distance of particles *a* and *b* while W_{ab} is the kernel function. In SPH, the field function $\boldsymbol{A}(\boldsymbol{r})$in domain Ω can be approximated by integral approximation as Eq (1) where *W* is kernel function and $\boldsymbol{r}$ is a vector of position.

The Eq (1) can be approximated into a discrete form by replacing the integral with a summation over the neighbouring particles in the compact support of particle *a* at the spatial position $\boldsymbol{r}$, thus leading to particle approximation in the Eq (2). In this study, the Wendland kernel function is used in all simulations. Eq (3) shows Wendland kernel function, where α_D is equal to $21/164\pi h^3$ in 3D. *q* is the non-dimensional distance between particles *a* and *b* that is given *r/h*.

Eq [4] is the continuity equation with the delta-SPH term to reduce spurious pressure in SPH [24]. Eq (5) is the momentum Eq in the SPH framework. Where **g** is gravity acceleration, P_a and P_b are pressure in a particle *a* and *b*. Π_{ab} is the artificial viscosity term, $\boldsymbol{\mu_{ab}} = \frac{\boldsymbol{h v_{ab} \cdot r_a}}{\boldsymbol{r_{ab}^2 + 0.01 h^2}}$, $\boldsymbol{v_{ab}} = \boldsymbol{v_a} - \boldsymbol{v_b}$ are vector velocity, and $\overline{\boldsymbol{c_{ab}}} = \boldsymbol{0.5}(\boldsymbol{c_a} + \boldsymbol{c_b})$ is the mean speed of sound and with α is a coefficient that needs to be tuned to get proper dissipation.

DualSPHysics is based on weakly compressible SPH (WCSPH), to get pressure in WCSPH an Eq of state was used based on Eq (6). Where c_o , ρ_0, and γ are the speed of sound at reference density, the reference density, and the polytrophic constant, respectively. This Eq is very stiff which a small change of density is made pressure fluctuation. This is one of the reasons there is a pressure oscillation in WCSPH. Eq (7) is the Eq to calculate the time step based on the work of Monaghan. Where $\Delta \boldsymbol{t_f}$ is based on the force per unit mass ($|\boldsymbol{f_a}|$) and Δt_{cv} combines the Courant and the viscous time step controls, where CFL is a coefficient in the range $0.1 \leq \text{CFL} \leq 0.3$.

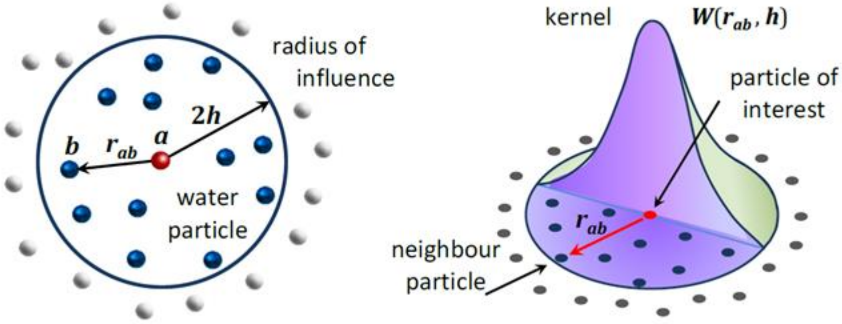


Fig. 5 Radius of smoothing length and kernel function in SPH

$$A(\boldsymbol{r}) = \int_{\Omega} A(\boldsymbol{r}) W(\boldsymbol{r} - \boldsymbol{r}', h)\, d\boldsymbol{r} \tag{1}$$

$$A(\boldsymbol{r}_a) \approx \sum_b A(\boldsymbol{r}_b) W(\boldsymbol{r}_a - \boldsymbol{r}_b, h) \frac{m_b}{\rho_b} \tag{2}$$

$$W(q) = \alpha_D \left(1 - \frac{q}{2}\right)^4 (2q+1) \quad 0 \le q \le 2 \tag{3}$$

$$\frac{d\rho_a}{dt} = \sum_b m_b \boldsymbol{v}_{ab} \cdot \nabla_a W_{ab} + 2\delta_{\Phi} h c_0 \sum_b (\rho_b - \rho_a) \frac{\boldsymbol{r}_{ab} \cdot \nabla_a W_{ab}}{\boldsymbol{r}_{ab}^2} \frac{m_b}{\rho_b} \tag{4}$$

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

$$where\ \Pi_{ab} = \begin{cases} \dfrac{-\alpha \overline{c_{ab}} \mu_{ab}}{\overline{\rho_{ab}}} & \boldsymbol{v}_{ab} \cdot \boldsymbol{r}_{ab} < 0 \\ 0 & \boldsymbol{v}_{ab} \cdot \boldsymbol{r}_{ab} > 0 \end{cases}$$

$$P = \frac{c_0^2 \rho_0}{\gamma} \left[\left(\frac{\rho}{\rho_0}\right)^{\gamma} - 1\right] \tag{6}$$

$$\Delta t_f = CFL \cdot min(\Delta t_f, \Delta t_{cv}) \tag{7}$$

$$\Delta t_f = min\left(\sqrt{\frac{h}{|\boldsymbol{f}_a|}}\right)$$

$$\Delta t_{cv} = min \frac{h}{C_s + max\left|\frac{h v_{ab} \cdot r_{ab}}{(r_{ab}^2 + \eta^2)}\right|}$$

Table 2. shows the parameters set up in SPH simulation. In this study, the Wendland kernel function was used in all computations with Sympletic time step algorithm. The artificial viscosity term with α is 0.01 to get proper dissipation. Based on the study conducted by Trimulyono et al. [18], the speed of sound has a significant impact on pressure magnitude. In this study, coefsound of 60 was used to reproduce the same accuracy on the pressure field.

Coefh is the coefficient of smoothing length. In 3D Coefh was define $Coefh = \frac{\boldsymbol{h}}{\boldsymbol{dp}\sqrt{\boldsymbol{3}}}$. CFL is coefficient of the Courant-Friedrichs-Lewy condition. Delta-SPH was used to reduce pressure oscillation, by default 0.1 is used in all simulations. Simulation time is set 28 seconds, as the motion is regular motion the motion is the same after the motion reach condition of steady-state condition (see Figure 4).

Table 2. Parameters setup of SPH computation.

Parameters	
Kernel function	Wendland
Time step algorithm	Sympletic
Artificial viscosity coefficient (α)	0.01
Coefsound	60
Particle spacing (mm)	1.6
Coefh	1.2
CFL	0.2
Delta-SPH (δ_φ)	0.1
Simulation time (s)	28

3. Result and discussion

3.1 Hydrostatic and hydrodynamic pressure

Figure 7. shows the hydrodynamics pressure in the bottom. The pressure was substracted with hydrostatic pressure, as result, the pressure is only dynamic pressure. Based on work Trimulyono et al. [18] the hydrostatic pressure is well reproduced by SPH with a difference under 3%. Figure 6. shows hydrostatic pressure in filling ratio 50% with T-shape baffle and without baffle. The hydrostatic pressure is well reproduced by SPH, moreover, the gradient of hydrostatic same with an analytic solution where the pressure at the bottom shows the highest, on contrary the pressure in the free surface shows the smallest value. A similar tendency shows in dynamic pressure. There is no significant pressure phase between SPH with experiment, It depicts SPH has similar velocity and displacement with the experiment. Moreover, it shows the timing of the pressure sensors in SPH to capture dynamic pressure similar to the experiment. It describes the fluid properties such as fluid kinematics has tendency same as physics.

The hydrodynamics pressure is consists of impact pressure and dynamic pressure. Figure 7. shows hydrodynamic pressure in the filling ratio of 25%. Redline is an experiment, purple line is SPH without baffle. The green line is dynamic pressure with a single baffle, yellow is for the double baffle, and the black line is for the T-shape baffle. The first magnitude is impact pressure, it can be seen from Figure 7 that the first magnitude is very high then it decreased. The second is dynamic pressure when fluid is start to run-up to the top of the tank. The magnitude of dynamic pressure is lesser than impact pressure because the pressure is affected by fluid movement without any sudden accelerated fluid movement. In the sloshing phenomena, impact pressure has to minimize to avoid structure damage or explosion for dangerous liquid cargoes such as LNG.

One of the ways to mitigate sloshing is using a baffle. The study shows vertical baffle has a significant effect on sloshing. Ma et al. shows the vertical baffles effectively reduce sloshing in a rectangular tank [17]. The present study is tried the same way using a prismatic tank with a combination of T-shape baffle. It revealed that fluid movement inside of the tank is decreased significantly, as a result, the pressure magnitude is decreased. Using one vertical baffle, the pressure is decreased by 85.80 %. Two vertical baffles have effectively decreased the pressure by 88.24 %. The T-shape baffle effectively decreased pressure by 82.60%.

Figure 8. shows the dynamic pressure for the filling ratio of 50%. The accuracy is a slight difference with a filling ratio of 25%. The impact pressure was not captured by SPH. However, the accuracy of the timing of the pressure sensor was similar to the experiment as well as in the filling ratio of 25%. It revealed that dynamic pressure is reproduced by SPH. the single baffle effect is reduced pressure up to 94.5%. The double vertical baffles are reduced pressure up to 91.2%. A T-shape baffle effectively reduced pressure by 91.0%.

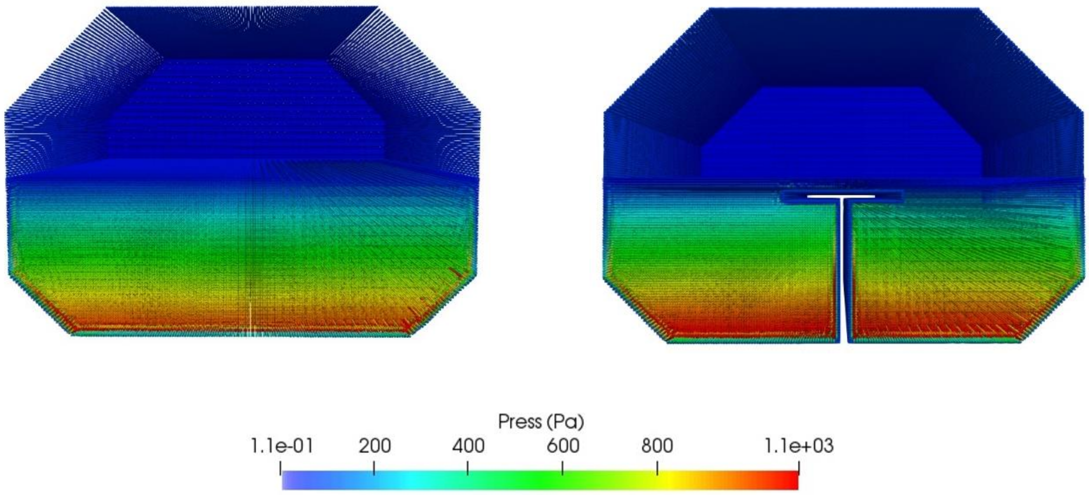


Fig. 6 Hydrostatic pressure in filling ratio 50% without and with T -shaped baffle.

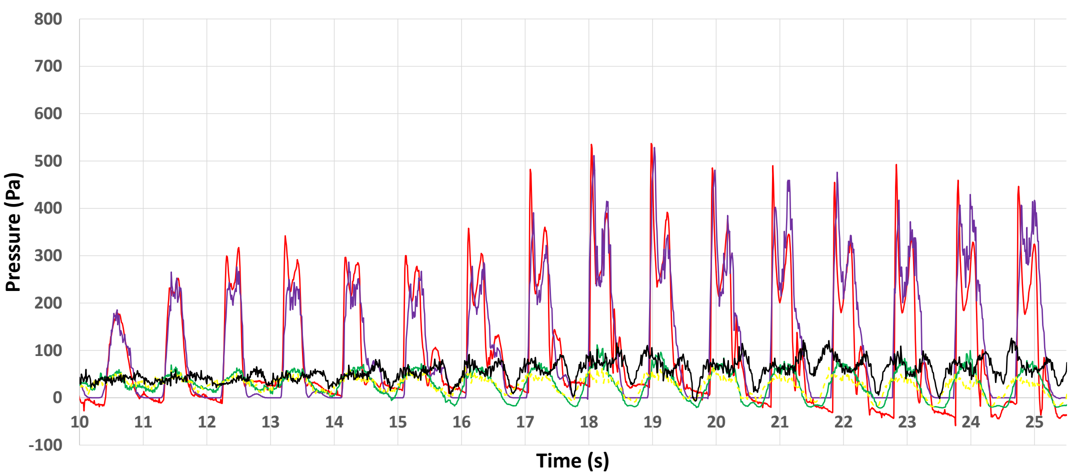


Fig. 7 Comparison of dynamic pressure of pressure gauge with and without baffles for filling ratio 25%.

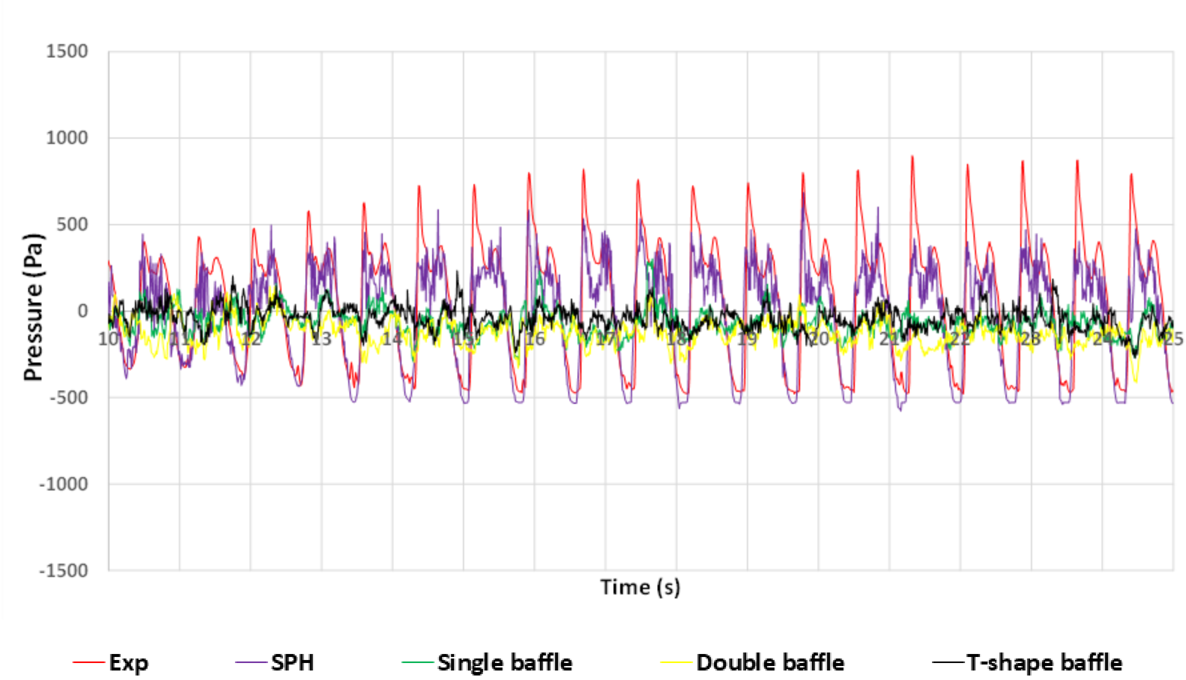


Fig. 8 Comparison of the dynamic pressure of pressure gauge with and without baffles for filling ratio 50%.

3.2 Free surface deformation

In the present paper, advanced visualization was conducted using open source blender version 2.92. The software is freely downloaded at https://www.blender.org/. Using this technique post-processing of SPH is more attractive and close to real physics. Figure 9. shows the comparison of visualization in particle, surface, and advanced surface texturing using a blender [25]. It can be seen in Figure 9. that fluid looks like real fluid. The post-processing of advanced texturing was done for all simulations.

The free surface deformation inside the tank was influenced by excitation force. When energetic sloshing has happened the fluid movement leads to chaos and complicated. The energetic sloshing could exist when the frequency of excitation force is close to the natural frequency of the tank. To mitigate the fluid movement inside of a tank, one of the effective ways is using baffle to reduce fluid movement. It can be seen in Figure 10, and Figure 11 without baffle installation the fluid run-up to the top of the tank. In contrast, after baffle installation in the tank, the fluid becomes calm.

The effect of a single vertical baffle is to suppress wave height up to 86.3%. It was indicated the impact pressure is reduced caused by baffle installation. As seen in Figure 10. the fluid becomes calm as a result the impact pressure caused by fluid-accelerated movement is suppressed. Similar results show using double vertical baffle and T-shape baffle. The double vertical baffle is suppressed wave height up to 91.7% and the T-shape baffle is suppressed wave height over 95.0%. Based on visual observation, it can be seen is using vertical baffle, the fluid is experience damped by vertical baffle and fluid undergo a suction after passing the vertical baffle. The kinetic energy is suppressed by a vertical baffle that made fluid movement becomes slower compare without baffle installation. For T-shape baffle shows similar phenomena, the fluid becomes calm caused by a fluid is damped by the T-shape baffle. It can be explained that the T-shape baffle is damped the fluid by suppressing fluid movement when it passes the baffle. The fluid becomes calm caused by a sudden change of water depth when it passes the T-shape baffle as result the wave height is suppressed and then the fluid becomes calm. It can see in Figure 10. the wave height is lesser compared to before passing the T-shape baffle.

In the filling ratio of 50%, using a single vertical baffle is suppress wave height 79.0%. Similar tendency phenomena show in the filling ratio of 50%. The vertical baffle is damped fluid movement because the fluid experiences a suction effect after passing the baffle as result the wave height is reduced and the fluid becomes calm. Double vertical baffle suppress wave height over 95.0%. The higher result is obtained by a double vertical baffle. Because the effect of the vertical baffle is double in this condition. Wave height is suppressed two times because pass double vertical baffle. Wave height near the tank is caused by movement of the tank that is lesser compared without baffle. Moreover, impact pressure is reduced and finally fluid becomes calm. Using T-shape baffle wave height is suppressed 79.0%. In the filling ratio of 50%, the T-shape baffle is a lesser damped fluid compared to the filling ratio of 25%. It can be explained that the fluid is damped when it passes the baffle and suction by T baffle, unfortunately, because deeper water depth is used, the effect of fluid near the wall is not reduced by a baffle that is why wave height still height as seen as in Figure 11. It can be one of future works to conduct the effective width of T–shape baffle to sloshing.

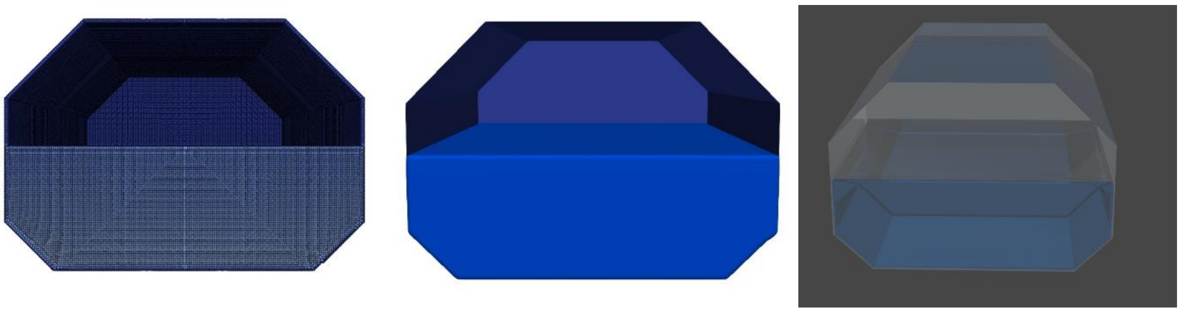
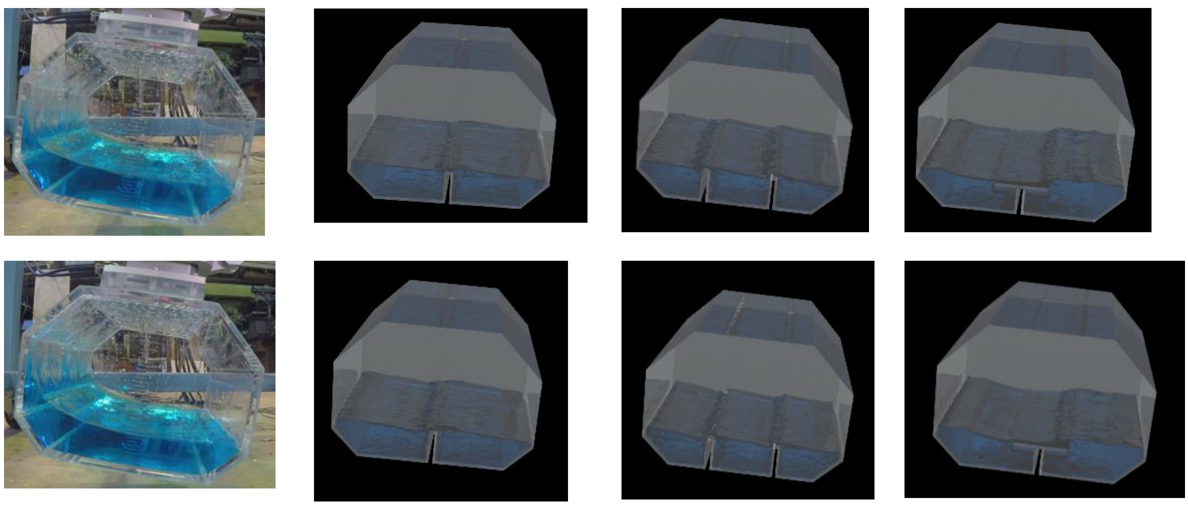


Fig. 9 Visualization of particle, iso-surface, and surface texture.



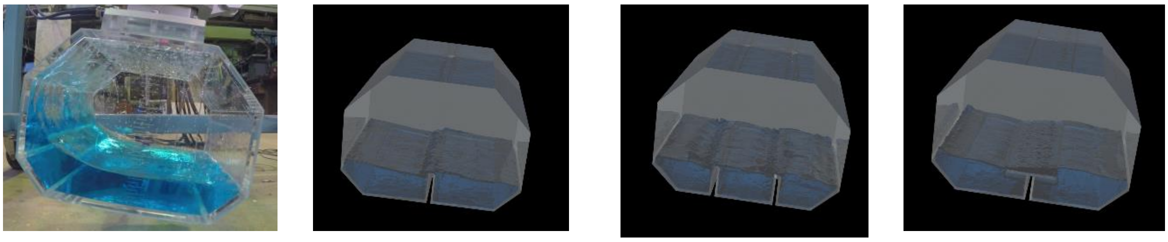


Fig. 10 Comparison of free surface deformation inside tank with and without baffles in the filling ratio 25%.

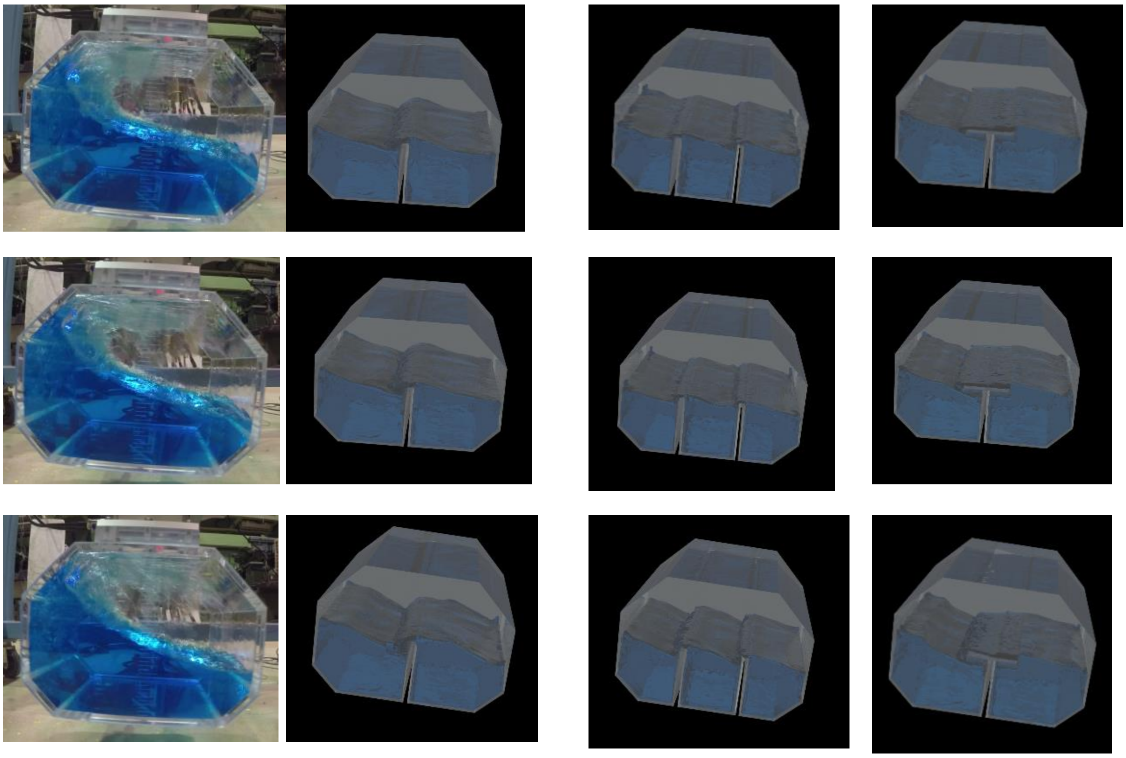


Fig. 11 Comparison of free surface deformation inside a tank with and without baffles in the filling ratio 50%.

3.3 Hydrodynamics force

The sloshing experiment was carried out with a forced oscillation machine in four degrees of freedom. The machine itself could conduct a regular and irregular motion. The couple motion can be conducted for sloshing experiment, for example, couple motion of roll and heave. In the present paper, only regular motion is used to reproduce the sloshing phenomenon. Because the effect of the baffle is can be seen in a regular or irregular motion.

Hydrodynamics force exists because the fluid inside the tank is forced to move by an oscillation machine. Figure 12 shows the hydrodynamics force in the filling ratio of 25%. Redline is hydrodynamics force without baffle, green, yellow, and black is single, double, and T-shape baffle. It shows that hydrodynamics force without baffle is higher than with baffle. Although the difference is not large enough like dynamics pressure or wave height. It can be explained that the hydrodynamics force act in the tank is caused by constantly forced oscillation during the sloshing period. As result the force constantly exists during sloshing, the difference will be significant to hydrodynamics force if the motion is not constant. in other words, the motion of the tank is free movement and then the movement of the tank is caused by external excitation force. The difference of hydrodynamics force without baffle with single baffle is 33%. A similar trend indicates by a double baffle that the difference is 35%. Using T-shape baffle the difference is 47%. The T-shape baffle shows a more effective reduced hydrodynamic force. It can be explained of the T-shape baffle reduce the force act in the mid of the tank caused by the shape of the T-baffle.

In the filling ratio of 50%, It shows the hydrodynamics force similar trend exists (see Figure 13). Single dan double vertical baffle effectively reduced the hydrodynamics force by 30%. The T-shape baffle effectively reduces by 49%. It indicates vertical baffle could be one alternative to reduce sloshing in the prismatic tank. The free motion of sloshing is one of the future works that need to carry out in the next study. Because in the present paper, the direct effect of sloshing motion does not exist due to motion is forced excitation.

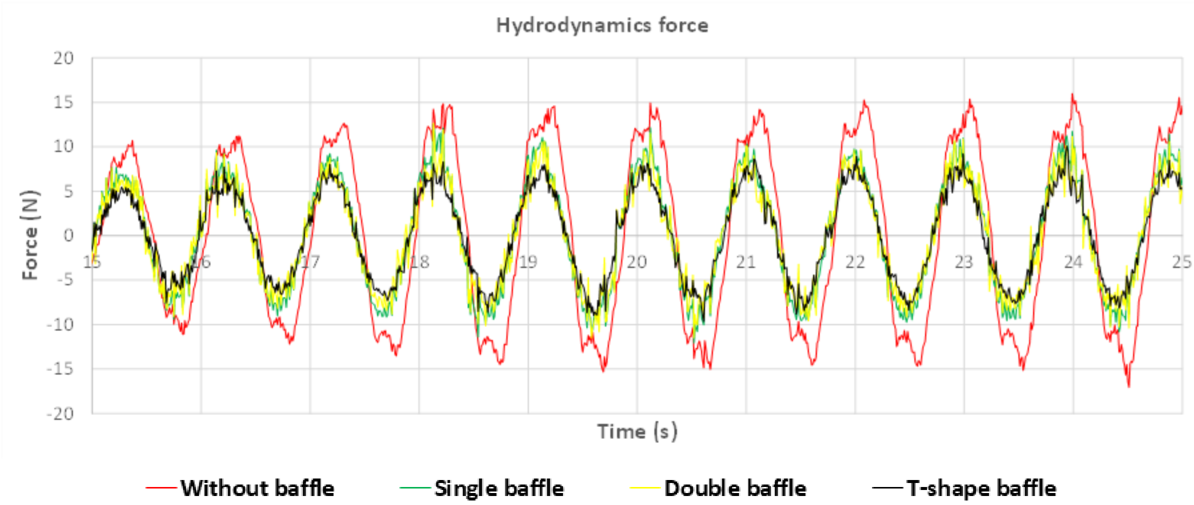


Fig. 12 Hydrodynamics force due to of sloshing in filling ratio 25% with and without baffle.

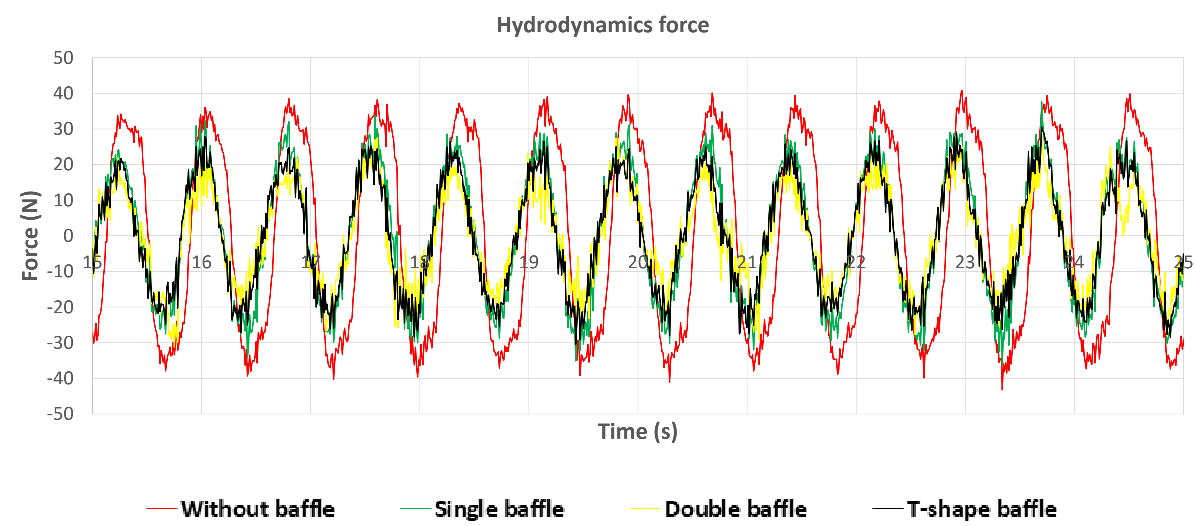


Fig. 13 Hydrodynamics force due to sloshing in filling ratio 50% with and without baffle.

4. Conclusion

Sloshing simulation in the prismatic tank was successfully carried out in two filling ratios. The current study indicates that SPH is one of the promising methods to reproduce sloshing in the tank. It was shown that single, double vertical baffle and T-shape baffle are effective to mitigate sloshing in the tank. The results revealed the baffle is effectively reduced the impact pressure caused by energetic sloshing. The wave height shows linear effect as impact pressure. The wave height is reduced by single, double, and T-shape baffle. Hydrodynamics force slightly decreased by the baffle. Though the excitation force is using forced oscillation motion. Future works of couple motion sloshing with ship motions need to conduct to know the effect of sloshing with ship motions.

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Cover letter to editors of journal Brodogradnja

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October 11th, 2021

Dear Editors,

I wish as a corresponding author to submit for consideration by journal Brodogradnja a research article entitled "The investigation of sloshing in the prismatic tank with vertical baffle and T-shape baffle" on behalf of the following authors: "Andi Trimulyono, Haikal Atthariq, Deddy Chrismianto, Samuel".

I confirm that this article refers with care to works of other researchers and that this work has not been published elsewhere, nor is it currently under consideration for publication elsewhere. This paper reports the investigation of sloshing in the prismatic tank using a single vertical, double vertical, and T-shape baffle. The mitigation of sloshing in LNG carriers is an important aspect as the capacity of LNG carriers is increasing year by year. One of the LNG carrier types is membrane type, which the tank shape is a prismatic tank. The model scale is 1:125, with the experiment of sloshing being carried out using a forced oscillation machine. Two filling ratios are used to reproduce roll motion, with a frequency of excitation force close to a natural frequency of the tank; as a result, energetic sloshing has happened. Sloshing is one of the challenging phenomena in fluid dynamics. To mitigate energetic sloshing, we use a single vertical, double vertical, and T-shape baffle. The numerical method was used meshless and Lagrangian approaches, i.e., smoothed particle hydrodynamics (SPH). The open-source SPH solver DualSPHysics version 5.0 is used to overcome sloshing with a baffle. The advanced visualization technique is carried out for post-processing. The free surface deformation is rendered using a blender application to get realistic fluid. The result shows that hydrodynamics pressure, wave height, and hydrodynamics force were significantly decreased. The research shows the ratio height of baffle and water depth 0.9 is proved the optimum heights of the baffle can be used. This is significant because few studies are carried out using advanced texturing for SPH post-processing. In addition, the sloshing model is validated using experiments. In addition, it was reproduced using open-source software for numerical computation.

We believe that this manuscript is appropriate for publication by Brodogradnja because it is fitted with Brodogradnja aim and scope of the journal regarding its focuses on ship hydrodynamics.

The natural phenomenon of a liquid carrier of an LNG ship is sloshing. Many studies of sloshing are carried out using a simple geometry tank, i.e., rectangular tank. In reality, they are rare for a liquid carrier using a rectangular tank. The sloshing model is based on an experiment conducted in the National Research Institute of Fisheries Engineering (NRIFE) Japan. Later on, a numerical method is carried out using the particle method, i.e., smoothed particle hydrodynamics (SPH). SPH is one of the emerging methods that is a promising method for free surface problems. Large deformation and non-linear phenomena are easy to handle. In addition, the study presents the latest method for advanced visualization. In the present study, sloshing in the prismatic tank with vertical baffle and T-shape was investigated. The result shows that the vertical baffle and T-shape baffle is effectively reduced the sloshing effect. Moreover, hydrodynamic pressure, hydrodynamic force, and wave height decreased due to baffle installation. We found that our parameter in the ratio of the height of baffle and water depth is effectively reduced the sloshing phenomenon.

We have no conflicts of interest to disclose.
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Reviewer's Remarks for Acceptance

(Note: extra sheets may be used if necessary in addition or instead)

Paper No	The comments how to improve the quality of the paper but not essential

Paper No	Changes which should be made prior to publication:

Who conducted the experiment, where is the experimental data taken from? In other words, this reviewer does not understand if the paper is using an original experiment or just takes some already conducted experiment from the literature.

What is the meaning of Fig. 6? Initial hydrostatic pressure field does not need to be visualized. The authors should include couple of figures of the total or dynamic pressure during the sloshing period.

Which boundary conditions on walls were used? How are they implemented?

Even though the pressure signal throughout the slosh period is important indicator, more important is the pressure impulse. In other words, a comparison between simulations should be made based on the pressure integral during a single referent slosh period. Please include relative differences between the experiment and simulations.

The languange should be improved. Almost every other sentence needs some improvement. A randomly taken sentence: “There was three pressure sensor used in the experiment” -> “Three pressure sensors were used in the experiment”, etc.

The authors write: “The hydrodynamics pressure is consists of impact pressure and dynamic pressure.”. Firstly, the sentence does not make sense (check the grammar). Secondly, it is wrong.

Figures 7 and 8 should explicitly note where is the pressure sensor locate. The paragraphs that refer to those figures as well.

Reasons for Rejection

Paper No	If the paper is evaluated as NOT ACCEPTABLE please give your explanation

Reviewer's Guidelines

While inserting the data into the **Paper Profile** the attention should be paid to the following:

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In scientific section of "Brodogradnja" journal scientific papers related to the field of naval architecture, shipbuilding, marine engineering, ocean engineering and supporting industry are published. Preference is given to the scientific papers whose basic intention is the development and application of shipbuilding industry products. Fundamental research papers written in a clear engineering style will be also published in the journal.

Ad **D. Type of Paper**

The paper categorisation should be done in accordance with the UNESCO Guide which recommends the following criteria:

Original scientific paper reports on unpublished results of original research. It should be written in such a way that a qualified research worker on the basis of presented information is able to:

a) repeat the experiment and obtain presented results with the same accuracy or within experimental error boundaries, or

b) repeat the author's observations, calculations or theoretical reasoning, and reach similar conclusions.

Preliminary communication contains new scientific research results which require urgent publication. It need not necessarily provide the basis for the repetition of the experiments by others.

Review should be an original, concise, and critical presentation of one subject area or a part of it, in which the information already published is assembled, analysed and discussed.

Professional paper presents high achievements in engineering practice.

Reviewer's Remarks for Acceptance

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- Do NOT use a comma every 10 words. The paper, as of right now, is just a bunch of sentences put one next to the other. There is no reading flow, which makes the paper very, very hard to follow.
- Review the language, the current level is not acceptable for a scientific publication. It is recommended to read the paper several times for improvements and to also send it out to native or technical English writers for a major reshape.
- Some figures are of very poor quality. Also, any image that is not your creation should be referenced.
- Check for typos and fix the punctuation.

I will be able to fully review the paper only when the above aspects have been addressed.

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Professional paper presents high achievements in engineering practice.

Author Responses to the Reviewers

Dear Prof. Nastia Degiuli
University of Zagreb

We would like thank for giving us an opportunity to revise our manuscript. We really appreciate editors and reviewers very much for their positive and constructive comments and suggestions on our article entitled "**The investigation of sloshing in the prismatic tank with vertical And T-shape baffles**" by Andi Trimulyono, Haikal Atthariq, Deddy Chrismianto, Samuel Samuel.

We have carefully studied the reviewer's comments and have made revisions comprehensively. We have tried our best to revise our manuscript according to the comments. Please find the attached revised manuscript version and author response to the reviewer comment at the end of the letter.

We would like to express our great appreciation to you and the reviewers for your comments on our work. We hope the revision has improved the manuscript to a level of your satisfaction. I look forward to hearing from you.

Thank you and with best regards.

Yours sincerely,

Andi Trimulyono, ST, MT, PhD

Reviewer #1

1. Who conducted the experiment, where is the experimental data taken from? In other words, this reviewer does not understand if the paper is using an original experiment or just takes some already conducted experiment from the literature.

   Author response: Thank you for your comments, the experimental data is based on a previous author study. Moreover, We state it ‘‘Detailed information of the sloshing experiment is stated in reference [18]’’

2. What is the meaning of Fig. 6? Initial hydrostatic pressure field does not need to be visualized. The authors should include couple of figures of the total or dynamic pressure during the sloshing period. Which boundary conditions on walls were used? How are they implemented?

   Author response: We want to show hydrostatic pressure is well reproduced by SPH and then offers the accuracy of dynamic pressure. We have added Figure 7 for dynamic pressure, and dynamic boundary particle (DBP) of Crespo et al. [26] used in the boundary condition. In addition, a new paragraph has been added.

   ‘‘DBPs are boundary particles that satisfy the same equations as fluid particles, but they are not moved by their forces. Instead, they either remain in a fixed position or move according to an imposed or assigned motion function. This includes the movement of objects, such as gates, wavemakers, or floating objects. When a fluid particle approaches a boundary, and the distance between its particles and that of the fluid is smaller than twice the smoothing length (h), the density of the affected boundary particles increases, thereby leading to a rise in pressure.’’

3. Even though the pressure signal throughout the slosh period is important indicator, more important is the pressure impulse. In other words, a comparison between simulations should be made based on the pressure integral during a single referent slosh period. Please include relative differences between the experiment and simulations.

   Author response: Thank you very much for your suggestion, because of our limitation using DualSPHyiscs, we could not provide pressure integral, in addition, we want to show the applicability of SPH in marine engineering using DualSPhysics code. We have added Figures 8 (b) and 9 (b) to compare average peak and average dynamic pressure. ‘‘Figure 8 (b) shows the comparison for average and peak pressure between SPH and Experiment. The difference for peak and average pressure is 4.6 % and 4.8 %.’’

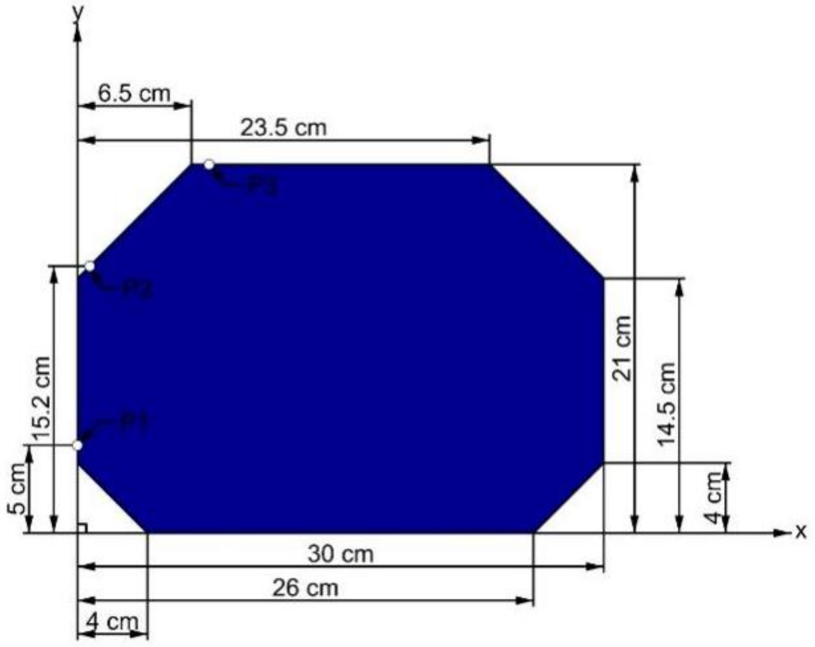
‘‘Figure 9 (b) indicates the peak pressure could not captured by SPH and made the average pressure accuracy lower than 25 % filling ratio. However, the trend of dynamic pressure similars after peak pressure.’’

4. The languange should be improved. Almost every other sentence needs some improvement. A randomly taken sentence: “There was three pressure sensor used in the experiment” -> “Three pressure sensors were used in the experiment”, etc.
   Author response: Thank you for your correction, we have changed ‘‘Figure 1 shows the experimental setup of sloshing in the prismatic tank, involving three pressure sensors [18].’’ In addition, we used professional English services.

5. The authors write: “The hydrodynamics pressure is consists of impact pressure and dynamic pressure.”. Firstly, the sentence does not make sense (check the grammar). Secondly, it is wrong.
   Author response: Thank you for your correction, we change it ‘‘the hydrodynamics pressure consists of static and dynamic pressures.’’

6. Figures 7 and 8 should explicitly note where is the pressure sensor locate. The paragraphs that refer to those figures as well.

Author response: Thank you for pointing this out, we added a new figure for the location pressure sensor (Figure 2 (b)).



Reviewer #2

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1. Do NOT use a comma every 10 words. The paper, as of right now, is just a bunch of sentences put one next to the other. There is no reading flow, which makes the paper very, very hard to follow.
   Author response: Thank you for your recommendations, we have changed it and used professional English services.

2. Review the language, the current level is not acceptable for a scientific publication. It is recommended to read the paper several times for improvements and to also send it out to native or technical English writers for a major reshape.
   Author response: Thank you for your advice, we have revised and used professional English services to improve our manuscript.

3. Some figures are of very poor quality. Also, any image that is not your creation should be referenced.
   Author response: Thank you for your suggestion, we have been changed the figure that is poor quality.

4. Check for typos and fix the punctuation.
   Author response: Thank you for your correction, we have been revised and carefully rechecked the manuscript and used Professional English Services to improve our manuscript.

I will be able to fully review the paper only when the above aspects have been addressed.

Author response: We hope our manuscript is ready for your review, we will grateful for any comments to improve our manuscript.

Reviewer #3

The paper is of interest, sufficiently innovative, and merits publication. The English language, however, is extremely poor, and must be improved.

Author response: Thank you very much for your positive comments, we have used Professional English Services to improve our manuscript. The certificate of professional English services is shown in the following.


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The Investigation of Sloshing in the Prismatic Tank with Vertical and T-Shape Baffles

Author(s)

Andi Trimulyono, Haikal Atthariq, Deddy Chrismianto, and Samuel

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Andi Trimulyono
Haikal Atthariq
Deddy Chrismianto
Samuel Samuel

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THE INVESTIGATION OF SLOSHING IN THE PRISMATIC TANK WITH VERTICAL AND T-SHAPE BAFFLES

UDC 629.5(05) Provided by the Author or by the Editor
Categorization suggested by the reviewers provided by the Editor

Summary

The demand for liquid carriers, such as liquefied natural gas (LNG), has increased in recent years. One of the most common types of LNG carriers is the membrane type, which is often built by a shipyard with a prismatic tank shape. This carrier is commonly known for its effective ways to mitigate sloshing using a baffle. Therefore, this study was performed to evaluate sloshing in a prismatic tank using vertical and T-shape baffles. The sloshing was conducted with 25% and 50% filling ratios because it deals with the nonlinear free-surface flow. Furthermore, the smoothed particle hydrodynamics (SPH) was used to overcome sloshing with ratio of a baffle and water depth is 0.9. A comparison was made for the dynamic pressure with the experiment. The results show that SPH has an acceptable accuracy for dynamic and hydrostatic pressures. Baffle installation significantly decreases the wave height, dynamic pressure and hydrodynamic force.

Keywords: *Smoothed particle hydrodynamics; Sloshing; Vertical baffle; T-shape baffle; Dynamic Pressure; Wave height; Hydrodynamic force.*

1. Introduction

The capacity of liquid carriers has increased in recent years, and this is caused by the increasing demand for liquefied Natural Gas (LNG). A common type is the membrane type, which is often built by a shipyard, and is shaped like a prismatic tank. One of the advantages of the membrane-type carrier is that its shape is similar to a ship hull and has a large capacity. A naturally occurring phenomenon in LNG carriers is sloshing, defined as the movement of fluid due to the excitation force in the tank, which is effectively mitigated using a baffle. Sloshing is a nonlinear phenomenon that is difficult to be overcome in fluid dynamics. Several preliminary studies have been performed, including experimental and numerical analyses, which have been made popular by the rapid advancement of computer technology in recent years. This study employed a numerical approach to analyze sloshing using smoothed particle hydrodynamics (SPH). SPH is a meshless and purely Lagrangian approach used to reproduce large deformation and nonlinear phenomena. In this study, weakly compressible SPH (WCSPH) is used to reproduce sloshing in the prismatic tank.

Initially, SPH was used to solve astrophysical problems [1]. However, Monaghan developed SPH for free surface flow for dam-break and water wave cases [2]. Moreover, it is widely applied and used for structural interactions between waves with breakwaters [3]. With an experimental validation, SPH was applied in a long-distance water propagation that occured in a large wave basin [4]. Furthermore, to reduce the reflections in a numerical wave tank (NWT), an active wave absorption was developed [5]. This was combined with open boundaries and used to conduct a water wave simulation [6]. The implementation of SPH for NWT with incompressible SPH (ISPH) was performed using GPU to reduce pressure noise in WCSPH scheme [7]. Therefore, SPH is used to solve the water wave and has good accuracy for free surface flow.

The SPH application in violent flow sloshing, which usually occurs with respect to a low filling ratio due to an obstacle in the rectangular tank, was carried out in one-phase SPH [8]. Furthermore, one- and two-phase SPH were used in a prismatic tank with a low-pass filter technique to reduce pressure oscillation due to the nature of WCSPH [9]. These were studied in a three-dimensional (3D) domain [10], and the results showed that the SPH had good accuracy and also highly a computational cost. A preliminary study was conducted using elastic baffle to reduce sloshing in the rectangular tank [11]. A two-dimensional analysis study was also performed using a T-shape baffle to reduce the effect of this phenomenon in a RANS solver [12]. SPH coupled with the smoothed finite element method was used to investigate the impact of sloshing in a rectangular tank with a flexible vertical and T-shape baffle [13]. The long-duration simulation of this phenomenon in rectangular-, pill-, spherical- and cylindrical-shaped tanks had been studied in a three-dimensional domain [14]. The implementation of δ-SPH and particle shifting with flexible baffle and elastic walls of the rectangular tank were used to tackle sloshing [15]. A comparison study was performed using volume of fluid (VOF), SPH, and arbitrary Lagrangian-Eulerian to analyze the braking and roll responses of partly filled tank vehicles [16]. Preliminary research was performed on single and double vertical baffles in rectangular tanks [17].

This study used single-, and double- vertical and T-shape baffles to investigate sloshing in a prismatic tank. Its heights were based on previous research [17], and the ratio of the baffles to water depth is relatively 0.75 to 0.9. The selected baffle height in this study was 0.9. A pressure sensor was used to verify the validity of the SPH simulation based on experimental research carried out by Trimulyono et al. [18]. Moreover, two water heights were set to capture free surface deformation inside the tank. Its oscillatory motion has 25% and 50% filling ratios. DualSPHysics version 5.0, an open-source SPH solver, was used to simulate sloshing in the prismatic tank [19]. DualSPHysics was implemented using general purpose computing on graphics processing units (GPGPU) [20]. It ensures a million particles are handled using a single GPU. Moreover, the advanced visualization was performed using Blender version 2.92.

Sloshing in the prismatic tank was used in a single-phase SPH, and the results revealed that the vertical baffle has a significant effect, such as reducing fluid movements and hydrodynamic pressure. Finally, hydrodynamic force and moment decreased.

2. Theoretical background and method

2.1 Experimental setup of sloshing and SPH simulation.

Figure 1 shows the experimental setup of sloshing in the prismatic tank, involving three pressure sensors [18]. However, only one of them was used to validate the SPH simulation, and only two filling ratios, i.e., 25% and 50%, were used (Figure 1). The pressure sensor located in the bottom was used to validate the SPH results. As a consequence, the 25% filling ratio was situated near a free surface, whereas that of the 50% was located in the mid-water depth. This is one of the reasons why pressure sensors located at the bottom were used to validate the SPH result. Reproducing the pressure caused by sloshing was also challenging, especially when the 25% filling ratio was used. Four cameras were used to capture free surface deformation, which was equally installed inside and outside the oscillation machine. The detailed information of the sloshing experiment is stated in Ref. [18].

Figure 2 shows the geometry of the prismatic tank for the SPH computation, where L, H, *l*, and *d* are its length, height, width, and water depth, respectively. Table 1 and Figure 3 show the tank's dimension and the three types of baffle shapes with the 25% filling ratio. The baffle height and water depth ratio were 0.9, and the vertical one was positioned in the middle of the tank. Meanwhile, the distance of the double baffle was equivalent to the tank's width, which was divided into three sections. The T-shape baffle was set in the middle of the tank, and its width is ¼*l*, where *l* is also equivalent to width. Its thickness was set as 6.0 mm, and *d1* and *d2* are water the depths in the 25% and 50% filling ratios, respectively.

Figure 4 shows the displacement of the tank in the experiment based on the constant oscillatory rolling motion. In this study, its movement was directly imposed from the experiment (Figure 4). A roll motion is one of the dangerous movements in the seakeeping area; so it was considered in the present study. Sloshing tends to endanger a ship when it is energetic, especially when the excitation frequency is near or identical to the natural frequency of the tank.

The amplitude of the roll motion is 8.66^0 with sloshing excitation frequencies of 1.04 and 1.30 Hz for the 25% and 50% filling ratios, respectively. The findings shows that the excitation frequency is close to the natural frequency of the prismatic tank [18].

Table 1:Principal dimensions of prismatic tank

Dimension	(m)
L	0.38
L	0.30
H	0.21
D	0.0525 (25%) 0.1050 (50%)

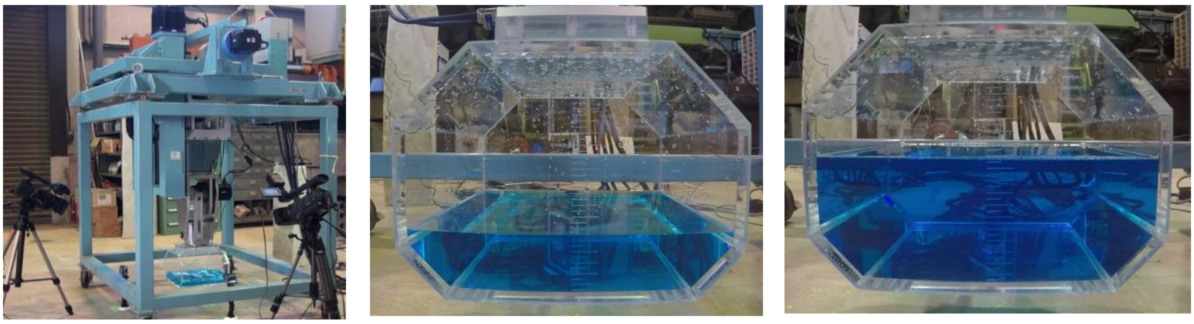


Fig. 1 Experimental condition of the sloshing filling ratio of 25% (a), condition of the water depth with filling ratios of 25% (b), and 50% (c) [18].

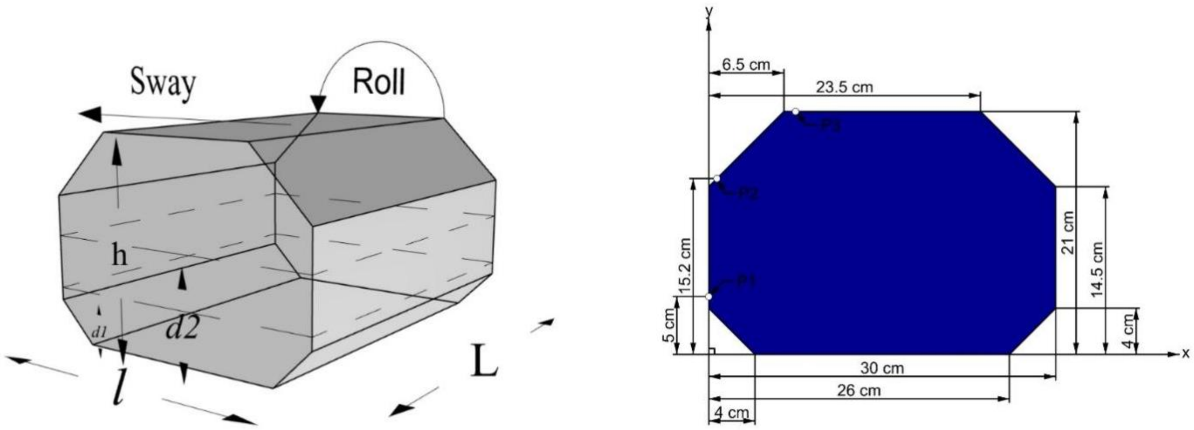


Fig. 2 Sketch of a prismatic tank with the principal dimension (a) and pressure sensor location (b).

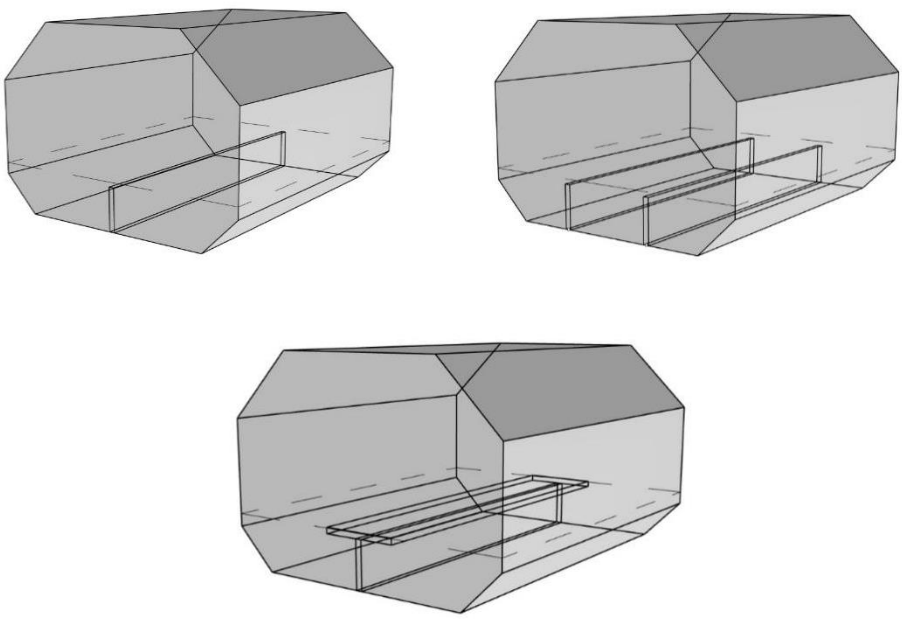


Fig. 3 Sketch of the prismatic tank with a single-vertical baffle (a) double-vertical baffle (b) and T-shape baffle (c).

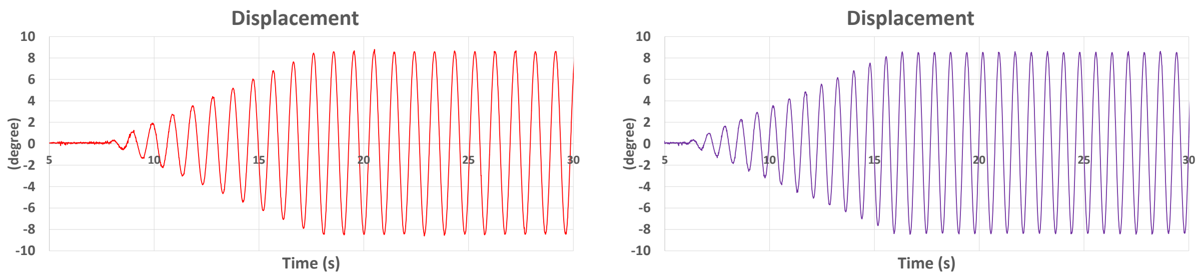


Fig. 4 Displacement of the prismatic tank in the SPH computation with filling ratio 25% (a) and 50% (b)

2.2 Smoothed particle hydrodynamics.

Smoothed particle hydrodynamics (SPH) was initially used in the astrophysical field developed by Monaghan [1] and Lucy [21]. Later on, It was applied to the free surface flow for dam breaks and water waves on the beach [2]. SPH is a meshless and pure Lagrangian approach that involves using an interpolation scheme to approximate the physical values and derivatives of a continuous field using discrete evaluation points. These are identified as smoothed particles with mass, velocity, and position. The quantities are obtained as a weighted average from adjacent particles within the smoothing length (h) to reduce the range of contribution from the neighboring ones. The main features of the SPH method, based on integral interpolants, are described in detail in Ref. [22] and [23].

Figure 5 shows the radius of particle a in the kernel function, and its contribution is weighed using the smoothing length, where $\boldsymbol{r_{ab}}$ is the distance between particles a and b and W_{ab} is the kernel function. In SPH, the field function $\boldsymbol{A}(\boldsymbol{r})$ in domain Ω is integrally approximated as Eq (1), where W and $\boldsymbol{r}$ are the kernel function and position of the vector, respectively.

Eq (1) is approximated into a discrete form by replacing the integral aspect with a summation of the neighboring particles regarding the compact support of particle a at spatial position $\boldsymbol{r}$, thereby leading to particle approximation in Eq (2). In this study, the Wendland kernel function was used in all simulations, where α_D is equal to $21/164\pi h^3$ in 3D, q is the nondimensional distance between particles a and b represented as r/h in Eq (3).

Eq [4] is the continuity equation with the delta-SPH term to reduce spurious pressure in SPH [24]. Eq (5) is the momentum equation in the SPH framework, where **g** is gravity due to acceleration, P_a and P_b are pressures in particles a and b. Π_{ab} is the artificial viscosity term, $\boldsymbol{\mu_{ab}} = \frac{h\boldsymbol{v_{ab}}.\boldsymbol{r_a}}{r_{ab}^2+0.01h^2}$, $\boldsymbol{v_{ab}} = \boldsymbol{v_a} - \boldsymbol{v_b}$ are vector velocities, $\overline{\boldsymbol{c_{ab}}} = \boldsymbol{0.5}(\boldsymbol{c_a} + \boldsymbol{c_b})$ is the mean speed of sound, and α is a coefficient that needs to be tuned to acquire proper dissipation.

DualSPHysics is based on WCSPH, to measure the pressure in WCSPH, an equation of state was used based on Eq (6), where c_o , ρ_0, and γ are the speed of sound at the reference density, and polytrophic constant, respectively. This equation is stiff, and a slight change in the density causes pressure fluctuation. This is one of the reasons why there is a pressure oscillation in WCSPH. Eq (7) is used to calculate the time step based on Monaghan's work, where $\boldsymbol{\Delta t_f}$ is based on the force per unit mass ($|\boldsymbol{f_a}|$) while Δt_{cv} combines the Courant and the viscous time step controls, where CFL is a coefficient within the range of $0.1 \leq \text{CFL} \leq 0.3$.

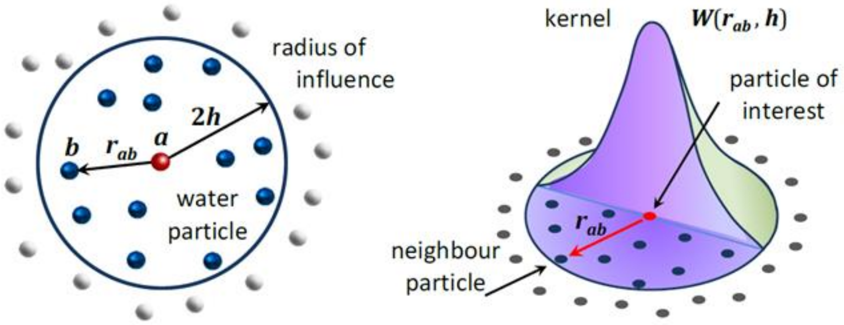


Fig. 5 Radius of the smoothing length and kernel function in SPH [25].

$$A(\boldsymbol{r}) = \int_{\Omega} A(\boldsymbol{r})W(\boldsymbol{r}-\boldsymbol{r}', h)\, d\boldsymbol{r} \tag{1}$$

$$A(\boldsymbol{r}_a) \approx \sum_b A(\boldsymbol{r}_b)W(\boldsymbol{r}_a-\boldsymbol{r}_b, h)\frac{m_b}{\rho_b} \tag{2}$$

$$W(q) = \alpha_D\left(1-\frac{q}{2}\right)^4 (2q+1) \quad 0 \le q \le 2 \tag{3}$$

$$\frac{d\rho_a}{dt} = \sum_b m_b \boldsymbol{v}_{ab}\cdot \nabla_a W_{ab} + 2\delta_\Phi h c_0 \sum_b (\rho_b - \rho_a)\frac{\boldsymbol{r}_{ab}\cdot\nabla_a W_{ab}}{\boldsymbol{r}_{ab}^2}\frac{m_b}{\rho_b} \tag{4}$$

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

$$where\ \Pi_{ab} = \begin{cases} \dfrac{-\alpha\overline{c_{ab}}\mu_{ab}}{\overline{\rho_{ab}}} & \boldsymbol{v}_{ab}\cdot\boldsymbol{r}_{ab} < 0 \\ 0 & \boldsymbol{v}_{ab}\cdot\boldsymbol{r}_{ab} > 0 \end{cases}$$

$$P = \frac{c_0^2\rho_0}{\gamma}\left[\left(\frac{\rho}{\rho_0}\right)^\gamma - 1\right] \tag{6}$$

$$\Delta t_f = CFL\cdot min(\Delta t_f, \Delta t_{cv}) \tag{7}$$

$$\Delta t_f = min\left(\sqrt{\frac{h}{|\boldsymbol{f}_a|}}\right)$$

$$\Delta t_{cv} = min\frac{h}{C_s + max\left|\frac{h v_{ab}\cdot r_{ab}}{(r_{ab}^2+\eta^2)}\right|}$$

Table 2 shows the parameters setup in SPH computation. In addition, the Wendland kernel function was applied in all computations using the symplectic timestep algorithm. The artificial viscosity term with α of 0.01 was used to obtain a proper dissipation. According to Trimulyono et al. [18], the speed of sound has a significant impact on the magnitude of pressure. A coefsound of 60 was used to reproduce similar accuracy on the pressure field. Coefh is the coefficient used to calculate smoothing length. In 3D, Coefh was defined as $Coefh = \frac{h}{dp\sqrt{3}}$. CFL is the coefficient used to obtain the Courant-Friedrichs-Lewy condition with 0.2 used for all computation. Delta-SPH was employed to reduce pressure oscillation, with a default value of 0.1 used in all computations. Dynamic boundary particles (DBPs) were adopted based on Crespo et al. [26]. DBPs are boundary particles that satisfy the same equations as fluid particles, but they are not moved by their forces. Instead, they either remain in a fixed position or move according to an imposed or assigned motion function. This includes the movement of objects, such as gates, wavemakers, or floating objects. When a fluid particle approaches a boundary, and the distance between its particles and that of the fluid is smaller than twice the smoothing length (h), the density of the affected boundary particles increases, leading to a pressure increase. The simulation time was set at 28 s due to the regular motion, which is the same with that after reaching a steady-state condition (Figure 4).

Table 2. Parameter setup of the SPH computation.

Parameters	
Kernel function	Wendland
Time step algorithm	Symplectic
Artificial viscosity coefficient (α)	0.01
Confound	60
Particle spacing (mm)	1.6
Coefh	1.2
CFL	0.2
Delta-SPH (δ_φ)	0.1
Simulation time (s)	28

3. Results and discussion

3.1 Hydrostatic and hydrodynamic pressures.

Figure 6 shows the hydrostatic pressure in the 50% filling ratio with and without a T-shape baffle. Based on Trimulyono research et al. [18], hydrostatic pressure was properly reproduced by SPH with a difference of 3%, as shown in Figure 6. Moreover, the hydrostatic pressure gradient is similar to an analytic solution where the pressure is the highest at the bottom and lowest on the free surface. Figure 7 depicts the dynamic pressure of sloshing with and without baffle configuration at t = 14.0 s. The free surface was violently deformed as compared to the use of baffle. The vertical baffle reduces the fluid movement by dampening through this instrument. T-shape baffle does the same by separating the fluid on each side, which also affects the water depth, thereby reducing the free surface deformation.

Figure 8 shows the dynamic pressure detected by a pressure sensor at the bottom of the tank (see Figure 2). The static pressure was subtracted from the hydrostatic pressure, thereby resulting in dynamic pressure. No significant pressure phase existed between SPH and experiment, which depicts that they have a similar velocity and displacement. Moreover, timing of the sensors used to capture dynamic pressure is similar. Hence certain properties such as fluid kinematics has similar tendencies as physics.

The hydrodynamic pressure consists of static and dynamic pressures. Figure 8(a) shows the impact of the hydrodynamic pressure on the 25% filling ratio, with the red and purple lines depicting an experiment, and SPH without a baffle, respectively. The green, yellow, and black lines are dynamic pressure with single-, double-, and T-shape baffles. Figure 8(b) shows the comparison of the average and peak pressures between SPH and experiment. The difference in the peak and average pressure is 4.6 % and 4.8 %. The first magnitude is referred to as the dynamic pressure, which is gradually reduced, as shown in Figure 7. The second is dynamic pressure resulting from the movement of fluid to the top of the tank. Its magnitude is lesser than first the dynamic pressure because it is affected by the fluid movement without any sudden acceleration. In the sloshing phenomena, dynamic or impact pressure has to be minimized to avoid structural damages or explosions from dangerous liquid cargoes such as LNG.

One of the effective ways to mitigate sloshing is the use of a vertical baffle. Ma et al. reported that the vertical baffles effectively reduce sloshing in a rectangular tank [17]. A similar outcome was obtained using a prismatic tank with a T-shape baffle. The results show that fluid movements inside the tank were significantly reduced causing a decrease in the pressure magnitude. Using one vertical baffle reduced the pressure by 85.80%, whereas the use of two vertical baffles effectively decreased the pressure by 88.24%. The T-shape baffle efficiently reduced the pressure by 82.60%.

Figure 9(a) shows the dynamic pressure of the 50% filling ratio and accuracy, which is slightly different from those of the 25% filling ratio. Figure 9(b) indicates that the peak pressure could not be captured by SPH and made the average pressure accuracy lower than that of the 25% filling ratio. However, the trend of the dynamic pressure is similar after the peak pressure. Although SPH could not capture the peak pressure, the timing accuracy of the pressure sensor was similar to those of the experiment and 25% filling ratio. The findings revealed that the dynamic pressure was reproduced by SPH, although the accuracy was slightly reduced as compared to that of the 25% filling ratio. The single-vertical baffle reduced the pressure by 94.5%, whereas the double-vertical baffles decreased the pressure by 91.2%. The T-shape baffle effectively reduced the pressure by 91.0%.

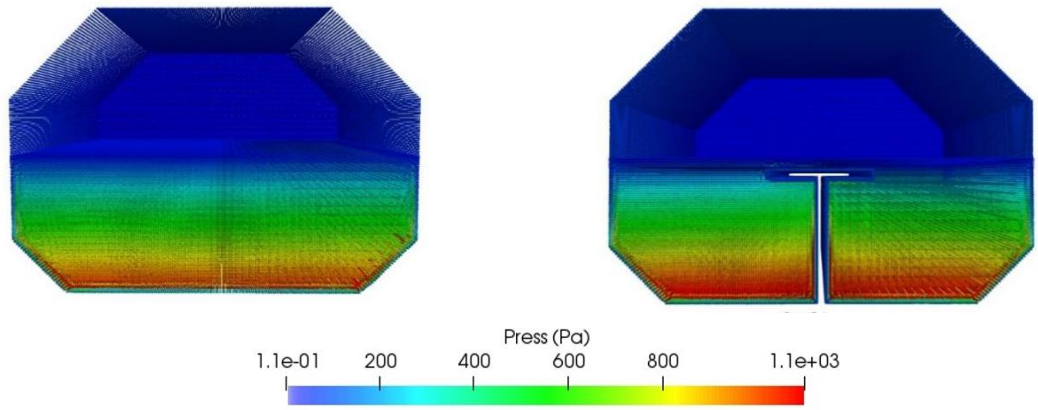
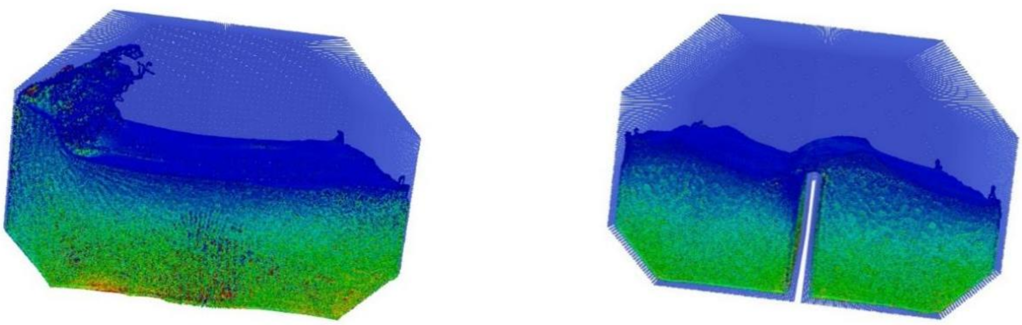


Fig. 6 Hydrostatic pressure in the 50% filling ratio without and with T -shaped baffle.



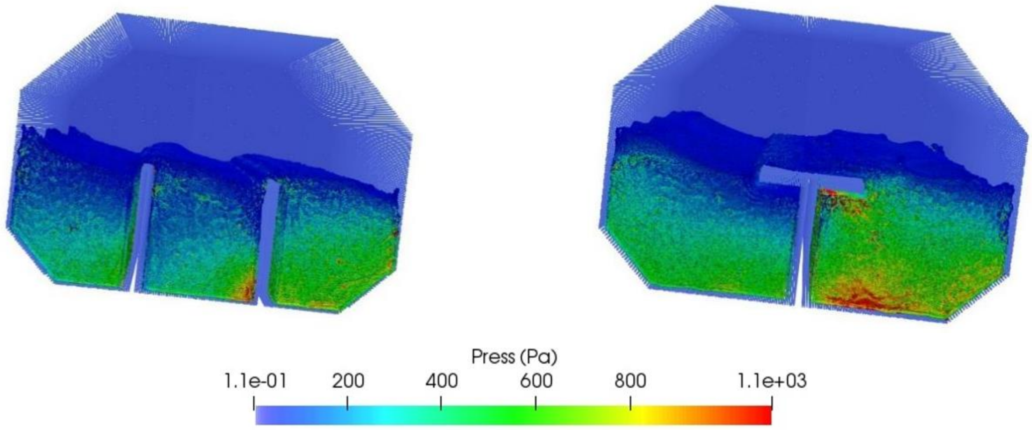
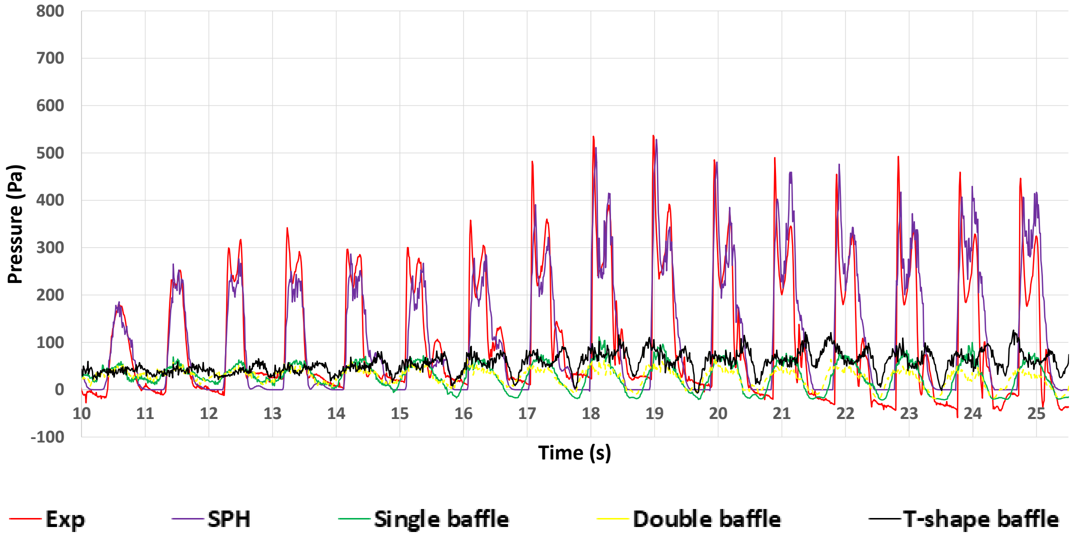
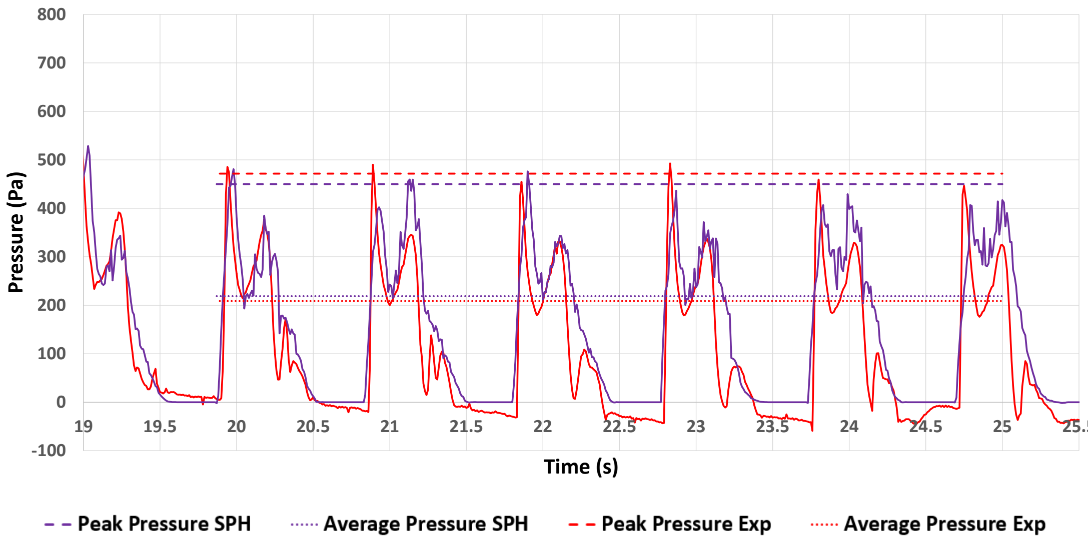


Fig. 7 Comparison of dynamic pressure in the 50% filling ratio with *t* = 14.0 s

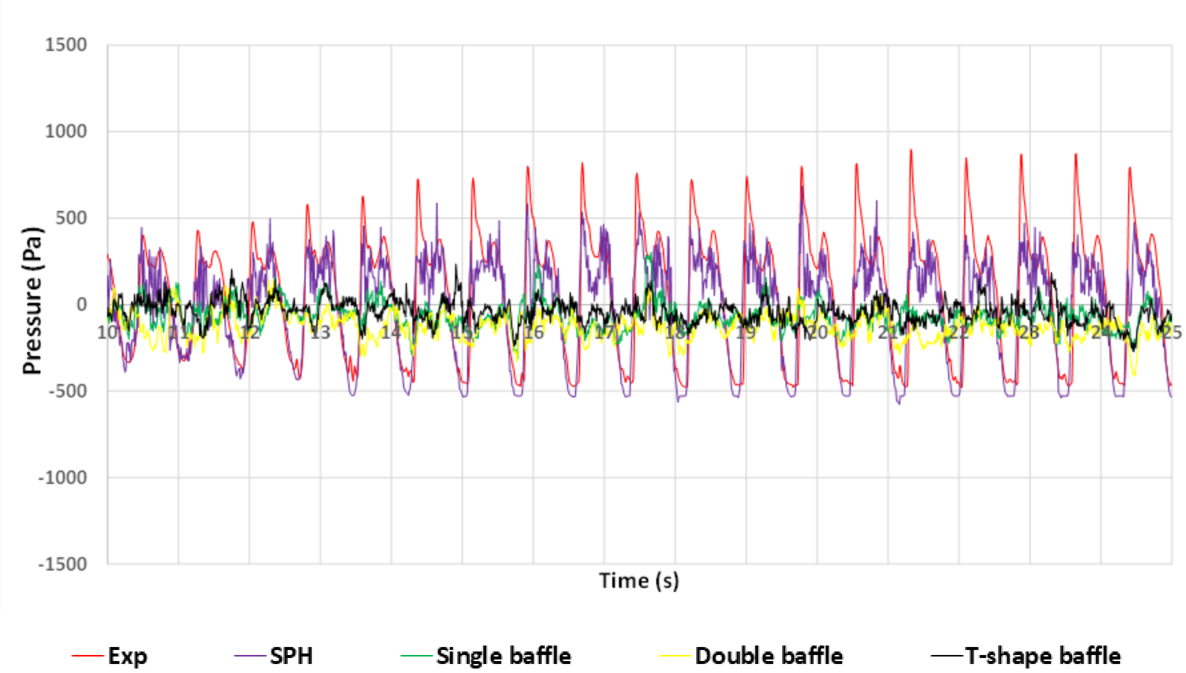


(a)

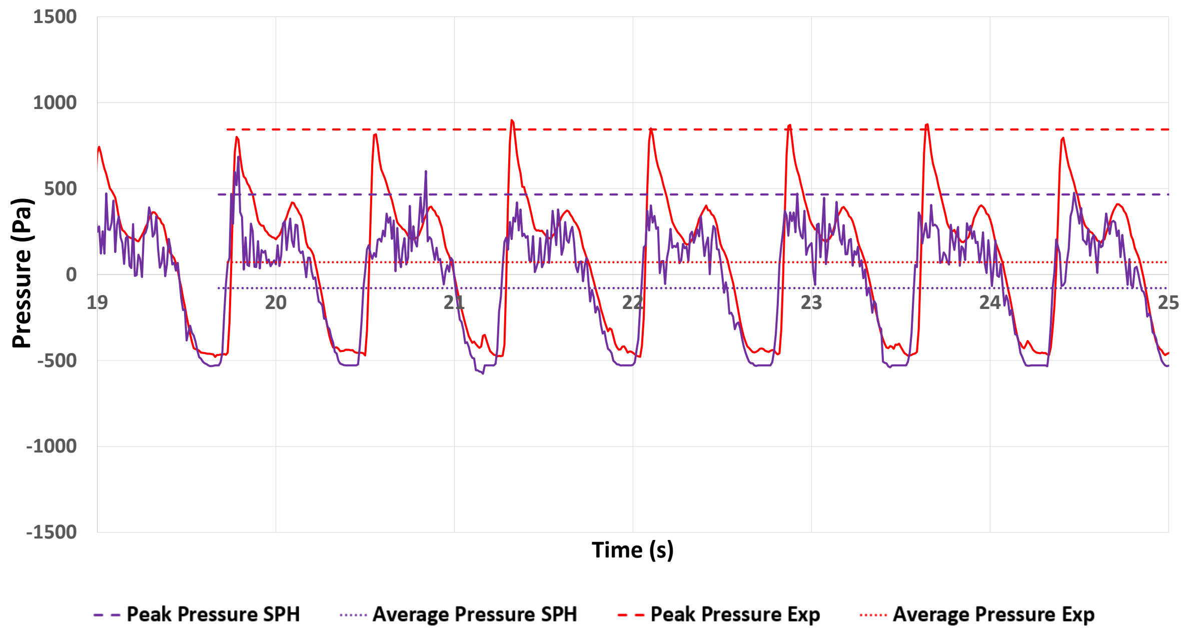


(b)

Fig. 8 Comparison of the dynamic pressure with and without baffles for the 25% filling ratio (a) and the difference in the dynamic pressure for the average and peak pressures (b).



(a)



(b)

Fig. 9 Comparison of the dynamic pressure with and without baffles for the 50% filling ratio (a) and the difference of the dynamic pressure for the average and peak pressures (b).

3.2 Free surface deformation

An advanced visualization process was conducted using the open-source Blender version 2.92, which was freely downloaded at https://www.blender.org/. Furthermore, with the present technique, the post-processing of SPH became more attractive and similar to physics. Figure

10 depicts the comparison of visualized particles and advanced surface texturing using Blender [27]. Figure 10 shows that the fluid looks like real fluid and is more attractive as compared with the particle form. The post-processing of advanced texturing was performed for all simulations using the GPU.

The free surface deformation in the tank was influenced by the excitation force. The existence of energetic sloshing in fluid movements is usually chaotic and complicated. It tends to exist when the frequency of the excitation force is close to the natural frequency of the tank. To effectively mitigate fluid movements, the use of baffles is recommended. Figures 11 and 12 show that the fluid run-up reaches the tank top without baffle installation. In contrast, after the installation of baffles it became calm.

The use of a single-vertical baffle suppress the wave height by approximately 86.3%. Moreover, it reduces the dynamic pressure, as shown in Figure 11. The fluid becomes calm because the dynamic pressure triggered by the fluid-accelerated movement is suppressed. Similar results were obtained using double-vertical and T-shape baffles. The double-vertical and T-shape baffles suppress the wave height by relatively 91.7% and 95.0%, respectively. Based on a visual observation, the use of a vertical baffle caused the fluid to be damped, and it also underwent suction after passing through the baffle. The vertical baffle suppressed the kinetic energy, thereby causing the fluid movement to become slower than that without its installation. The T-shape baffle showed similar phenomena, and the fluid became calm because was damped. This condition is based on the fact that the fluid movement was suppressed when it passed through the baffle. The fluid became calm due to a sudden change in the water depth, especially when it passes the T-shape baffle, thereby suppressing the height. Figure 12 shows that it is lesser when compared with that without baffle installation.

In the 50% filling ratio, the use of a single vertical baffle suppressed the wave height by approximately 79.0%. The 25% filling ratio exhibited similar tendency phenomena. The vertical baffle dampened the fluid movement because it experienced a suction effect after passing through it, thereby reducing the wave height and ensuring calmness. The double-vertical baffle suppressed the wave height by approximately 95.0%. Therefore, a high result was obtained using this equipment because it was suppressed twice. The height near the tank was affected by its movement, which is lesser compared with that without a baffle. The dynamic pressure was reduced, and the fluid became calm. The T-shape baffle was used to suppress the wave height by relatively 79.0%. In the 50% filling ratio, the T-shape baffle produced a lesser damped fluid than that in the 25% filling ratio. Therefore, when the fluid was suctioned, the water depth closer to the wall increased the wave height, as shown in Figure 12. Future research can be performed on the effect of the T–shaped baffle width on sloshing.

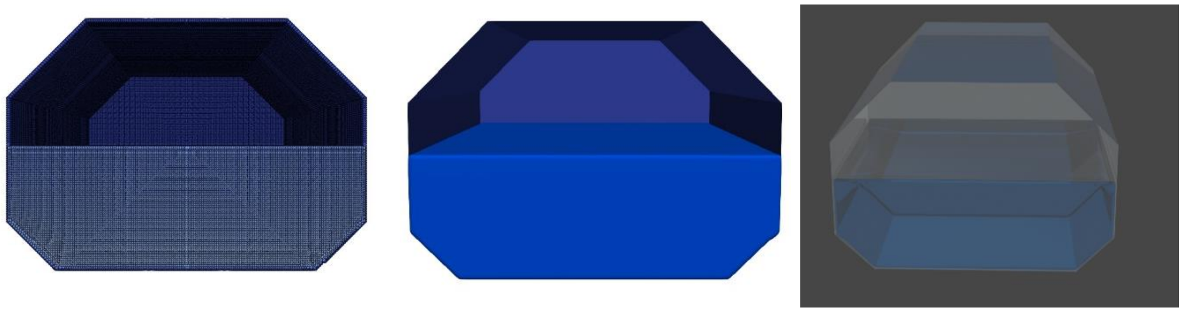


Fig. 10 Visualizations of the particle, iso-surface, and surface texture.

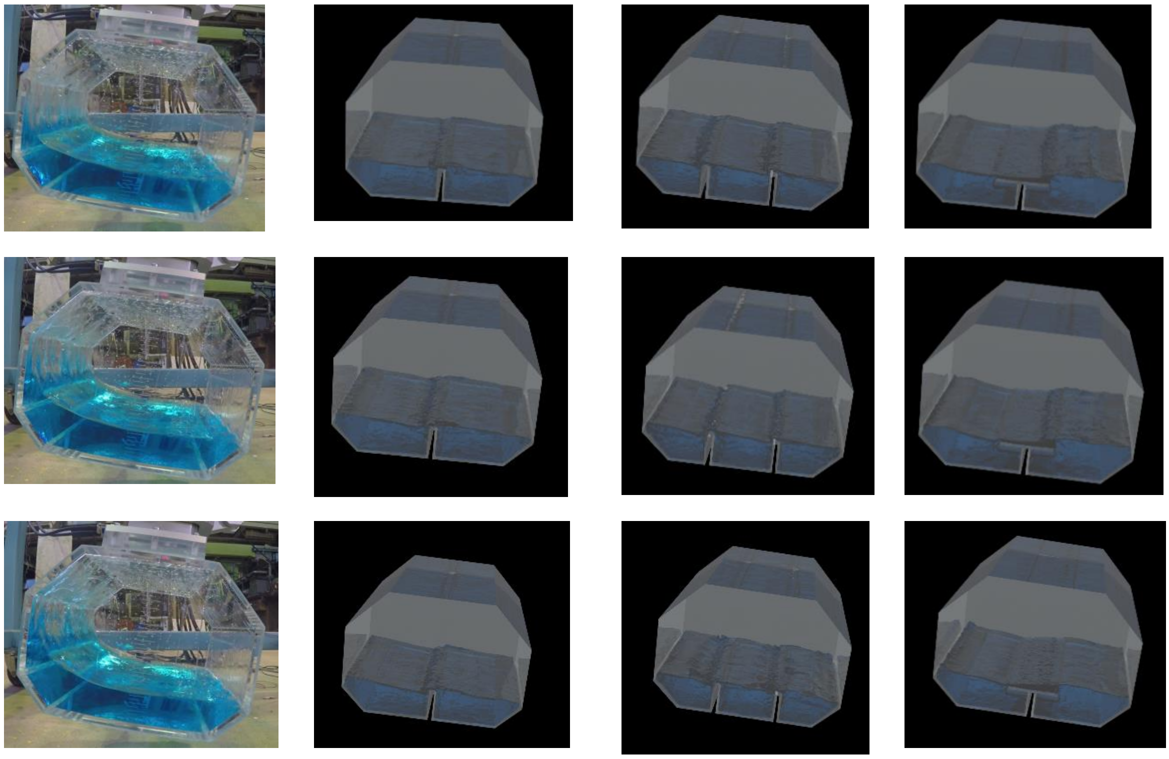


Fig. 11 Comparison of the free surface deformations inside a tank with and without baffles in the 25% filling ratio.

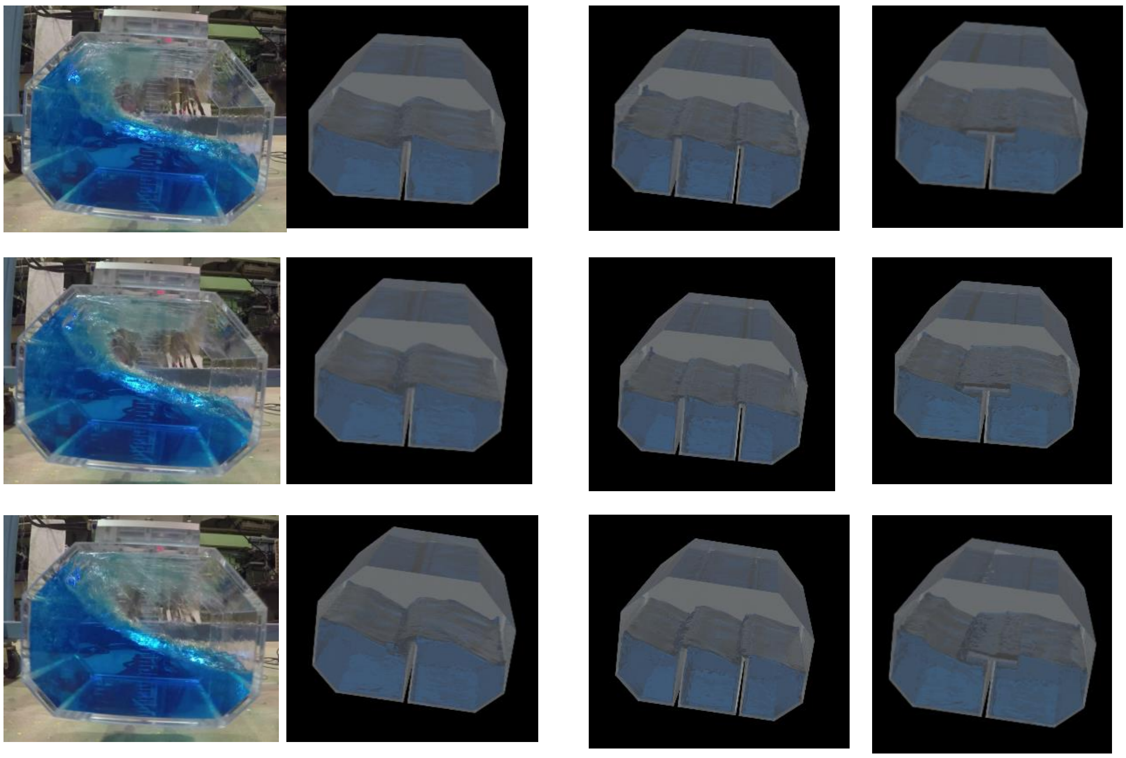


Fig. 12 Comparison of the free surface deformations inside a tank with and without baffles in the 50% filling ratio.

3.3 Hydrodynamic force

The sloshing experiment was conducted with a forced oscillation machine in 4 degrees of freedom [18]. The instrument performed both regular and irregular motions. Coupled motions, such as roll and heave, were utilized during the sloshing experiment. This research used only regular motions to reproduce the sloshing phenomenon. Because of the baffle effect is evident in regular and irregular motions.

Hydrodynamic force exists because the fluid inside the tank was forced to move by an oscillation machine. Figure 13 shows the impact of the hydrodynamic force on the 25% filling ratio. The red line represents hydrodynamic force without baffles, and the green, yellow, and black lines represent the use of single-, double-, and T-shape baffles, respectively. The hydrodynamic force without a baffle is higher than that with the installation with a slight difference, unlike the dynamic pressure or wave height. The hydrodynamic force in the tank was caused by constant forced oscillation during the sloshing period. As a result, the difference tends to be minor compared with the dynamic pressure, assuming the motion is forced oscillation. The difference between hydrodynamic force without and with a single- vertical baffle is relatively 33%. A similar trend involving double and T-shape baffles shows that the difference is 35% and 47%, respectively. The T-shape baffle was effectively used to reduce the hydrodynamic force and the force acting in the middle of the tank, which is caused by its shape.

The 50% filling ratio showed that the hydrodynamic force have a similar trend, as shown in Figure 14. The single- and double-vertical baffles effectively reduced the hydrodynamic force by 30%, whereas the T-shape reduced it by 49%. Hence, the use of baffles could be an alternative to reduce sloshing in the prismatic tanks. Furthermore, sloshing is a forced motion, sloshing induced by external force excitation needs to be investigated in the future.

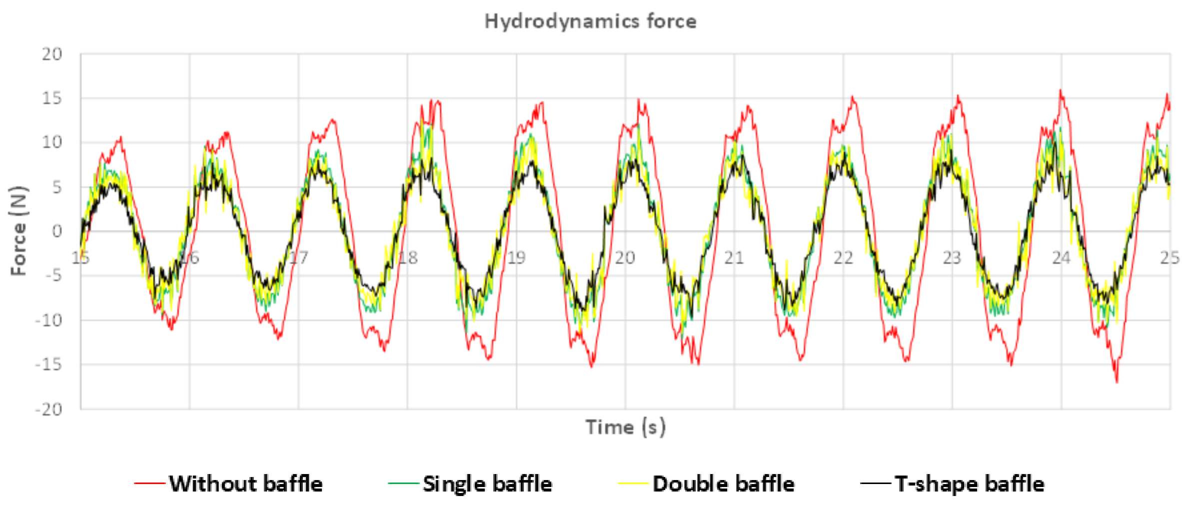


Fig. 13 Hydrodynamic force due to sloshing in the 25% filling ratio with and without baffles.

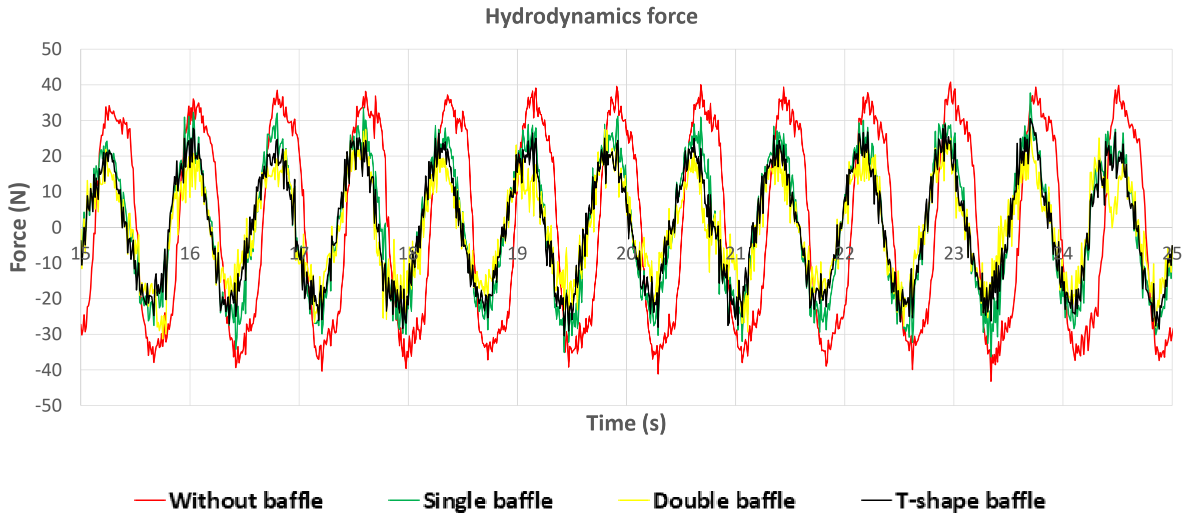


Fig. 14 Hydrodynamics force due to sloshing in filling ratio 50% with and without baffle.

4. Conclusions

The sloshing simulation in the prismatic tank was successfully conducted in two filling ratios. It was reproduced with SPH, one of the promising methods. The results prove that single- and double-vertical and T-shape baffles can be effectively used to mitigate sloshing in a prismatic tank. The results also reveal that they efficiently reduced the impact pressure caused by energetic sloshing. The wave height shows the linear effect as the dynamic pressure, which was reduced by the single- and double-vertical, and T-shape baffles. Hydrodynamic force was slightly decreased by these baffles, although the excitation force exhibited an oscillatory motion. Nonetheless, future research needs to be conducted to determine the effect of sloshing on coupled or ship motions.

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Author Responses to the Reviewers

Dear Prof. Nastia Degiuli
University of Zagreb

We want to thank you for allowing us to revise our manuscript and resubmit it. We appreciate the editors and reviewers for their constructive comments and suggestions on our article entitled "**Investigation of sloshing in the prismatic tank with vertical and T-shape baffles**" by Andi Trimulyono, Haikal Atthariq, Deddy Chrismianto, Samuel Samuel.

We had been used professional English reading Enago https://www.enago.com/ to fulfill standard journal and reviewer comments. Finally, we hope our manuscript has improved to a level of your satisfaction. Thank you very much

With best regards.

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THE INVESTIGATION OF SLOSHING IN THE PRISMATIC TANK WITH VERTICAL AND T-SHAPE BAFFLES

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Summary

The demand for liquid carriers, such as liquefied natural gas (LNG), has increased in recent years. One of the most common types of LNG carriers is the membrane type, which is often built by a shipyard with a prismatic tank shape. This carrier is commonly known for its effective ways to mitigate sloshing using a baffle. Therefore, this study was performed to evaluate sloshing in a prismatic tank using vertical and T-shape baffles. The sloshing was conducted with 25% and 50% filling ratios because it deals with the nonlinear free-surface flow. Furthermore, the smoothed particle hydrodynamics (SPH) was used to overcome sloshing with ratio of a baffle and water depth is 0.9. A comparison was made for the dynamic pressure with the experiment. The results show that SPH has an acceptable accuracy for dynamic and hydrostatic pressures. Baffle installation significantly decreases the wave height, dynamic pressure and hydrodynamic force.

Keywords: *Smoothed particle hydrodynamics; Sloshing; Vertical baffle; T-shape baffle; Dynamic Pressure; Wave height; Hydrodynamic force.*

1. Introduction

The capacity of liquid carriers has increased in recent years, and this is caused by the increasing demand for liquefied Natural Gas (LNG). A common type is the membrane type, which is often built by a shipyard, and is shaped like a prismatic tank. One of the advantages of the membrane-type carrier is that its shape is similar to a ship hull and has a large capacity. A naturally occurring phenomenon in LNG carriers is sloshing, defined as the movement of fluid due to the excitation force in the tank, which is effectively mitigated using a baffle. Sloshing is a nonlinear phenomenon that is difficult to be overcome in fluid dynamics. Several preliminary studies have been performed, including experimental and numerical analyses, which have been made popular by the rapid advancement of computer technology in recent years. This study employed a numerical approach to analyze sloshing using smoothed particle hydrodynamics (SPH). SPH is a meshless and purely Lagrangian approach used to reproduce large deformation and nonlinear phenomena. In this study, weakly compressible SPH (WCSPH) is used to reproduce sloshing in the prismatic tank.

Initially, SPH was used to solve astrophysical problems [1]. However, Monaghan developed SPH for free surface flow for dam-break and water wave cases [2]. Moreover, it is widely applied and used for structural interactions between waves with breakwaters [3]. With an experimental validation, SPH was applied in a long-distance water propagation that occured in a large wave basin [4]. Furthermore, to reduce the reflections in a numerical wave tank (NWT), an active wave absorption was developed [5]. This was combined with open boundaries and used to conduct a water wave simulation [6]. The implementation of SPH for NWT with incompressible SPH (ISPH) was performed using GPU to reduce pressure noise in WCSPH scheme [7]. Therefore, SPH is used to solve the water wave and has good accuracy for free surface flow.

The SPH application in violent flow sloshing, which usually occurs with respect to a low filling ratio due to an obstacle in the rectangular tank, was carried out in one-phase SPH [8]. Furthermore, one- and two-phase SPH were used in a prismatic tank with a low-pass filter technique to reduce pressure oscillation due to the nature of WCSPH [9]. These were studied in a three-dimensional (3D) domain [10], and the results showed that the SPH had good accuracy and also highly a computational cost. A preliminary study was conducted using elastic baffle to reduce sloshing in the rectangular tank [11]. A two-dimensional analysis study was also performed using a T-shape baffle to reduce the effect of this phenomenon in a RANS solver [12]. SPH coupled with the smoothed finite element method was used to investigate the impact of sloshing in a rectangular tank with a flexible vertical and T-shape baffle [13]. The long-duration simulation of this phenomenon in rectangular-, pill-, spherical- and cylindrical-shaped tanks had been studied in a three-dimensional domain [14]. The implementation of δ-SPH and particle shifting with flexible baffle and elastic walls of the rectangular tank were used to tackle sloshing [15]. A comparison study was performed using volume of fluid (VOF), SPH, and arbitrary Lagrangian-Eulerian to analyze the braking and roll responses of partly filled tank vehicles [16]. Preliminary research was performed on single and double vertical baffles in rectangular tanks [17].

This study used single-, and double- vertical and T-shape baffles to investigate sloshing in a prismatic tank. Its heights were based on previous research [17], and the ratio of the baffles to water depth is relatively 0.75 to 0.9. The selected baffle height in this study was 0.9. A pressure sensor was used to verify the validity of the SPH simulation based on experimental research carried out by Trimulyono et al. [18]. Moreover, two water heights were set to capture free surface deformation inside the tank. Its oscillatory motion has 25% and 50% filling ratios. DualSPHysics version 5.0, an open-source SPH solver, was used to simulate sloshing in the prismatic tank [19]. DualSPHysics was implemented using general purpose computing on graphics processing units (GPGPU) [20]. It ensures a million particles are handled using a single GPU. Moreover, the advanced visualization was performed using Blender version 2.92.

Sloshing in the prismatic tank was used in a single-phase SPH, and the results revealed that the vertical baffle has a significant effect, such as reducing fluid movements and hydrodynamic pressure. Finally, hydrodynamic force and moment decreased.

2. Theoretical background and method

2.1 Experimental setup of sloshing and SPH simulation.

Figure 1 shows the experimental setup of sloshing in the prismatic tank, involving three pressure sensors [18]. However, only one of them was used to validate the SPH simulation, and only two filling ratios, i.e., 25% and 50%, were used (Figure 1). The pressure sensor located in the bottom was used to validate the SPH results. As a consequence, the 25% filling ratio was situated near a free surface, whereas that of the 50% was located in the mid-water depth. This is one of the reasons why pressure sensors located at the bottom were used to validate the SPH result. Reproducing the pressure caused by sloshing was also challenging, especially when the 25% filling ratio was used. Four cameras were used to capture free surface deformation, which was equally installed inside and outside the oscillation machine. The detailed information of the sloshing experiment is stated in Ref. [18].

Figure 2 shows the geometry of the prismatic tank for the SPH computation, where L, H, *l*, and *d* are its length, height, width, and water depth, respectively. Table 1 and Figure 3 show the tank's dimension and the three types of baffle shapes with the 25% filling ratio. The baffle height and water depth ratio were 0.9, and the vertical one was positioned in the middle of the tank. Meanwhile, the distance of the double baffle was equivalent to the tank's width, which was divided into three sections. The T-shape baffle was set in the middle of the tank, and its width is ¼*l*, where *l* is also equivalent to width. Its thickness was set as 6.0 mm, and *d1* and *d2* are water the depths in the 25% and 50% filling ratios, respectively.

Figure 4 shows the displacement of the tank in the experiment based on the constant oscillatory rolling motion. In this study, its movement was directly imposed from the experiment (Figure 4). A roll motion is one of the dangerous movements in the seakeeping area; so it was considered in the present study. Sloshing tends to endanger a ship when it is energetic, especially when the excitation frequency is near or identical to the natural frequency of the tank.

The amplitude of the roll motion is 8.66^0 with sloshing excitation frequencies of 1.04 and 1.30 Hz for the 25% and 50% filling ratios, respectively. The findings shows that the excitation frequency is close to the natural frequency of the prismatic tank [18].

Table 1:Principal dimensions of prismatic tank

Dimension	(m)
L	0.38
L	0.30
H	0.21
D	0.0525 (25%)
	0.1050 (50%)

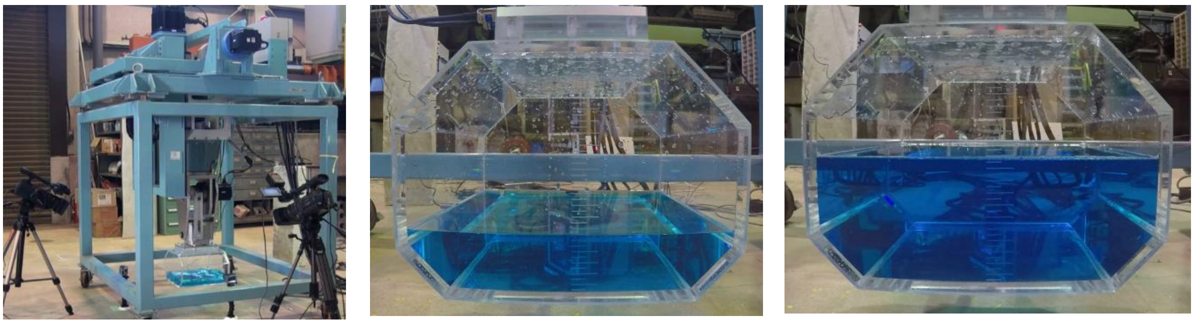


Fig. 1 Experimental condition of the sloshing filling ratio of 25% (a), condition of the water depth with filling ratios of 25% (b), and 50% (c) [18].

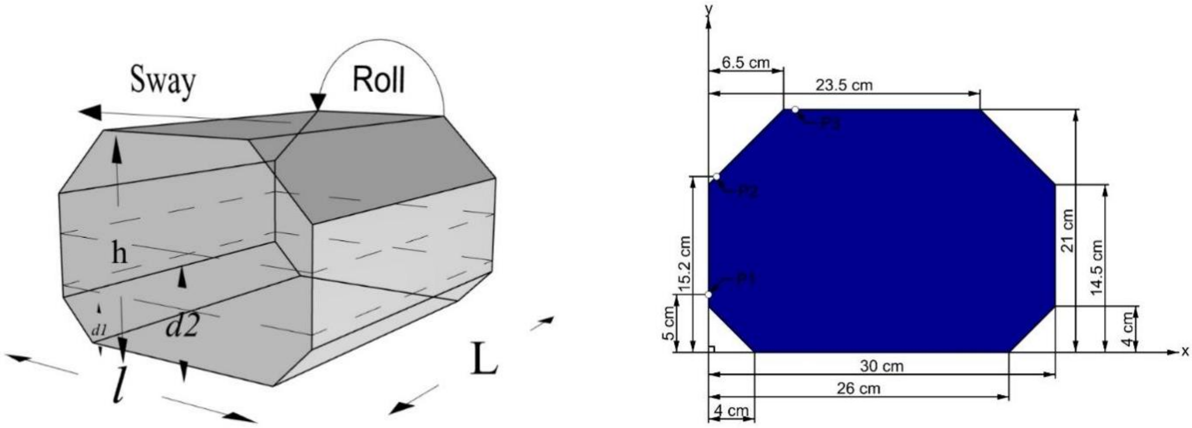


Fig. 2 Sketch of a prismatic tank with the principal dimension (a) and pressure sensor location (b).

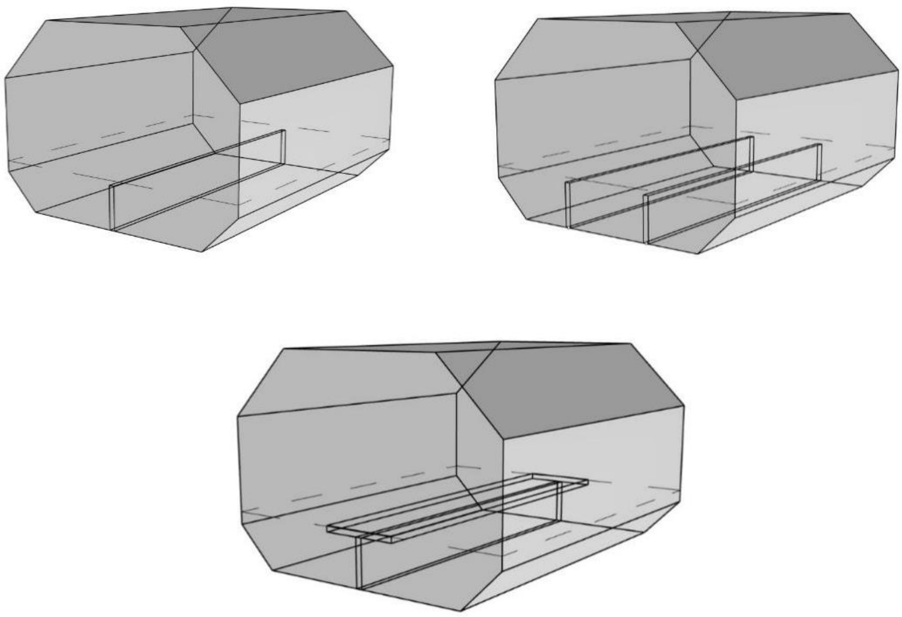


Fig. 3 Sketch of the prismatic tank with a single-vertical baffle (a) double-vertical baffle (b) and T-shape baffle (c).

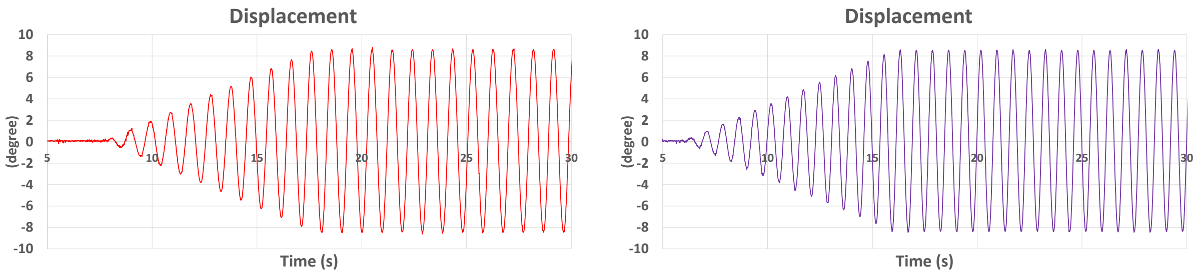


Fig. 4 Displacement of the prismatic tank in the SPH computation with filling ratio 25% (a) and 50% (b)

2.2 Smoothed particle hydrodynamics.

Smoothed particle hydrodynamics (SPH) was initially used in the astrophysical field developed by Monaghan [1] and Lucy [21]. Later on, It was applied to the free surface flow for dam breaks and water waves on the beach [2]. SPH is a meshless and pure Lagrangian approach that involves using an interpolation scheme to approximate the physical values and derivatives of a continuous field using discrete evaluation points. These are identified as smoothed particles with mass, velocity, and position. The quantities are obtained as a weighted average from adjacent particles within the smoothing length (h) to reduce the range of contribution from the neighboring ones. The main features of the SPH method, based on integral interpolants, are described in detail in Ref. [22] and [23].

Figure 5 shows the radius of particle a in the kernel function, and its contribution is weighed using the smoothing length, where $\boldsymbol{r_{ab}}$ is the distance between particles a and b and W_{ab} is the kernel function. In SPH, the field function $\boldsymbol{A}(\boldsymbol{r})$ in domain Ω is integrally approximated as Eq (1), where W and $\boldsymbol{r}$ are the kernel function and position of the vector, respectively.

Eq (1) is approximated into a discrete form by replacing the integral aspect with a summation of the neighboring particles regarding the compact support of particle a at spatial position $\boldsymbol{r}$, thereby leading to particle approximation in Eq (2). In this study, the Wendland kernel function was used in all simulations, where α_D is equal to $21/164\pi h^3$ in 3D, q is the nondimensional distance between particles a and b represented as r/h in Eq (3).

Eq [4] is the continuity equation with the delta-SPH term to reduce spurious pressure in SPH [24]. Eq (5) is the momentum equation in the SPH framework, where $\mathbf{g}$ is gravity due to acceleration, P_a and P_b are pressures in particles a and b. Π_{ab} is the artificial viscosity term, $\boldsymbol{\mu_{ab}} = \frac{h\boldsymbol{v_{ab}}.\boldsymbol{r_a}}{\boldsymbol{r_{ab}^2}+0.01\boldsymbol{h^2}}$, $\boldsymbol{v_{ab}} = \boldsymbol{v_a} - \boldsymbol{v_b}$ are vector velocities, $\overline{\boldsymbol{c_{ab}}} = \mathbf{0.5}(\boldsymbol{c_a} + \boldsymbol{c_b})$ is the mean speed of sound, and α is a coefficient that needs to be tuned to acquire proper dissipation.

DualSPHysics is based on WCSPH, to measure the pressure in WCSPH, an equation of state was used based on Eq (6), where c_o , ρ_0, and γ are the speed of sound at the reference density, and polytrophic constant, respectively. This equation is stiff, and a slight change in the density causes pressure fluctuation. This is one of the reasons why there is a pressure oscillation in WCSPH. Eq (7) is used to calculate the time step based on Monaghan's work, where $\Delta \boldsymbol{t_f}$ is based on the force per unit mass ($|\boldsymbol{f_a}|$) while Δt_{cv} combines the Courant and the viscous time step controls, where CFL is a coefficient within the range of $0.1 \leq \text{CFL} \leq 0.3$.

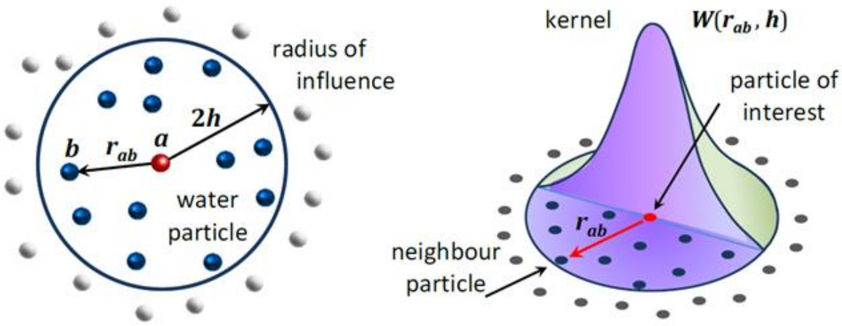


Fig. 5 Radius of the smoothing length and kernel function in SPH [25].

$$A(\boldsymbol{r}) = \int_{\Omega} A(\boldsymbol{r})W(\boldsymbol{r}-\boldsymbol{r}', h)\, d\boldsymbol{r} \tag{1}$$

$$A(\boldsymbol{r}_a) \approx \sum_b A(\boldsymbol{r}_b)W(\boldsymbol{r}_a-\boldsymbol{r}_b, h)\frac{m_b}{\rho_b} \tag{2}$$

$$W(q) = \alpha_D\left(1-\frac{q}{2}\right)^4 (2q+1) \quad 0 \le q \le 2 \tag{3}$$

$$\frac{d\rho_a}{dt} = \sum_b m_b \boldsymbol{v}_{ab}\cdot \nabla_a W_{ab} + 2\delta_\Phi h c_0 \sum_b (\rho_b - \rho_a)\frac{\boldsymbol{r}_{ab}\cdot \nabla_a W_{ab}}{\boldsymbol{r}_{ab}^2}\frac{m_b}{\rho_b} \tag{4}$$

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

$$where\ \Pi_{ab} = \begin{cases} \dfrac{-\alpha\overline{c_{ab}}\mu_{ab}}{\overline{\rho_{ab}}} & \boldsymbol{v}_{ab}\cdot\boldsymbol{r}_{ab} < 0 \\ 0 & \boldsymbol{v}_{ab}\cdot\boldsymbol{r}_{ab} > 0 \end{cases}$$

$$P = \frac{c_0^2\rho_0}{\gamma}\left[\left(\frac{\rho}{\rho_0}\right)^\gamma - 1\right] \tag{6}$$

$$\Delta t_f = CFL \cdot min(\Delta t_f, \Delta t_{cv}) \tag{7}$$

$$\Delta t_f = min\left(\sqrt{\frac{h}{|\boldsymbol{f}_a|}}\right)$$

$$\Delta t_{cv} = min \frac{h}{C_s + max\left|\frac{h v_{ab}\cdot r_{ab}}{(r_{ab}^2+\eta^2)}\right|}$$

Table 2 shows the parameters setup in SPH computation. In addition, the Wendland kernel function was applied in all computations using the symplectic timestep algorithm. The artificial viscosity term with α of 0.01 was used to obtain a proper dissipation. According to Trimulyono et al. [18], the speed of sound has a significant impact on the magnitude of pressure. A coefsound of 60 was used to reproduce similar accuracy on the pressure field. Coefh is the coefficient used to calculate smoothing length. In 3D, Coefh was defined as $Coefh = \frac{h}{dp\sqrt{3}}$. CFL is the coefficient used to obtain the Courant-Friedrichs-Lewy condition with 0.2 used for all computation. Delta-SPH was employed to reduce pressure oscillation, with a default value of 0.1 used in all computations. Dynamic boundary particles (DBPs) were adopted based on Crespo et al. [26]. DBPs are boundary particles that satisfy the same equations as fluid particles, but they are not moved by their forces. Instead, they either remain in a fixed position or move according to an imposed or assigned motion function. This includes the movement of objects, such as gates, wavemakers, or floating objects. When a fluid particle approaches a boundary, and the distance between its particles and that of the fluid is smaller than twice the smoothing length (h), the density of the affected boundary particles increases, leading to a pressure increase. The simulation time was set at 28 s due to the regular motion, which is the same with that after reaching a steady-state condition (Figure 4).

Table 2. Parameter setup of the SPH computation.

Parameters	
Kernel function	Wendland
Time step algorithm	Symplectic
Artificial viscosity coefficient (α)	0.01
Confound	60
Particle spacing (mm)	1.6
Coefh	1.2
CFL	0.2
Delta-SPH (δ_{φ})	0.1
Simulation time (s)	28

3. Results and discussion

3.1 Hydrostatic and hydrodynamic pressures.

Figure 6 shows the hydrostatic pressure in the 50% filling ratio with and without a T-shape baffle. Based on Trimulyono research et al. [18], hydrostatic pressure was properly reproduced by SPH with a difference of 3%, as shown in Figure 6. Moreover, the hydrostatic pressure gradient is similar to an analytic solution where the pressure is the highest at the bottom and lowest on the free surface. Figure 7 depicts the dynamic pressure of sloshing with and without baffle configuration at t = 14.0 s. The free surface was violently deformed as compared to the use of baffle. The vertical baffle reduces the fluid movement by dampening through this instrument. T-shape baffle does the same by separating the fluid on each side, which also affects the water depth, thereby reducing the free surface deformation.

Figure 8 shows the dynamic pressure detected by a pressure sensor at the bottom of the tank (see Figure 2). The static pressure was subtracted from the hydrostatic pressure, thereby resulting in dynamic pressure. No significant pressure phase existed between SPH and experiment, which depicts that they have a similar velocity and displacement. Moreover, timing of the sensors used to capture dynamic pressure is similar. Hence certain properties such as fluid kinematics has similar tendencies as physics.

The hydrodynamic pressure consists of static and dynamic pressures. Figure 8(a) shows the impact of the hydrodynamic pressure on the 25% filling ratio, with the red and purple lines depicting an experiment, and SPH without a baffle, respectively. The green, yellow, and black lines are dynamic pressure with single-, double-, and T-shape baffles. Figure 8(b) shows the comparison of the average and peak pressures between SPH and experiment. The difference in the peak and average pressure is 4.6 % and 4.8 %. The first magnitude is referred to as the dynamic pressure, which is gradually reduced, as shown in Figure 7. The second is dynamic pressure resulting from the movement of fluid to the top of the tank. Its magnitude is lesser than first the dynamic pressure because it is affected by the fluid movement without any sudden acceleration. In the sloshing phenomena, dynamic or impact pressure has to be minimized to avoid structural damages or explosions from dangerous liquid cargoes such as LNG.

One of the effective ways to mitigate sloshing is the use of a vertical baffle. Ma et al. reported that the vertical baffles effectively reduce sloshing in a rectangular tank [17]. A similar outcome was obtained using a prismatic tank with a T-shape baffle. The results show that fluid movements inside the tank were significantly reduced causing a decrease in the pressure magnitude. Using one vertical baffle reduced the pressure by 85.80%, whereas the use of two vertical baffles effectively decreased the pressure by 88.24%. The T-shape baffle efficiently reduced the pressure by 82.60%.

Figure 9(a) shows the dynamic pressure of the 50% filling ratio and accuracy, which is slightly different from those of the 25% filling ratio. Figure 9(b) indicates that the peak pressure could not be captured by SPH and made the average pressure accuracy lower than that of the 25% filling ratio. However, the trend of the dynamic pressure is similar after the peak pressure. Although SPH could not capture the peak pressure, the timing accuracy of the pressure sensor was similar to those of the experiment and 25% filling ratio. The findings revealed that the dynamic pressure was reproduced by SPH, although the accuracy was slightly reduced as compared to that of the 25% filling ratio. The single-vertical baffle reduced the pressure by 94.5%, whereas the double-vertical baffles decreased the pressure by 91.2%. The T-shape baffle effectively reduced the pressure by 91.0%.

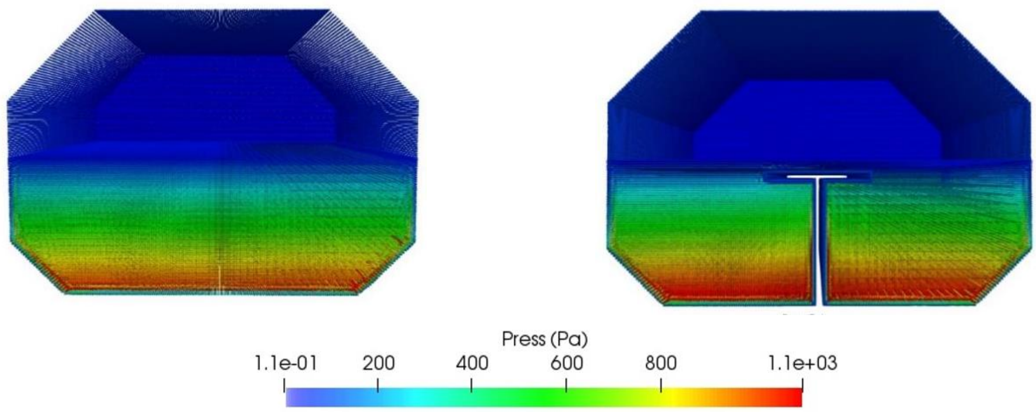
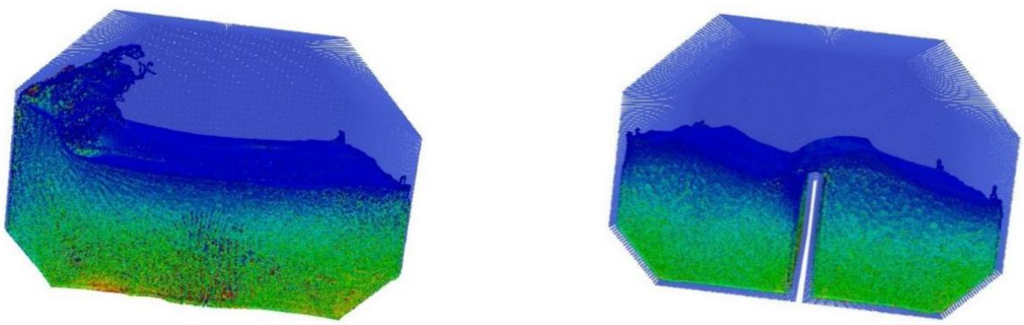


Fig. 6 Hydrostatic pressure in the 50% filling ratio without and with T -shaped baffle.



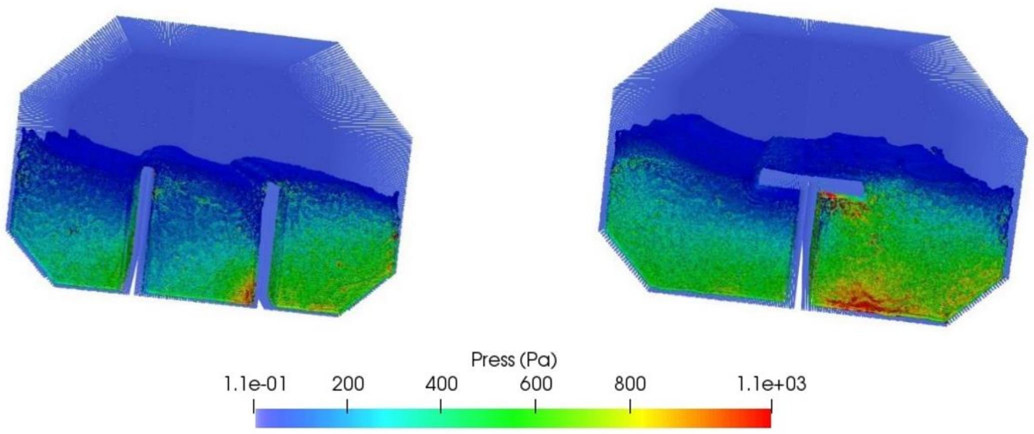
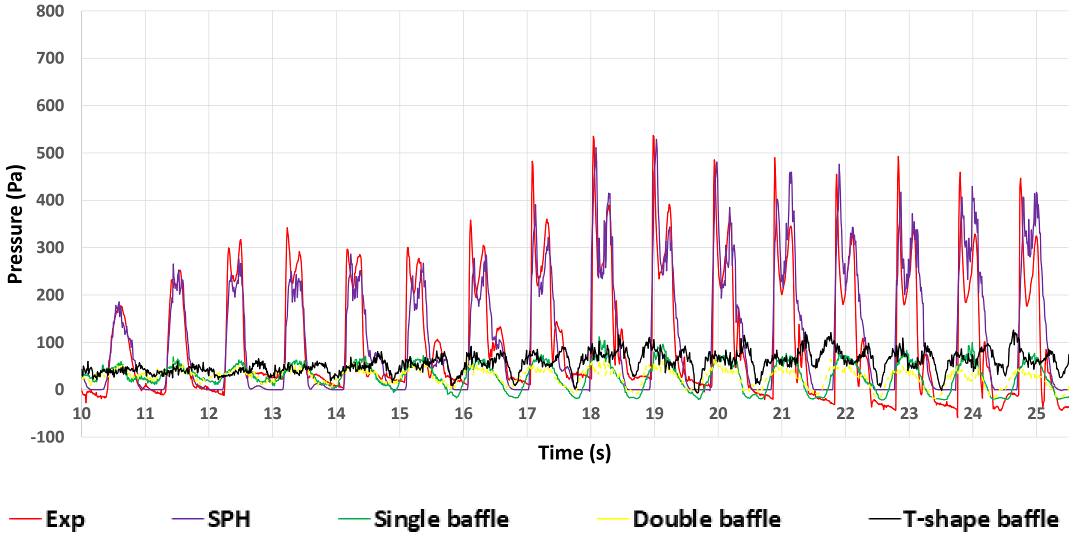
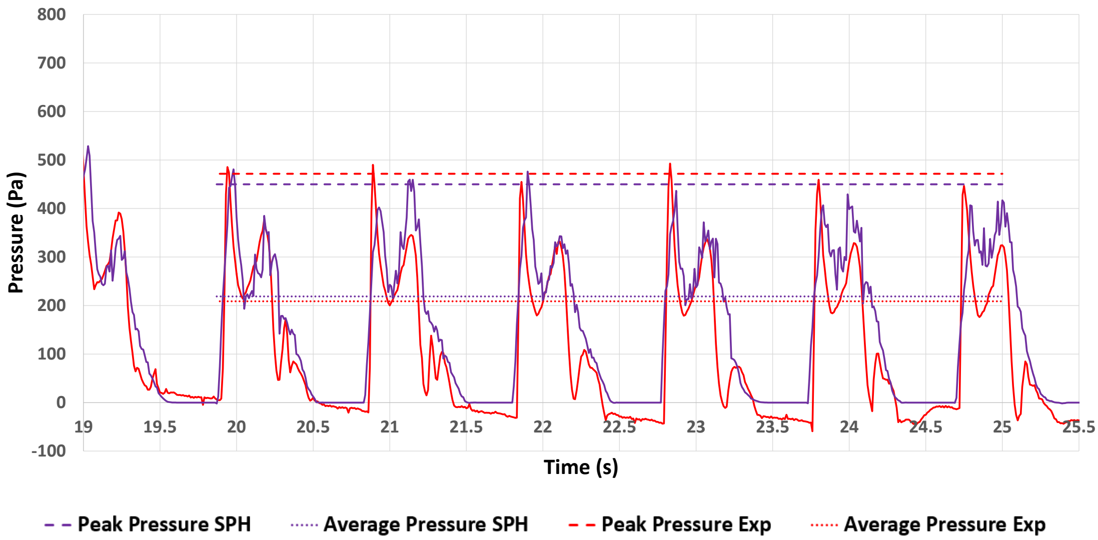


Fig. 7 Comparison of dynamic pressure in the 50% filling ratio with *t* = 14.0 s

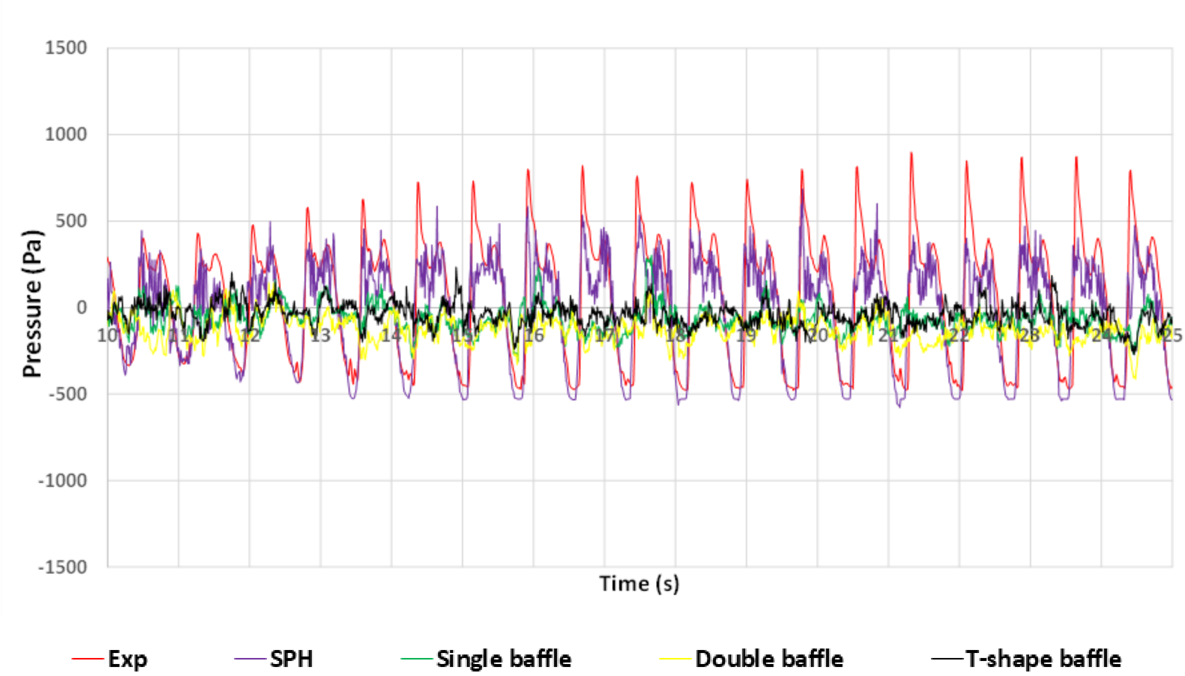


(a)

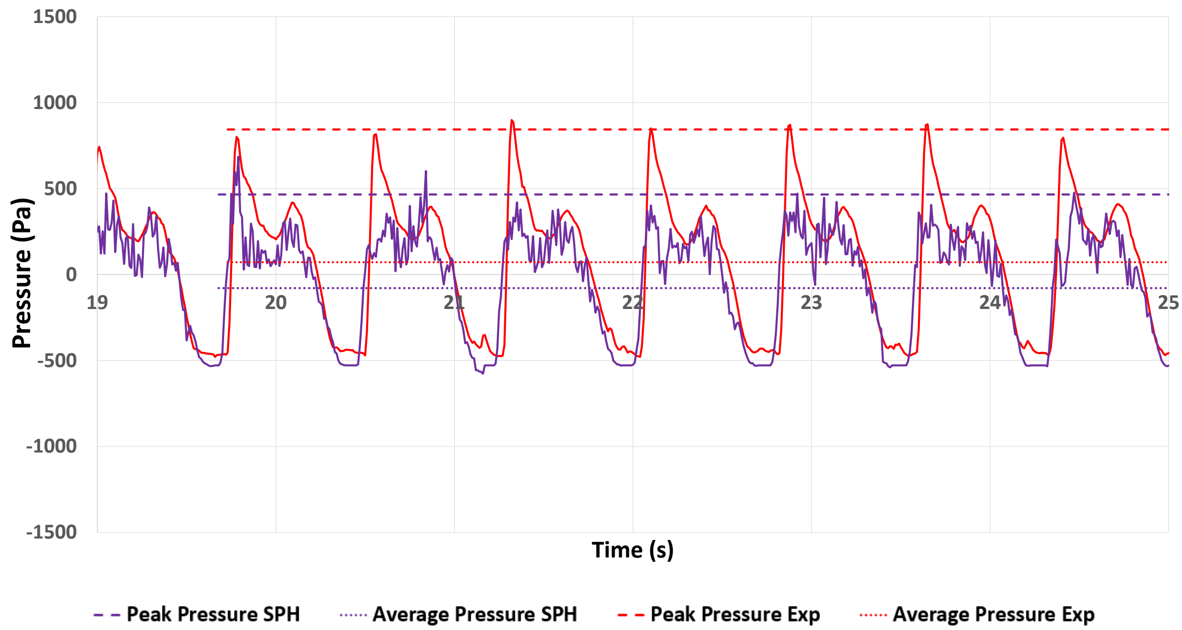


(b)

Fig. 8 Comparison of the dynamic pressure with and without baffles for the 25% filling ratio (a) and the difference in the dynamic pressure for the average and peak pressures (b).



(a)



(b)

Fig. 9 Comparison of the dynamic pressure with and without baffles for the 50% filling ratio (a) and the difference of the dynamic pressure for the average and peak pressures (b).

3.2 Free surface deformation

An advanced visualization process was conducted using the open-source Blender version 2.92, which was freely downloaded at https://www.blender.org/. Furthermore, with the present technique, the post-processing of SPH became more attractive and similar to physics. Figure

10 depicts the comparison of visualized particles and advanced surface texturing using Blender [27]. Figure 10 shows that the fluid looks like real fluid and is more attractive as compared with the particle form. The post-processing of advanced texturing was performed for all simulations using the GPU.

The free surface deformation in the tank was influenced by the excitation force. The existence of energetic sloshing in fluid movements is usually chaotic and complicated. It tends to exist when the frequency of the excitation force is close to the natural frequency of the tank. To effectively mitigate fluid movements, the use of baffles is recommended. Figures 11 and 12 show that the fluid run-up reaches the tank top without baffle installation. In contrast, after the installation of baffles it became calm.

The use of a single-vertical baffle suppress the wave height by approximately 86.3%. Moreover, it reduces the dynamic pressure, as shown in Figure 11. The fluid becomes calm because the dynamic pressure triggered by the fluid-accelerated movement is suppressed. Similar results were obtained using double-vertical and T-shape baffles. The double-vertical and T-shape baffles suppress the wave height by relatively 91.7% and 95.0%, respectively. Based on a visual observation, the use of a vertical baffle caused the fluid to be damped, and it also underwent suction after passing through the baffle. The vertical baffle suppressed the kinetic energy, thereby causing the fluid movement to become slower than that without its installation. The T-shape baffle showed similar phenomena, and the fluid became calm because was damped. This condition is based on the fact that the fluid movement was suppressed when it passed through the baffle. The fluid became calm due to a sudden change in the water depth, especially when it passes the T-shape baffle, thereby suppressing the height. Figure 12 shows that it is lesser when compared with that without baffle installation.

In the 50% filling ratio, the use of a single vertical baffle suppressed the wave height by approximately 79.0%. The 25% filling ratio exhibited similar tendency phenomena. The vertical baffle dampened the fluid movement because it experienced a suction effect after passing through it, thereby reducing the wave height and ensuring calmness. The double-vertical baffle suppressed the wave height by approximately 95.0%. Therefore, a high result was obtained using this equipment because it was suppressed twice. The height near the tank was affected by its movement, which is lesser compared with that without a baffle. The dynamic pressure was reduced, and the fluid became calm. The T-shape baffle was used to suppress the wave height by relatively 79.0%. In the 50% filling ratio, the T-shape baffle produced a lesser damped fluid than that in the 25% filling ratio. Therefore, when the fluid was suctioned, the water depth closer to the wall increased the wave height, as shown in Figure 12. Future research can be performed on the effect of the T–shaped baffle width on sloshing.

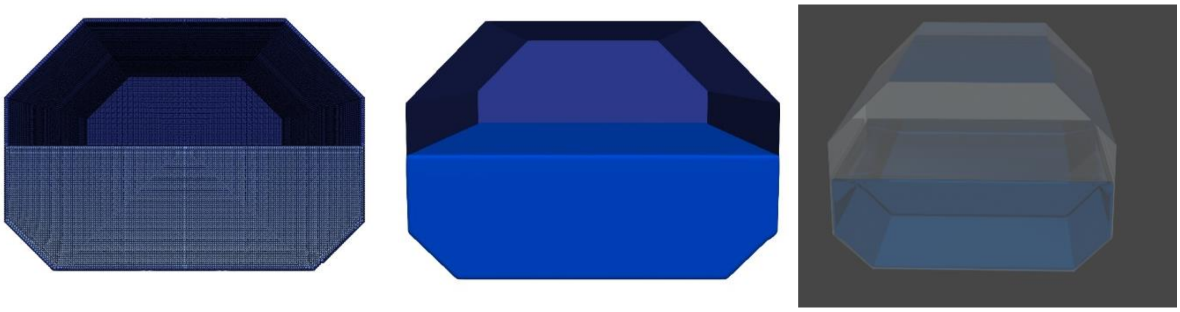


Fig. 10 Visualizations of the particle, iso-surface, and surface texture.

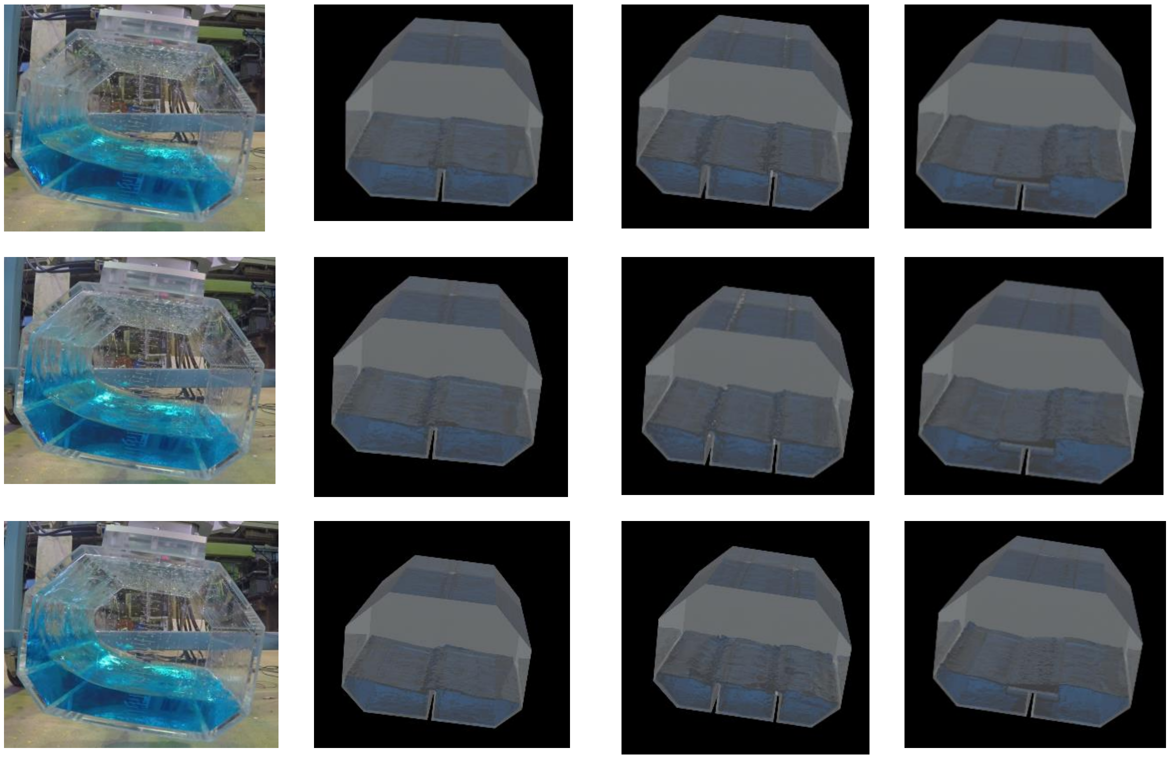


Fig. 11 Comparison of the free surface deformations inside a tank with and without baffles in the 25% filling ratio.

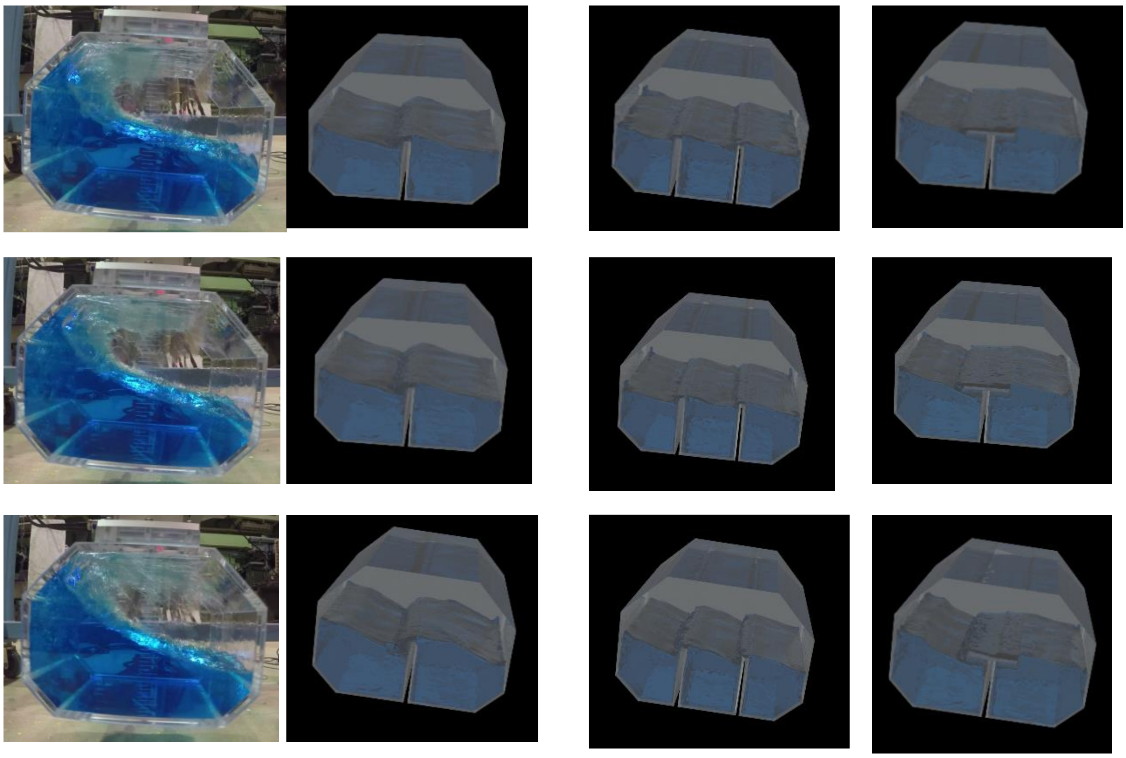


Fig. 12 Comparison of the free surface deformations inside a tank with and without baffles in the 50% filling ratio.

3.3 Hydrodynamic force

The sloshing experiment was conducted with a forced oscillation machine in 4 degrees of freedom [18]. The instrument performed both regular and irregular motions. Coupled motions, such as roll and heave, were utilized during the sloshing experiment. This research used only regular motions to reproduce the sloshing phenomenon. Because of the baffle effect is evident in regular and irregular motions.

Hydrodynamic force exists because the fluid inside the tank was forced to move by an oscillation machine. Figure 13 shows the impact of the hydrodynamic force on the 25% filling ratio. The red line represents hydrodynamic force without baffles, and the green, yellow, and black lines represent the use of single-, double-, and T-shape baffles, respectively. The hydrodynamic force without a baffle is higher than that with the installation with a slight difference, unlike the dynamic pressure or wave height. The hydrodynamic force in the tank was caused by constant forced oscillation during the sloshing period. As a result, the difference tends to be minor compared with the dynamic pressure, assuming the motion is forced oscillation. The difference between hydrodynamic force without and with a single- vertical baffle is relatively 33%. A similar trend involving double and T-shape baffles shows that the difference is 35% and 47%, respectively. The T-shape baffle was effectively used to reduce the hydrodynamic force and the force acting in the middle of the tank, which is caused by its shape.

The 50% filling ratio showed that the hydrodynamic force have a similar trend, as shown in Figure 14. The single- and double-vertical baffles effectively reduced the hydrodynamic force by 30%, whereas the T-shape reduced it by 49%. Hence, the use of baffles could be an alternative to reduce sloshing in the prismatic tanks. Furthermore, sloshing is a forced motion, sloshing induced by external force excitation needs to be investigated in the future.

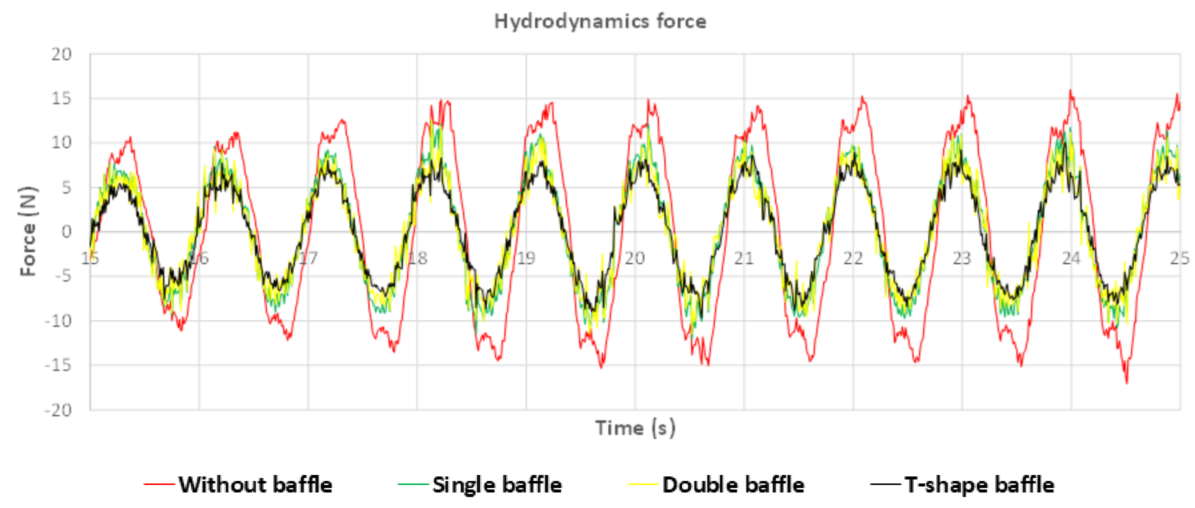


Fig. 13 Hydrodynamic force due to sloshing in the 25% filling ratio with and without baffles.

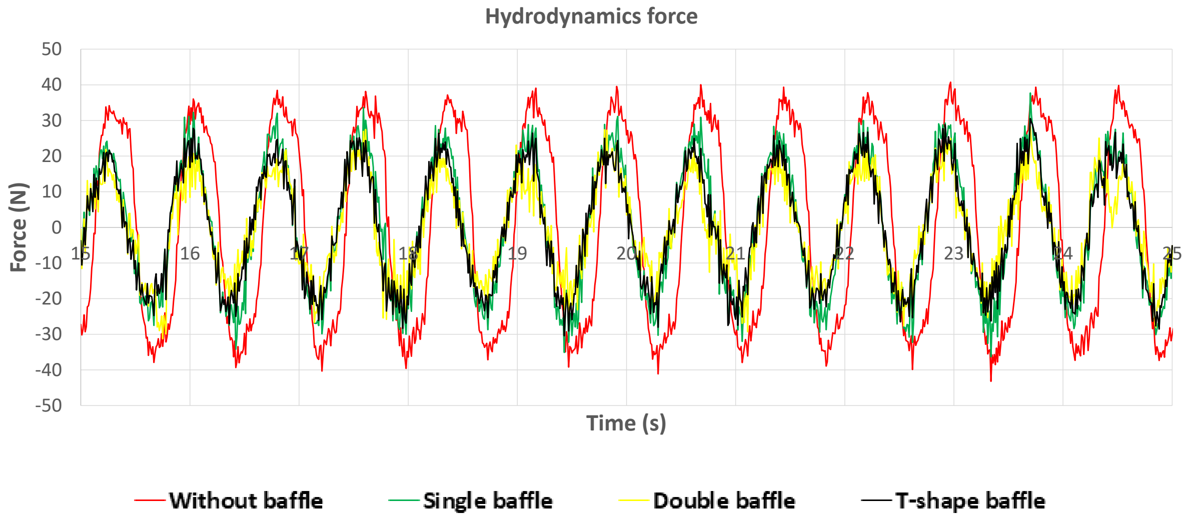


Fig. 14 Hydrodynamics force due to sloshing in filling ratio 50% with and without baffle.

4. Conclusions

The sloshing simulation in the prismatic tank was successfully conducted in two filling ratios. It was reproduced with SPH, one of the promising methods. The results prove that single- and double-vertical and T-shape baffles can be effectively used to mitigate sloshing in a prismatic tank. The results also reveal that they efficiently reduced the impact pressure caused by energetic sloshing. The wave height shows the linear effect as the dynamic pressure, which was reduced by the single- and double-vertical, and T-shape baffles. Hydrodynamic force was slightly decreased by these baffles, although the excitation force exhibited an oscillatory motion. Nonetheless, future research needs to be conducted to determine the effect of sloshing on coupled or ship motions.

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