Numerical Simulation of Sloshing in The Prismatic Tank with Vertical Baffle using Smoothed Particle Hydrodynamics

by Deddy Chrismianto

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NUMERICAL SIMULATION OF SLOSHING IN THE PRISMATIC TANK WITH VERTICAL BAFFLE USING SMOOTHED PARTICLE HYDRODYNAMICS

H Atthariq, A Trimulyono, D Chrismianto, Department of Naval Architecture, Diponegoro University, Indonesia

SUMMARY

The capacity of LNG carriers is increasing year by year due to the demand for liquified natural gas (LNG). One of the types of LNG carriers is membrane type that the tank is prismatic. A natural phenomenon in a liquid carrier such as LNG is sloshing. Sloshing is a violent phenomenon in fluid dynamics caused by excitation force. The present study will conduct sloshing with a baffle shape to reduce the free surface inside the tank and impact pressure. In this study, a single vertical baffle and a double vertical baffle are used to reduce sloshing. In the present study, the meshless approach, so-called Smoothed particle hydrodynamics (SPH), is used to reproduce sloshing in the prismatic tank. The three-dimensional prismatic tank was used to capture sloshing with the baffle. Regular roll motion with one pressure sensor uses to validate the SPH results. The result shows that vertical baffle effectively reduced fluid movement inside the tank and impact pressure. As a result, the hydrodynamic force and moment decreased. The ratio of the baffle and the water depth 0.9 shows has significant influence to sloshing.

1. INTRODUCTION

Sloshing on an LNG ship is a dangerous phenomenon caused by a tank encountering an external oscillation. If the tank moves very energetic, it will be dangerous when the value is close to the natural frequency [1]. Violent sloshing could happen and cause damage to the tank due to impact pressure caused by violent fluid inside the tank with the wall.

One of the ways to reduce sloshing is to use additional blocks in the tank. These blocks are called baffles or internal blocks. The configuration of the baffles is needed properly well designed to get an effective effect reduce fluid movement. Baffle with proper height will reduce fluid movement. As a result, it reduces the impact pressure [2,3]. It was showed the ratio of baffles height and water depth is essential. The quantity of baffles affects the reduction in wave height and pressure on the tank wall [4]. Additional factors such as slosh amplitude, frequency, liquid level, and tank geometry shall be accounted [5].

Computational fluid dynamics (CFD) is a widely known approach to calculating fluid problems. One of the methods is Mesh-based CFD that uses an Eulerian scheme to solve Navier-Stokes equations. The finite element method was used to solve sloshing problems on a three-dimensional tank [6]. Kim et al. [7] calculate impact load on sloshing problems using the finite difference method.

The sloshing phenomenon is related to free-surface flow. As a result, the meshless method has the advantage for sloshing cases. One of the methods is smoothed particle hydrodynamics (SPH), also known as mesh-free computational fluid dynamics (CFD). This method is often applied to sloshing problems because the particle methods are fully Langrangian. The first research related to the use of the SPH method on free surface flow was carried out by Monaghan [8].

The use of the SPH method in recent years is increasing. SPH method is used to calculate obstacles in the rectangular tank [9]. SPH application for sloshing was carried out for prismatic tank with low pass filter to reduce pressure noise [10]. Long duration sloshing of single-phase and two-phase SPH was used to calculate the impact pressure [11]. The results were showed SPH has fairly agreement with the experiment, although computation time was costly. Long duration sloshing in ractangular tank in single-phase was carried out by Green and Peiró[12]. Moreover, long duration of sloshing using the SPH approach in different tank shapes was successfully carried out in three-dimesion [13]. It was shown that SPH has the advantage to overcome sloshing phenomena because of the nature of the meshless approach that SPH easily captures large deformation.

The present study aims to know the vertical baffle's effect on sloshing in the prismatic tank. The variations of baffles use single and double vertical baffles. Roll motion with one pressure gauge near the free surface is used, and the tank filling ratio is 25%. It shows that the filling ratio of baffle height and water depth significantly affects reducing the sloshing phenomenon.

2. PRISMATIC TANK DIMENSION

In this study, we use a prismatic tank from a previous study that has been successfully conducted in the experiment facility in Tokyo [14]. Figure 1. shows the sketch of three dimensions of the prismatic tank that will use for SPH computation. The detail is shown in Table 2, which explains the principal dimension of the prismatic tank used in the present study. Figure 1. shows the movement tank is roll motion.

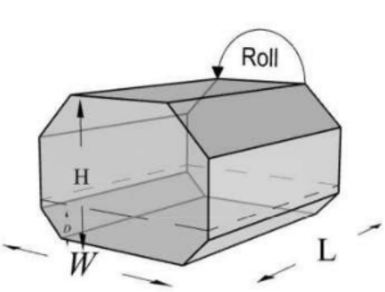

Figure 1. Prismatic Tank

Table 2. Principal Dimension of Prismatic Tank

Dimension of the Prismatic Tank			
Length	(L)	0.21	m
Width	(W)	0.38	m
Height	(H)	0.30	m
Draught	(D)	0.0525	m

3. BAFFLE CONFIGURATION

The tank model based on the prismatic tank is shown in the reference [14]. The variations single and double vertical baffle are made in the present study. The baffle thickness in this study is 0.006 meters. The ratio of the height of the baffle and water depth is found using the following equation.

$$\frac{h_b}{d} = 0.9 \tag{1}$$

Where h_b is the height of the baffle, d is the height of the liquid.It shows that the optimal ratio between the baffle's height and the liquid's height was 0.9 to avoid fluid run-up to the top of the tank [2].Meanwhile, the position of baffles evenly will reduce the impact pressure on the tank wall [4]. The position on a single vertical baffle was in the mid of the tank. The baffles are placed distributively on the left and right sides of the tank wall (see **Figure 4**.). **Figure 2**. shows the geometry of the tank model without baffle and **Figure 3**. shows a single baffle. In this study, the filling ratio tank is 25%, with external oscillation motion rolling.

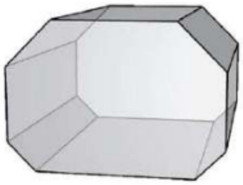

Figure 2. Prismatic tank without baffles.

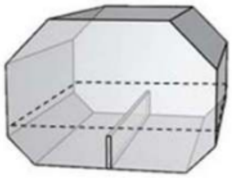

Figure 3. Prismatic tank with single vertical baffle.

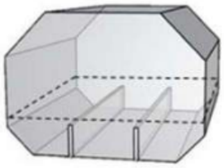

Figure 4. Prismatic tank with double vertical baffle.

4. EXTERNAL OSCILLATION AND SENSOR

The external oscillation force was based on reference [14]. **Figure 5** depicts the movement of the tank. The roll motion is regular motion with a time simulation is 30 second. Table 3 shows the frequency and amplitude of oscillation. There is a pressure gauge to measure impact pressure near the free surface. **Figure 6** shows the position of the pressure gauge. The pressure gauge was set in the mid of the tank.

Table 3. External Force

External Force	Frequency (Hz)	Amplitude (°)
Roll	1.04	8.66

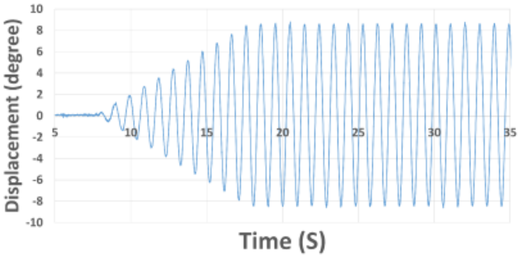

Figure 5. Time history of tank motion

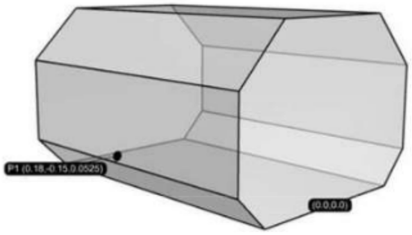

Figure 6. Pressure Gauge location.

5. SMOOTHED PARTICLE HYDRODYNAMICS (SPH)

Smoothed Particle Hydrodynamics (SPH) is a meshless and Lagrangian approach. The method is discretized the computation domain using point or particle. This method was first applied to the astrophysical problem. This study uses an open-source SPH solver DualSPHysics version 5.0 [15] to overcome sloshing. DualSPHysics is software based on C++ and CUDA programming languages. In the DualSPHysics XML programming structure, there is a command structure consisting of a casedef and an execution program. Casedef consists of several parts, which is constantsdef, i.e., constant required in simulation, mkconfig is a label configuration between fluid and boundaries. Creation of geometry particle to determine the location of the object, geometry mainlist to create a tank model, and fluid settings. Moreover, a motion is a label about movement performed at the tanks. After working on casedef, settings are carried out to execution to set the parameters in the DualSPHysics application.

6. RESULTS

a. Hydrostatic Pressure

In the rest conditions, the tank continues to experience hydrostatic pressure from the static fluid. The hydrostatic pressure is compared with the analytical solution. In order to determine the hydrostatic pressure accuracy that occurs in rest conditions, the following pressure equation can be used.

$$P = \rho \, . g \, . h \qquad (2)$$

The hydrostatic pressure calculation was carried out at a filling ratio of 25% (0.0525 m). The hydrostatics pressure in the SPH simulation shows in **Figure 7**.

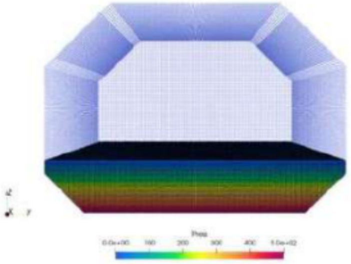

Figure 7. Hydrostatic pressure

b. Hydrodynamic Pressure

Figure 8. shows the comparison between the experimental results and SPH simulation. The red line is the impact pressure of the experiment, green is the tank with a single baffle, and the purple line is a tank with two baffles. The mean peak of the experiment is 498.51 Pa, and the mean peak of SPH without baffle is 645.33 Pa. Moreover, the mean peak of SPH simulation with a single baffle is 141.2 Pa. The mean of peak SPH simulation with double baffles is 100.615 Pa. The results showed that the difference between SPH simulation and experiment is 22%. Meanwhile, baffles can reduce the impact pressure up to 78% using a single baffle and 85% using a double baffle.

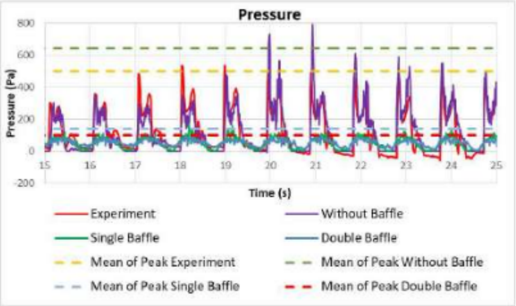

Figure 8. Hydrodynamic pressure without and with baffle.

c. Water Level

Figure 9. shows the difference in water level with or without baffle. The water level without baffles is 0.0891 m. Using single baffles is 0.073 m, and double baffles are 0.0674 m, respectively. The use of baffles can reduce baffle height up to 18% for the single baffle and 24.3% for double baffles.

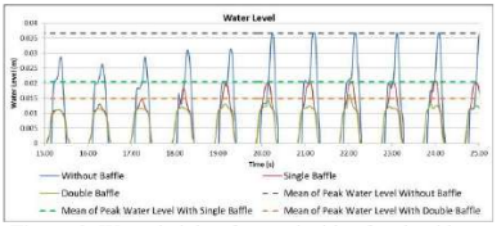

Figure 9. Water height of water inside of tank without and with baffle.

d. Free surface deformation

In this paper, we use advanced visualization of the SPH model using blender [16]. Time simulation 22.06 s had used to see the baffle effect to free surface deformation inside the tank. Time simulation 22.06 s is the highest point of water that runs up to the top of the tank in the original shape (see **Figure 10**).

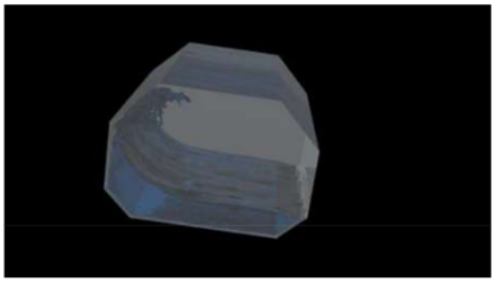

Figure 10. Prismatic tank without baffle

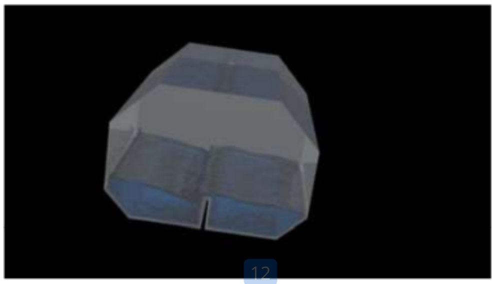

Figure 11. Prismatic tank with single baffle

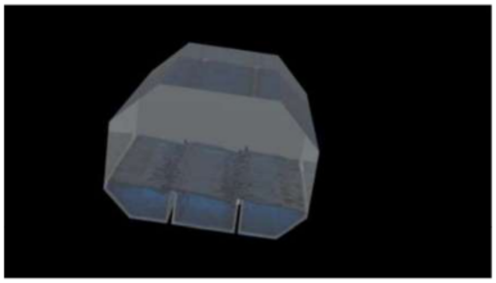

Figure 12. Prismatic tank with double Baffle

Figure 11. Shows the free surface deformation using a single baffle. It depicts vertical baffle effectively reducing the run-up of water as a consequence. The impact pressure has decreased. A similar result has shown in **Figure 12.**

e. Hydrodynamics Force

Figure 13. shows hydrodynamics forces that occur during sloshing. The hydrodynamics force without baffles shows the mean of peak force 15.451 N. For single baffle is 12.65 N. The double baffle is 12.78 N. The use of baffles can reduce the hydrodynamics force a difference of 18% for a single baffle. The double baffle is 17.2%, respectively.

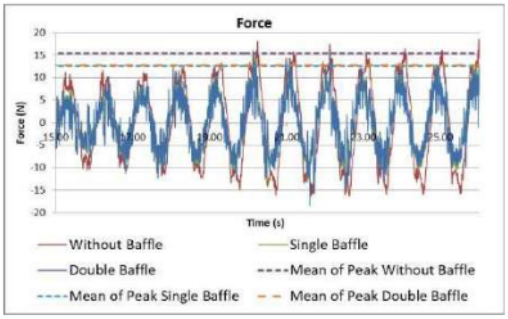

Figure 13. Hydrodynamics forcewithoutand with baffles

f. Hydrodynamics Moment

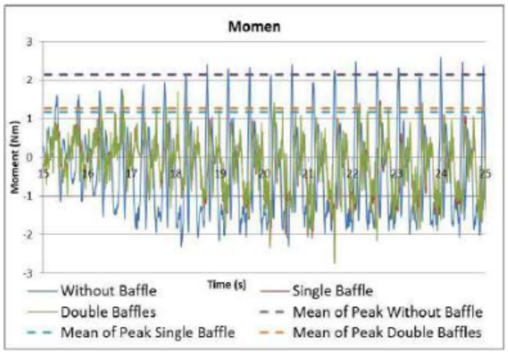

Figure 13. Hydrodynamics moment of without and using baffle

Figure 13. shows a graph of moments that occur during sloshing. The graph of moments without baffles reached its mean peak at 2.146 Nm, while for single baffle is 1.177, and for double baffles is 1.276 Nm. The use of baffles effectively decreases moments during sloshing, up to 45.1% for the single baffle and 40.4% for double baffles.

7. CONCLUSION

The present study shows that the results of hydrostatic pressure have reasonably good accuracy. In addition, for dynamic pressure, the accuracy is acceptable compared with experimental results. The use of vertical baffle in the tank has a significant effect on the sloshing phenomenon. The baffle can reduce the dynamic pressure by 85%, hydrodynamic forces are 18%, and hydrodynamics moment is 45.1%. The use of vertical baffles reduces fluid movement effectively in the sloshing phenomenon. Meanwhile, the comparison of the effects of single and double vertical baffles does not have a significant difference. Future works of sloshing in two-phase SPH need to be conducted to know the effect of compressibility of air into impact pressure [17].

8. ACKNOWLEDGEMENT

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10. AUTHORS BIOGRAPHY

H Atthariq, Undergraduatestudent at Department of Naval Architecture, Diponegoro University(UNDIP). He research interest is smoothed particle hydrodynamics (SPH) and computational fluid dynamics (CFD).

A Trimulyono, Assistant Profesor and head of ship hydrodinamics laboratory at department of naval architecture Diponegoro University (UNDIP), He teachs hydrodynamics, fluid mechanics and computational fluid dynamics (CFD).

D Chrismianto, Assistant Profesor and head ofship design and computer aided design laboratory at Department of Naval Architecture Diponegoro University (UNDIP).He teachs hydrodynamics, ship design and CAD.

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