The Sloshing Test of the Bilobe Tank Type Due to LNG Ship Motions in Regular Wave

Aries Sulisetyono[1,a], Aditya P. Wibawa[1], Yoyok S. Hadiwidodo[2]
[1]*Department of Naval Architecture, Institut Teknologi Sepuluh Nopember, Indonesia*
[2]*Department of Ocean Engineering, Institut Teknologi Sepuluh Nopember, Indonesia*

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Abstract: This paper describes the sloshing test of the Bilobe LNG tank type due to the LNG ship's motion in regular wave. Two-dimensional sloshing of the transverse tank was analysed due to the considered rolling excitation. The experimental device developed with a principal work to oscillate the filling liquid tank under the controlled amplitude and period of platform motion. Three variations of the LNG filling level inside the tank which were an empty condition, 10%, a half condition, 50%, and a full condition, 90%, considered to be investigated the occurred maximum pressure on the inner wall of LNG tank for certain amplitude and period of times. The test results represented in terms of free surface patterns that its compared with the simulation results which computed by the computational fluid dynamics approach for all cases of liquid filling level of the tank. The comparison results of the sloshing test and the numerical simulation had shown a close with the root mean square (RMSE) about 4%. Furthermore, the effect of baffle in reducing the sloshing pressure on the inner wall of tank was also investigated numerically.

1 INTRODUCTION

The sloshing can be interpreted as all movements of a fluid free surface inside a container, occur as a result of container's interference with a fluid partially filled in a container. The sloshing phenomenon was source of concern because the pressure that arises can cause result in destructive stresses (Ibrahim, 2005), as well as the ship motion stability (Hu et. all, 2017).

The study of sloshing had been carried out by several researchers using the numerical CFD approaches such as conducted by (Hou et. all, 2012) and the testing approaches as conducted by (Brar and Sigh, 2014). Sloshing tests in the laboratory were generally intended to validate the results of CFD simulations (Sinaga, 2014). The way to validate numerical results could be done by comparing the pressure value on the numerical results with the test results under the same tank excitation conditions as conducted by (Xue et. All, 2017). And another way of validation was to compare the surface shape of the numerical liquid results with the results of the tank test when given the same tank oscillation conditions as performed by (Chen, 2018). In this last method, the sloshing was done in 2 dimensions due to the single motion of ship.

The sloshing test on a box-shaped tank under the sinusoidal motion performed by author (Pradana and Sulisetyono, 2018), wherein the test also proposed to investigate the effect of baffles on the magnitude of pressures due to sloshing. The results shown that the addition of a buffer could reduce the pressure on the tank significantly. The same method was also shown by (Coulibal et. all, 2018) with a CFD simulation which states the baffle could reduce the pressure due to sloshing in the same case of a box tank.

Generally, sloshing studies on LNG tanks were mostly done for the case of the rectangular tanks (Coulibal et. all, 2018), or moss tank (Hasheminejad et. all, 2014), but few study for the cases of Bilobe tank (Sulisetyono, 2017). Bilobi shape was a type C of LNG tank or an independent tank which was formed by the merge of two circular cross section tank, and it had a certain length.

This paper discusses sloshing testing on the Bilobi type tank that were originally designed for LNG vessel tanks (Sulisetyono, 2018). The tank motion would follow the ship's motion in regular or sinusoidal waves. The test results were represented in terms of some snapshot images per time step which were the shape of the water surface in the tank. These results were compared with the CFD simulation

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results under the same conditions of the filled water, the motion period, and the motion amplitude. The sloshing tests were performed with three different filling levels including 10% h, 50% h and 90% h (h is of the water surface height from the bottom of tank). The comparison results had clarified the level accuracy of the numerical set up which was quantified in terms of the Root Mean Square Error (RMSE). Using the same set up running of software, the sloshing test able to compute the pressure values in the inner tank. Furthermore, the effects of the baffle, which was placed inside the tank, was discussed in this paper.

2 METHODOLOGY

2.1 Dimension of Ship and Tank

The LNG vessel was operating in the Makassar waters as shown in Figure 1. The ship had a waterline length (LWL) 103.26 m, width (B) 16.8m, draft (T) 3.4 m, displacement of 5257.62 tons with service speed of 11 knots.

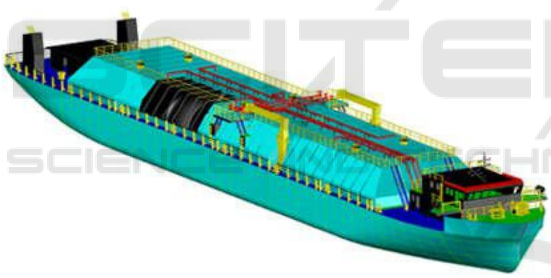

Figure 1: The LNG Vessel (Sulisetyono, 2018).

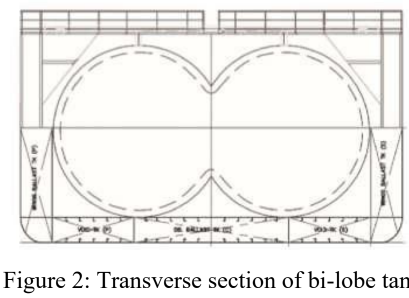

Figure 2: Transverse section of bi-lobe tank.

Inside the ship, there were 3 (three) distinct type C tanks also known as Bilobe tanks. each tank on the vessel had a capacity of 1270 m^3 with a length of 17.2 m, height of 6.9 m and half the width of the tank of 6.65 m. In this study, a tank in the middle of the ship was used to be analysed, and it was located the centre of gravity of ship longitudinally. The transverse section of tank is presented in Figure 2 since the only ship rolling motion was considered discuss in this paper.

2.2 Experimental Setup

The equipment test was developed to oscillate the model tank for some difference of periods and amplitudes. This equipment had four main components, namely docking plate, DC motor low rpm, motion converter, and model tank. The plate docking was built to place the model tank in which it could be rotated by the DC motor with respect to the axes. Another component was the motion converter which was to change the rotational of motor into the translation motion on the edge docking plate. The advantages of this equipment were the period, and the amplitude of motion might be controlled by adjusting the RPM of motor and setup motion converter, respectively. The sloshing equipment test was shown in Figure 3.

Figure 3: The sloshing equipment test.

The transverse tank was a symmetrical shape, and the half tank might be possibly used for a sloshing test as well as a numerical simulation. The Froude similitude approach was adopted to set up a dimensional of tank, an angular velocity, and an amplitude of motion. The tank model was built with scale of 1:50 from the full-scale tank which is the width of 13.3 cm, and the height of 13.8 cm. Length of the model tank did not follow the scale, because it did not have any influences to the 2D sloshing analysis.

The procedure in carrying out the sloshing test was determined to produce a fluid surface motion in the tank. The sloshing test procedures included: (i) filling the bilobe tank with water at the specified filling level, (ii) put the bilobe tank on the docking plate by paying attention to the midpoint location, (iii) adjust the bolt position on the converter wheel to adjust the amplitude of motion, (iv) adjust the motion period by the speed controller, (v) use the camera recorder to produce the video of sloshing, and the location of camera must be adjusted, and (vi) sloshing test with the specified filling level variation had been recorded with the camera.

The experiment set up were determined such as, (i) the filing level were variated in 10%, 50%, and 90 % of the tank height, (ii) the variations of amplitude were obtained such as 2, 3, and 4 cm, and (iii) the rolling period were including 2, 4, 6, and 8 second, (iv) the data were taken for 5 second at each filling level condition.

The sloshing test results were obtained in form of video, and it was needed to be processed into snapshot picture at each second. The free surface pattern was analysed. Figure 4 explained the measurement way of the free surface elevation, while obtaining the base line. The elevation of free surface was measured from the base line for each station of 13 station lines.

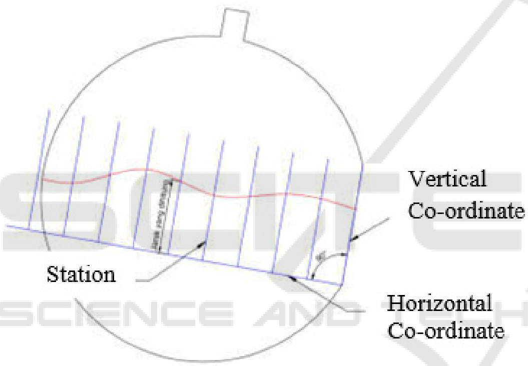

Figure 3: Validation process.

2.3 Numerical Setup

Numerical analysis was performed by using Computational Fluid Dynamic (CFD) that consider to rolling motion. The numerical procedures were developed using a modified version of the approach as described by (Sulisetyono, 2017) in the UDF program.

The Bilobe tank was modeled numerically using GAMBIT in a triangular meshing, and the number of meshing was determined based on the study of grid independence. It known to the optimum number for the simulation was about 8192 panels. The meshing was modeled evenly and equally throughout the fluid and gas portions in the tank. The sloshing simulation was conducted using the FLUENT software by first importing model from GAMBIT. The FLUENT was a popular CFD application program with the approach of Fluid Volume Method (VOF).

The simulations used solver-based pressure solving model with set up of implicit, unsteady, and non-iterative time advancement formula. The fluid flow was modelled in two phases with the Volume of Fluid method. The parameters were explicitly determined, and the implicit body force formula was selected. The flow type was assumed turbulent with k-epsilon, and standard model with standard wall function. The density of two-phase materials which were water and air, were specified. The operational conditions including pressure, gravity, density, and temperature were determined according to fluid characteristics. Fluid boundary condition of tank wall was specified as a zero-velocity condition. User defined was determined by uploading the libudf (library user defined function) file into the UDF library which was a ship rolling code, and compiled it. Meshing was modelled in dynamic mesh using layering method and set dynamic mesh zone in the rigid body of the tank wall.

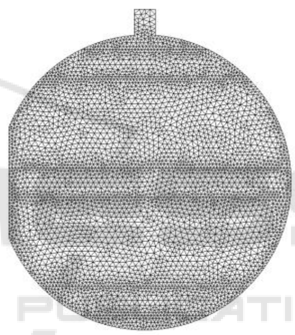

Figure 5: Meshing with 8192 panels.

2.4 Validation Setup

Validation of the numerical simulation method would be conducted by comparing the shape of the water surface due to sloshing tank which produced by the numerical simulations and the tank tests at the same conditions of filling level, period, and amplitude. The comparison of both results carried out under conditions of filling levels 10%, 50%, and 90% of the tank height.

For validation, the surface motion of the water were considered at time steps of 3, 4, 5, 6, 7, and 8 second. The results at time step of 1 and 2 second were not used since the inert force still influence the surface motion and it could affect to the accuracy of results. The results of surface pattern which come from the CFD analysis and test were expected to give the same trend, so that the numerical set up obtained could be said valid. For validation purposed, the equipment was set up at an amplitude of 5.7o and a period of 5.98 second. And the different between both results were expressed in terms of Root Mean Square Error (RMSE) as formulated in Equation 1.

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(CFD - Test_1)^2} \qquad (1)$$

After the numerical setup was declared valid, then the numerical approach was used further to find the effect of the buffle on sloshing phenomenon. The existence of the buffle was expected to reduce the amount of sloshing pressure. In this case, the buffle was placed at the middle of the bottom tank as shown in Figure 6 for tank with and without baffles.

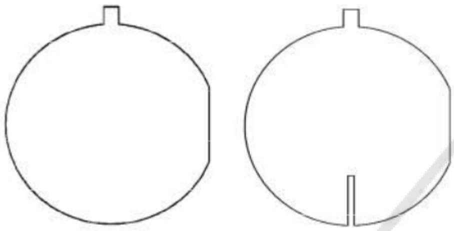

Figure 6: Tank without and with buffle.

3 RESULTS

Figure 7 illustrates the comparison between the surface shape of the test results with the CFD results at the condition of filling level 10% of the tank height for time steps 3 and 4 seconds.

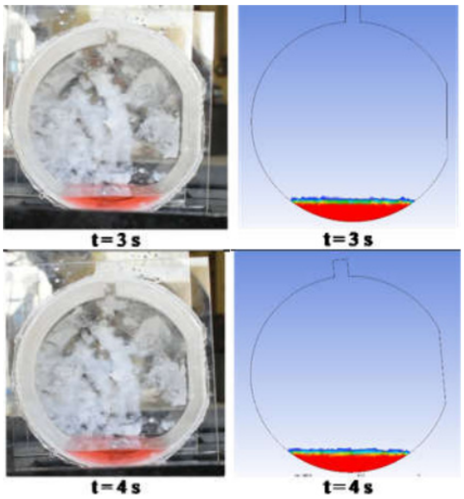

Figure 7: Comparison sloshing test and CFD in 10% h.

Figure 8 and 9 explained the comparison between the surface shape of the test and the CFD results at the condition of filling level 50% and 90% of the tank height for time steps 5 and 6 seconds, respectively.

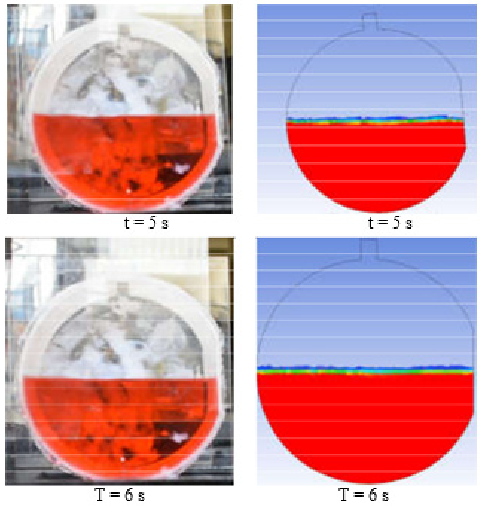

Figure 8: Comparison sloshing test and CFD in 50% h.

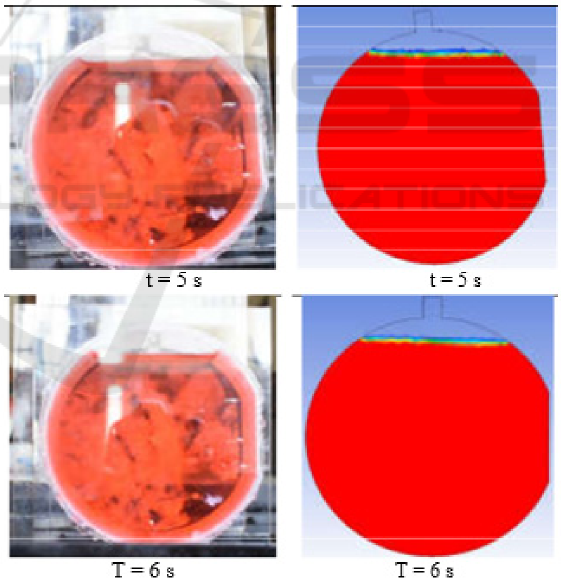

Figure 9: Comparison sloshing test and CFD in 90% h.

To determine the amount of error that occurs between the test results and CFD results, were first calculate an average difference between the elevation of the test results with the CFD results, and secondly to calculate the RMSE using Equation (1) for all time steps. Table 1 shown the results of RMSE calculation for a case of 50% filling level. The same procedure was applied for the case of 10% and 90% filling level, and the RMSE of 4.13% and 1.74% respectively.

Based on the RMSE, it could be stated the setup of CFD simulation was suitable used for further sloshing analysis.

The CFD simulation results were recorded for the filling level case of 50% h presented in terms of static and dynamic pressure values. Figure 10 explain the pressure of static and dynamic in the internal of bilobe tank for all filling level cases using time step of 0.005 second with the total number of 4000.

Table 1: RMSE of sloshing test and CFD for 50%.

Filling Level	Time Step (second)	Error (%)	RMSE (%)
50%	3	2.26	2.1
	4	2.72	
	5	1.45	
	6	4.58	
	7	3.52	
	8	0.71	

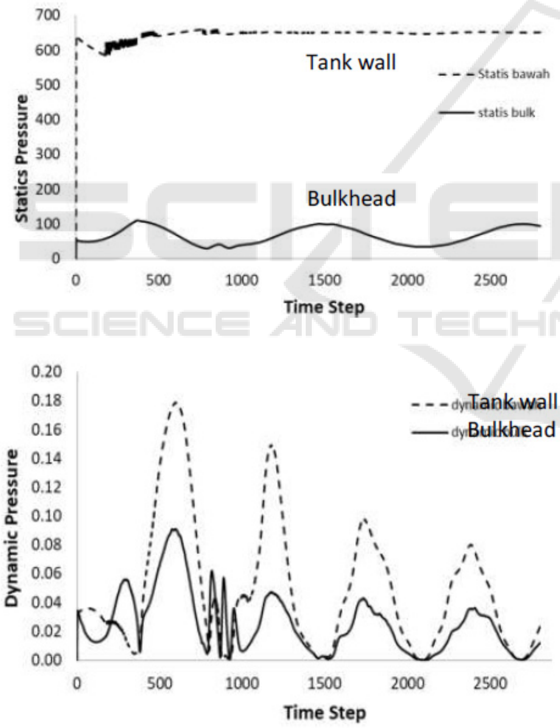

Figure 10: Static and dynamic pressures filling level 50%h.

Figure 10 shown that the static pressure give more contribute to the total pressure than the dynamic pressure, and it shown also for the other cases of filling level. The value of dynamic pressure was always different for all the time, and it shown the bottom area gave more pressure than the other location.

Table 2 explained the recapitulation of dynamic pressure results for different level filling such as 10%, 50%, and 90% which were located at the Tank Longitudinal Bulkhead (TLB) and Tank Wall (TW).

Basically, the dynamics pressure on the inner tank were occurred because of the sloshing on the liquid, and it was becoming a parameter used to quantify the sloshing effect. Table 2 shown the most sloshing effect occurred while the filling level of liquid was 50%h, and it explained that the sloshing effect had linear with the surface are of liquid.

Table 2: Recapitulation of maximum dynamic pressure.

Filling Level	Dynamic Pressure (Pa)	
	Tank Wall	Long Bulkhead
10%h	0.143	0.000
50%h	0.051	0.066
90%h	0.045	0.053

Table 3 explored the difference of the maximum dynamic pressure between the sloshing results on the tank without and with buffle for the filling level case of 10%, 50% and 90% respectively. All figures shown the baffle installed on the inner bottom tank could reduce the maximum pressure on longitudinal bulkhead up to 50%, 33%, and 30% for filling level of 10% h, 50% h, and 90% h respectively. The most contribution of baffle was in filling level 10% because of the free surface area was reduced by buffle significantly. Although the free surface area of the filling level 50% and 90% did not reduced, but the buffle had contribute increasing the viscous damping. It was correlation with other research for the case of rectangular tank (Xue et. all., 2017).

Table 3: Recapitulation of the maximum dynamic pressure for case with and without buffle.

	Filling Level 10%h	
Baffle	Tank Wall	Long Bulkhead (Pa)
With	0.049	0.000
Without	0.199	0.000
	Filling Level 50%h	
Baffle	Tank Wall	Long Bulkhead (Pa)
With	0.040	0.062
Without	0.177	0.092
	Filling Level 90%h	
Baffle	Tank Wall	Long Bulkhead (Pa)
With	0.032	0.148
Without	0.369	0.212

4 CONCLUSIONS

The innovation equipment was developed to numerically validate the sloshing simulation that was conducted by the CFD approach. Results were validated by looking at the surface water pattern. Validation was done by comparing the numerical result with the tank test results with the RMSE method, and the different was less than 5% for all cases of filling level. It is shown that the numerical set up on the FLUENT was made to utilize the simulation of sloshing. The most sloshing effect occurred while when the liquid filling level of liquid was 50% h, and it explained the sloshing effect had linear to the liquid surface area The use of baffle on the tank model resulted in a reduction in the maximum value of dynamic pressure for all cases of filling level carried out up to 50%. However, the irregular motion of ship's sloshing must be performed in future work complete this work.

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