

Chapter 12

Prediction of the Fibre-Reinforced Polymer Hull on the Wave Slamming Impact



Roslin Ramli, Mohd Hisbany Mohd Hashim, Anizahyati Alisibramulisi, Suhailah Mohamed Noor, and Noorlee Boonadir

Abbreviations

FD	Finite difference
FEA	Finite element analysis
FRP	Fibre reinforced polymer
FSI	Fluid-structure interaction
MEKP	Methyl ethanol ketone peroxide
MetMalaysia	Malaysian meteorological department
UTM	Universal testing machine

R. Ramli (✉) · N. Boonadir
Universiti Kuala Lumpur Malaysian Institute of Marine Engineering Technology, 32200 Lumut,
Perak, Malaysia
e-mail: roslin@unikl.edu.my

N. Boonadir
e-mail: noorlee@unikl.edu.my

M. H. Mohd Hashim · A. Alisibramulisi
Faculty of Civil Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia
e-mail: hisbany@uitm.edu.my

A. Alisibramulisi
e-mail: aniza659@uitm.edu.my

S. Mohamed Noor
Faculty of Civil Engineering, Universiti Teknologi MARA, 13500 Permatang Pauh, Pulau Pinang,
Malaysia
e-mail: suhailahmn@uitm.edu.my

12.1 Introduction

Ships, boats, and small crafts are the primary sea transportation modes in most parts of the world. It is a complicated vehicle meant to transfer people and cargo by water from one destination to another. The hull is the primary body of a ship or boat, which includes the bottom, sides, and deck. However, this research is focused on examining the prediction of the fibre-reinforced polymer (FRP) hull on the wave slamming impact.

The hull is available in various materials, including aluminium, steel, mild steel, wood, and FRP. Note that FRP was selected for the hull lamination in this study due to its corrosion resistance, non-magnetic characteristics, high tensile strength, lightweight, and simplicity of handling compared to aluminium, mild steel, and wood. A structural composite is a strong material that can replace conventional materials such as steel (Coppe et al. 2012).

Thus, the maximum strength FRP configuration was used in an actual boat model simulation with wave impact of slamming on fluid-structure interaction (FSI). The impact of a ship's bottom structure on the water surface is known as slamming. It causes exceptionally high loads on boat or ship structures and is considered during the design. Other than that, hydrodynamics and structural dynamics are involved in slamming occurrences. This event shows complex physics, which is still not well understood.

The complexity of FSI experiments and numerical simulations for ships is currently a key concern in studying full-scale slamming in real-world situations (Volpi et al. 2017). More resolved, higher fidelity simulations and FSI replications are required. However, the results of slam pressure on the bottom hull have shown the significant effects of composite material design on the structural response of slamming.

This research paper aims to predict the impact of bottom slamming on the FRP hull. The wave impact location was based on the Northern Straits of Malacca and the parent hull selected was the planning hull, which is the C945 model.

12.2 Methodology

The hull laminate method will be used in this research, which is a stacked sequence with a $+45^\circ$ layer orientation with different types of fibre mats (tissue mat, chopped strand mat, and woven roving). Thus, using the highest strength FRP composition in real boat model simulation with wave impact of the slamming on FSI was also studied. Slamming is the impact of the bottom structure of a ship onto the sea surface.

The simulation of the FSI was performed for this hydrodynamic diffraction. The fluid interacts with a solid object in the FSI and is a multiphysics combination of

fluid dynamics and structural mechanics. This phenomenon is characterised by interactions between a deformable or moving structure and an external or internal fluid flow, which could be stable or oscillatory.

This FSI is restricted to the slamming's wave effect. Hence, the FSI model is constructed using the 3D slamming technique to produce the wave-induced loads and response on the shell. The combination of a pulsating source distribution over the mean wetted surface of the hull is used in the shell finite element analysis (FEA) idealisation.

ANSYS Aqwa's simulation can effectively predict the interaction between fluids and solids based on pressure (Siyuan 2012; Lefrançois et al. 2014; Xu et al. 2019; Zullah and Lee 2016). Furthermore, it can assess the FSI's wave impact from slamming. Therefore, the methodology is divided into four components: the produced hull, wave components, and FSI simulation.

12.2.1 *Material*

Due to seawater ageing in marine applications, the mechanical characteristics of materials deteriorate in composites (Neşer 2017; Rajak et al. 2019). Note that the properties of the composite material deteriorate because of poor adhesion between the fibre and matrix in the composite structure caused by moisture absorption. These sandwich composite panels with glass or carbon fibre skins and a polymeric core have been used to build whole hulls and marine craft structures (Verma and Goh 2019). Correspondingly, a polymer matrix reinforces the fibres making FRP a composite material (Bai and Jin 2015).

ASTM D 3039 was followed in the processing of the specimen at $S + 45^\circ$. The woven roving 600 (WR600), chopped strand mat 450 (CSM450), and tissue mat (T) were utilised in the specimen $S + 45^\circ$ preparation. Other than that, the catalyst was methyl ethyl ketone peroxide (MEKP), and the polymer is an unsaturated polyester.

There is a kind of isotropic stacking sequence in the specimen $S + 45^\circ$ laminate, with each layer arranged in a stacking pattern. T/CSM450/WR600/CSM450/WR600/CSM450/T is the lamination sequence, and $[0/0/+45^\circ/0/+45^\circ/0/0]$ is the angle orientation, as shown in Table 12.1. The specimen $S + 45^\circ$ complies with earlier studies (Ramli and Mohd Hashim 2017).

12.2.2 *Created Hull*

To construct a hull, the parent hull must include precise information about its size, capabilities, stability, and performance. The planning vessel's parent hull is a C954 type. It was created using the C954 model, which is depicted in Fig. 12.1. An extensive experimentation programme in a towing tank, with or without interceptors, demonstrated that the C954 model had a good performance (Luca and Pensa 2017).

Table 12.1 S + 45° stacking sequence and angle orientation (Ramli et al. 2022)

Stacking sequence	Angle orientation
T	0°
CSM450	0°
WR600	+45°
CSM450	0°
WR600	+45°
CSM450	0°
T	0°

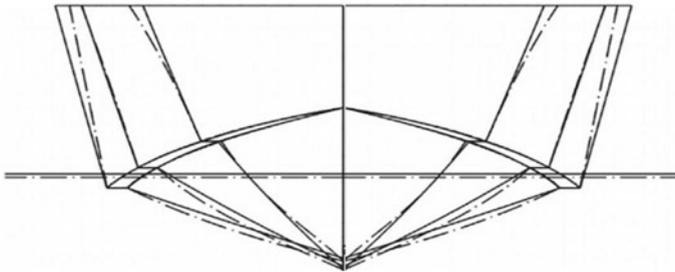


Fig. 12.1 Parent hull C954

Moreover, the planning hull with the chine hull shape was the reason for the good performance during the manoeuvre, as the chine functions as an oscillating dynamic roll.

Table 12.2 shows that the hull parameters had been changed by 4.3 m. On the other hand, the fibre-reinforced polymer (FRP) material was S + 45°. Tensile test results for S + 45° show that the manual and automatic Universal Testing Machines (UTM) have the highest tensile strengths of 151.78 MPa and 137.48 MPa, respectively (Ramli and Mohd Hashim 2017), whereas the American Bureau of Shipping rules section 4 (4.4.2) states that the minimum tensile strength values for the specimen S + 45° are 18,000 psi or 124 MPa. This research uses the FRP laminate method of S + 45°. The material property values are applied to the hull based on the results of the S + 45° test.

The Maxsurf software creates the hull. There are several processes involved in obtaining the required shape: adding up the surface, keying in the size surface, merging in the surface, and smoothening the hull utilising the control point positions for each of the columns. The hull dimensions of the real boat were 4.3 m × 1.4 m × 0.95 m with 8 mm thickness, as shown in Fig. 12.2.

Table 12.2 Parameters of the hull

Parameters	Model 1
Length	4.3 m
Beam	1.4 m
Draft	0.475 m
Depth	0.95 m
Thickness	0.008 m
Longitudinal centre of buoyancy (LCB)	1.539 m
Longitudinal centre of gravity (LCG)	2.15 m
Speed	2.779 knots
Material FRP	S + 45°

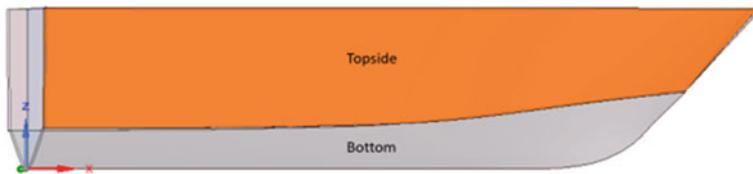


Fig. 12.2 The planing hull in ANSYS Aqwa

12.2.3 Wave Components

The FSI requires wave components and the boat’s position through which it will navigate. Figure 12.3 shows the instances of wave components required in the FSI. Note that the components consist of a significant wave, maximum wave, amplitude wavelength, and wind speed.

Apart from that, the details of the wave component were collected for two months from 4th Oct until the 4th Dec 2020. These were part of quarter 4 of the year, in which the data wave height and wave component were usually collected by the Malaysian Meteorological Department (MetMalaysia) (Yaakob and Zainudin 2010).

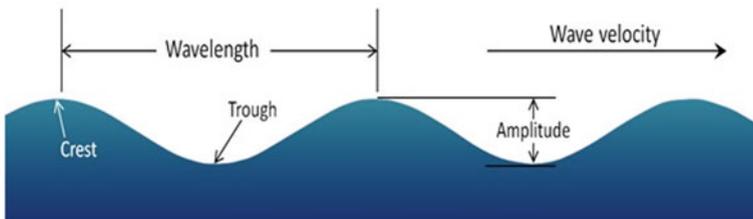


Fig. 12.3 The parameters of water wave (Earle 2019)

Table 12.3 Data of wave components

Deepwater significant wave (Hs) characteristic 60 days	
Location	Northern straits of Malacca
Depth description	Shallow water
Significant wave height (m)	1.0
Shallow water starting depth (m)	3
Wave amplitude (m)	0.5
Wave frequency (Hz)	10
Wavelength (m)	0.94
Maximum wave height (m)	3.5
Minimum wind speed (m/s)	10
Maximum wind speed (m/s)	50
Transition zone starting depth (m)	28
Velocity (m/s)	9.4

The data of significant wave height, maximum wave height, and wind speed on the website MetMalaysia were generated every seven days. The final data of wave components of the Northern Straits of Malacca are shown in Table 12.3.

12.2.4 Hydrodynamic Diffraction—FSI

In the FSI simulation, the ANSYS Aqwa software sets up coordinates in the XY plane, imports the external geometry hull (Rhino.3dm files), and generates the hull. The hull appeared as shown in Fig. 12.4. First, the hull must be divided into the surface and the bottom, with the bottom immersed in the water level. Subsequently, the step to immerse the bottom hull was to add a new XY plane, types from coordinates, and the FD13 point 2 of -500 mm (Z-axis). After that, the file is saved and edited to form the model in the hydrodynamic diffraction analysis.

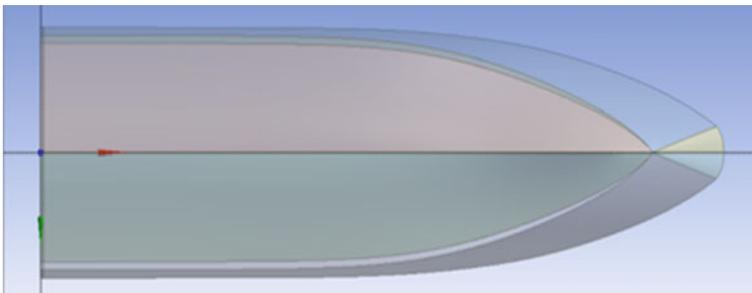
**Fig. 12.4** Setup the coordinate of the hull



Fig. 12.5 The completed mesh of the hull

The mesh element of 4 mm is added with the growth rate of 1.05, while the mesh metric is skewness. Furthermore, the mesh is solved with 26,946 nodes and 3402 elements under programme control from the ANSYS software. Figure 12.5 shows the complete meshed hull.

The analytic parameters, structure selection, wave direction, and wave frequency are all configured. The analysis mode is set to program-controlled, and the hull is selected as a structure. Other than that, the wave direction type was a range of directions with a forward speed of 1.542 m/s and a wave range of -180° to 180° .

The details of wave frequencies are 10 for target encounter frequencies, while 24 is the actual encounter frequencies. Apart from that, it displayed all wave directions and frequencies. The lowest and highest frequency definitions are controlled by the program. In the solution, the hydrodynamic, pressure, and motion are inserted.

12.3 Results and Discussion

The hydrodynamic diffraction analysis of fluid-structure interaction (FSI) is based on a $4.3 \text{ m} \times 1.4 \text{ m} \times 0.91 \text{ m}$ hull with a thickness of 8 mm. The implementation of simulation to the real model to address real impacts found that the maximum hydrodynamic pressure of 14,689.90 MPa occurred at the middle of the hull on the first laminate layer. Figure 12.6 shows the impact of pressure on the hull surface. The impact is more on the bottom of the hull on the starboard side.

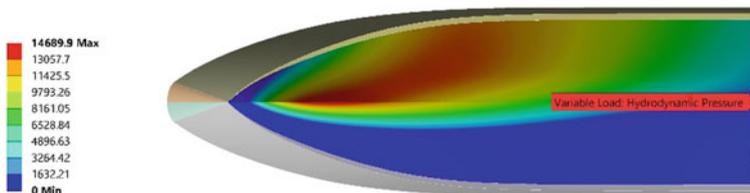


Fig. 12.6 Hydrodynamic pressure (MPa) distribution on the bottom of the hull

The second impact of wave slamming was 13,057.70 MPa, which also occurred on the starboard side. Hence, the impact of the hydrodynamic pressure was more on the starboard side, where the minimum amount was 163.21 MPa. The yellow area is the biggest impact on the starboard side of the hull after and forward, with the impact of the hydrodynamic pressure being 9793.56 MPa.

On the other hand, the port side of the hull has an impact on the middle line of the hull, which is 13057.70 MPa. This is followed by 9793.26 MPa (yellow), 8161.05 MPa (light green), 6528.63 MPa (green), 48,996.63 MPa (cyan), 3264.42 MPa (light blue), 163.21 MPa (dusty blue), and the biggest areas was 0 MPa (dark blue). The dark blue area was 90% on the port side. Moreover, the remaining 10% was combined with the various hydrodynamic pressure. These results are the same for the bottom side of the hull, as shown in Fig. 12.6.

12.4 Conclusion

Based on the real boat model, the hydrodynamic diffraction analysis of fluid-structure interaction (FSI) of the model size of $4.3 \text{ m} \times 1.4 \text{ m} \times 0.95 \text{ m}$ and the 8 mm thickness and a material selection of $S + 45^\circ$ were selected. The real boat hull model is designed according to the parent hull C945 model. Moreover, the wave impact components collected from the Malaysian Meteorological Department (MetMalaysia) website were located in the Northern strait of Malacca. Note that sixty days of data had been collected for accurate results.

The results indicate that subject to moderate slamming loads, the strains of composite bottom panels essentially scale with their static stiffness. However, the most severe slamming events deviated from the static stiffness relationship. Estimates of water impact velocity suggest that impact speeds for these slamming events approach a critical value at which hydrodynamic and inertial effects become significant.

Slamming loads were modelled as a high-intensity peak followed by a lower-intensity hydrostatic pressure moving across the panel at a constant speed. Other than that, hydroelastic effects were ignored or included only as a constantly added mass term. The structural response during the initial loading and later vibration phases was investigated for a constant load of 30 MPa.

Consequently, the FSI occurs when a fluid interacts with a solid structure, exerting pressure that may cause deformation in the structure and, thus, alter the flow of the fluid itself. The maximum impact was 14,689.90 MPa on the starboard side in the slamming wave. Meanwhile, the minimum impact was 163.21 MPa on the port side in the slamming wave.

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