NUMERICAL INVESTIGATION OF BOW SLAMMING ON SHIPS WITH LARGE FLARE

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ABSTRACT

Prediction of slamming loads due to wave impact is important not only for structural design but also for safe maneuvering of ship. In the present study, computational fluid dynamics simulation technique is used for predicting the slamming loads on ships with large bow flare advancing in waves. Finite volume method (FVM) is used for discretization of time-dependent Reynold's averaged Navier-Stokes (RaNS) equation. Overlapping grids technique is employed for simulating waves, ships interaction with waves and resultant motion of ships. The free surface is captured by density-function method. The numerical results of two container ship models SR108 and KCS with F_n=0.33, λ/L_{PP}=0.133and high amplitude regular head sea and 120 deg. Oblique waves are considered. Simulations are conducted for 3 degrees of freedom (Heave, Pitch and Roll). First, motions data are validated with experimental results and finally slamming phenomena is analyzed by visualization technique.

Keywords: *Slamming, Bow flare, Container ships, Visualization technique.*

1. INTRODUCTION

Twenty first century is the age of containerization for maritime transportation. Now-a-days almost 90% of sea transport is by container. Therefore, the number of container ships is increasing rapidly. For larger accommodation of containers and; safe and convenient cargo handling for containers, the recent tendency has been to widen the bow flare angle. This raises the flare slamming pressure excessively and causes structural damage. Yamamoto et al. [1] reported a serious structural damage due to bow flare slamming.

Flare slamming describes dynamic wave impact on the bow side shell structure above the design waterline and during water entry, the bow structure is subject to high pressure loads. It is therefore necessary to evaluate the slamming loads in a practical and sufficiently accurate manner. Computational Fluid Dynamics (CFD) is one of the possible method.

During design stage, slamming pressures are usually obtained by using empirical formulae given by the classification societies. However, there is sizeable difference in the quantitative levels of slamming pressure obtained by these formulae as mentioned by Boitsov and Koudrin [2]. Therefore, the necessity for direct calculation methods is increasing for novel design.

Slamming has challenged many researchers since von Karman's work [3]. He idealized the impact as 2D wedge entry problem on calm water surface to estimate the water impact load on a seaplane during landing with small deadrise angle. Zhao and Faltinsen [4,5] used Boundary Element Method (BEM) for predicting slamming loads on 2D wedge and flared ship sections for splash effects and variations in impact velocity. Their numerical results for ship section compared favorably with the experiments but over predicted for case of wedge sections. They also showed that 3D flow effects are significant and the numerical results were sensitive to the length of the induced jet part. Sun and Faltinsen [6] also used BEM for 2D slamming of bow-flare ship with roll angle. They pointed out that large roll angle causes very high localized pressure in the flare area. Hermundstad and Moan [7,8] used non-linear strip theory for predicting slamming loads on ship hulls and validate the procedure for a 120m car carrier and 290m cruise vessel in bow and bow quartering regular and irregular waves of different heights.

To obtain slam loads on 2D sections, Arai et al. [9,10] used finite difference method for discretization of the Euler equations and volume of fluid (VOF) method for free surface evolution. He obtained favorable trends but the pressure did not co-relate well with drop tests results probably due to negligence of impact velocity variations in the numerical procedure. Muzaferija et al. [11] and Sames et al. [12] used finite volume method (FVM) for discretization of the Navier-Stokes equations and high resolution interface capturing (HRIC) scheme for free surface to predict the slamming loads on a 2D sections by considering varying re-entry velocities. Muzaferija et al. [11] obtained slam loads on wedge section considering three-dimensional effects and numerical results matched reasonably well with the experimental results of Zhao et al. [5]. Sames et al. [12] mentioned that prescribed vertical velocity histories significantly affected the determination of realistic pressure levels. Reddy et al. [13] simulated slam loads on 2D wedge section using CFD techniques. They concluded that impact velocity variations, domain size and three dimensionality of flow are significant on the numerical procedure for slamming loads prediction.

Ogawa et al. [14] conducted model tests of a post-panamax container carrier to examine the relationship between ship motions and the water impact pressure on the bow flare in heave and pitch free conditions. They reported that the large magnitude of the impact pressure is rare or not frequently occurred in the long crested wave and the flare angle has an effect on it.

Most recently Kapsenberg and Thornhill [15] used modified version of classical momentum theory (monty) to capture the effects of wave steepness, wave direction and CFD application ANSYS CFX to predict slam loads on the bow section of a 173 m ferry. They conclude that when the incoming wave was well matched to the wave profile data, CFD results are in good agreement with experiment. Comprehensive review on slamming has also been reported in [16,17].

2. NUMERICAL METHODS

WISDAM-X, developed at Miyata & Akimoto Laboratory, The University of Tokyo utilizes overlapping grid systems for obtaining ship's interaction with waves and resultant ship motions. The total solution domain has two parts; inner solution domain (O-H type grid) near the vicinity of the hull and outer domain (rectangular grid) located several ship lengths away from hull surface. The numerical modeling of WISDAM-X is mentioned in Table 1. Details are mentioned in Orihara and Miyata [18].

The inner solution domain provides high resolution around free surface and hull whereas the outer solution domain extends to the outer boundary, located several ships' length away from the hull surface. In half ship simulation, symmetry boundary conditions are used at the center plane.

Table 1. Numerical modeling

Governing equation	RaNS equation, continuity equations
Pressure solution algorithm	Marker-and-Cell (MAC) method
Spatial discretization	3rd order upstream (advection term) 2nd order central (others)
Time discretization	Explicit Euler method
Variables arrangement	Staggered mesh
Turbulence model	Baldwin-Lomax model Dynamic SGS model
Free surface treatment	Marker density function (MDF) method

The size of computational grids for the present analysis is mentioned in Table 2.

Table 2. Size of computational grids

Ship types and hull conditions		**Inner**	**Outer**
SR108	Half	131×21×71	146×31×41
	Full	131×21×141	
KCS	Half	130×21×70	
	Full	130×21×139	

3. SIMULATION TOPOLOGY

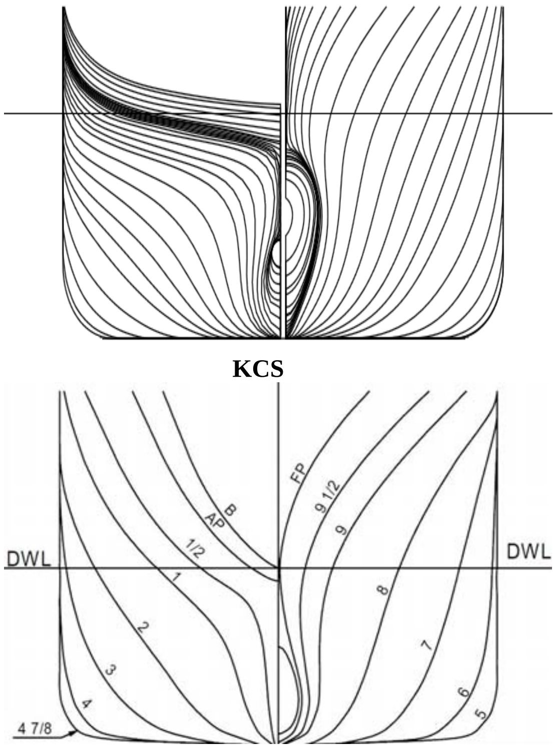
3.1 Ship geometry

In real seas, among different types of slamming, the occurrence of bow flare slamming is significant and violent in case of container ships due to its geometrical shape. Therefore, two different types of container ship model SR108 (designed by National Maritime Research Institute (NMRI), Japan formerly Ship Research Institute, Japan) and KCS (KRISO Container Ship; developed by Korean Ship Research Institute now KORDI) are chosen for the present analysis. The main principal particulars and body plan of these two container ships are shown in Table 2 and Figure 1 respectively.

Table 2. Principal particulars of ships

Particulars	**SR108**	**KCS**
Length between perpendiculars (m)	175.00	230.00
Length of waterline (m)	178.20	232.50
Breadth, moulded (m)	25.40	32.20
Depth (m)	15.40	19.00
Draught (m)	9.50	10.80
Displacement Volume (m^3)	24742	52030
Block coefficient	0.5716	0.6505

The geometrical shape differences between the two ships are mentioned in Table 3.



SR108

Figure 1. Body plan of container ship models

Table 3. Geometrical shape difference

Item	SR108	KCS
Bulbus bow	Small Bulb	Present
Flare angle	High	Moderate
Stern shape	Round	Transom

3.2 Simulation conditions

The designed Froude's number for KCS and SR108 is 0.26 and 0.275 respectively. In present numerical investigation, one extreme case is considered. Therefore, simulations are conducted with Froude's number, F_n= 0.33 and wave length ratio, λ/L_{PP}=1.33 in regular head waves and 120 degree oblique wave with heave and pitch (HP) free, and heave, pitch and roll (HPR) free conditions . The wave amplitude ratio is 1.12% of L_{PP} for KCS and 1.21% for SR108.

4. ANALYSIS METHOD

Due to unavailability of experimental results for slamming, present analysis is made in the following procedure.

- KCS's motion data is validated with experimental data
- SR108 is simulated with same conditions of KCS
- Flow field data in the region of bow flare section is visualized
- Finally, slamming phenomena is analyzed based on visualization technique

5. RESULTS AND DISCUSSIONS

Figures 2 and 3 represent the time history comparison of numerical results with experimental data [19] for heave and pitch motions respectively in case of KCS. In the figures, the amplitude of heave motions matches well with experiment but phase difference occurs with increase of time whereas the pitch agrees well with experiment.

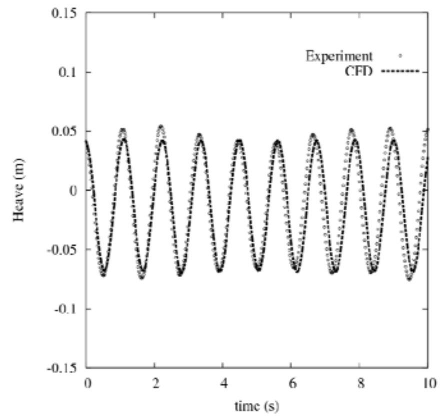


Figure 2. Time history of heave motion

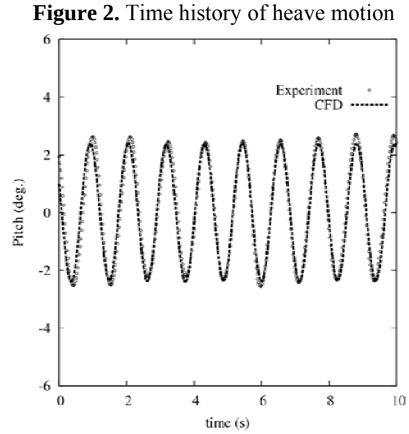


Figure 3. Time history of pitch motion

Figure 4 shows the time history comparison of total drag coefficient in head sea and oblique wave conditions with heave and pitch (HP) free; and oblique wave with heave, pitch and roll (HPR) free conditions for KCS. The total drag co-efficient, C_T is calculated from the total drag, R_T.

$$C_T = \frac{R_T}{\frac{1}{2}\rho v^2 S}$$

where S is the wetted surface, v is speed of the ship and ρ is the density of water.

It is seen from Figure 4 that inclusion of roll motion reduces the total drag coefficient. The peak drag co-efficient for head wave with HP, oblique wave with HP and oblique wave with HPR is 0.0181, 0.0116 and 0.0115 respectively. So, from practical point of view roll motion must be considered in the analysis of slamming.

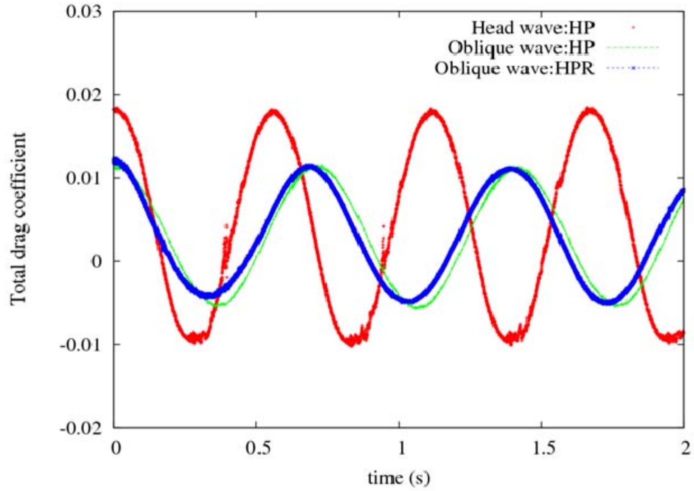


Figure 4. Comparison of time history of total drag coefficient

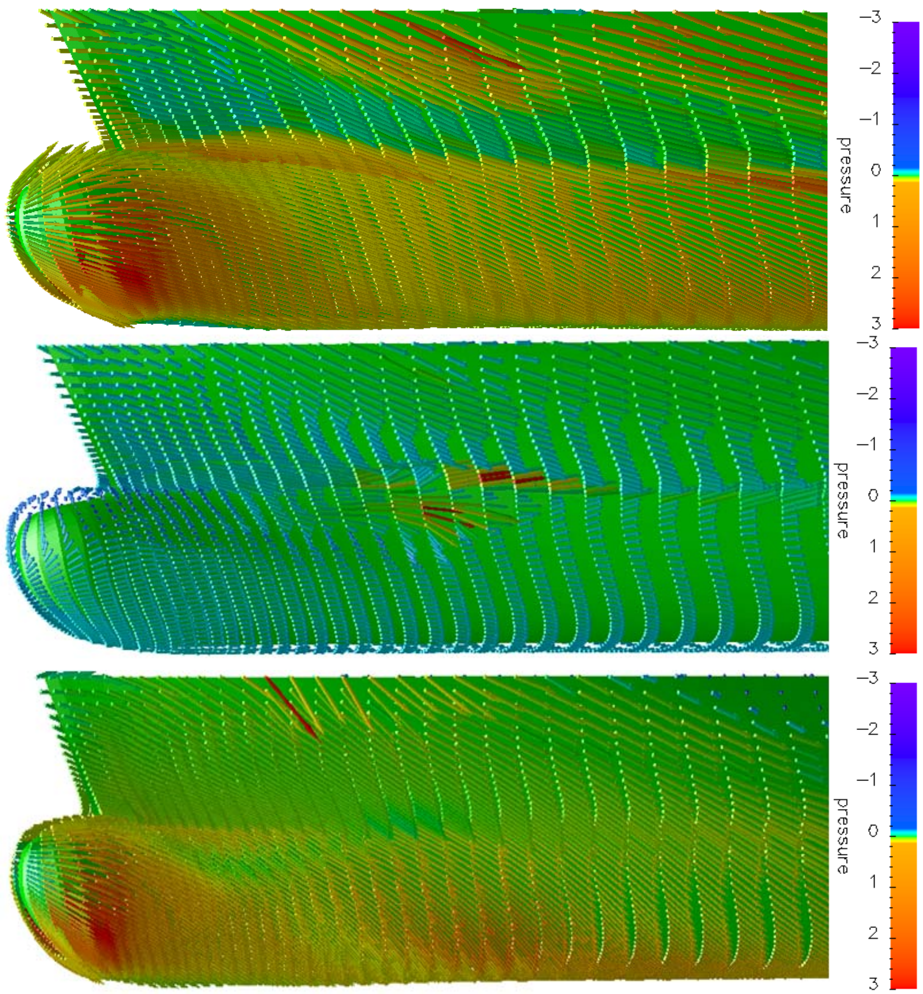


Figure 5. Velocity vector on KCS in head wave with heave and pitch motions for initial instance, wave crest and wave trough at FP of the ship

Slamming in the bow flare section is a local phenomenon which has the global effects on the ship's hull. Present analysis is carried out by visualization of velocity vector relative to the hull with pressure color bar on the bow section with ship motions in waves. However, due to unsteady characteristics, three time instances in a single steady wave period are considered like initial instance, wave crest and wave trough at FP of the ship.

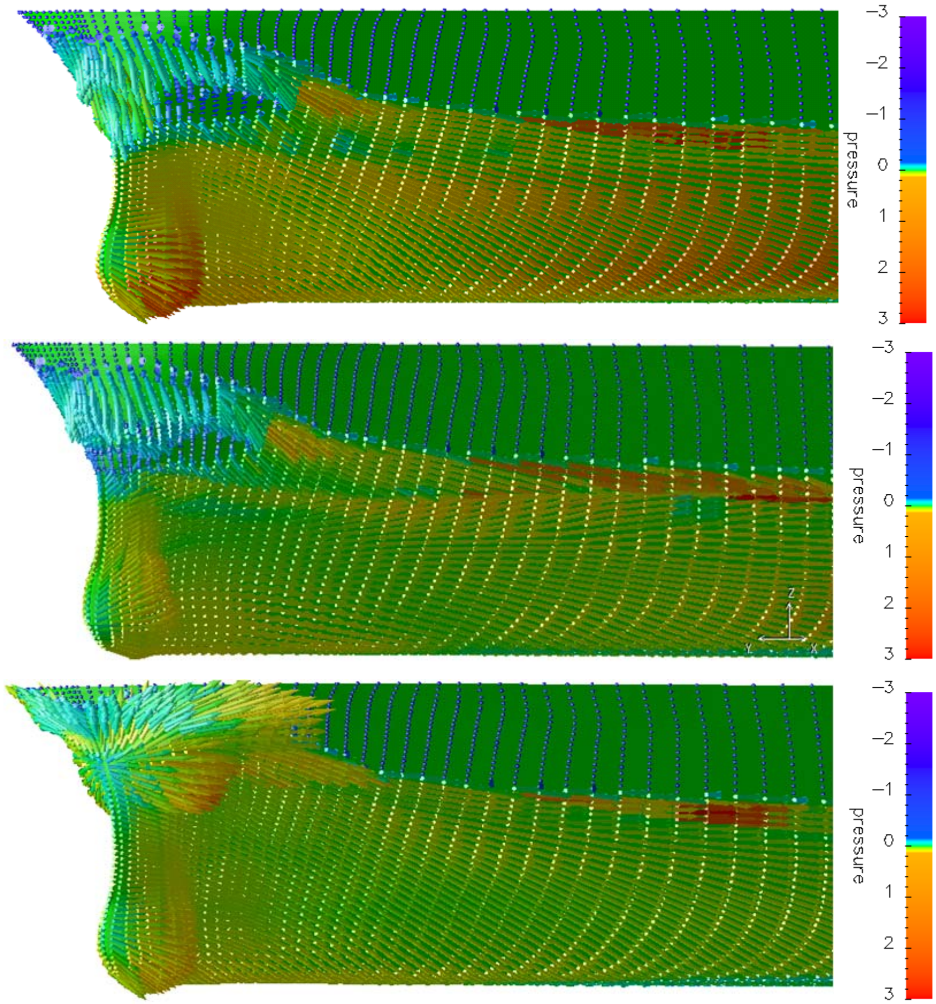


Figure 6. Velocity vector on SR108 in head wave with heave and pitch motions for initial instance, wave crest and wave trough at FP of the ship

Figures 5 and 6 show the time sequence visualization of velocity vector relative to the hull with ship motions in the bow flare section on KCS and SR108 in head wave with heave and pitch free conditions respectively. In the figures, at the initial instance of wave hit, for SR108, there is no velocity in the flare section.

In Figure 5, when the ship is on the wave crest, separation of velocity vector occurs close to the design water line in case of KCS. Again when the ship is on the wave trough, the magnitude of velocity is higher at some particular points in the upper part of the bow flare section for KCS.

Both in KCS and SR108, the velocity vector is inclined with flow directions but the angle of inclination is higher in case of KCS.

There will be difference in the total drag, ship's motion in the two different kinds of ship models but the differences that are identified from Figure 5 are because of different bow shapes and flare angle.

Figures 7 and 8 show comparison of the time history of heave and pitch motions for KCS in head wave and oblique wave. In the figures, around 1.5 deg. pitch up and 0.1 meter heave difference occur in case of head wave. Also there is a difference in encounter frequencies.

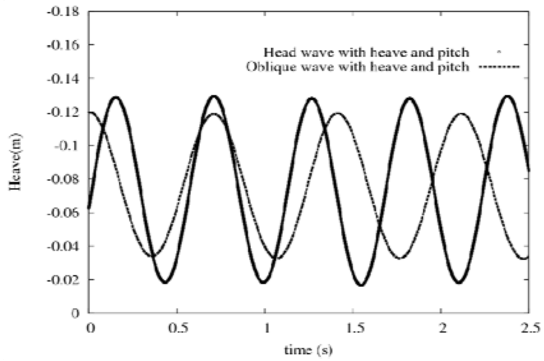


Figure 7. Time history of heave motion

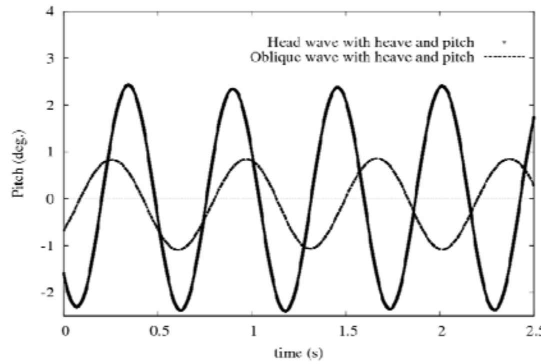


Figure 8. Time history of pitch motion

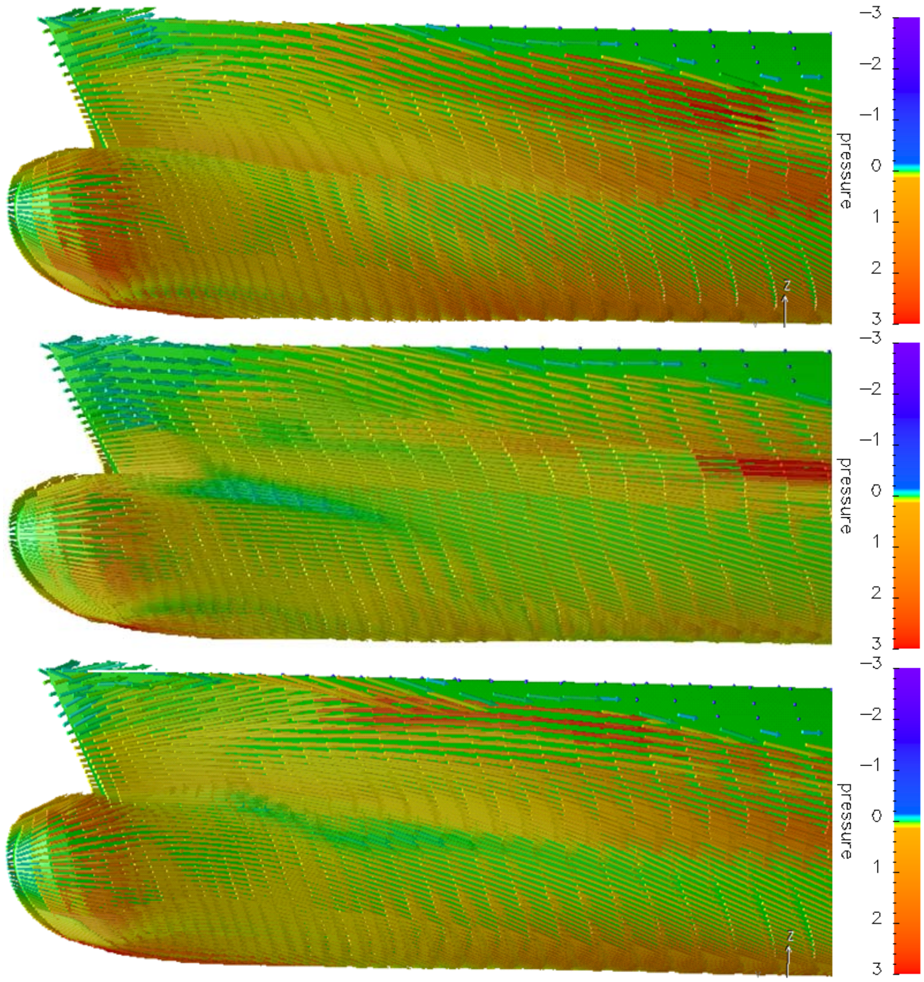


Figure 9. Velocity vector on KCS in oblique wave with heave and pitch motions for initial instance, wave crest and wave trough at FP of the ship

Figure 9 shows the time sequence visualization of velocity vector relative to the hull with ship motions in the bow flare section on KCS in oblique wave with heave and pitch free conditions. No separation of velocity vector near the design water line like head wave in Figure 5 occur in this condition when the ship is on the wave crest. However, when the ship is on the wave trough, the velocity vector before the flare section is going upward towards bow region and after that it is nearly parallel to the flow direction. It is also noticed that the inclination of velocity vector for oblique wave is low when comparing with head wave in Figure 5.

Figures 10 and 11 show the comparison of time history of heave and pitch motions for KCS in oblique wave with HP; and oblique wave with HPR free conditions. In the figures, there are almost no differences in the amplitude of motions and encounter frequencies.

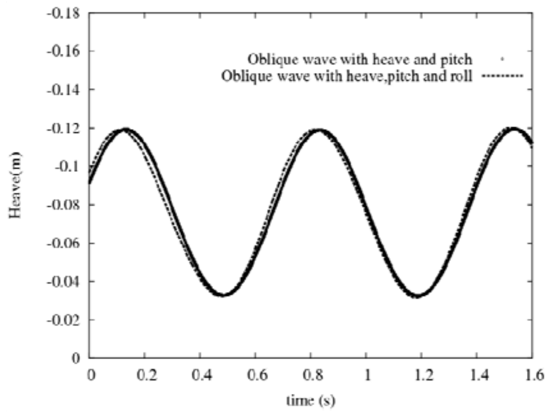


Figure 10. Time history of heave motions

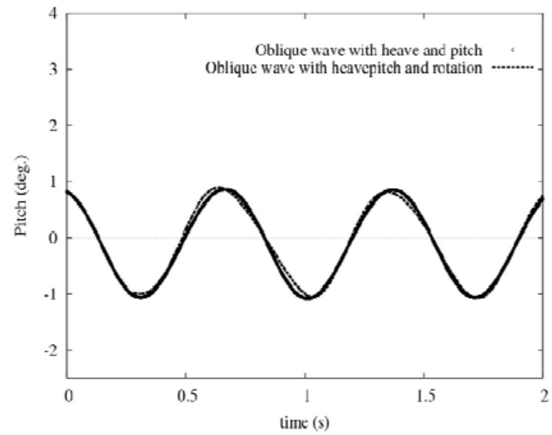


Figure 11. Time history of pitch motion

Figure 12 shows the time sequence visualization of velocity vector relative to the hull with ship motions in the bow flare section on KCS in oblique wave with heave, pitch and roll free conditions. No significant differences occur in the velocity vector for KCS on oblique wave with HP (Figure 9) and oblique wave with HPR (Figure 12).

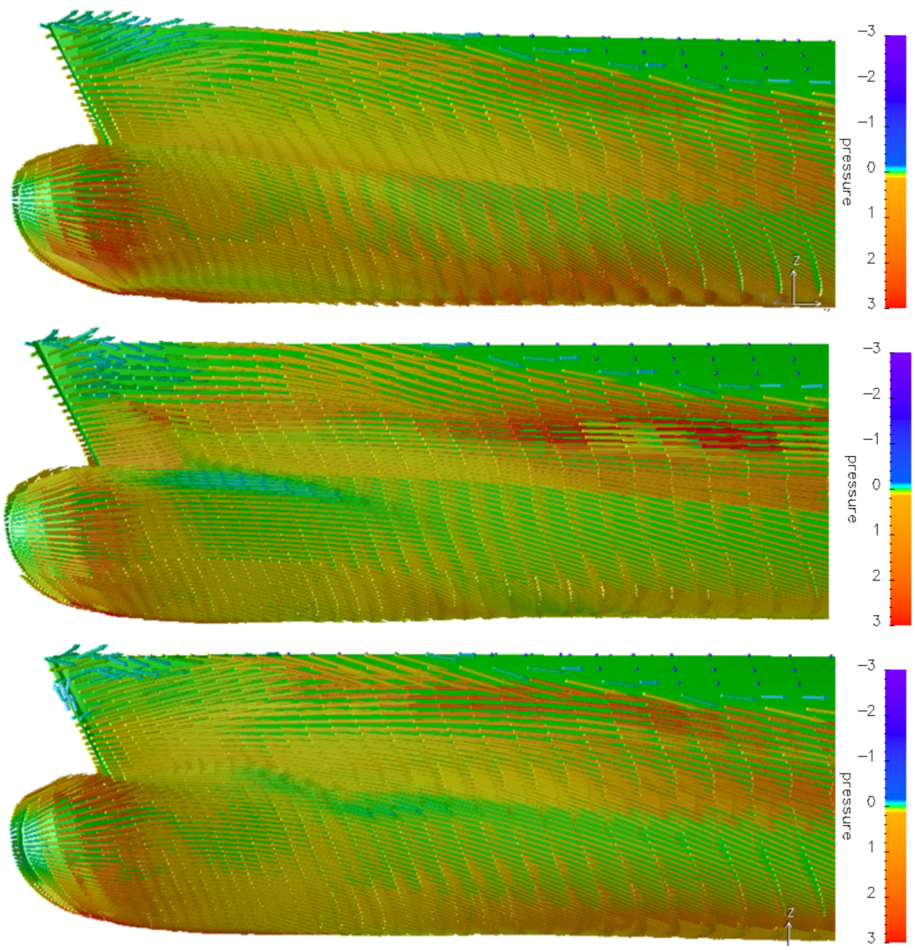


Figure 12. Velocity vector on KCS in oblique wave with heave, pitch and roll motions for initial instance, wave crest and wave trough at FP of the ship

In present numerical simulation, pressure is non-dimensionalized by density and free stream velocity. The non-dimensional pressure values of the cases for the present analysis are given in Table 4.

Table 4. Non-dimensional pressure value

Model	Condition	Value
KCS	Oblique wave with HP	0.00088
	Oblique wave with HPR	0.00094
	Head wave with HP	0.00158
SR108	Head wave with HP	0.00211

It is seen from Table 4 that increasing the degrees of freedom reduces the pressure and in head wave with heave and pitch free conditions, SR108 has the higher pressure than KCS.

6. CONCLUSIONS

A computational fluid dynamics technique, called WISDAM-X and visualization technique has been presented for investigating the slamming phenomena on the bow region of two container ship models. The degree of accuracy of ship motions with experimental results is satisfactory and the visualization technique describes which kinds of ships motions would be included and specific region of bow to be considered for analysis of ship slamming. In future, detailed analysis of flow particulars and prediction of loads due to slamming in the specific bow region that is indentified by the present study will be carried out.

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