Journal of Ship Technology, Vol. 6, No.2, July 2010, pp 58-72

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Experimental Investigation of Characteristics of Dynamics of Ship to Ship Collision

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ABSTRACT

This paper investigates the characteristics of dynamics of ship to ship collisions. Model experiments were conducted using two ship models of similar size. The models are a 2.38 m tanker as the struck ship and a 2.25 m container ship as the striking ship. The parameters considered for the experiments include the speed of the striking ship, angle between the ships and the point of collision at the struck ship. Data collected are the amplitude of rolling, pitching and yawing motion of the struck ship. Dynamic characteristics of the striking ship model are observed. The experimental results for yaw are also compared with the numerical simulation results. The outcome of the research shows that when two ships collide with one another ship, they experience significant yawing motion risking dangerous ports and canals accidents. It is also found that collision angle and speed of the striking ship play a vital role for the dynamic characteristics of the struck ship.

***Keywords**: Collision, Dynamics, Yaw Motion, Roll motion, Capsize*

1. INTRODUCTION

Collision dynamics are the dynamic motions that a ship experience when it collides. The amplitude of motions may greatly increase during ship collision which heavily affect and compromise the stability of the ship. At some point during the collision the persons and properties aboard the ship may be thrown overboard and the ship may capsize. In a collision in ports or canals, there is also the probability for the ship to collide other objects near it. This may extend the damages and losses not only on the ship but also on to the ports, canals and other ships.

It is important to study the characteristics of dynamics of ships during collision. By investigating them, the behaviour of the ship during and after collision can be observed and analyzed. By doing so, prediction and anticipation can be done on the dynamics characteristics of the ship. These characteristics can be incorporated in the design process towards designing a ship. This is necessary in order to prevent extensive loss of lives and properties during ship collision.

2. LITERATURE REVIEW

In October 1959, V.U. Minorsky [1] related the energy dissipated in a collision event to the volume of damaged structure. The objective of his work was to predict the conditions under which the nuclear material compartment aboard a ship would remain intact after collision to suggest what structural strength should be built into the hull of a nuclear ship outboard of the reactor plant so that it can sustain the collision impact.

Between 1962 and 1976, a number of model tests for ship to ship collision were carried out by investigators. In Italy, 24 model tests were conducted to examine the efficiency of different types of side structures towards various types of striking ships. These models were based on actual existing ships with scales ranging from 1:5 to 1:10. Striking bow was launched along an inclined path towards side structure model mounted on a carriage. The carriage was immersed in the water tank and was free to move along the path and wings were attached on both sides to provide the effect of surrounding water. Similar tests were carried out in Germany Woisin, 1979 [2] with the bow being launched from an inclined railway. The scale for the 12 models ranged from 1:7.5 to 1:12.

Research was carried out from 1991 to 1997 in Japan to develop a method to predict structural failure of a tanker focusing on two aspects, the dynamic process of structural damage caused by collisions or grounding and the resulting process of structural oil spill and/or water ingress through damaged hull. A series of full-scale ship collision experiments were later carried out in the Netherlands jointly with Japan using two 80 meters long inland waterways tankers. In November 1997, Germany, the Netherlands and Japan jointly carried out a test in the Netherlands using two 1500 tonnes tankers colliding with each other. The striking bow was a relatively hard bulb and the test section was installed at the middle of the struck ship. Several authors have been given detailed reviews on these experiments, for example, Amdahl [3], Jones [4], Ellina and Valsgard [5], Samuaelides and Frieze [6] and Pedersen et al. [7].

A full-scale dynamic collision test of a 40,000 dead weight tanker was carried out by Qvist et al. [8]. A 2.75 ton rigid ball was used to simulate a striking bow, which was dropped from a height of 5 meters simulating a striking velocity of 20 knots. A series of similar tests were also carried out in Japan between 1992 and 1996 on the models of large oil tankers for simulating side collision. In 1999 Zhang [9] developed a mathematical model for ship collision. The procedures of his analysis were divided into two parts, the external dynamics and internal mechanics of the ship. By combining both procedures, he analyzed a number of examples of full scale ship collision. He also developed a method relating the absorbed energy and the volume of destroyed material. His research took into account the structural arrangement of the ship, material properties and the damages mode which overcame a major drawback in Minorsky's method.

In 2008, Islam et al. [10] developed a mathematical model for ship to ship collision. The model was fundamentally divided into two parts, model for before and after collision. For the first part, a model was derived to determine the possibility of a collision, determining the location of collision and identification of the contact points on the ships. The authors then developed a mathematical model in order to study the kinetic energy losses, collision forces and dynamic responses of ship collision with respect to different variables that included the ship speed, angle and point of striking, coefficient of restitution and added mass for sway force and others. In the model, expressions for collision forces were derived based on changes in linear momentum. The collision force was then incorporated into the equation of motion. The authors calculated the dynamic responses of ship for different collision scenarios.

Tabri et al. [11, 12] in 2008 published a paper on analytical modelling of ship collision based on fullscale experiments. They developed a theoretical model that enabled them to predict the consequences of ship to ship collision where large forces arise due to the sloshing in ship ballast tanks. They considered the inertia forces of the moving bodies, the effects of the surrounding water, the elastic bending of the hull girder of the struck ship, the elasticity of the deformed ship structures and the sloshing effects in partially filled ballast tanks for the model. Internal mechanics, presenting the collision force as a function of penetration, was obtained from experiments. The model was validated with two full-scale collision experiments, one with a significant sloshing effect and the other without it.

There are numerous other researches done regarding the topic of ship collision. However, for the exception of Islam et. al [10], most of these researches and tests were interested in the structural damage of the ships after collision. The prime objectives of the researchers were to investigate the structural performance of the ship with respect to providing watertight integrity and safeguarding the passenger, cargo and other properties. So far, none had tried to emphasize the importance of the dynamics behaviour of the ship during collision. This is the reason why this research is carried out, to investigate the characteristics of dynamics of ship to ship collision.

3. SHIP COLLISION MODEL EXPERIMENTS

3.1 Models Particulars and Preparation

The particulars of the ships and models are given in Table 1. The models have a common scale of 100. The struck ship is a tanker, designated Ship A. It is placed in the towing tank with the strut attached to a platform. The gyrometer is attached at the centre of gravity of the model and connected

Table 1: Ship and model particulars at a scale of 1:100				
Particulars	**Ship A (struck)**	**Ship B (striking)**	**Model A**	**Model B**
Length Between Perpendiculars, LBP (m)	238.00	225.00	2.38	2.25
Breadth, B (m)	37.1	36.00	0.37	0.36
Draft, T (m)	10.00	14.00	0.10	0.14
Displacement, Δ (kg)	65,040,000.00	61,880,000.00	65.04	61.88

to the computer to read and record the experiment data. Specifications of the Gyrometer are given in Table 2.

The striking ship colliding into Ship A is represented by a containership, designated Ship B. It is a single screw self propelled model equipped with a battery powered DC motor with speed controller. The ship is not equipped with a speed logging device. A speed test was conducted to determine the range of speeds of the containership by measuring the time taken for the ship to traverse a 10m distance in the towing tank.

3.2 Experimental Parameters

Earlier studies by Islam et al. [10] and Awal [13] indicate that the parameters that impose the most influence on the characteristics of the dynamics of ship to ship collision include the speed of collision, angle between the two ships, collision point on the struck ship along with the draught and loading condition of both ships. The experimental variables are given in Table 3.

Table 2: Specifications of 3DM-GX1 Gyrometer	
Parameters	**Specifications**
Orientation Range (Pitch, Roll and Yaw)	±90, ±180, ±180
Sensor Range	Gyros ±300°/sec FS
Static Accuracy	±0.5°
Dynamic Accuracy	±2° rms
Repeatability	±2°
Resolution	2°

For this experiment the parameters considered are:

(i) Collision Speed

The selected collision speeds, for this experiment are 0.07, 0.14 and 0.21 m/s, equivalent to 1.36, 2.72 and 4.08 knots at Ship B in scale of 100. These speeds are selected because the collision is assumed to occur in a port area. Furthermore, the operator/pilot/master/captain of the striking ship will try to reduce the speed as much as possible before collision. Therefore, the striking ship cannot move at high speed. The struck ship however, is assumed to be stationary in harbour.

(ii) Collision Angle and Collision Point

The collision angles selected are 90° and 45°. Three collision points were selected which are L/4 fwd of amidship, amidship and L/4, aft of amidship of the struck ship. They are selected because they represented 3 different ranges of position along the length of the ship which are forward, middle and aft.

3.3 Experimental Procedures

(a) Model A is placed across the towing tank.

(b) Model B is placed 10 meter from the struck ship as shown in the Figure 1.

(c) The DC motor is started and Model B is propelled at the required speed.

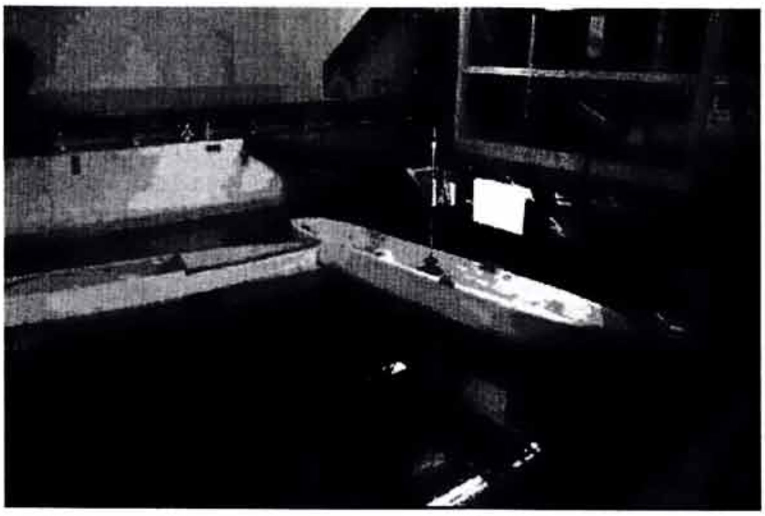
(d) The DC motor is immediately stopped after collision and the data read by the gyrometer are recorded.

(e) Data recording process is stopped when the motion of the struck ship becomes constant or stopped.

Table 3: Experimental Variables			
	Parameters		
	Collision Speed		
Run No	Prototype, knots	Collision Angle (degree)	Collision Point
1	1.36	90	L/4 fwd
2			Midship
3			L/4 aft
4		45	L/4 fwd
5			Midship
6			L/4 aft
7	2.7	90	L/4 fwd
8			Midship
9			L/4 aft
10		45	L/4 fwd
11			Midship
12			L/4 aft
13	4.08	90	L/4 fwd
14			Midship
15			L/4 aft
16		45	L/4 fwd
17			Midship
18			L/4 aft

4. VALIDATION

The results obtained from experiment for yaw are compared with the simulation results. The simulation code is developed based on Islam et al. [10] and Awal [13]. It is seen from these Figures (Figure 2 to Figure 5) that the trend or nature of the curves are similar, actual results vary. These variations may be due to slightly different conditions during experiment and simulation. For safety purpose, a strut was used to hold Model A and also to avoid the gyrometer cable to be detached from the model. On the other hand, although the hydrodynamic coefficients from experimental results are used in the simulation program, coupling effects were not considered. These are may be the reasons for deviation of the results between experimental and simulation results. The better agreement is obtained for hitting at 45 degree for both the hitting positions. The deviation of results for hitting at 90 degree may be due to use the strut.



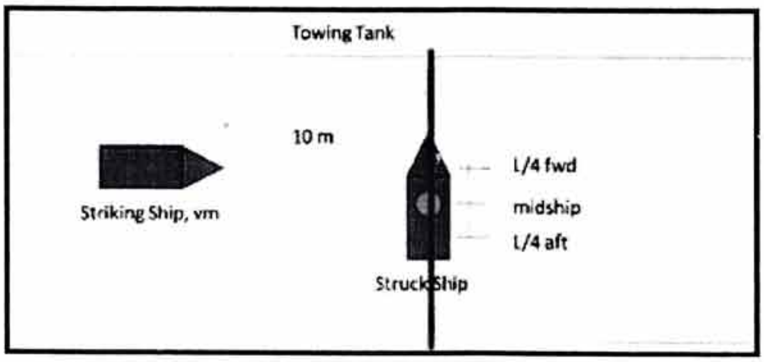


Fig. 1: Experimental Setup and an experimental shot

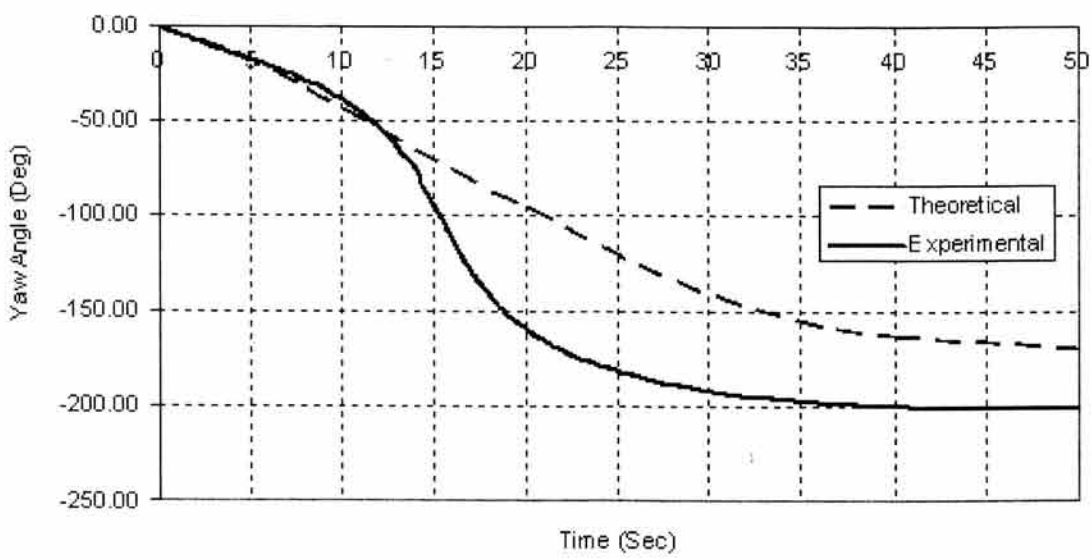


Fig. 2: Comparison of yaw motion between experimental results and simulation results (hitting position at L/4 fwd of amidship and at an angle 90 degree, speed 1 knot)

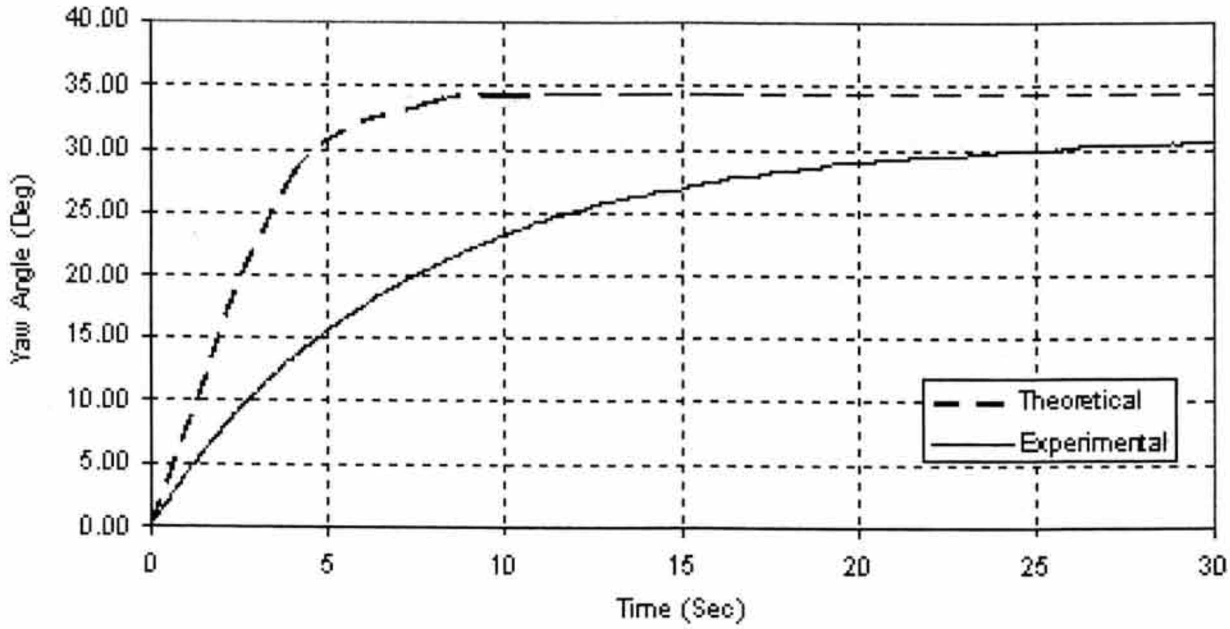


Fig. 3: Comparison of yaw motion between experimental results and simulation results (hitting position at L/4 aft of amidship and at an angle 90 degree, speed 1 knot) -45.00

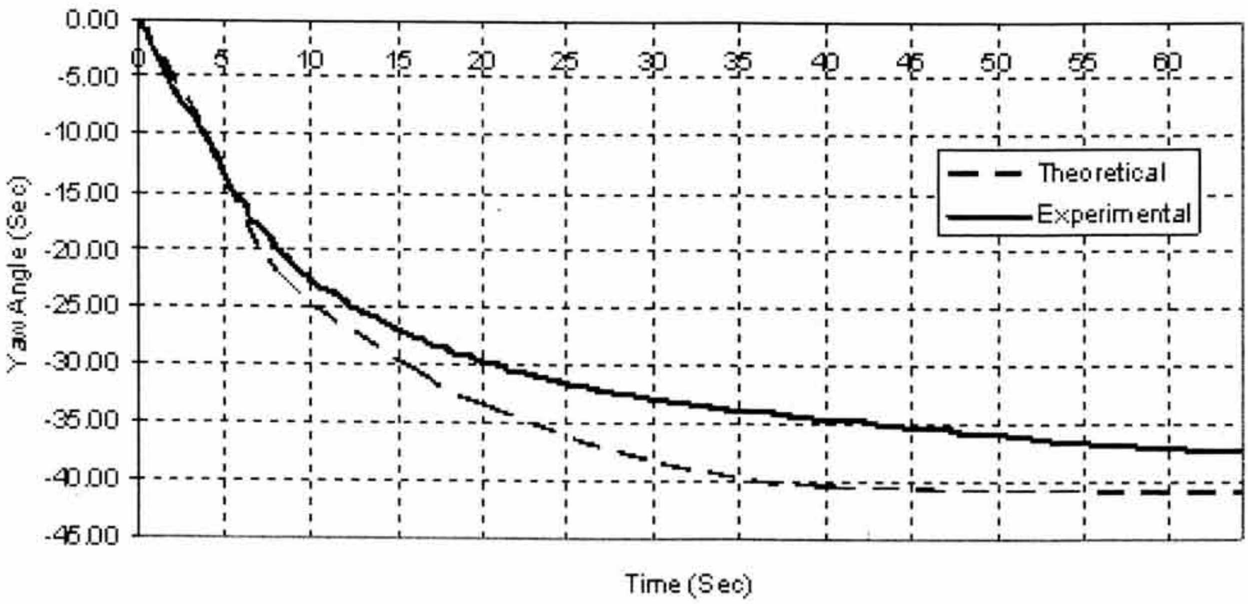


Fig. 4: Comparison of yaw motion between experimental results and simulation results (hitting position at L/4 aft of amidship and at an angle 45 degree, speed 1 knot)

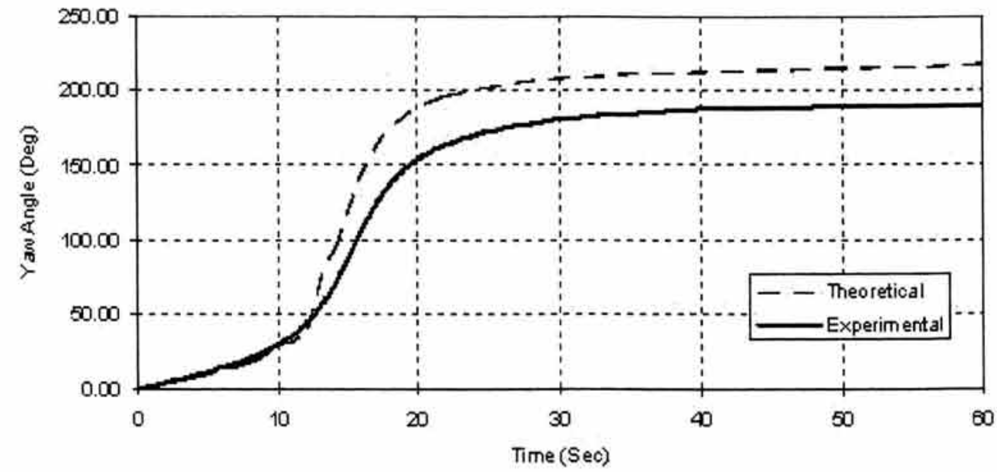
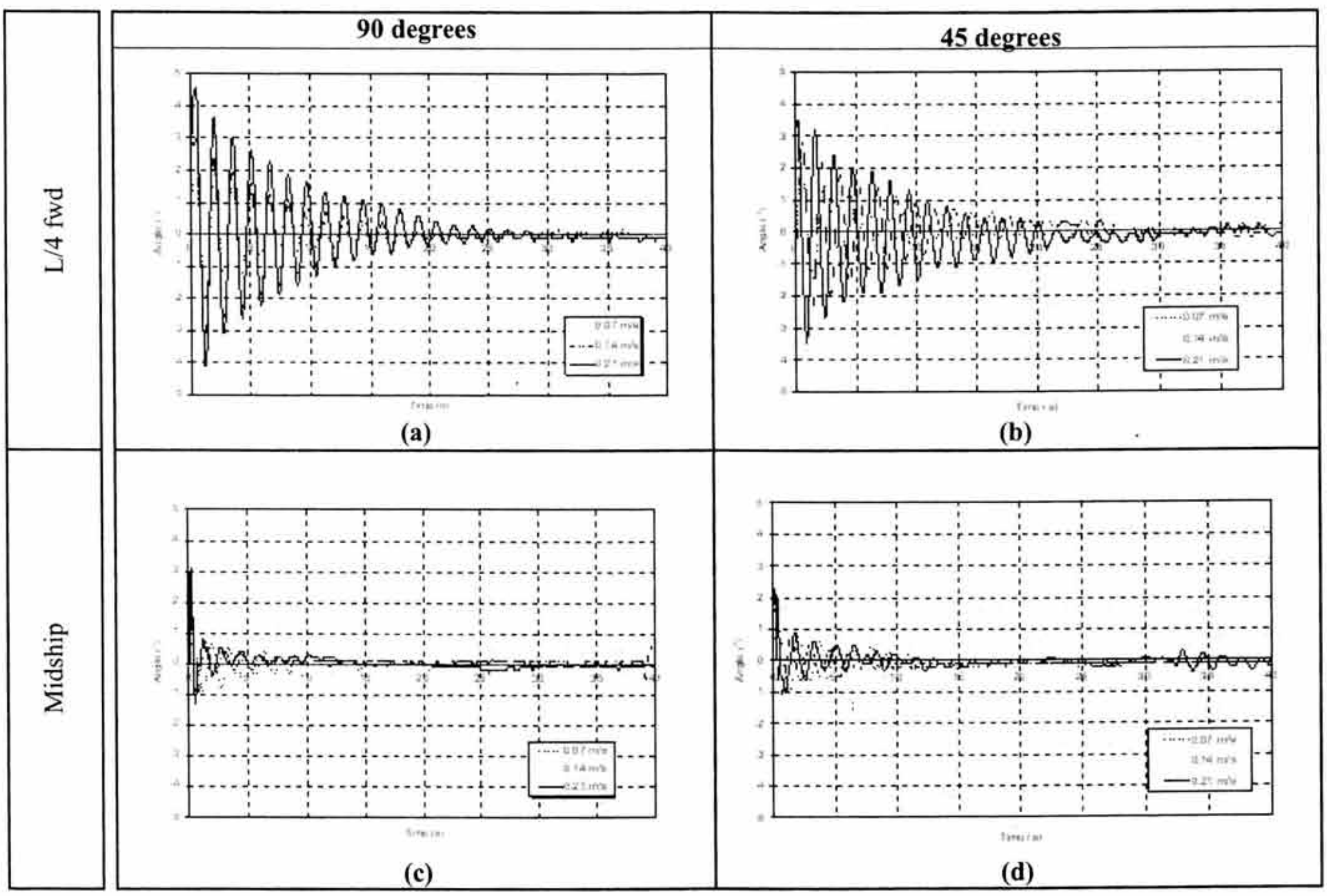


Fig. 5: Comparison of yaw motion between experimental results and simulation results (hitting position at L/4 aft of amidship and at an angle 45 degree, speed 1 knot)

5. RESULTS AND DISCUSSIONS

Results from the experiment are given in Figures 6 to 13 and described in the following sections. The figures show the behaviour of Model A after it was struck by Model B.

Case 1 : Collision Point L/4 fwd of amidship, Collision Angle 90° It is seen from Figure 6 (a), the highest roll angle achieved at the highest collision speed is 4.6°, which is quite small. The model took around 30 seconds to regain stability.



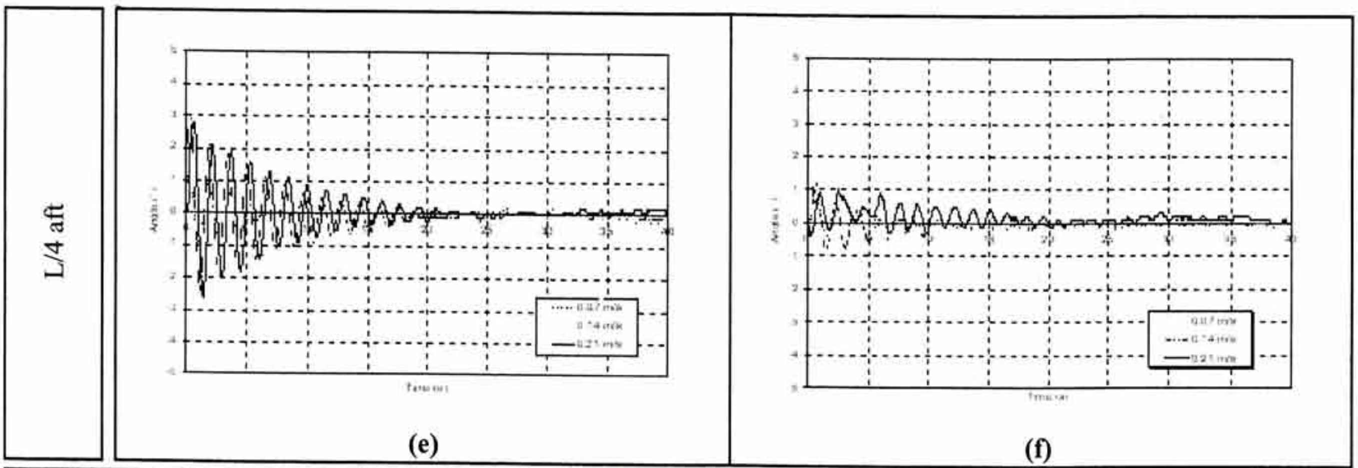


Fig. 6: Roll Motion of Model A after Collision in various conditions

The collision causes Model A to spin uncontrollably (Figure 7(a)). At the highest collision speed, the model rotated to 222 degrees in 40 seconds. This can be dangerous as a spinning ship especially in a canal or in a port area may hit other ships or structures nearby and extend the damage and loss of ship collision. The negative sign indicates the counter-clockwise spinning of the model.

Case 2 : Collision Point amidship, Collision Angle 90°

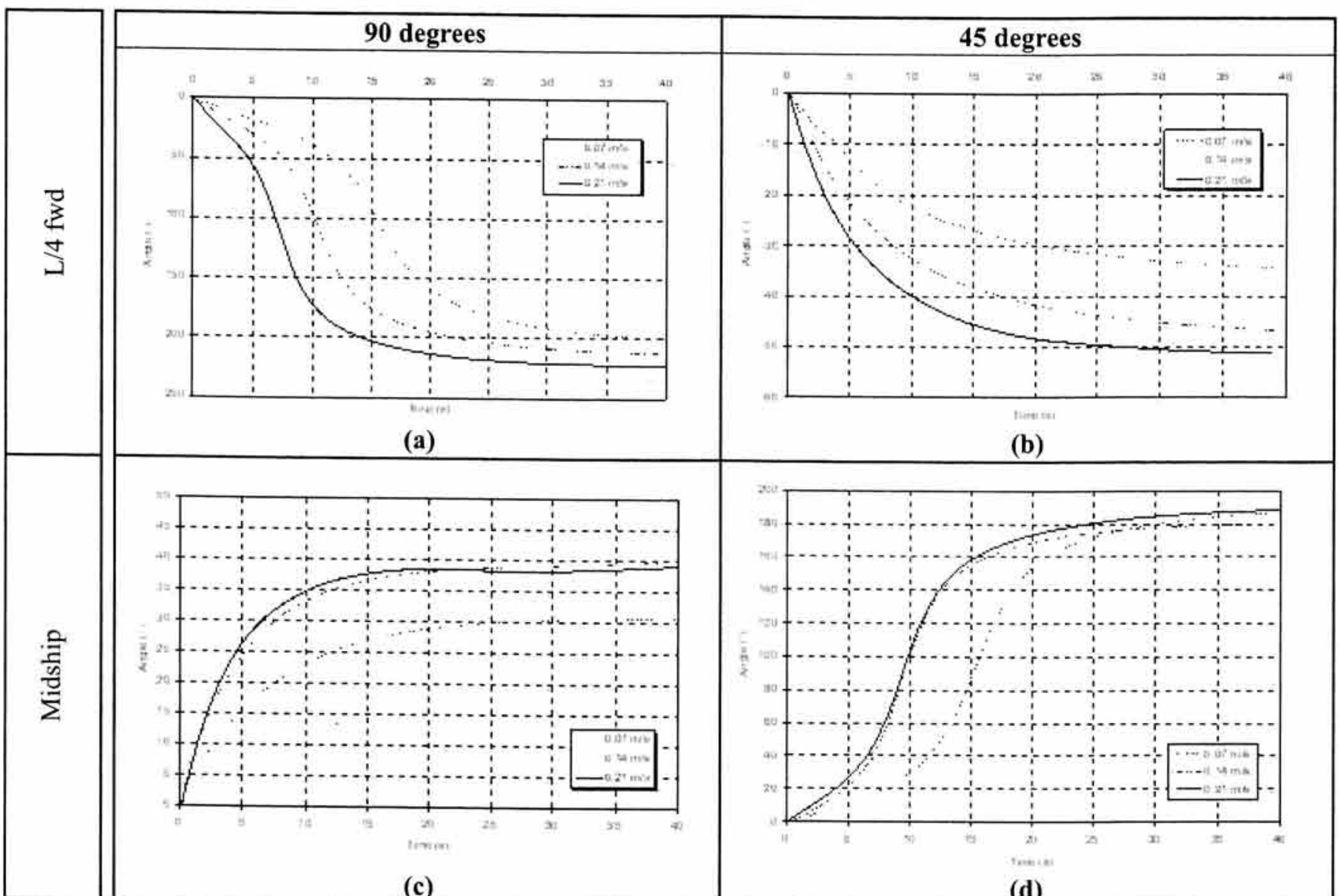


Fig. 7: Rotation of Model A after Collision in Various Conditions

Except for the initial jolt for collisions at 0.14 ms^{-1} and 0.21 ms^{-1}, the rolling motion (Figure 6(c)) is almost similar for all three speeds.

This may have happened because the strut that towed the model absorbed most of the impact from the collision therefore making the roll effect less pronounced. For collision at amidship with collision speed 0.21 ms^{-1}, the rolling motion took about 15 seconds to damp, half the duration taken by collision at L/4 fwd of amidship at the same speed.

Case 3 : Collision Point L/4 aft of amidship, Collision Angle 90°

The Figure 6(e) shows that rolling amplitude is smallest at the lowest speed. However, for the other two speeds, the rolling amplitude is almost similar. Compared to collision at L/4 fwd of amidship, for corresponding speed the amplitude is about 1° smaller and it took around 5 seconds less to damp. This may have happened due to the difference between the shapes of both parts. The fuller shape of the aft side of the model made it possible for it to absorb more impact from the collision compared to the forward side hence the smaller rolling amplitude.

The Figure 7(c) shows that the amplitude of yawing motion of the model increased as the collision speed increased. Positive sign indicates that the model spun clock-wise. The amplitude of yawing motion at collision speed 0.21 ms^{-1} intersected with 0.14 ms^{-1} because at the former speed the model experienced second collision with the striking ship model while turning clockwise. This caused the model to turn the other way before turning back again. Maximum yawing amplitude is also smaller compared to collision at L/4 fwd of amidship for corresponding speed, probably due to the difference between the shapes of both sides.

Case 4 : Collision Point L/4 fwd of amidship, Collision Angle 45°

The pattern in the Figure 6(b) is similar to collision at the same point with angle 90°. However, the rolling amplitude is around 1° smaller for each corresponding speed. As discussed before, the amplitude of the motion increases as the collision speed increases. Time taken by the model to dampen is about 5 to 10 seconds less than by collision at the same point with angle 90° at corresponding speeds.

According to the Figure 7(b), the model turned more than 45° durin0g collision with speeds 0.14 ms^{-1} and 0.21 ms^{-1} in about 30 seconds. If the striking ship model managed to stay on its course after collision, the models might have collided again, this time side by side. Although the second collision did not occur in this experiment, in reality this may happen and cause further damages for both ships. The second collision also might send both ships the other way and risking them to hit other surrounding objects.

Case 5 : Collision Point amidship, Collision Angle 45°

Except for the initial jolt for collision at 0.14 ms^{-1} and 0.21 ms^{-1}, the amplitude of rolling motion is almost similar for all three speeds (Figure 6(a)). For collision at 0.07 ms^{-1}, the model did not jolt as much probably because the second impact was not as big. Rolling motion is lighter compared to previous cases probably because the strut absorbed most of the impact of the collision.

Case 6 : Collision Point L/4 aft of amidship, Collision Angle 45°

The amplitude of rolling motion (Figure 6(f)) for all three speeds is very small and almost similar. After five seconds, at each speed the model jolted due to the second collision. After 27 seconds, the rolling motion for collision with speed 0.14 ms^{-1} increased a little due to heavy impact of the third collision.

The pattern shown in Figure 7(d) is almost similar to collision at L/4 fwd of amidship with angle 90° but in this case the model turned clockwise. For collision at 0.14 ms^{-1}, the line intersected because of the subsequent collision that dampened its yawing motion. The model made a big turn, around 180° in less than half a minute. As previously discussed, this may bring more damages to both ships and any objects close to them.

6. SUMMARY OF RESULTS

(i) Maximum Amplitude of Motions: Collision Angle 90°

Except for collision at L/4 aft of amidship with speed 0.14 ms^{-1}, Figure 8 shows that for each speed, rolling amplitude increases as the collision speed increases and the collision point approaches the forward part of the struck ship model. This may have happened due to the difference among the shapes along the length of the model. The fuller shape at the aft part of the model made it heavier therefore more absorbent of the impact of the collision preventing heavy rolling motion from occurring.

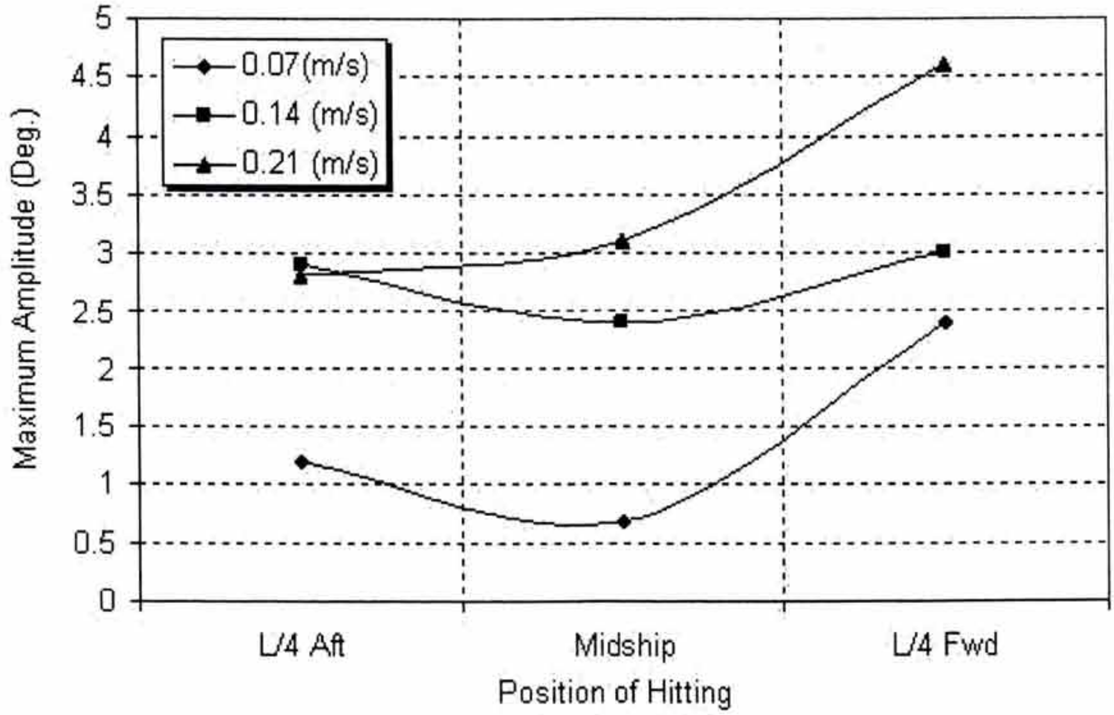


Fig. 8 : Roll motion at various speed

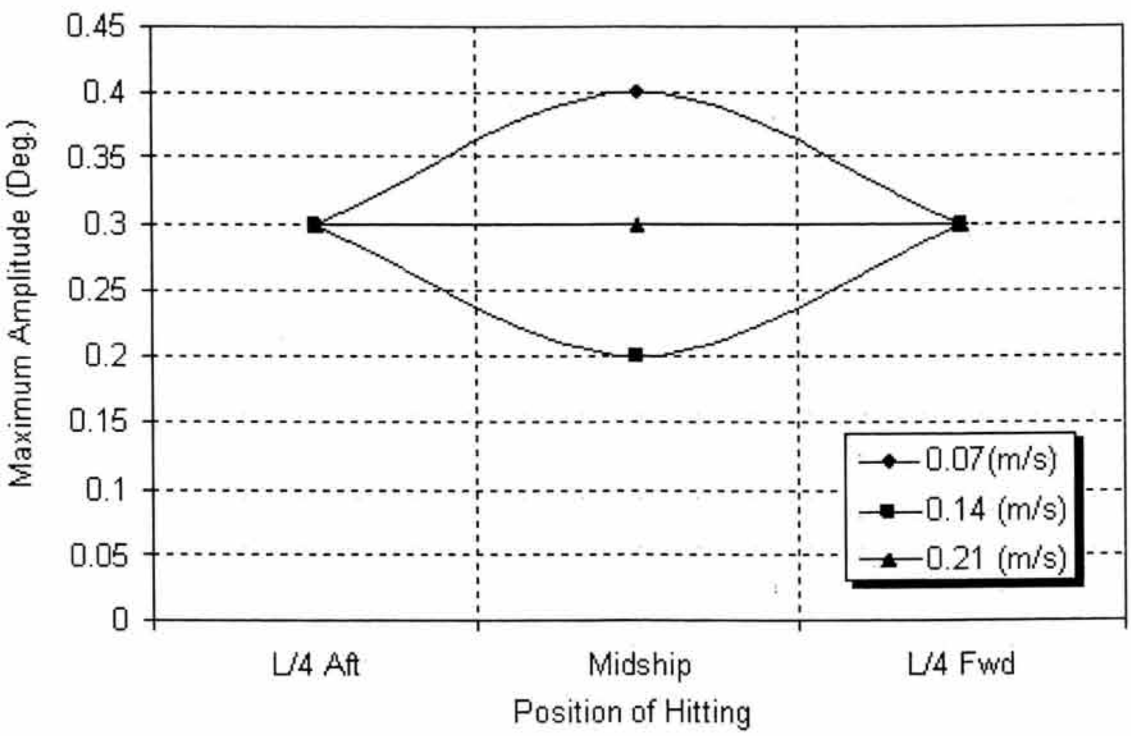


Fig. 9: Pitch motion at various speeds

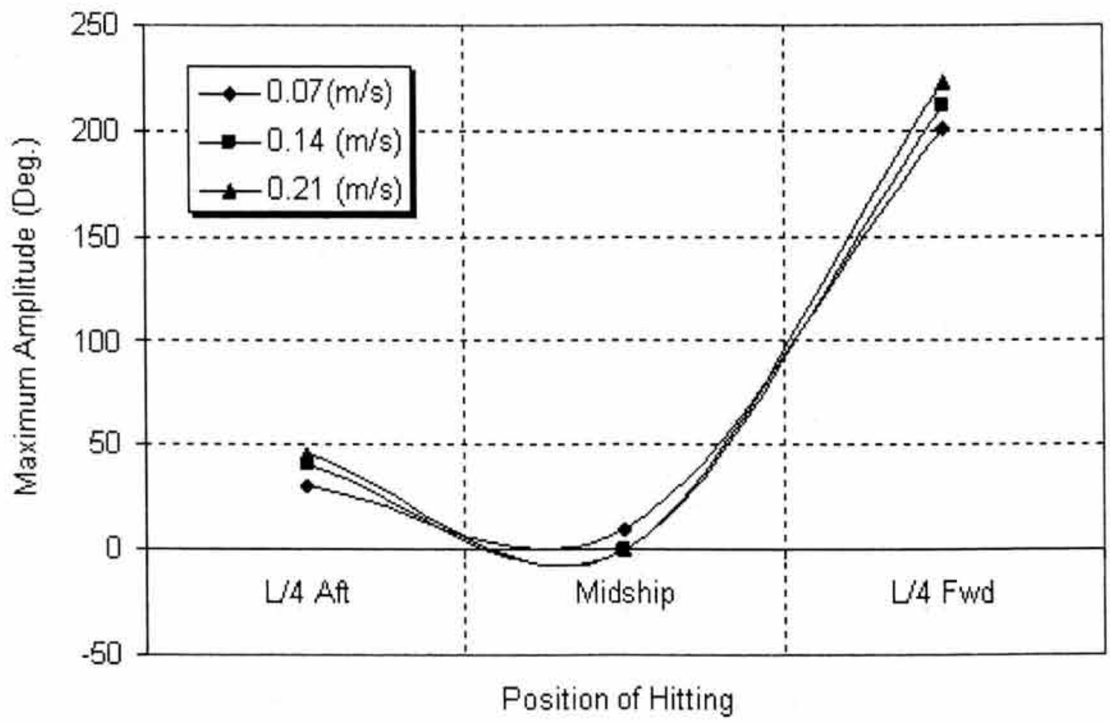


Fig. 10 : Yaw motion at various speed

For pitching motion (Figure 9), the largest amplitude occurred when the collision point is at L/4 fwd of amidship confirming the influence of the model shape on the dynamics characterisitic of ship collision. As with rolling motion, the maximum amplitude occurred at the highest speed. This confirms that higher collision speed will produce bigger impact during collision. It is observed from Figure 10 that the highest amplitude of yawing motion is also occurred at the forward part of the model and at the highest speed. The amplitude decreases during collision at amidship because the strut absorbed the impact of the collision. Therefore the amplitude of this motion is the smallest and very minimal compared to collision at the aft and forward part of the model.

Also, the difference in the amplitude of yawing motion of the model between collisions at aft and forward parts is very big due to the difference between the model shapes and forms along its length.

(ii) Maximum Amplitude of Motions: Collision Angle 45°

As with collision with angle 45°, the maximum amplitude of rolling motion for this case also occurred at the highest speed (Figure 11). The amplitude also increases as the collision points shifted from aft to forward part of the model. However, compared to collision with angle 90°, the rolling amplitude for this case is around 1° to 2° smaller for the same speeds and collision points. The largest rolling amplitude is 3.5°. The maximum amplitude for all cases of collision should be referred to the GZ curve of the model to assess its stability during the collision.

Figure 12 shows that the amplitude of pitching motion change a little or did not change at all as the collision speed increased. The amplitude did not differ much as the collision points shift from aft to forward part of the model. For the same collision points and speeds, the maximum amplitude is 0.1° to 0.2° bigger than collision with angle 90°. The maximum amplitude is only 0.5°. This shows that longitudinal stability of the model was the least compromised during collision at any speed or angle.

The maximum amplitude of yawing motion for all speeds occurred at collision point L/4 aft of amidship (Figure 13). Except for the case of collision with speed 0.14 ms-1, yawing amplitude decreases rapidly as the collision point

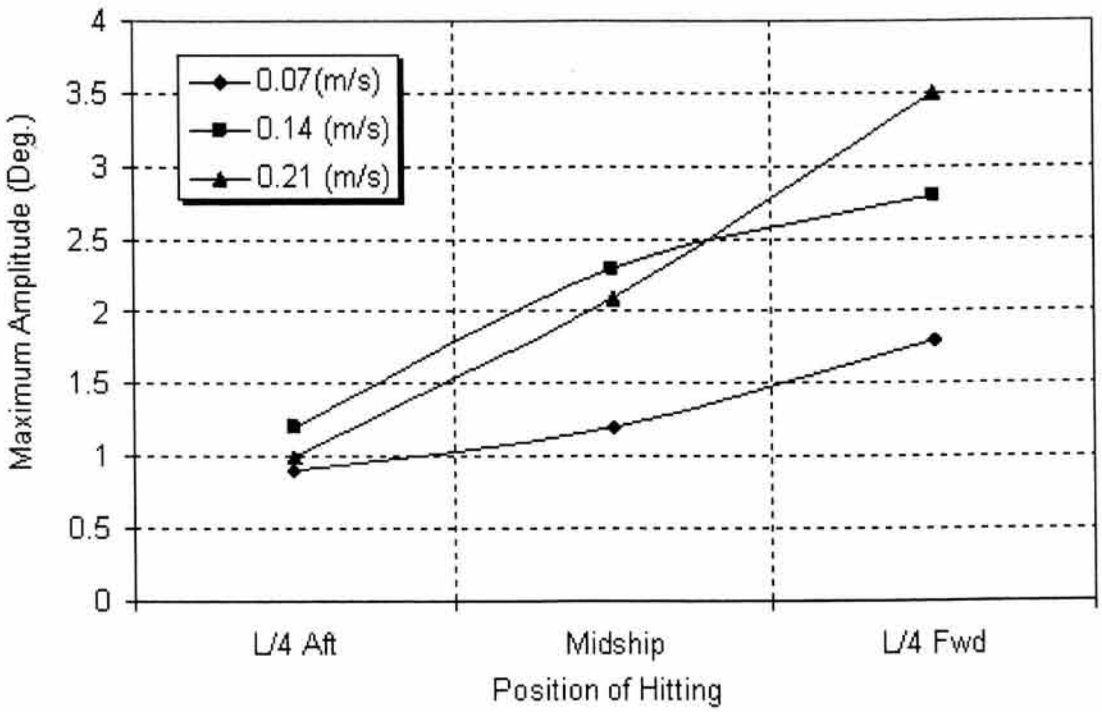


Fig. 11 : Roll motion at various speed

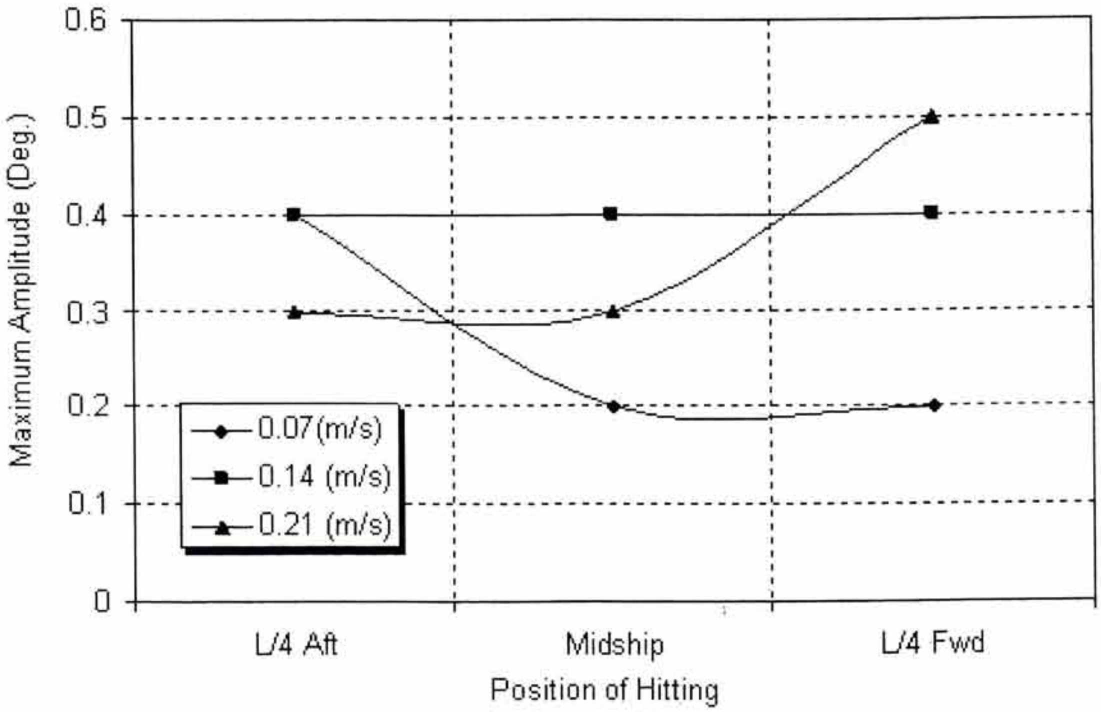


Fig. 12 : Pitch motion at various speed hit at 45 degree.

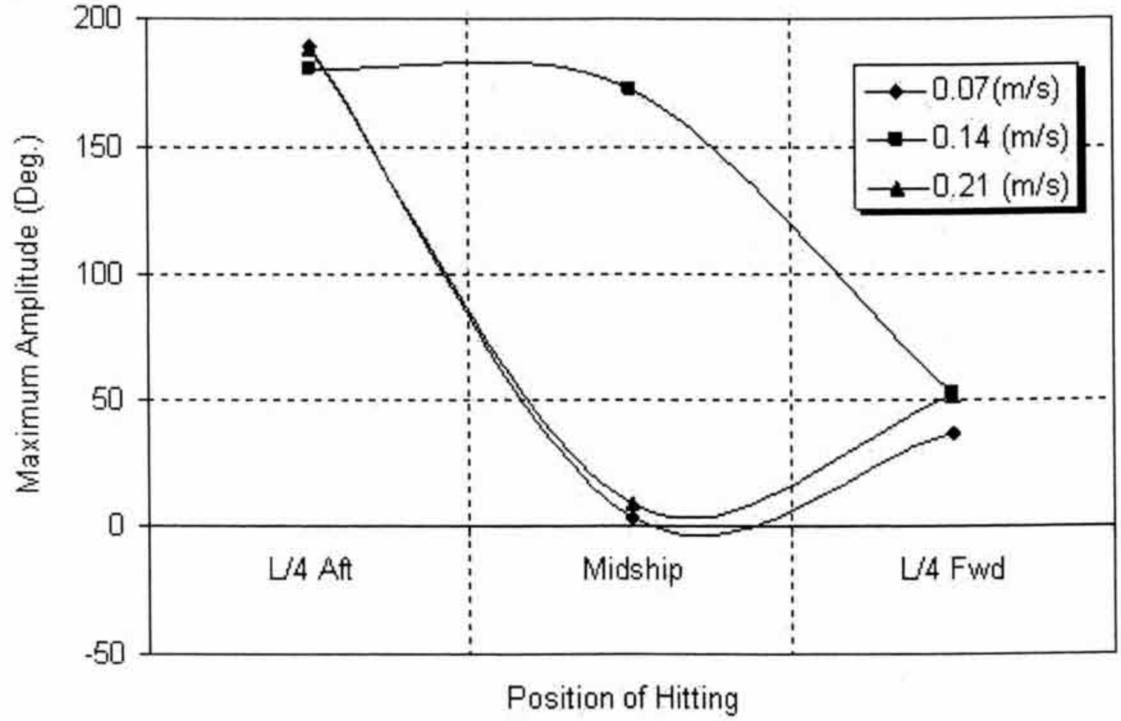


Fig. 13 : Yaw motion at various speed hit at 45 degrees.

approaches amidship and increases again as it approaches the forward part of the model. This may have happened because the strut absorbed the impact of the collision. At the same speed, yawing amplitude for collision at L/4 fwd of amidship is about the same as collision at L/4 aft of amidship with angle 90°. The difference of amplitude between the aft and forward part of the model also may have happened due to the difference between their shapes.

7. CONCLUSIONS

In general, for any collision point, collision at L/4 fwd of amidship with angle 90° and collision at L/4 aft of amidship with angle 45° will cause the struck ship to turn with very large angle. This is potentially harmful as it may cause the ship to hit any objects surrounding them. In the present study, an attempt has been made to compare the experimental results with simulation results. From the study, it is seen that the experimental results are comparable to simulation results although no fender material has been used and for which the coefficient of restitution was higher (about 1.0) and because of that the struck ship experiences significant yaw and roll motions. These motions can be reduced using lower coefficient of restitution fender material. So in future, the authors are recommending extending this research work with different kinds of material as fender.

8. ACKNOWLEDGEMENT

The authors acknowledge the support and cooperation of the Marine Technology Center, Universiti Teknologi Malaysia (UTM) for conducting the experiment.

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