

# Experimental Investigation of Wave-Induced Motions of an Obliquely Moving Ship

Faizul Amri Adnan<sup>1</sup> Hironori Yasukawa<sup>2</sup>

<sup>1</sup>Ph.D, E-mail: faizul@fkm.utm.my

<sup>2</sup>Professor, E-mail: yasukawa@naoe.hiroshima-u.ac.jp

**Correspondence Address:**

Faculty of Mechanical Engineering,  
Universiti Teknologi Malaysia, 81310 UTM Skudai, Johor Bahru, Johor, Malaysia.  
Tel No.:+607-5534569

## Abstract

The lateral drift appears due to the effects of wind forces and/or wave drifting forces for a ship sailing in actual sea. The effects of wind forces and / or wave drifting forces in views of lateral drift for ship moving with certain forward speed have not been studied previously. Therefore, it is important to investigate experimentally the influence of the lateral drift to ship seakeeping performance. In this paper experimental results for the ship motions and drift forces on a container ship SR108 obliquely moving in waves are presented. An outline of the model test are also presented in this paper. It is shown that sway, yaw and roll motions are significantly occurred even in head waves. In general it is also found that the ship motions and drift forces are influenced mostly by hull drift motion.

**Key words:** wave-induced motions, drift forces, lateral drift

## 1 Introduction

Waves and/or winds continually cause ships to deviate from its course and track, and the helmsman may find it necessary to take corrective actions[1]. For ships moving with a certain drift angle, considerable influence on ship motion appears[2]. It is therefore important to capture the influence of lateral drift on seakeeping performance to come up with a rational treatment for ship design. Recently, Ali et al. pointed out the necessity to take the steady drift motion into account in view of ship motion theory for accurate prediction of roll motion of a ship in heavy seas[3]. However, no attempt to take the steady drift motion in view of all ship motion modes includes surge into consideration.

In this study, we measured the ship motions and drift forces for an obliquely moving ship in regular head and beam waves as shown in Fig.1 This paper describes the outline of the model test and the results for a ship with lateral drift.

## 2 Outline of Model Test

Model tests were carried out in the seakeeping & maneuvering basin, Nagasaki R & D centre, Mitsubishi Heavy Industries. The size of the tank is 190m in length, 30m in width and 3.5m in water depth. SR108 container ship was selected for the test. Fig.2 shows the body plan. The principal dimensions of the ship and experimental conditions are given in Table 1. The scale ratio is 1:50. The metacentric height was set to be the standard condition and check by the inclining test. A roll decay test was also were carried out to obtain the natural roll period,  $T_\phi$ .

The experiments were carried out at a several drift angles,  $\beta_0$  (-10.0, -5.0, 0.0, 5.0 deg) while the ship model towed by X-Y carriage at forward speed  $U^*=0.879\text{m/s}$  which is equivalent to Froude number,  $F_n=0.15$ . Wave height  $H_W$  used in this experiment is 70mm ( $H_W/L_{pp} = 0.02$ ). In order to produce the lateral drift condition, the model

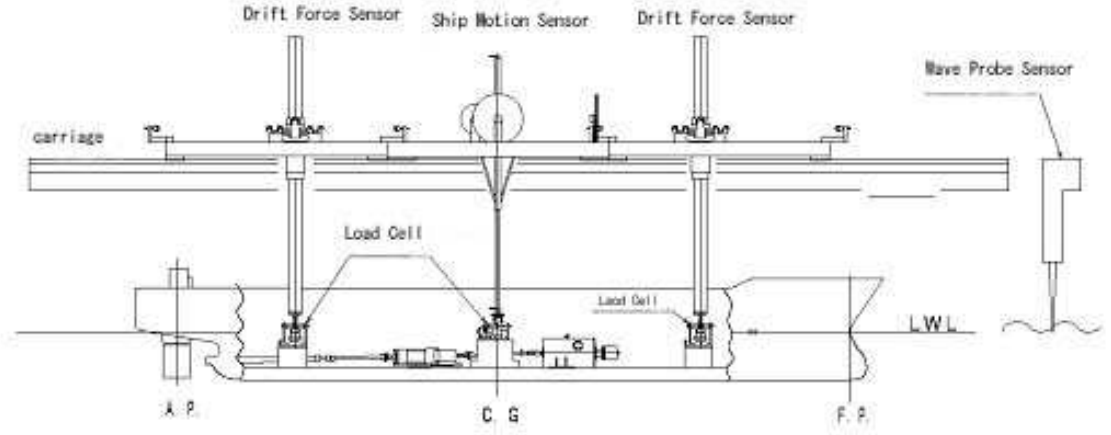


Figure 4: Arrangement of measuring equipment and dynamometer

Table 1: Principal dimensions of SR108 and experimental conditions

	Model	Ship
Ship length $L_{pp}$	3.500m	175.0m
Breadth $B$	0.508m	25.40m
Draft $d$	0.190m	9.50m
Displacement $\nabla$	193.57kg	24,801ton
$x_G/L$	-0.05089m	-2.545m
$KM$	0.21	10.5m
$GM$	0.0250m	1.250m
Roll period $T_\phi$	2.430s	17.2s
$k_{yy}/L_{pp}$	0.272	0.272

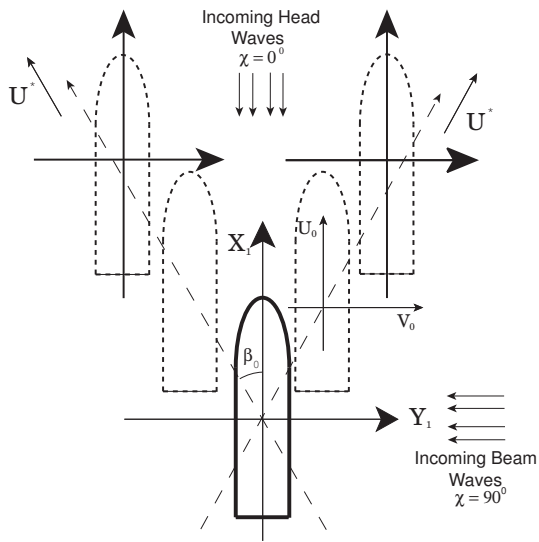


Figure 1: Schematic diagram of experiment

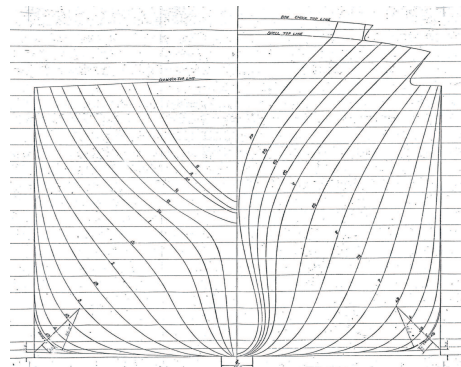


Figure 2: Body plan of SR108 container ship

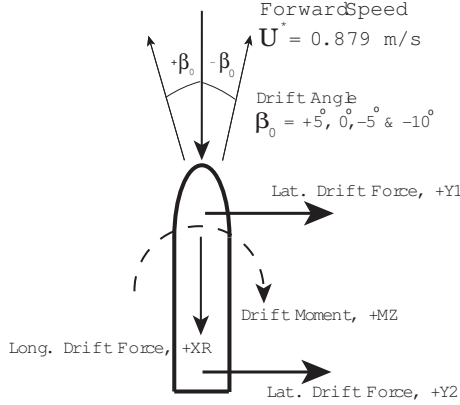


Figure 3: Definition of drift angle and drift force components in the measurement system

is towed in transverse direction by a towing carriage at a constant lateral drift velocity with respect to the magnitude of drift angles used in each experiment. The definitions of this experiment are shown in Fig.3. Ship motion amplitudes and steady drift forces are measured in regular head and beam wave cases ( $\chi = 0^\circ, 90^\circ$ ). The experiments were conducted at wave lengths  $\lambda/L_{pp}=0.5, 0.7, 1.0, 1.2$  &  $1.5$ .

Fig.4 shows the arrangement of measuring equipment and dynamometer on board of ship model SR108. The ship model is attach to X-Y towing carriage. In experiments, we defined three types of steady drift forces, namely longitudinal steady drift forces  $X_R$ , lateral steady drift forces  $Y_D(Y_1 + Y_2/2)$  and steady yawing moment  $M_Z$ . Experiments of drift forces were conducted in waves and still water. Measurements of these steady drift forces and yawing moment were carried out by putting the load cell at the specified position on board of a ship model. The steady drift forces and moment are obtain by subtracting the experiment results in waves with the results obtained in still water as follows:

$$X_R \text{ in waves} - X_R \text{ in still water} = X_R \quad (1)$$

$$Y_D \text{ in waves} - Y_D \text{ in still water} = Y_D \quad (2)$$

$$M_Z \text{ in waves} - M_Z \text{ in still water} = M_Z \quad (3)$$

### 3 Results of Ship Motions

All ship motions amplitudes  $|\xi_j|$  ( $j = 1, 2, \dots, 6$ ) with  $j=1$  to 6 are refer to surge, sway, heave, roll, pitch and yaw respectively. All these ship motion amplitudes are non-dimensionalised as follows:

$$|\xi'_j| = \frac{|\xi_j|}{A} \quad (j = 1, 2, 3), \quad |\xi'_j| = \frac{|\xi_j|}{A\nu} \quad (j = 4, 5, 6) \quad (4)$$

where  $A$  and  $\nu$  denotes wave amplitude and wave number respectively. Graphs of the resulting ship motions are plotted as a function of  $\lambda/L$ .

Fig.5 shows that heave and pitch motion are slightly increase in short waves and significantly reduced in long waves region by increasing the drift angle and/or lateral drift velocity. However, the changes of amplitudes of motion from hull without drift motion to hull with drift motion case are not so remarkable.

The experiment result shows that an obliquely moving ship in regular head waves is not confined only to vertical motions, the sway, yaw and roll motions also occurred significantly. The amplitudes of sway, yaw and roll motion in head waves are consistently increase by increasing the drift motion. These results confirmed that the lateral drift velocity gave a significant impact to all ship motions modes including surge motion.

Fig.6 shows that the amplitude of heave and pitch for ship with lateral drift in beam waves was slightly increased by increasing the drift angle and/or lateral drift velocity. However these tendencies are not very clear. Fig.6 also shows that the heave and pitch motion are reduced significantly if the direction of the drift angle is changes. This result shows the dependency of heave and pitch motion on the direction of drift angle for beam waves case.

The amplitudes of sway, yaw, and roll motion with and without lateral drift effects in regular beam waves ( $\chi=90.0\text{deg}$ ) are also shown in fig.6. The amplitudes of motions are found consistently decreased by increasing the drift angle and were slightly increased by decreasing the drift angle (for positive values of drift angle). These experimental results confirmed that the lateral drift has a significant impact on reducing the ship motion in beam waves. The dependency of the lateral motions (sway, roll & yaw) on the direction of drift angle is very clear.

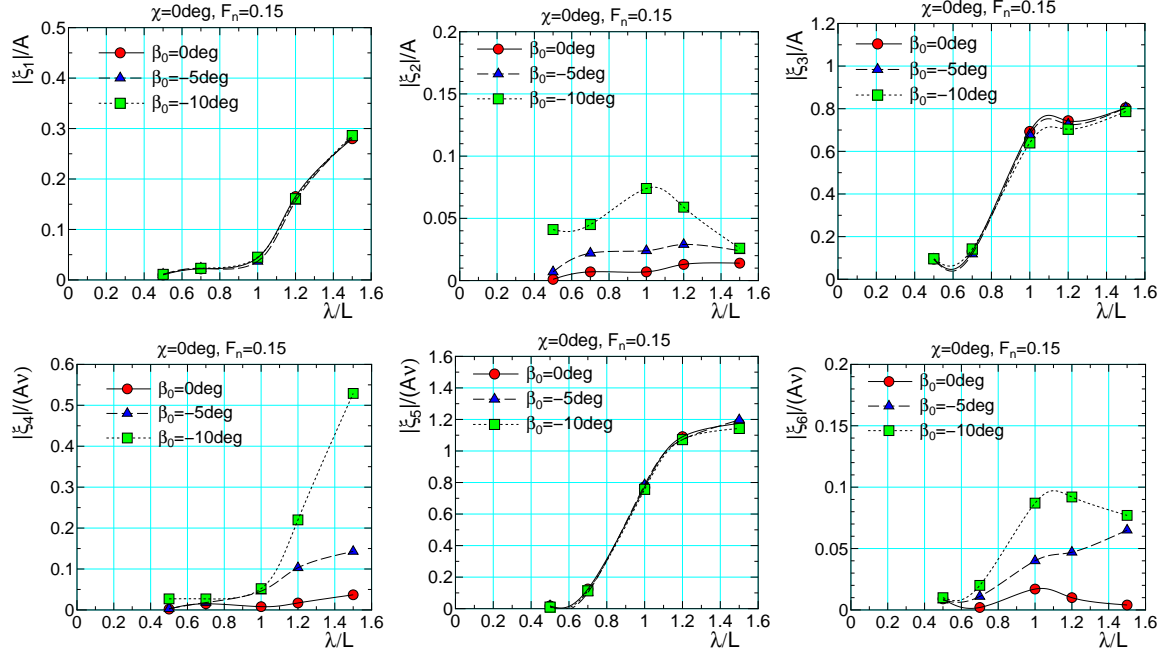


Figure 5: Effect of hull drift angle on ship motions in regular head waves

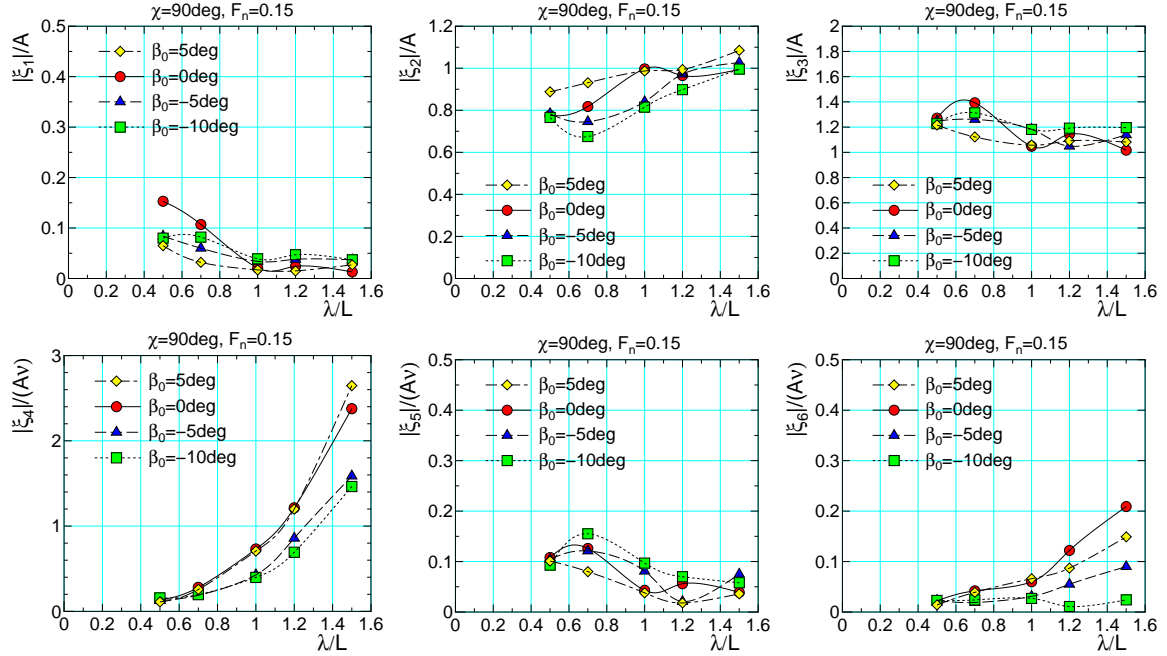


Figure 6: Effect of hull drift angle on ship motions in regular beam waves

## 4 Results of Drift Forces

Experimental results of the wave drift forces for a ship obliquely moving in waves are presented. In views of a ship obliquely moving in waves, there exist a kind of steady drift forces, due to the waves and hull drifting velocity. Steady drift forces and yawing moment denoted by  $X_R$ ,  $Y_D$  and  $M_Z$  are non-dimensionalised as follows:

$$X'_R, Y'_D = \frac{X_R, Y_D}{\rho g A^2 (B^2 L_{pp})}, \quad M'_Z = \frac{M_Z}{\rho g A^2 B^2} \quad (5)$$

with  $\rho$  is density of water and  $g$  is acceleration gravity. Graphs of the resulting steady drift forces are plotted as a function of  $\lambda/L$ .

Fig.7 shows the results of  $X'_R$ ,  $Y'_D$  &  $M'_Z$  in head waves case. This figure shows that the steady drift forces and moment for hull without drift angle are confined only to longitudinal steady drift force  $X'_R$ . The lateral steady drift force  $Y'_D$  and steady yawing moment  $M'_Z$  are seemed very closed to zero at zero drift angle case.

Furthermore, experimental results of  $X'_R$ ,  $Y'_D$  &  $M'_Z$  at non-zero drift angle (fig.7) shows that the steady drift forces and yawing moment was significantly occurred especially at  $\lambda/L = 1.0$ .

Fig.8 shows the results of  $X'_R$ ,  $Y'_D$  &  $M'_Z$  in beam waves case. This figure shows that the steady drift forces and yawing moment was significantly occurred even at zero drift angle case. The experimental result at non-zero drift angle in beam waves shows that the steady drift forces and yawing moment are significantly decreased by increase the drift angle. This figure also shows that the direction of the specified drift angles have a significant impact to the  $X'_R$ ,  $Y'_D$  &  $M'_Z$ . The lateral steady drift force  $Y'_D$  & yawing moment  $M'_Z$  were slightly increased by changes the direction of drift angle.

## 5 Concluding Remarks

The experimental results of a ship obliquely moving in waves were presented. It was found that the wave-induced motion for a ship obliquely moving in head waves are not confined only to vertical motion, but lateral motion namely sway, yaw, and roll motion are also occurred. Furthermore, we also found that the vertical motion in head waves and

lateral motion in beam waves are slightly decreased by increasing the lateral drift and/or drift angle.

The effects of drift angle on steady drift forces were investigated. The lateral drift force  $Y'_D$  and yawing moment  $M'_Z$  occurred significantly even in head waves case. The longitudinal drift forces  $X'_R$  is found increase in head waves when increasing the lateral drift. However, this drift force  $X'_R$  is looks decreased in beam waves.

According to the experimental results, it is confirmed that in order to obtain accurate prediction of ship motions; namely surge, sway, heave, roll, pitch and yaw, there is a necessity to take the hull lateral drift velocity into consideration.

It is important to note here that, the theoretical approach for a ship obliquely moving in waves has been formulated recently in the framework of a strip method by Faizul A.A & H. Yasukawa (2007)[5]. A comparison between experiment results by means of model test reported in this paper and computed results based on established theory will be performed soon.

## Acknowledgments

This research work has been supported by the Fundamental Research Developing Association for Shipbuilding and Offshore (REDAS), and by the Universiti Teknologi Malaysia. The authors are grateful for their support. The authors also would like to express their appreciation to all staff of Mitsubishi R & D centre for their help and cooperation in conducting the experiment.

## References

- [1] Lloyd, A. R. J. M. (1998), Seakeeping: Ship Behaviour in Rough Weather, Gosport, Hampshire, UK, ISBN 0 9532634 0 1 (Revised edition).
- [2] Tanaka, Y. (2003), Economical Speed and Life Cycle Value of Ship, 4th JTTC Symp. on Ship Performance at Sea, Soc. Nav. Archit. Japan, pp.10-19 (in Japanese).
- [3] Ali, B., Katayama, T., Ikeda, Y.(2004), Roll Damping Characteristics of Fishing Boats With and Without Drift Motion, Int. Ship-build. Progr., 51, no.2/3, pp.237-250.

- [4] Winchers, J.E.W and Huijsmans, R. H. M. (1984) On the Low Frequency Hydrodynamic Damping Force Acting on Offshore Moored Vessel, Offshore Technology Conference, Houston, Paper 4813.
- [5] Faizul A. A. and H. Yasukawa (2007), Strip Method for a Laterally Drifting Ship in Waves, J. Marine Science and Technology, Springer-Verlag, Vol.12:139-149.

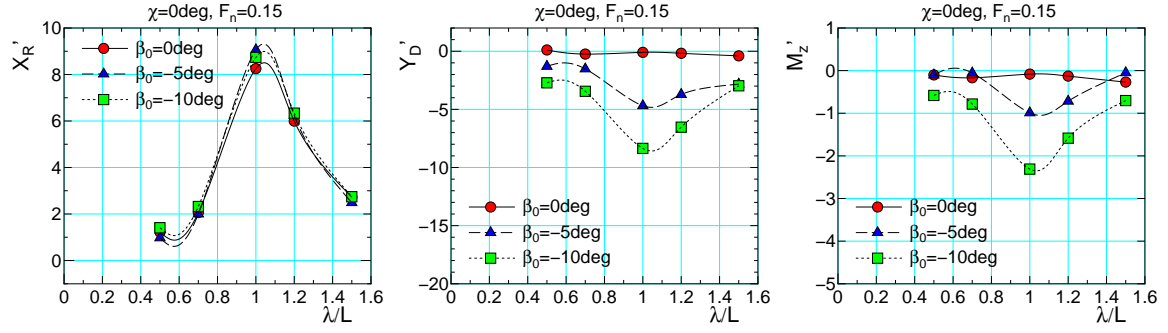


Figure 7: Effect of hull drift angles on wave drift forces in regular head waves

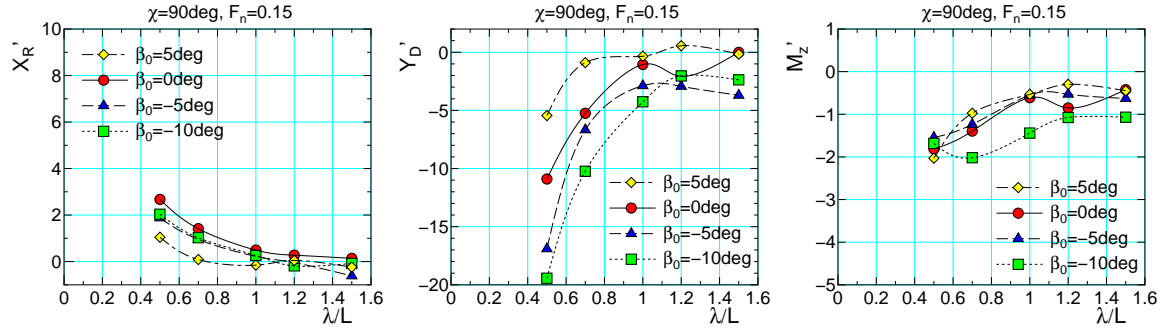


Figure 8: Effect of hull drift angles on wave drift forces in regular beam waves