

EMAIL KORESPONDENSI

[IJTech] Submission Acknowledgement: IJTech-3704

External

Inbox

dparoka@g.unhas.ac.id



Dr. Nyoman Suwartha <nsuwartha@eng.ui.ac.id>

Thu, Apr 14, 2016,
5:11 PM

to me

Dear Daeng Paroka,

Your submission entitled "PREDICTION OF SHIP TURNING MANEUVERING IN CONSTANT

WIND AND REGULAR WAVES" has been received by editorial board of International Journal of Technology (IJTech). The editorial board will evaluate and review the paper for consideration to be published.

You will be able to track the progress through the editorial process by logging in to the journal web site:

Manuscript URL:

<http://www.ijtech.eng.ui.ac.id/index.php/journal/author/submission/3704>

Username: dparoka

If you have any questions, please contact me. Thank you for considering this journal as a venue for your work.

Kind regards,

Dr. Nyoman Suwartha
International Journal of Technology (IJTech)
p-ISSN : 2086-9614
e-ISSN 2087-2100, <http://www.ijtech.eng.ui.ac.id>



ReplyForward

IJTech-07-140] Please Revised Based on Reviewer Comment

External

Inbox

dparoka@g.unhas.ac.id



IJTech <ijtech@eng.ui.ac.id>

Tue, Feb 28, 2017,
11:46 AM

to me, andi_haris, sa_tanri_kapal83

Dear Mr./Mrs. Daeng Paroka,

The editorial board is pleased to inform you that your paper entitled "PREDICTION OF SHIP TURNING MANEUVERING IN CONSTANT WIND AND REGULAR WAVES" has been reviewed by referee.

Please find in the attachment referee's comments, and please make a necessary revision based on the comments. Also please read the submission guidelines.

Any revision of the paper should be submitted to ijtech@eng.ui.ac.id no later than **March 7, 2017**.

It is compulsory to return the revise paper with response comment as attached.

Please state clearly the revision based on reviewer's comment.

We look forward to receiving your revised paper at your earliest convenience.

--

Kind regards,
Secretariat IJTech
International Journal of Technology (IJTech)
ISSN : 2086-9614
<http://www.ijtech.eng.ui.ac.id>

2 Attachments

[IJTech-07-140] Please Revised Based on Reviewer Comment

External

Inbox

dparoka@g.unhas.ac.id



IJTech <ijtech@eng.ui.ac.id>

Mon, Mar 27, 2017,
1:05 PM

to me, andi_haris, sa_tanri_kapal83

Dear Mr./Mrs. Daeng Paroka,

The editorial board is pleased to inform you that your paper entitled "PREDICTION OF SHIP TURNING MANEUVERING IN CONSTANT WIND AND REGULAR WAVES" has been reviewed by referee.

Please find in the attachment referee's comments, and please make a necessary revision based on the comments. Also please read the submission guidelines.

Any revision of the paper should be submitted to ijtech@eng.ui.ac.id no later than **April 2, 2017**.

It is compulsory to return the revised paper with response comment as attached.

Please state clearly the revision based on reviewer's comment.

We look forward to receiving your revised paper at your earliest convenience.

--

Kind regards,
Secretariat IJTech
International Journal of Technology (IJTech)
ISSN : 2086-9614
<http://www.ijtech.eng.ui.ac.id>

2 Attachments

[IJTech-07-140] Please resend the revised paper

External

Inbox

dparoka@g.unhas.ac.id



IJTech <ijtech@eng.ui.ac.id>

Thu, Mar 30,
2017, 2:33 PM

to me

Dear Mr./Mrs. Daeng Paroka,

We didn't receive your revised paper and please resend by replying this mail.
Thank you for your understanding and cooperation.

--

Kind regards,
Secretariat IJTech
International Journal of Technology (IJTech)
ISSN : 2086-9614
<http://www.ijtech.eng.ui.ac.id>

On 2017-03-30 09:58, dparoka@eng.unhas.ac.id wrote:

Dear the Editorial Board of IJTech,

Thank you very much for the reviewing process of our paper entitled "PREDICTION OF SHIP TURNING MANEUVERING IN CONSTANT WIND AND REGULAR WAVES". Herewith we send you the revised version following the reviewer recommendation as attachment files of this email.

With best regards

Daeng Paroka

[IJTech-07-140] Acknowledgement of Receiving 2nd Revised Paper

External

Inbox

dparoka@g.unhas.ac.id



IJTech <ijtech@eng.ui.ac.id>

Fri, Mar 31, 2017,
11:40 AM

to me

Dear Mr./Mrs. Daeng Paroka,

We confirmed that the editorial board has received your second revised paper. We appreciate your effort to refine your paper to meet the quality of IJTech publication standard. We will contact you again to inform the status of your manuscript. Thank you.

--

Kind regards,
Secretariat IJTech
International Journal of Technology (IJTech)
ISSN : 2086-9614
<http://www.ijtech.eng.ui.ac.id>

On 2017-03-30 15:57, dparoka@eng.unhas.ac.id wrote:

Dear the Editorial Board of IJTech,

I am sorry for the mistake sending email. We are trying to send the revised manuscript and also the reviewer comments and recommendation by this email. Thank you very much for your information.

With best regards

Daeng Paroka

[IJTech-07-140] Please Revised Based on Reviewer Comment

External

Inbox

dparoka@g.unhas.ac.id



IJTech <ijtech@eng.ui.ac.id>

Mon, Apr 10, 2017,
4:49 PM

to me, andi_haris, sa_tanri_kapal83

Dear Mr./Mrs. Daeng Paroka,

The editorial board is pleased to inform you that your paper entitled "PREDICTION OF SHIP TURNING MANEUVERING IN CONSTANT WIND AND REGULAR WAVES" has been reviewed by referee.

Please find in the attachment referee's comments, and please make a necessary revision based on the comments. Also please read the submission guidelines.

Any revision of the paper should be submitted to ijtech@eng.ui.ac.id no later than **April 14, 2017**.

It is compulsory to return the revise paper with response comment as attached.

Please state clearly the revision based on reviewer's comment.

We look forward to receiving your revised paper at your earliest convenience.

--

Kind regards,
Secretariat IJTech
International Journal of Technology (IJTech)
ISSN : 2086-9614
<http://www.ijtech.eng.ui.ac.id>

2 Attachments

[IJTech-07-140] Acknowledgement of Receiving 3rd Revised Paper

External

Inbox

dparoka@g.unhas.ac.id



IJTech <ijtech@eng.ui.ac.id>

Thu, Apr 13, 2017,
12:55 PM

to me

Dear Mr./Mrs. Daeng Paroka,

We confirmed that the editorial board has received your third revised paper. We appreciate your effort to refine your paper to meet the quality of IJTech publication standard. We will contact you again to inform the status of your manuscript. Thank you.

--

Kind regards,
Secretariat IJTech
International Journal of Technology (IJTech)
ISSN : 2086-9614
<http://www.ijtech.eng.ui.ac.id>

On 2017-04-13 10:48, dparoka@eng.unhas.ac.id wrote:

Dear Editor of IJTECH,

Thank you very much for reviewing of our paper in tittle "PREDICTION OF SHIP TURNING MANEUVERING IN CONSTANT WIND AND REGULAR WAVES". Some necessary revisions have been made and was written in the comments form. we state the revision with blue color in the manuscript. The revised paper as well as the comments form can be found in the files attachments of this email.

With best regards

Daeng Paroka

[IJTech-07-140] Acknowledgement of IJTech Acceptance Letter

External

Inbox

dparoka@g.unhas.ac.id



IJTech <ijtech@eng.ui.ac.id>

Thu, Apr 13, 2017,
3:02 PM

to me

Dear Mr./Mrs. Daeng Paroka,

On behalf of the Editorial Board, I am pleased to inform you that your paper entitled: "PREDICTION OF SHIP TURNING MANEUVERING IN CONSTANT WIND AND REGULAR WAVES" has been accepted to be published in International Journal of Technology (IJTech).

We will notify you again for the next process required toward publication. Thank you.

With warm regards,

Dr. Mohammed Ali Berawi
Editor-in-Chief
International Journal of Technology
ISSN : 2086-9614

[IJTech-07-140] Result of Line-editing of the Paper

External

Inbox

dparoka@g.unhas.ac.id



IJTech <ijtech@eng.ui.ac.id>

Mon, Apr 17, 2017,
10:44 AM

to me, andi_haris, sa_tanri_kapal83

Dear Mr./Mrs. Daeng Paroka,

We have conducted line editing to your paper as part of the publication process in IJTech. Enclosed, please find the comments from the line editor indicated by character in color beside black. We would like to ask you to complete the following:

1. Please make necessary revise of the paper accordingly to the line editor comments.
2. Please complete detail information for: name of author(s), and affiliation of each author(s). Please refer to Guideline for Author to write the affiliation section.

After the revision complete, please send it back to ijtech@eng.ui.ac.id or by reply this email, no later than **April 20, 2017**. We will proceed to the next step (Layouting, Final proof & Copyright) of the revised paper before printing.

We look forward to receiving your revised paper soon.

--

Kind regards,
Secretariat IJTech
International Journal of Technology (IJTech)
ISSN : 2086-9614
<http://www.ijtech.eng.ui.ac.id>

2 Attachments

[IJTech-07-140] Acknowledgement of Receipt of Your Line Editing Revised Manuscript

External

Inbox

dparoka@g.unhas.ac.id



IJTech <ijtech@eng.ui.ac.id>

Fri, Apr 21, 2017,
9:22 AM

to me

Dear Mr./Mrs. Daeng Paroka,

Herewith, we confirm that we have received your revised manuscript based on the line-editing comments. The editorial board will conduct last process of editing on your paper and preparation for publication. Soon, after the process finish, IJTech secretariat will send you email for the proof reading and copyright confirmation.

--

Kind regards,
Secretariat IJTech
International Journal of Technology (IJTech)
ISSN : 2086-9614
<http://www.ijtech.eng.ui.ac.id>

On 2017-04-20 18:24, dparoka@eng.unhas.ac.id wrote:

Dear the Editor of IJTech,

Thank you very much for editing of our manuscript. Herewith we send you the revised version based on Editor's recommendations. The explanations about the performed revision are indicated by blue color just below the comments from the editor. The name and affiliation of authors as well as the corresponding author was put just below the tittle following the guideline for author.

With best regards

Daeng Paroka

[IJTech-07-140] Final proof reading & copyright

External

Inbox

dparoka@g.unhas.ac.id



IJTech <ijtech@eng.ui.ac.id>

Fri, Apr 28, 2017,
1:50 PM

to me, andi_haris, sa_tanri_kapal83

Dear Mr./Mrs. Daeng Paroka,

The editorial boards delighted to inform you that your paper has been accepted to be published in IJTech next Volume 8 Issue 3, 2017. Congratulations!

We have carried out necessary layouting and editing of your manuscript. Prior to publication we need your final proof and copyright of the paper.

Enclosed please find the copyright form and the paper for a final check and please confirm that the article ready for printing.

Any confirmation of the final check should be submitted no later than **April 28, 2017**. Copyright form can be printed, signed, scanned and send by email to ijtech@eng.ui.ac.id.

On behalf of editorial boards, we want to express you and your collaborators our deep appreciation for your contribution to IJTech.

We look forward to receiving the copyright form and proofs at your earliest convenience.

With kind regards,
Nyoman Suwartha
Managing Editor
International Journal of Technology (IJTech)
ISSN : 2086-9614
<http://www.ijtech.eng.ui.ac.id>

2 Attachments

[IJTech] Acceptance Letter for Publication

External

Inbox

dparoka@g.unhas.ac.id



IJTech Secretariat <ijtech@eng.ui.ac.id>

Fri, Apr 28, 2017,
1:53 PM

to me

Dear Daeng Paroka,

The editorial board is delighted to inform you that your paper entitled "PREDICTION OF SHIP TURNING MANEUVERING IN CONSTANT WIND AND REGULAR WAVES" has been accepted to be published in the next issue of IJTech. Congratulation.

As the next stage, we will finalize the manuscript for typo, clarity,

grammar and formatting. We will notify you when the manuscript is ready.

On behalf of IJTech, we want to express you and your collaborators the Editorial Boards appreciation for your paper submission.

Regards,
IJTech Secretariat
ijtech@eng.ui.ac.id
International Journal of Technology (IJTech)
p-ISSN : 2086-9614
e-ISSN 2087-2100, <http://www.ijtech.eng.ui.ac.id>

[IJTech] Notification on publication

External

Inbox

dparoka@g.unhas.ac.id



IJTech Secretariat <ijtech@eng.ui.ac.id>

Fri, Apr 28, 2017,
1:56 PM

to me

Dear Daeng Paroka,

Your manuscript entitled "Prediction of Ship Turning Maneuvers in Constant Wind and Regular Waves" is scheduled to be published on IJTecth Vol 8, No 3 (2017). Congratlation.

Dr. Nyoman Suwartha
International Journal of Technology (IJTech)
p-ISSN : 2086-9614
e-ISSN 2087-2100, <http://www.ijtech.eng.ui.ac.id>

[IJTech-07-140] Acknowledgement of Receiving Final Proof & Copyright of The Paper

External

Inbox

dparoka@g.unhas.ac.id



IJTech <ijtech@eng.ui.ac.id>

Fri, Apr 28, 2017,
3:55 PM

to me, andi_haris, Sa_tanri

Dear Mr./Mrs. Daeng Paroka,

We confirmed that the editorial board has received your final proof and copyright of the paper. We appreciate your effort to refine your paper to meet the quality of IJTech publication standard and we already revise the final paper. Thank you.

--

Kind regards,
Secretariat IJTech
International Journal of Technology (IJTech)
ISSN : 2086-9614

On 2017-04-28 14:32, dparoka@eng.unhas.ac.id wrote:

Dear the Editor of IJTech,

Many thanks for the proof reading of our manuscript with publication schedule of Volume 8 Issue 3, 2017. we have proof reading with some comments shown with red box within the manuscript. We also attach the copyright statement in this email.

With best regards

Daeng Paroka

[Acknowledgement]: Your Article has been Published Online

External

Inbox

dparoka@g.unhas.ac.id



IJTech <ijtech@eng.ui.ac.id>

Tue, May 2, 2017,
11:22 AM

to me

Dear Mr./Mrs. Daeng Paroka,

Greetings from Depok!

On behalf of the Editorial Board, I am pleased to inform you that your article has been published online in the IJTech website Volume 8 Issue 3, April 2017. Please

visit: <http://www.ijtech.eng.ui.ac.id/old/index.php/journal/issue/view/34/showToc>

You can access and download the article for free of charge. The hardcopy version is being printed and will be delivered 1 copy for the corresponding author.

Thank you for your contribution to IJTech and looking forward to a good collaboration in the next future.

With kind regards,
Dr. Nyoman Suwartha
Managing Editor
International Journal of Technology
ISSN : 2086-9614



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Drafts

Sent

Junk

Trash

[IJTech] Submission ...Message 97 of 1171 

From **Dr. Nyoman Suwartha**
To **Daeng Paroka**
Date **2016-04-14 17:11**

Dear Daeng Paroka,

Your submission entitled "PREDICTION OF SHIP TURNING MANEUVERING IN CONSTANT WIND AND REGULAR WAVES" has been received by editorial board of International Journal of Technology (IJTech). The editorial board will evaluate and review the paper for consideration to be published.

You will be able to track the progress through the editorial process by logging in to the journal web site:

Manuscript URL:

<http://www.ijtech.eng.ui.ac.id/index.php/journal/author/submission/37>

Username: dparoka

If you have any questions, please contact me. Thank you for considering this journal as a venue for your work.

Kind regards,

Dr. Nyoman Suwartha
International Journal of Technology (IJTech)
p-ISSN : 2086-9614
e-ISSN 2087-2100, <http://www.ijtech.eng.ui.ac.id>

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Submission
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Journal Metrics
by Scopus 2013

Source Normalized
Impact per Paper (SNIP):
0.064

Impact per Publication
(IPP): 0.085

SCImago Journal Rank
(SJR): 0.123

[Home](#) > [User](#) > [Author](#) > [Submissions](#) > [#3704](#) > Summary

#3704 Summary

Title PREDICTION OF SHIP TURNING MANEUVERING IN CONSTANT WIND AND REGULAR WAVES

Abstract

A ship usually perform maneuvering under influence of external forces and moments such as wind, waves and current. Therefore, the maneuvering behaviour of ships under action of the external forces becomes important to understand. This paper discusses regarding turning maneuvering of an Indonesian ro-ro ferry under influence of combined constant wind and regular waves by using MMG model. The ship position relative to the wave through is added to the original MMG model in order to estimate the exciting forces and moment induced by waves. The results of numerical simulation show that effect of wave height on turning ability is more significant in small wave length and this effect decreases as the wave length increases. Effect of wave length on the sway force and yaw moment is more significant compared with its effect on surge force. The ship initial position relative to the wave through does not have significant effect on turning characteristic and its can be neglected in case for the present subject ship.

Keywords

Turning; Maneuvering; Wind; Waves

Authors

1. [Daeng Paroka](#) (corresponding author)
2. [Andi Haris Muhammad](#)
3. [Syamsul Asri](#)

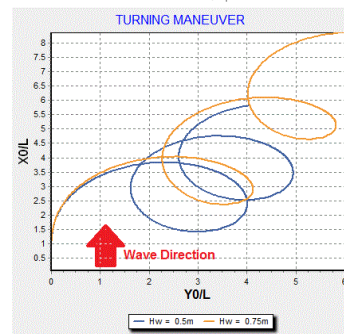
Section

Mechanical Engineering

Manuscript file

[3704-5380-1-SM.docx](#) (uploaded at 2016-04-14)

Preview image



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Supp. files

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Submission detail

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Suggested

Reviewers

1. [Adi Maimun bin Abdul Malik](#) from Universiti Teknologi Malaysia, Malaysia (field: Ship Hydrodynamic)
2. [Ketut Aria Pria Utama](#) from Sepuluh Nopember Institute of Technology, Surabaya (field: Ship Hydrodynamic)
3. [Achmad Fitriadhny](#) from Universiti Trengganu, Malaysia (field: Ship Maneuvering)
4. [Baharuddin Ali](#) from Indonesian Hydrodynamic Laboratory, Surabaya (field: Ship Hydrodynamic)

Editor in charge

1. [Agus Sunjarianto Pamitran](#)
2. [Nandy Putra](#)
3. [Bambang Sugiarto](#)

History

[view history](#)

Status

Under Review Round 1 : no decision yet

Revision

Round 1: None

You are logged in as...

dparoka

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IJTech

p-ISSN 2086-9614
e-ISSN 2087-2100



Office:
IJTech secretariat, Gd. Engineering Center Lt.2, Faculty of Engineering, Universitas Indonesia
Depok 16424, Indonesia.

PREDICTION OF SHIP TURNING MANEUVERING IN CONSTANT WIND AND REGULAR WAVES

ABSTRACT

A ship usually perform maneuvering under influence of external forces and moments such as wind, waves and current. Therefore, the maneuvering behaviour of ships under action of the external forces becomes important to understand. This paper discusses regarding turning maneuvering of an Indonesian ro-ro ferry under influence of combined constant wind and regular waves by using MMG model. The ship position relative to the wave through is added to the original MMG model in order to estimate the exciting forces and moment induced by waves. The results of numerical simulation show that effect of wave height on turning ability is more significant in small wave length and this effect decreases as the wave length increases. Effect of wave length on the sway force and yaw moment is more significant compared with its effect on surge force. The ship initial position relative to the wave through does not have significant effect on turning characteristic and its can be neglected in case for the present subject ship.

Keywords: Turning; Maneuvering; Wind; Waves

1. INTRODUCTION

Maneuvering performance of ship in the initial design stage is typically predicted in calm water condition. However, the ships usually maneuver in presence of external forces such as wind, wave and current. Therefore, it is important to understand the maneuvering behaviour of ship in combined action of the environment forces.

Some mathematical models for predicting the maneuvering of a ship in wind and wave have been developed by several authors. Fang, et al. (2005) used a 6 DOF nonlinear mathematical model to simulate turning maneuver in waves by taking into account effect of wave encounter frequency on inertia, damping and linear hydrodynamic derivative of forces and moments acting on ship hull. Similar approach was used by Zipfel and Maksoud (2011) to determine ship maneuvering motion in regular waves. The frequency-dependent of hydrodynamic coefficients were transfer into time-dependent by using impuls response function. A unified seakeeping and maneuvering problem with second order regular waves was proposed by Skejic and Faltinsen (2008) to analysis seakeeping and maneuvering of a ship in wave. Here, the wave drift force was estimated by using two-time-scale model in order to separate low-frequency motion (maneuvering motion) and high-frequency motion (seakeeping motion). The same method for estimating the wave drift force was used by Seo and Kim (2011) to predict ship maneuvering in waves by using combination of MMG model for ship maneuvering and seakeeping mathematical model. The second order wave force was also used by Chroni, et al. (2015) to investigate effect of environmental forces on ship maneuvering with 4 DOF mathematical model. This second order wave force was also used by Skejic (2013) to simulate ship maneuvering in irregular waves. The two-time-scale method seems to be unefficient because solution of the seakeeping motion can be obtained after the maneuvering motion has been solved.

The most practical method for predicting maneuvering behaviour of ship in the initial design stage may be the MMG model because empirical formula for estimating the coefficients of hydrodynamic derivative have been developed (Yoshimura & Masumoto, 2012). Even the original MMG model is pure maneuvering motion problem with 3 DOF mathematical model, some researchers included the roll or heeling effect on the original model to be 4 DOF model. Fujiwara, et al. (2006) and Paroka, et al. (2015) used the MMG model to investigate steady state equilibrium of ship maneuvering in wind and wave.

The discrepancy between the MMG model and the previous mentioned methods is the encounter frequency dependency of forces and moment induced by ship hull. In cases of long wave (the wave length is larger than the ship length) some authors neglected the effect of encounter frequency (Munif & Umeda, 2000; Umeda & Hashimoto, 2002) on hydrodynamic forces and moments induced by ship hull but it was taken into account for forces and moments induced by the waves. With long waves, the heave and pitch motion may not be significant as shown by Munif and Umeda (2000). Following this assumption, the MMG model seems to be applicable to predict the turning characteristic of ship in waves.

This paper discusses regarding turning maneuverability of a small Indonesian ro-ro ferry under combined action of wind and wave by using the modified MMG model. The effect of wave characteristic such as wave heigh, wave length and the initial position of ship relative to the wave will be investigated. For small ships, such wave characteristics may have significant effect on maneuvering performance as indicated by Fang, et al. (2005).

The wind velocity is assumed to be constant and to be uncorrelated with the wave characteristic.

2. RESEARCH METHODOLOGY

In order to describe the present mathematical model, two coordinate systems are used as shown in Figure 1. The fixed coordinate system $0-x_0y_0z_0$ is fixed on the calm water surface and is used to describe the coordinate of ship position and wave propagation, respectively. The second coordinate system is $G-xyz$ with its origin on the ship center of gravity, G , and moving with the ship motion. The symbols u , v and r indicate the surge, sway and yaw velocity, respectively. The drift angle is designated by β and δ for the rudder angle. The propeller thrust is indicated by T_j and the heading angle is indicated by ψ . ψ_w is the angle of wave direction which is assumed to be the same as the wind angle.

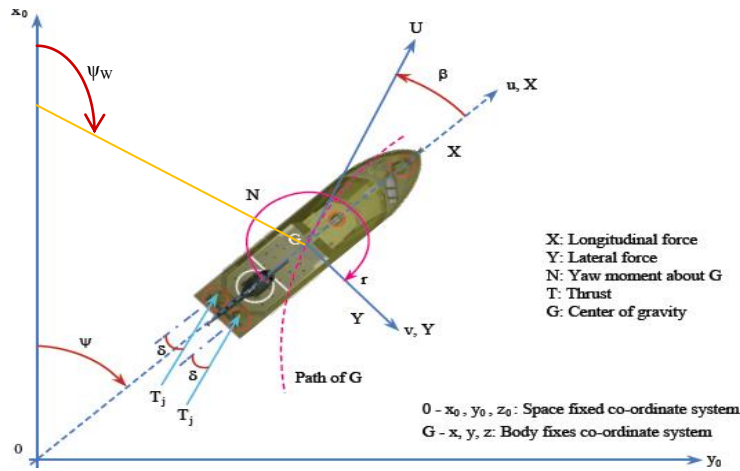


Figure 1 Coordinate system

According to the Newton's second law, the equation of ship maneuvering in combined action of wind and wave is written as follows:

$$\dot{\xi}_G = u \cos \chi - v \sin \chi \quad (1)$$

$$(m + m_x)(\dot{u} - vr) = X_H + X_P + X_R + X_A + X_W \quad (2)$$

$$(m + m_y)(\dot{v} - ur) = Y_H + Y_R + Y_A + Y_W \quad (3)$$

$$(I_{zz} + J_{zz})\dot{r} = N_H + N_R + N_A + N_W - x_G(Y_H + Y_R + Y_A + Y_W) \quad (4)$$

Here, m , m_x and m_y indicate the ship mass, the added mass in surge and the added mass in sway, respectively. \dot{u} , \dot{v} and \dot{r} are the surge, the sway and the yaw accelerations, respectively. The subscripts H, P, R, A and W indicate the hull, the propeller, the rudder, the wind and the wave forces and moments in surge, sway and yaw directions. The equation (1) is added to the original maneuvering equation in order to avoid the two step solution of combination between seakeeping dan maneuvering motions. Integration of equation (1) over time results in the relative position of ship center of gravity relative to the

wave trough. The equation (1) – (4) therefore can be solved at the same time without separation between seakeeping motion and maneuvering motion. The symbol χ in the equation (1) indicates the angle of wave encounter relative to the ship heading angle.

The hull forces and moment in the equation (1) – (4) are empirically estimated by using polynomial regression of the non-dimensional hydrodynamic derivatives (Yoshimura, 2005; Yoshimura & Masumoto, 2012). The ship resistance is estimated by using Holtrop method. The propeller thrust is estimated by using the equation proposed by Kijima, et al. (1990). The thrust coefficient is modelled as a quadratic polynomial equation as function of advance coefficient. The coefficients of this polynomial equation are determined based on statistical data of open water test of B series propeller (Carlton, 2007). The rudder forces and moment are calculated by using formula proposed by Kijima, et al. (1990) for twin propeller and twin rudder.

The forces and moment induced the wave are estimated using formula proposed by Umeda and Hashimoto (2002). A correction factor depending on the block coefficient is used on estimating the wave force in surge direction (Ito, et al., 2014). The equation for estimating the wave force in surge and sway direction as well as the wave moment in yaw direction are shown in the equation (5) – (7).

$$X_W = -\alpha\rho g\zeta_W k \cos \chi \int_{AE}^{FE} C_1(x) S(x) e^{-kd(x)/2} \times \sin(k(\xi_G + x \cos \chi)) dx \quad (5)$$

$$\begin{aligned} Y_W = & \rho g\zeta_W k \sin \chi \int_{AE}^{FE} C_1(x) S(x) e^{-kd(x)/2} \times \sin(k(\xi_G + x \cos \chi)) dx + \zeta_W \omega \omega_e \\ & \sin \chi \int_{AE}^{FE} \rho S_y(x) e^{-kd(x)/2} \times \sin(k(\xi_G + x \cos \chi)) dx - \zeta_W \omega u \sin \chi \\ & \times [\rho S_y(x) e^{-kd(x)/2} \cos(k(\xi_G + x \cos \chi))]_{AE}^{FE} \\ & + (1 + a_H) \frac{\rho}{2} A_R f_\alpha \varepsilon_R (1 - w_p) u \sqrt{1 + \kappa_p \frac{8K_T}{\pi J^2} u_{WR}} \end{aligned} \quad (6)$$

$$\begin{aligned} N_W = & \rho g\zeta_W \sin \chi \int_{AE}^{FE} C_1(x) S(x) e^{-kd(x)/2} \times x \sin(k(\xi_G + x \cos \chi)) dx + \zeta_W \omega \omega_e \\ & \times \sin \chi \int_{AE}^{FE} \rho S_y(x) e^{-kd(x)/2} x \sin(k(\xi_G + x \cos \chi)) dx \\ & + \zeta_W \omega u \sin \chi \int_{AE}^{FE} \rho S_y(x) e^{-kd(x)/2} \times \cos(k(\xi_G + x \cos \chi)) dx \\ & - \zeta_W \omega u \sin \chi \\ & \times [\rho S_y(x) e^{-kd(x)/2} x \cos(k(\xi_G + x \cos \chi))]_{AE}^{FE} \\ & + (x_R + a_H x_H) \frac{\rho}{2} A_R f_\alpha \varepsilon_R (1 - w_p) u \sqrt{1 + \kappa_p \frac{8K_T}{\pi J^2} u_{WR}} \end{aligned} \quad (7)$$

Here, α is the correction factor depend on the block coefficient. ζ_w , k , $S(x)$, $d(x)$ are the wave amplitude, wave number, area and draught of section at longitudinal distance x from midship, respectively. The symbols ω , ω_e and $S_y(x)$ indicate the wave frequency, the wave encounter frequency and the added mass of section in sway direction. x_R , x_H , a_H and A_R are the longitudinal position of rudder from midship, the longitudinal position of center of interaction force between hull and rudder, the interaction factor between hull and rudder as well as the rudder area, respectively. The rudder coefficient is indicated by f_a and the effective propeller wake fraction is designated by w_p . ϵ_R , κ_p , J and K_T are the wake ratio between propeller and rudder, the interaction factor between propeller and rudder, the advance coefficient and the thrust coefficient respectively. $C_1(x)$ and v_{WR} are calculated by using the equation (8) and the equation (9), respectively.

$$C_1(x) = \frac{\sin(k \sin \chi \cdot B(x)/2)}{(k \sin \chi \cdot B(x)/2)} \quad (8)$$

$$v_{WR} = \zeta_w \omega \sin \chi \exp(-kz_R) \cos(2\pi \xi_G/\lambda + kx_R \cos \chi) \quad (9)$$

Here, $B(x)$, z_R and λ are the breadth of section, the center of rudder from baseline and wave length, respectively.

The wind forces and moment in surge, sway and yaw direction are calculated using empirical formula proposed by Fujiwara, et al. (2006). The angle of wind attack is determined based on the wind direction and the ship heading angle. The wave angle is assumed to be the same as the wind angle.

Ship data

The subject ship using in the numerical simulation is an Indonesian ro-ro ferry with principle dimension shown in Table 1 and her propeller and rudder geometry are shown in Tabel 2, respectively.

Table 1 Principle dimension of the subject ship

Items	Dimension
Length overall (L_{OA})	36.40 m
Length between perpendicular (L_{BP})	31.50 m
Breadth (B)	8.70 m
Height (H)	2.65 m
Draught (T)	1.65 m
Ship speed (V_S)	10.5 knot
Lateral projected windage area (A_L)	36.40 m ²
Transverse projected windage area (A_F)	93.61 m ²
Lateral projected area of superstructure (A_{OD})	187.21 m ²
Center of windage are from midship (C)	-0.558 m
Vertical center of A_L (H_C)	0.720 m
Vertical center of A_{OD} (H_L)	4.930 m
Height of transverse projected area (H_{BR})	10.73 m

Table 2 Propeller and rudder geometry

Items	Dimension
Number of propeller	2
Propeller blade (Z)	4
Propeller diameter (D_P)	1.10 m
Propeller revolution (n)	8.58 rps
Transverse position propeller (y_P)	± 2.55 m
Long. position propeller (x_P)	15.50 m
Rudder area (A_R)	2.08 m ²
Rudder coefficient (f_λ)	2.10
Transverse rudder position (y_R)	± 2.55 m
Long. Rudder position (x_R)	15.75 m

3. RESULTS

The numerical results of turning maneuvering simulation for wave height of 0.50 meters and 0.75 meters are shown in Figure 2a for wave length the same as the ship length and in Figure 2b for the wave length of 50.0 meters, respectively. The wind velocity for all wave characteristics is 6.75 m/s (beaufort scale 4). The turning diameter decreases as the wave height increases. The second turning circle moves away from the first one with longer distance for larger wave height. A similiar result is obtained for larger wave length. The distance of turning circles movement becomes smaller when the wave length increases. These results show that the wave height has more significant effect on the ship turning maneuvering for smaller wave length compared with the longer one.

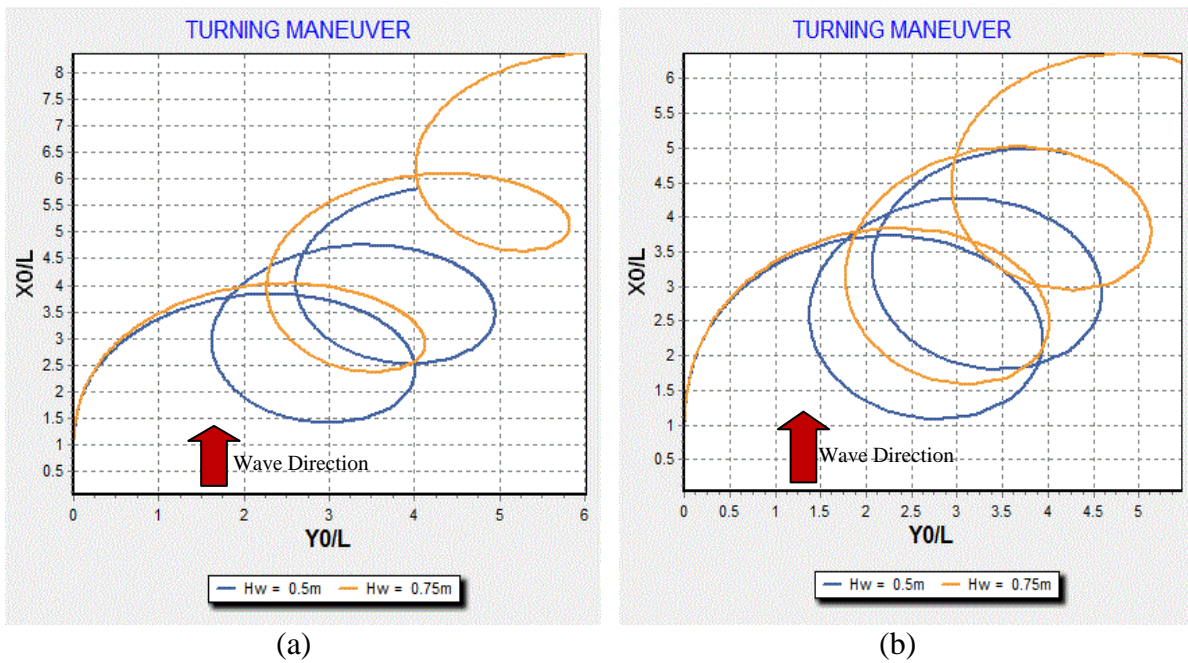


Figure 2 Trajectory of turning circle

The surge and the sway velocities of ship during the turning simulation are shown in Figure 3a for the wave length the same as the ship length with wave height of 0.50 meters and 0.75 meters. For the wave length of 50.0 meters with the same wave heights are shown in Figure 3b. The yawrate for wave length the same as the ship length with the same wave heights are shown in Figure 3c and in Figure 3d for the wave length of 50.0 meters. The surge and the sway velocities oscillate depend on the angle of wave encounter relative to the ship deading angle. The minimum velocities occur in cases of heading wave (the angle of wave encounter is 0.0 degrees) and its maximum in following wave (the angle of wave encounter is 180.0 degrees). An oscillation of surge, sway and yaw motions also occurs in all conditions of wave height and wave length. These are purely affected by the ship position relative to the wave. Oscillation of surge velocity become significant in heading and following waves, while the oscillation of sway velocity becomes significant in cases of beam seas.

Alteration of surge velocity when the ship in following waves and in heading waves is significantly increase as the wave height increases. However, effect of wave height on the alteration of surge velocity decreases in cases of larger wave length. The same trend as the surge velocity alteration is also obtained for the sway velocity. The yawrate are more sensitive to the alteration of angle of wave encounter compared with the surge and sway velocities. This is because the yaw moment exist even in beam seas as result of non-homogenous of hull form between the after part and the forward part. The minimum yawrate will occur in cases of following and heading waves but such condition appears in very short time in case of turning maneuver.

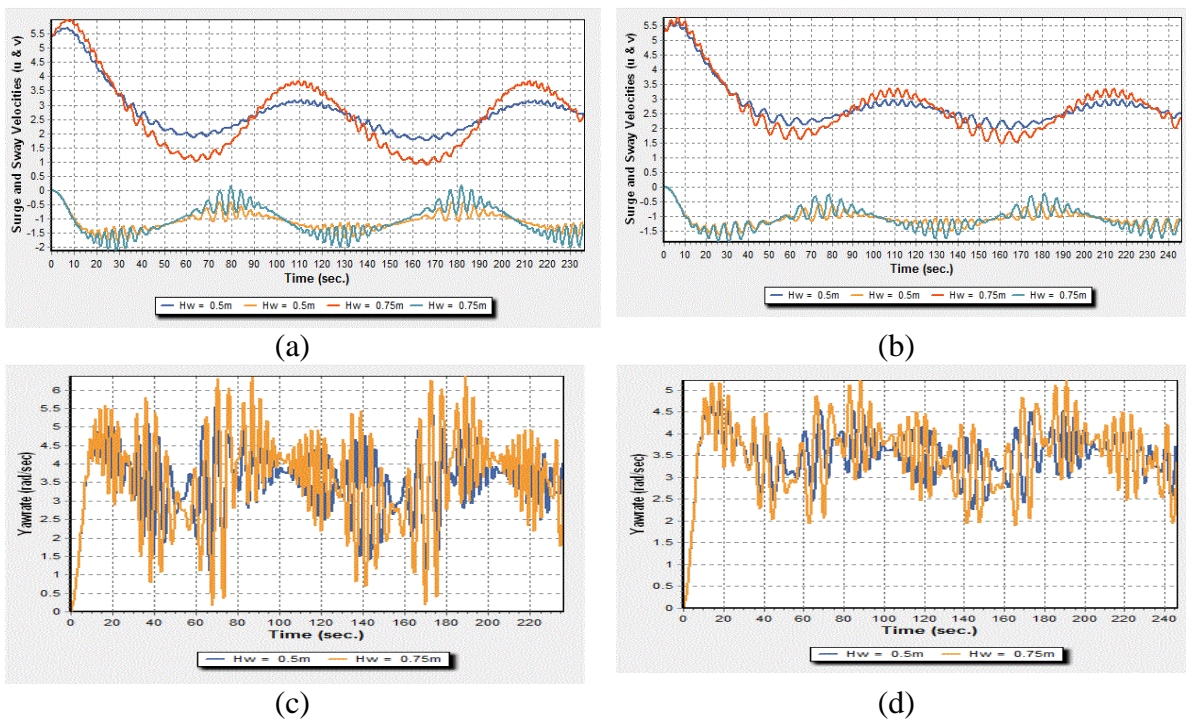


Figure 3 Ship motion during turning maneuver

Figures 4a – 4f show the nondimensional forces and moment in surge, sway and yaw direction with the two different wave height and the two different wave length. The left figures are for the wave length the same as the ship length and the right figures are the forces and moment for the wave length of 50.0 meters. Effect of wave length on force in surge direction is not significant compared with its effect on force in sway direction and on moment in yaw direction. Therefore, the characteristic of turning trajectory significantly change as the wave length increase for the same wave height.

The wave height significantly affect the forces and moment even for wave length of 50.0 meters. However, effect of wave height on the forces and moment tends to decrease as the wave length increases. Similar with the sway velocity, the force in sway direction is negligible small in heading and following waves and becomes maximum in beam waves. The same trend is obtained for surge force in angle of wave encounter of 90.0 degrees and 270.0 degrees (beam waves). The minimum value on yaw moment occur in cases of head and following waves. The yaw moment is still significant in beam wave condition as effect of longitudinal center of buoyancy.

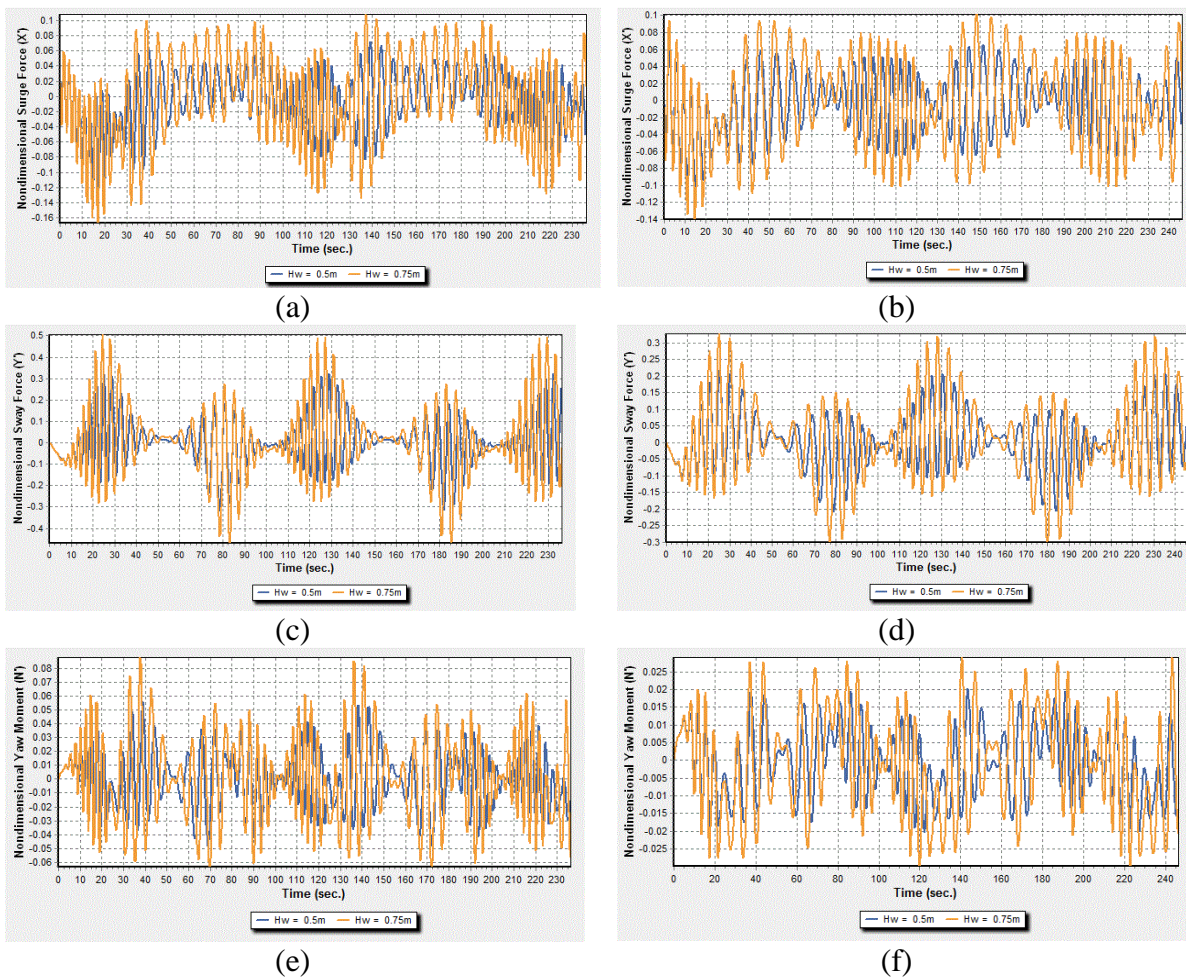


Figure 4 Resultant of forces and moment acting on ship hull during turning maneuver

4. DISCUSSION

The obtained turning trajectory for two different wave height and wave length are similar with the results of previous study (Fang, et al., 2005; Seo & Kim, 2011; Skejck, 2013; Chroni, et al., 2015). The turning circle becomes smaller as the wave height increases for both wave length of the same as the ship length and 50.0 meters. The turning circle for smaller wave length is larger than the larger one. It shows that the drift motion significantly increases when the wave height increases and it tends to decrease as the wave length increases. Figure 3 shows that the surge velocity becomes minimum in beam seas, in which the sway velocity is maximum. The larger yaw moment for larger wave height and smaller wave length will also induce faster turning motion compared with smaller wave height and larger wave length. These turning motion characteristics also induce longer distance of movement between the first turning circle and the second turning circle as shown in Figure 2.

Fang, et al. (2005) shown that both the surge and the sway velocities oscillate depend on the angle of wave encounter relative to the ship heading angle. The same results is obtained in the present study. A more significant amplitude of surge and sway velocities oscillation has also identified in the transition from the following waves to the beam waves and from the beam waves to the heading waves and so on. This phenomena did not appear in study conducted by Fang, et al. (2005). A similar results with the present study was obtained by Skjick (2013) for ship turning in irregular waves. This phenomena may depend on the wave characteristics compared with the ship geometry. It may disappear in cases of large ships compared to the wave height and it may arise for small ship as the subject of present study even for small wave height. Figure 3(a) and Figure 3(b) show that the oscillation due to the transition from the following waves to the beam waves and so on decreases when the wave length increases. It may disappear for smaller wave height and larger wave length.

The initial position of ship relative to the wave does not have significant effect of turning maneuvering of ship in waves. The same results was obtained by Fang, et al. (2005) but they stated that effect of the initial position relative to the wave may significant for small ships. That effect does not obtained in the present study. The initial position of ship relative the wave surface does not significantly affect the forces and moment induced by the wave during turning maneuver. The initial position makes only changing phase of the forces and moment. Therefore its effect to the turning maneuver becomes negligible small.

The subject ship cannot perform turning maneuver in wave height of 1.0 meters and the wave length the same as the ship length or smaller. The numerical simulation can be conducted for the wave height of 1.0 meters when the wave length is larger than the ship length. However the turning circle become very small and it seems to be unrealistic in practical point of view. The very small turning circle occurs due to large drift motion with small surge velocity in beam waves condition up to heading waves condition during turning simulation. The large drift motion may occurs due to small draught of the subject ship so that the hydrodynamic damping force in sway direction becomes smaller compared with the ship with larger draught. This had been shown by Chroni, et al. (2015) with wave length of a half of ship length, wave height of 5.50 meters and wind velocity of 19.0 m/s (Beaufort Scale 8). The subject ship used in their simulation was more larger than that used in the present simulation. Therefore, the weather condition to perform sea trial in guidance of International Maritime Organization (IMO) (2002) may not be applied for small ships.

5. CONCLUSION

The mathematical model for predicting turning maneuvering in constant wind and regular wave has been developed by using the 3 DOF of MMG model. A mathematical model to describe the ship position relative to the wave profile as function of ship velocity relative to the wave celerity has been included in the original MMG model. Therefore the mathematical model can be simultaneously solved to obtain maneuvering characteristics. Based on the numerical results for a small Indonesian ro-ro ferry, some conclusion can be remarked as follows:

1. Effect of wave height on ship turning maneuver is more significant in small wave length. This effect decreases as the wave length increases.
2. The sway force and yaw moment of wave significantly decrease when the wave length increases. Alteration of surge force due to increasing the wave length is smaller compared with the sway force and yaw moment. This means that the drift motion may have an important role on ship maneuvering in short waves.
3. The initial position of ship relative to the wave does not have significant effect on ship turning maneuver and its effect can be neglected in case of the present subject ship.

6. ACKNOWLEDGEMENT

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7. REFERENCES

- Carlton, J.S., (2007), *Marine Propellers and Propulsion*, Second Edition, Elsevier, Ltd., pp. 103 – 106.
- Chroni, D., Liu, S., Plessas, T., Papanikolaou, A., (2015), Simulation of the maneuvering behaviour of ships under the influence of environmental forces. *In: Proceedings of the 16th International Congress of the International Maritime Association of the Mediterranean (IMAM 2015) 2015*, Pula, 21 – 24 September, Croatia.
- Fang, M.C., Luo, J.H., Lee, M.L., (2005), A nonlinear mathematical model for ship turning circle simulation in waves, *Journal of Ship Research*, Volume 49, pp. 69 – 79.
- Fujiwara, T., Ueno, M., Ikeda, Y., (2006), Cruising performance of a large passenger ship in heavy sea. *In: Proceedings of the 16th International Offshore and Polar Engineering Conference 2006*, California, 28 May – 2 June, USA.
- IMO, (2002), *Maritime Safety Committee on Ship Maneuverability of International Maritime Organization (IMO), MSC &6/23, Resolution MSC 137(36)*, IMO, London.
- Ito, Y., Umeda, N., Kubo, H., (2014), Hydrodynamic aspects on vulnerability criteria for surf-riding of ships, *Jurnal Teknologi (Science and Engineering) Volume 66*, pp. 127 – 132.
- Kijima, K., Katsuno, T., Nakiri, Y., Furukawa, Y., (1990), On the maneuvering performance of a ship with the parameter of loading condition, *Journal Society of Naval Architects of Japan*, Volume 168, pp. 141 – 148.

- Munif, A. and Umeda, N., (2000), Modelling extreme roll motions and capsizing of a moderate-speed ship in astern waves, *Journal of Society of Naval Architects of Japan*, Volume 187, pp. 51 – 58.
- Paroka, D., Muhammad, A.H., Asri, S., (2015), Steady state equilibrium of ship maneuvering under combined action of wind and wave, *Jurnal Teknologi (Science and Engineering)*, Volume 76, pp. 67 – 75.
- Seo, M.G. and Kim, Y., (2011), Effect of ship motion on ship maneuvering in waves. *In: Proceedings of the 26th International Workshop on Water Waves and Floating Bodies 2011*, Athens, 17 – 20 April, Greece.
- Skejck, R. and Faltinsen, O.M., (2008), A unified seakeeping and maneuvering analysis of ships in regular waves, *Journal of Marine Science and Technology*, Volume 13, pp. 371 – 394.
- Skejck, R., (2013), Ships maneuvering simulations in a seaway – How close are we to reality, *In: Proceedings of the International Workshop on Next Generation Nautical Traffic Models 2013*, Delf, 22 Nopember, Netherlands.
- Umeda, N. and Hashimoto, H., (2002), Qualitative aspects of nonlinear ships motion in following and quartering seas with high forward velocity, *Journal of Marine Science and Technology*, Volume 6, pp. 111 – 121.
- Yoshimura, Y., (2005), Mathematical model for maneuvering ship motion (MMG Model). *In: Proceedings of Workshop on Mathematical Model for Operations Involving Ship – Ship Interaction 2005*, Tokyo, 4 – 5 August, Japan.
- Yoshimura, Y. and Masumoto, Y., (2012), Hydradynamic database and maneuvering prediction method with medium – high speed merchant ships and fishing vessels. *In: Proceedings of MARSIM 2012, International Conference on Marine Simulation and Ship Maneuverability 2012*, Singapore, 23 April, Singapore.
- Zipfel, J.S and Maksoud, M.A., (2011), A numerical model to determine ship maneuvering motion in regular waves, *In: Proceedings of International Conference on Computational Methods in Marine Engineering (MARINE) 2011*, Lisbon, 28 – 30 September, Portugal.

PREDICTION OF SHIP TURNING MANEUVERS IN CONSTANT WIND AND REGULAR WAVES

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ABSTRACT

A ship usually performs maneuvers under the influence of external forces and moments, such as wind, waves, and current. Therefore, it is important to understand the maneuvering behavior of ships under the action of external forces. This paper discusses the turning maneuvers of an Indonesian ro-ro ferry under the combined influence of constant wind and regular waves using the mathematical modelling group (MMG). The ship's position relative to the wave trough is added to the original MMG model to estimate the exciting forces and moment induced by the waves. The results of a numerical simulation show that the effect of wave height on turning ability is more significant for a small wavelength; this effect decreases as the wavelength increases. The effect of wavelength on the sway force and yaw moment is more significant compared with its effect on the surge force. The ship's initial position relative to the wave trough does not have a significant effect on the turning characteristic and it can be neglected for the present study's subject ship. Overall, the results of the present work compare well with published data.

Keywords: Maneuvering; Turning; Waves; Wind

1. INTRODUCTION

The maneuvering performance of a ship during the initial design stage is typically predicted in calm water conditions. However, ships usually maneuver in the presence of external forces, such as wind, waves, and current. Therefore, it is important to understand the maneuvering behavior of a ship under the combined actions of the environmental forces.

Some mathematical models for predicting the maneuvering of a ship in conditions of wind and waves have been developed by several authors. Fang et al. (2005) used a 6 degree of freedom (6 DOF) nonlinear mathematical model to simulate a ship's turning maneuver in waves by taking into account the effect of the wave encounter frequency on the inertia, damping, and linear hydrodynamic derivative of the forces and moments acting on the ship's hull. A similar approach was used by Zipfel and Maksoud (2011) to determine a ship's maneuvering motion in regular waves. The frequency-dependent hydrodynamic coefficients were transferred to the time-domain using the impulse response function. A unified seakeeping and maneuvering theory with second-order regular waves was proposed by Skejic and Faltinsen (2008) to analyze the behavior of a ship in waves. Here, the wave drift force was estimated using a two-time scale

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model to separate the low-frequency motion (maneuvering motion) and the high-frequency motion (seakeeping motion). The same method for estimating the wave drift force was used by Seo and Kim (2011) to predict ship maneuvering in waves using a combination between the mathematical modelling group (MMG) and seakeeping mathematical model. The second-order wave force was also used by Chroni et al. (2015) to investigate the effect of environmental forces on ship maneuvering with a 4 degree of freedom (4 DOF) mathematical model. Skejic (2013) also used the second-order wave force to simulate ship maneuvering in irregular waves. However, the two-time scale method seems to be inefficient because the solution to the seakeeping motion can be obtained after the maneuvering motion has been solved.

The most practical method for predicting the maneuvering behavior of a ship in the initial design stage may be the MMG model because empirical formulas for estimating the coefficients of the hydrodynamic derivatives have been developed (Yoshimura & Masumoto, 2012). Even the original MMG model is a pure maneuvering motion problem with a 3 DOF mathematical model; some researchers included the roll or heeling effect using a 4 DOF model. Fujiwara et al. (2006) and Paroka et al. (2015) used the MMG model to investigate the steady state equilibrium of a ship maneuvering in wind and waves.

The discrepancy between the MMG model and the previously mentioned methods is the encounter frequency of forces and moments induced by the ship's hull. In cases of long wavelengths in which the length of the wave is larger than the length of the ship, some authors neglected the effect of the encounter frequency on hydrodynamic forces and moments induced by the ship's hull, although it was taken into account for the forces and moments induced by the waves (Munif & Umeda, 2000; Umeda & Hashimoto, 2002). Munif and Umeda (2000) showed that with long waves, the heave and pitch motion may not be significant. Following this assumption, the MMG model seems to be able to predict the turning characteristics of ships in waves. However, it is necessary to add a mathematical equation to the MMG model to describe the ship's position relative to the wave. This is important because the forces and moments induced by the wave depend on the ship's position in the wave surface.

This paper discusses the turning maneuverability of a small Indonesian Roro ferry under the combined action of wind and waves using the modified MMG model. The effect of the characteristics of the waves, such as wave height, wavelength, and the initial position of the ship relative to the wave, was investigated. For small ships, these wave characteristics may have a significant effect on the maneuvering performance as indicated by Fang et al. (2005). The wind velocity is assumed to be constant and to be uncorrelated with the wave characteristics.

2. RESEARCH METHODOLOGY

To describe the present mathematical model, two coordinate systems are used as shown in Figure 1. The first coordinate system, $o-x_o y_o z_o$, is fixed on the calm water surface and is used to describe the coordinates of the ship's position and wave propagation, respectively. The second coordinate system, $G-xyz$, has its origin on the ship's center of gravity, G , and moves with the ship's motion. The symbols u , v , and r indicate the surge, sway, and yaw velocity, respectively. The drift angle is designated by β , and δ is used for the rudder angle. The propeller thrust is indicated by T_j and the heading angle is indicated by ψ . The angle of the wave direction ψ_w is assumed to be the same as the wind angle.

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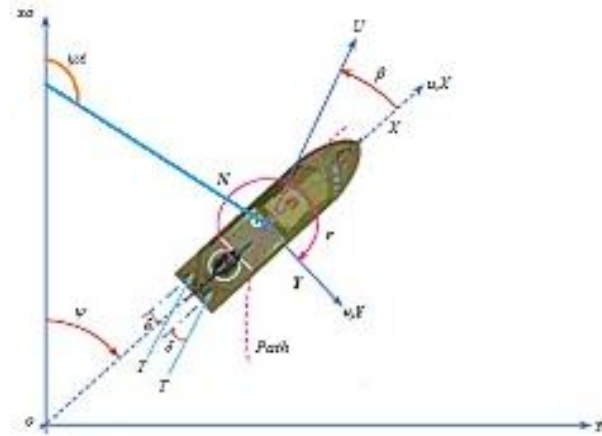


Figure 1 The coordinate systems

According to Newton's second law of motion and following the MMG model, the equation for a ship maneuvering in the combined action of wind and wave according to Fujiwara et al. (2006) is written as:

$$\xi_G = u \cos \chi - v \sin \chi \quad (1)$$

$$(m + m_x)(\dot{u} - vr) = X_H + X_P + X_R + X_A + X_W \quad (2)$$

$$(m + m_y)(\dot{v} - ur) = Y_H + Y_R + Y_A + Y_W \quad (3)$$

$$(I_{zz} + J_{zz})\dot{r} = N_H + N_R + N_A + N_W - x_G(Y_H + Y_R + Y_A + Y_W) \quad (4)$$

Here, m , m_x , and m_y indicate the ship's mass, the added mass in the surge, and the added mass in the sway, respectively, while \dot{u} , \dot{v} , and \dot{r} are the surge, the sway, and the yaw accelerations, respectively. The subscripts H , P , R , A , and W indicate the hull, propeller, rudder, wind, and the wave forces and moments in the surge, sway, and yaw directions. Equation 1 is added to the MMG model (Equations 2 to 4) to take into account the effect of the ship's position relative to the wave surface on the wave forces and moments. This equation was used by Fang et al. (2005) and Umeda and Hashimoto (2002) to estimate the wave forces and moments acting on a ship's hull. Integration of Equation 1 over time results in the relative position of a ship's center of gravity relative to the wave trough. Therefore, Equations 1 to 4 can be solved at the same time without separating the seakeeping and maneuvering motions. The symbol χ in Equation 1 indicates the angle of the wave encounter relative to the ship heading angle.

The forces and moments of the hull in Equations 2 to 4 are empirically estimated using the polynomial regression of the nondimensional hydrodynamic derivatives (Yoshimura, 2005; Yoshimura & Masumoto, 2012). The ship's resistance is estimated using a method developed by Holtrop and Mennen (1982). The propeller thrust is estimated using the equation proposed by Kijima et al. (1990). The thrust coefficient as a function of the advance coefficient are estimated based on statistical data of the open water test for B series propeller (Carlton, 2007). The rudder forces and moments are calculated using a formula proposed by Kijima et al. (1990) for a twin propeller and twin rudder.

The forces and moments induced by the waves are estimated using formula proposed by Umeda and Hashimoto (2002). A correction factor, which depends on the block coefficient, is used to estimate the wave force in the surge direction (Ito et al., 2014). The equation for estimating the wave force in the surge and sway directions, as well as the wave moment in the yaw direction are shown in Equations 5 to 7.

$$X_W = -\alpha \rho g \zeta_W k \cos \chi \int_{AE}^{FE} C_1(x) S(x) e^{-kd(x)/2} \times \sin(k(\xi_G + x \cos \chi)) dx \quad (5)$$

$$Y_W = \rho g \zeta_W k \sin \chi \int_{AE}^{FE} C_1(x) S(x) e^{-kd(x)/2} \times \sin(k(\xi_G + x \cos \chi)) dx + \zeta_W \omega \omega_e$$

$$\sin \chi \int_{AE}^{FE} \rho S_y(x) e^{-kd(x)/2} \times \sin(k(\xi_G + x \cos \chi)) dx - \zeta_W \omega u \sin \chi$$

$$\times [\rho S_y(x) e^{-kd(x)/2} \cos(k(\xi_G + x \cos \chi))]_{AE}^{FE}$$

$$+ (1 + a_H) \frac{\rho}{2} A_R f_a \varepsilon_R (1 - w_p) u \sqrt{1 + \kappa_p \frac{8K_T}{\pi J^2} v_{WR}} \quad (6)$$

$$N_W = \rho g \zeta_W \sin \chi \int_{AE}^{FE} C_1(x) S(x) e^{-kd(x)/2} \times x \sin(k(\xi_G + x \cos \chi)) dx + \zeta_W \omega \omega_e$$

$$\times \sin \chi \int_{AE}^{FE} \rho S_y(x) e^{-kd(x)/2} x \sin(k(\xi_G + x \cos \chi)) dx$$

$$+ \zeta_W \omega u \sin \chi \int_{AE}^{FE} \rho S_y(x) e^{-kd(x)/2} \times \cos(k(\xi_G + x \cos \chi)) dx$$

$$- \zeta_W \omega u \sin \chi$$

$$\times [\rho S_y(x) e^{-kd(x)/2} x \cos(k(\xi_G + x \cos \chi))]_{AE}^{FE}$$

$$+ (x_R + a_H x_H) \frac{\rho}{2} A_R f_a \varepsilon_R (1 - w_p) u \sqrt{1 + \kappa_p \frac{8K_T}{\pi J^2} v_{WR}} \quad (7)$$

Here, α is the correction factor dependent on the block coefficient, and ζ_W , k , $S(x)$, and $d(x)$ are the wave amplitude, wave number, area, and draught of section at a longitudinal distance x from the midship, respectively. The symbols ω , ω_e , and $S_y(x)$ indicate the wave frequency, wave encounter frequency, and added mass of section in the sway direction, while x_R , x_H , a_H , and A_R are the longitudinal position of the rudder from the midship, the longitudinal position of the center of the interaction force between the hull and the rudder, the interaction factor between the hull and the rudder, and the rudder area, respectively. The rudder coefficient is indicated by f_a and the effective propeller wake fraction is designated by w_p . The symbols ε_R , κ_p , J , and K_T are the wake ratio between propeller and rudder, the interaction factor between propeller and rudder, the advance coefficient, and the thrust coefficient, respectively. $C_1(x)$ and v_{WR} are calculated using Equation 8 and Equation 9, respectively.

$$C_1(x) = \frac{\sin(k \sin \chi \cdot B(x)/2)}{(k \sin \chi \cdot B(x)/2)} \quad (8)$$

$$v_{WR} = \zeta_W \omega \sin \chi \exp(-kz_R) \cos(2\pi \xi_G/\lambda + kx_R \cos \chi) \quad (9)$$

Here, $B(x)$, z_R , and λ are the breadth of section, the center of the rudder from the baseline, and the wavelength, respectively.

The wind forces and moments in the surge, sway, and yaw directions are calculated using the empirical formula proposed by Fujiwara et al. (2006). The angle of wind attack is determined by the wind direction and the ship heading angle. The wave angle is assumed to be the same as the wind angle.

2.1. Ship Data

The ship used in the numerical simulation is an Indonesian ro-ro ferry with the principle dimensions shown in Table 1. The dimensions of the propeller and the rudder are shown in Table 2.

Table 1 Principle dimensions of the subject ship

Items	Dimension
Length overall (L_{OA})	36.40 m
Length between perpendicular (L_{BP})	31.50 m
Breadth (B)	8.70 m
Height (H)	2.65 m
Draught (T)	1.65 m
Ship speed (V_S)	10.5 knot
Lateral projected windage area (A_L)	36.40 m ²
Transverse projected windage area (A_F)	93.61 m ²
Lateral projected area of superstructure (A_{OD})	187.21 m ²
Center of windage area from midship (C)	-0.558 m
Vertical center of A_L (H_C)	0.720 m
Vertical center of A_{OD} (H_L)	4.930 m
Height of transverse projected area (H_{BR})	10.73 m

Table 2 Propeller and rudder dimensions

Items	Dimension
Number of propellers	2
Number of propeller blades (Z)	4
Propeller diameter (D_P)	1.10 m
Propeller revolution (n)	8.58 rps
Transverse position propeller (y_P)	± 2.55 m
Longitude position propeller (x_P)	15.50 m
Rudder area (A_R)	2.08 m ²
Rudder coefficient (f_{λ})	2.10
Transverse rudder position (y_R)	± 2.55 m
Longitude rudder position (x_R)	15.75 m

3. RESULTS

The numerical results of the turning maneuver simulation for a wave height of 0.50 m and 0.75 m are shown for a wavelength that is the same as the ship's length (Figure 2a) and for a wavelength of 50.0 m (Figure 2b). The wind velocity for all wave characteristics is 6.75 m/s (Beaufort scale 4). The turning diameter decreases as the wave height increases. The distance between the first and the second turning circles is longer for a larger wave height. A similar result is obtained for a larger wavelength. The distance of the turning circles movement becomes smaller as the wavelength increases. These results show that the wave height has a more significant effect on the ship turning maneuver for a shorter wavelength compared with a longer wavelength.

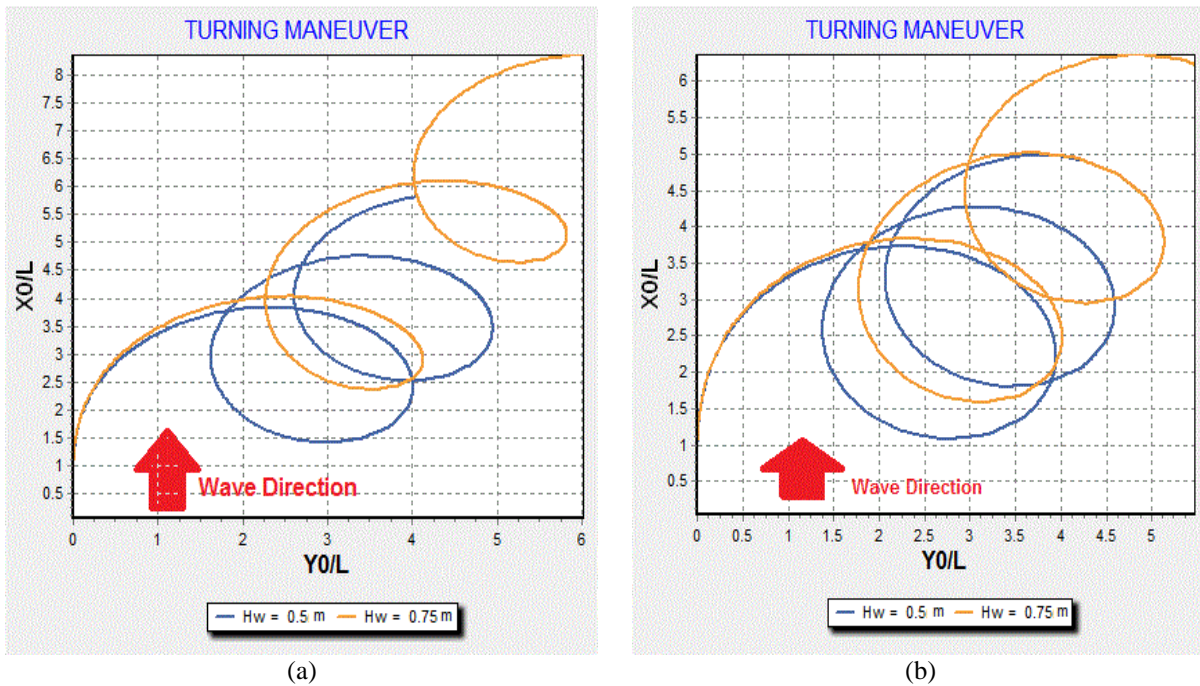


Figure 2 Trajectory of the turning circle: (a) Wavelength is the same as the ship's length; and (b) Wave length is 50.00 meters

The surge and sway velocities of the ship during the turning simulation are shown in Figure 3a for a wavelength that is the same as the ship's length for a wave height of 0.50 m and 0.75 m. The results for a wavelength of 50.0 m with the same wave heights are shown in Figure 3b. The yaw rates for a wavelength that is the same as the ship's length for the same wave heights are shown in Figure 3c, while Figure 3d shows the results for a wavelength of 50.0 m. The surge and sway velocities oscillate depending on the angle of the wave encounter relative to the ship heading angle. The minimum velocity occurs when there is a heading wave in which the angle of the wave encounter is 0.0 degrees, while the maximum velocity occurs in a following wave in which the angle of the wave encounter is 180.0 degrees. The oscillation of the surge, sway, and yaw motions also occur in all conditions of wave height and wavelength. These are purely affected by the ship's position relative to the wave. The oscillation of the surge velocity becomes significant in heading and following waves, while the oscillation of the sway velocity becomes significant in beam seas. Therefore, the phase between the surge and sway motions becomes 90.0 degrees as shown in Figures 3a and 3b.

An alteration in surge velocity when the ship is in following waves and heading waves significantly increases as the wave height increases. However, the effect of wave height on the alteration in surge velocity decreases as the wavelengths increase. The same trend is also obtained for the sway velocity. The yaw rate is more sensitive to the alteration in wave direction compared with the surge and sway velocities. This is because the yaw moment exists even in beam seas depend on the position of longitudinal center of gravity. The minimum yaw rate will occur in following and heading waves, although this condition appears in a very short time in case of a turning maneuver.

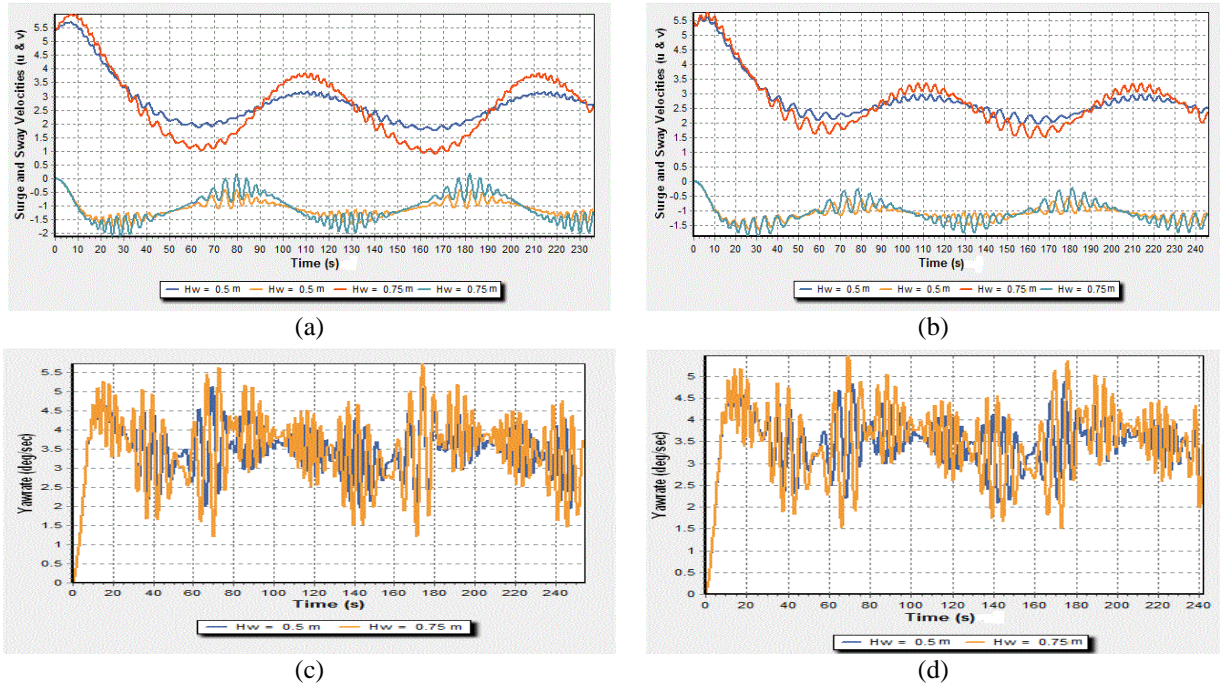


Figure 3 Ship motion during a turning maneuver: (a) Surge and sway velocities for wavelength the same as ship's length; (b) Surge and sway velocities for wave length of 50.00 meters; (c) Yaw rate for wavelength the same as ship's length; (d) Yaw rate for wavelength of 50.00 meters

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Figures 4a to 4f show the nondimensional forces and moments in surge, sway and yaw directions at two different wave heights and two different wavelengths. The figures on the left are for a wavelength that is the same as the ship's length, and the figures on the right are the forces and moments for a wavelength of 50.0 m. The effect of wavelength on the force in the surge direction is not significant compared with its effect on the force in the sway direction and on the moment in the yaw direction. Therefore, the characteristic of turning trajectory significantly changes as the wavelength increases for the same wave height.

The wave height significantly affects the forces and moments for a wavelength of 50.0 m. However, the effect of wave height on the forces and moments tends to decrease as the wavelength increases. Similar to the sway velocity, the force in the sway direction is negligibly small in heading and following waves, although it reaches its maximum in beam seas. The same trend is obtained for the surge force when the angle of the wave encounter is 90.0 degrees and 270.0 degrees (beam waves). The minimum value of the yaw moment occurs in cases of heading and following waves. The yaw moment is still significant in a beam wave because of the effect of the longitudinal center of buoyancy.

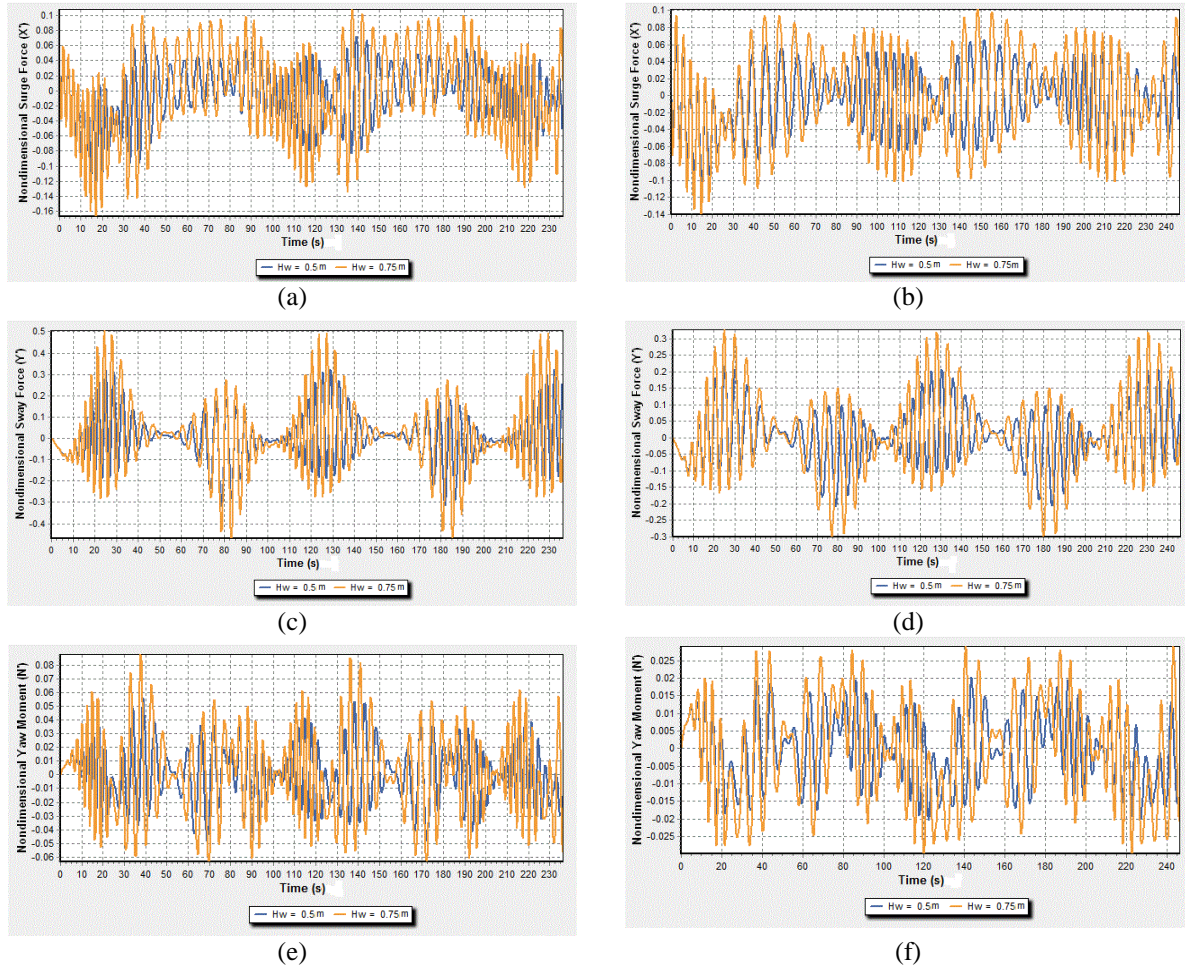


Figure 4 Resultant forces and moments acting on a ship hull during a turning maneuver: (a) Surge force for wavelength the same as the ship's length; (b) Surge force for wavelength of 50.00 meters; (c) Sway force for wavelength the same as the ship's length; (d) Sway force for wavelength of 50.00 meters; (e) Yaw moment for wavelength the same as the ship's length; (f) Yaw moment for wavelength of 50.00 meters

4. DISCUSSION

The obtained turning trajectory for two different wave heights and wavelengths are similar to the results found in previous studies (Fang et al., 2005; Seo & Kim, 2011; Skejck, 2013; Chroni et al., 2015). The turning circle becomes smaller as the wave height increases for both a wavelength that is the same as the ship's length and a wavelength of 50.0 m. The turning circle for a shorter wavelength is larger than for a larger wavelength. This indicates that the drift motion significantly increases when the wave height increases and decreases as the wavelength increases. Figure 3 shows that the surge velocity is minimum in beam seas, which produces a maximum sway velocity. The yaw moment tends to increase when the wave slope increases. As a result, the turning motion for a large wave slope is faster than with a small wave slope. These turning motion characteristics also induce a longer distance of movement between the first turning circle and the second turning circle as shown in Figure 2.

Fang et al. (2005) showed that the oscillations of both the surge and sway velocities depend on the angle of the wave encounter relative to the ship heading angle. The same results are obtained in the present study. A more significant amplitude of oscillation of the surge and sway velocities has also been identified in the transition from following waves to beam seas and from beam waves to heading waves and so on. This phenomenon did not appear in a study conducted

by Fang et al. (2005). Skjick (2013) had similar results as this study for a ship turning in irregular waves. This phenomenon may depend on the wave characteristics compared with the ship geometry. Thus, it may not occur in cases of large ships compared with the wave height, although it may be seen in small ships even for a small wave height as seen in this study. Figures 3a and 3b show that the oscillation due to the transition from following waves to beam waves and so on decreases when the wavelength increases. It may disappear for smaller wave slopes.

The initial position of a ship relative to the wave does not have a significant effect on the turning maneuvers of a ship in waves. The same results were obtained by Fang et al. (2005), although they stated that the effect of the initial position relative to the wave may be significant for small ships. This effect is not obtained in the present study. The initial position of a ship relative to the wave surface does not significantly affect the forces and moments induced by the wave during a turning maneuver. The initial position only makes the changing phase of the forces and moments. Therefore, its effect on the turning maneuver becomes negligibly small.

The subject ship cannot perform a turning maneuver in a wave height of 1.0 m when the wavelength is the same as the ship's length or is smaller. The numerical simulation can be conducted for a wave height of 1.0 m when the wavelength is longer than the ship. However, the turning circle becomes very small and it seems to be unrealistic from a practical point of view. The very small turning circle occurs due to the large drift motion with a small surge velocity in beam seas up to heading waves during the turning simulation. The large drift motion may occur due to the small draught of the subject ship so that the hydrodynamic damping force in the sway direction becomes smaller compared with a ship with a larger draught. This was shown by Chroni et al. (2015) using a wavelength that was half the ship's length, a wave height of 5.50 m, and a wind velocity of 19.0 m/s (Beaufort scale 8). The subject ship used in their simulation was larger than that used in the present study. These facts show that the required weather conditions to perform a sea trial of small ships should be smaller than that in the guidance of the International Maritime Organization (IMO, 2002).

5. CONCLUSION

The mathematical model for predicting a ship's turning maneuver in constant wind and regular waves has been developed based on the 3 DOF of the MMG model. In order to directly calculates wave forces and moment, an equation to describe the ship's position relative to the wave profile as a function of the surge and sway velocities, as well as the heading angle has been included in the MMG model. The present mathematical model can be simultaneously solved to obtain the maneuvering characteristics. Based on the numerical results for a small Indonesian ro-ro ferry, some conclusions can be made as follows: (1) The effect of the wave height on a ship's turning maneuver is more significant for a short wavelength. This effect decreases as the wavelength increases; (2) The sway force and yaw moment of a wave significantly decrease when the wavelength increases. Alteration of the surge force due to an increasing wavelength is smaller compared with the sway force and yaw moment. This means that the drift motion

The initial position This should be conclusion number (3) not have a significant effect on the ship's turning maneuver; its effect can be neglected in the subject ship of the present study.

6. ACKNOWLEDGEMENT

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7. REFERENCES

- Carlton, J.S., 2007. *Marine Propellers and Propulsion, Second Edition*. Elsevier Ltd., Jordan Hill, Oxford, UK., pp. 103–106
- Chroni, D., Liu, S., Plessas, T., Papanikolaou, A., 2015. Simulation of the Maneuvering Behaviour of Ships under the Influence of Environmental Forces. *In: Proceedings of the 16th International Congress of the International Maritime Association of the Mediterranean (IMAM 2015) 2015*, Pula, 21-24 September, Croatia
- Fang, M.C., Luo, J.H., Lee, M.L., 2005. A Nonlinear Mathematical Model for Ship Turning Circle Simulation in Waves. *Journal of Ship Research*, Volume 49, pp. 69–79
- Fujiwara, T., Ueno, M., Ikeda, Y., 2006. Cruising Performance of a Large Passenger Ship in Heavy Sea. *In: Proceedings of the 16th International Offshore and Polar Engineering Conference 2006*, California, 28 May–2 June, USA
- Holtrop, J., Mennen, G.G.J., 1982. An Approximate Power Prediction Method. *International Shipbuilding Progress*, Volume 29, pp. 166–170
- IMO, 2002. *Maritime Safety Committee on Ship Maneuverability of International Maritime Organization (IMO)*. MSC &6/23, Resolution MSC 137(36), IMO, London
- Ito, Y., Umeda, N., Kubo, H., 2014. Hydrodynamic Aspects on Vulnerability Criteria for Surf-riding of Ships. *Jurnal Teknologi (Science and Engineering)*, Volume 66, pp. 127–132
- Kijima, K., Katsuno, T., Nakiri, Y., Furukawa, Y., 1990. On the Maneuvering Performance of a Ship with the Parameter of Loading Condition. *Journal Society of Naval Architects of Japan*, Volume 168, pp. 141–148
- Munif, A., Umeda, N., 2000. Modelling Extreme Roll Motions and Capsizing of a Moderate-Speed Ship in Astern Waves. *Journal of Society of Naval Architects of Japan*, Volume 187, pp. 51–58
- Paroka, D., Muhammad, A.H., Asri, S., 2015. Steady State Equilibrium of Ship Maneuvering under Combined Action of Wind and Wave. *Jurnal Teknologi (Science and Engineering)*, Volume 76, pp. 67–75
- Seo, M.G., Kim, Y., 2011. Effect of Ship Motion on Ship Maneuvering in Waves. *In: Proceedings of the 26th International Workshop on Water Waves and Floating Bodies 2011*, Athens, 17-20 April, Greece
- Skejck, R., Faltinsen, O.M., 2008. A Unified Seakeeping and Maneuvering Analysis of Ships in Regular Waves. *Journal of Marine Science and Technology*, Volume 13, pp. 371–394
- Skejck, R., 2013. Ships Maneuvering Simulations in a Seaway – How Close are We to Reality. *In: Proceedings of the International Workshop on Next Generation Nautical Traffic Models 2013*, Delft, 22 November, Netherlands
- Umeda, N., Hashimoto, H., 2002. Qualitative Aspects of Nonlinear Ships Motion in Following and Quartering Seas with High Forward Velocity. *Journal of Marine Science and Technology*, Volume 6, pp. 111–121
- Yoshimura, Y., 2005. Mathematical Model for Maneuvring Ship Motion (MMG Model). *In: Proceedings of Workshop on Mathematical Model for Operations Involving Ship – Ship Interaction 2005*, Tokyo, 4-5 August, Japan
- Yoshimura, Y., Masumoto, Y., 2012. Hydrodynamic Database and Manoeuvring Prediction Method with Medium-high Speed Merchant Ships and Fishing Vessels. *In: Proceedings of MARSIM 2012, International Conference on Marine Simulation and Ship Maneuverability 2012*, Singapore, 23 April, Singapore

Zipfel, J.S., Maksoud, M.A., 2011. A Numerical Model to Determine Ship Maneuvering Motion in Regular Waves. *In: Proceedings of the International Conference on Computational Methods in Marine Engineering (MARINE) 2011, Lisbon, 28–30 September, Portugal*

PREDICTION OF SHIP TURNING MANEUVERING IN CONSTANT WIND AND REGULAR WAVES

ABSTRACT

A ship usually perform maneuvering under influence of external forces and moments such as wind, waves and current. Therefore, the maneuvering behaviour of ships under action of the external forces becomes important to understand. This paper discusses ~~regarding~~ turning maneuvering of an Indonesian ro-ro ferry under influence of combined constant wind and regular waves by using MMG model. The ship position relative to the wave through is added to the original MMG model in order to estimate the exciting forces and moment induced by waves. The results of numerical simulation show that effect of wave height on turning ability is more significant in small wave length and this effect decreases as the wave length increases. Effect of wave length on the sway force and yaw moment is more significant compared with its effect on surge force. The ship initial position relative to the wave through does not have significant effect on turning characteristic and its can be neglected in case for the present subject ship. **Overall, the results of the present work compare well with published data.**

Keywords: Turning; Maneuvering; Wind; Waves

1. INTRODUCTION

Maneuvering performance of ship in the initial design stage is typically predicted in calm water condition. However, the ships usually maneuver in presence of external forces such as wind, wave and current. Therefore, it is important to understand the maneuvering behaviour of ship in combined action of the environment forces.

Some mathematical models for predicting the maneuvering of a ship in wind and wave have been developed by several authors. Fang, et al. (2005) used a 6 DOF nonlinear mathematical model to simulate turning maneuver in waves by taking into account effect of wave encounter frequency on inertia, damping and linear hydrodynamic derivative of forces and moments acting on ship hull. Similar approach was used by Zipfel and Maksoud (2011) to determine ship maneuvering motion in regular waves. The frequency-dependent of hydrodynamic coefficients were transfer into time-dependent by using impuls response function. A unified seakeeping and maneuvering problem with second order regular waves was proposed by Skejic and Faltinsen (2008) to analyse seakeeping and maneuvering of a ship in wave. Here, the wave drift force was estimated by using two-time-scale model in order to separate low-frequency motion (maneuvering motion) and high-frequency motion (seakeeping motion). The same method for estimating the wave drift force was used by Seo and Kim (2011) to predict ship maneuvering in waves by using combination of MMG model for ship maneuvering and seakeeping mathematical model. The second order wave force was also used by Chroni, et al. (2015) to investigate effect of environmental forces on ship maneuvering with 4 DOF mathematical model. This second order wave force was also used by Skejic (2013) to simulate ship maneuvering in irregular waves. The two-time-scale method seems to be un-efficient because solution of the seakeeping motion can be obtained after the maneuvering motion has been solved.

The most practical method for predicting maneuvering behaviour of ship in the initial design stage may be the MMG model because empirical formula for estimating the coefficients of hydrodynamic derivative have been developed (Yoshimura & Masumoto, 2012). Even the original MMG model is pure maneuvering motion problem with 3 DOF mathematical model, some researchers included the roll or heeling effect on the original model to be 4 DOF model. Fujiwara, et al. (2006) and Paroka, et al. (2015) used the MMG model to investigate steady state equilibrium of ship maneuvering in wind and wave.

The discrepancy between the MMG model and the previous mentioned methods is the encounter frequency dependency of forces and moment induced by ship hull. In cases of long wave (the wave length is larger than the ship length) some authors neglected the effect of encounter frequency (Munif & Umeda, 2000; Umeda & Hashimoto, 2002) on hydrodynamic forces and moments induced by ship hull but it was taken into account for forces and moments induced by the waves. With long waves, the heave and pitch motion may not be significant as shown by Munif and Umeda (2000). Following this assumption, the MMG model seems to be applicable to predict the turning characteristic of ship in waves.

This paper discusses regarding turning maneuverability of a small Indonesian ro-ro ferry under combined action of wind and wave by using the modified MMG model. The effect of wave characteristic such as wave height, wave length and the initial position of ship relative to the wave was investigated. For small ships, such wave characteristics may have significant effect on maneuvering performance as indicated by Fang, et al. (2005). The

wind velocity is assumed to be constant and to be uncorrelated with the wave characteristic.

2. RESEARCH METHODOLOGY

In order to describe the present mathematical model, two coordinate systems are used as shown in Figure 1. The fixed coordinate system $0-x_0y_0z_0$ is fixed on the calm water surface and is used to describe the coordinate of ship position and wave propagation, respectively. The second coordinate system is $G-xyz$ with its origin on the ship center of gravity, G , and moving with the ship motion. The symbols u , v and r indicate the surge, sway and yaw velocity, respectively. The drift angle is designated by β and δ for the rudder angle. The propeller thrust is indicated by T_j and the heading angle is indicated by ψ . ψ_w is the angle of wave direction which is assumed to be the same as the wind angle.

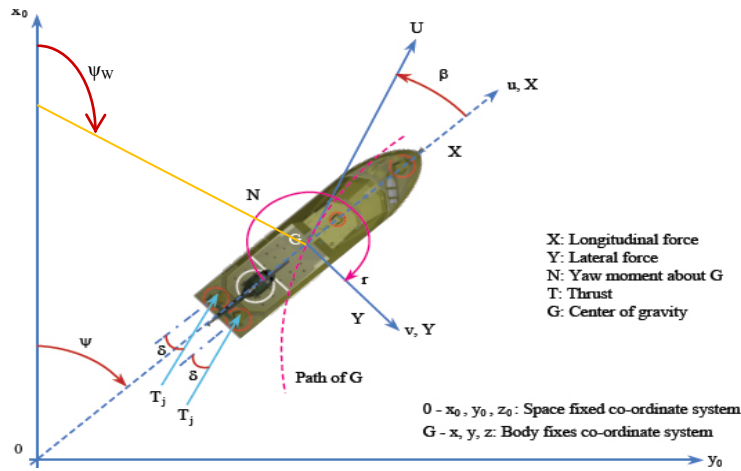


Figure 1 Coordinate system

According to the Newton's second law, the equation of ship maneuvering in combined action of wind and wave is written as (Chroni, et al, 2015; Seo and Kim, 2011):

$$\dot{\xi}_G = u \cos \chi - v \sin \chi \quad (1)$$

$$(m + m_x)(\dot{u} - vr) = X_H + X_P + X_R + X_A + X_W \quad (2)$$

$$(m + m_y)(\dot{v} - ur) = Y_H + Y_R + Y_A + Y_W \quad (3)$$

$$(I_{zz} + J_{zz})\dot{r} = N_H + N_R + N_A + N_W - x_G(Y_H + Y_R + Y_A + Y_W) \quad (4)$$

Here, m , m_x and m_y indicate the ship mass, the added mass in surge and the added mass in sway, respectively. \dot{u} , \dot{v} and \dot{r} are the surge, the sway and the yaw accelerations, respectively. The subscripts H, P, R, A and W indicate the hull, the propeller, the rudder, the wind and the wave forces and moments in surge, sway and yaw directions. The equation (1) is added to the original maneuvering equation in order to avoid the two step solution of combination between seakeeping dan maneuvering motions. Integration of equation (1) over time results in the relative position of ship center of gravity relative to the

wave trough. The equation (1) – (4) therefore can be solved at the same time without separation between seakeeping motion and maneuvering motion. The symbol χ in the equation (1) indicates the angle of wave encounter relative to the ship heading angle.

The hull forces and moment in the equation (1) – (4) are empirically estimated by using polynomial regression of the non-dimensional hydrodynamic derivatives (Yoshimura, 2005; Yoshimura & Masumoto, 2012). The ship resistance is estimated by using Holtrop and Mennen method (Holtrop and Mennen, 1982). The propeller thrust is estimated by using the equation proposed by Kijima, et al. (1990). The thrust coefficient is modelled as a quadratic polynomial equation as function of advance coefficient. The coefficients of this polynomial equation are determined based on statistical data of open water test of B series propeller (Carlton, 2007). The rudder forces and moment are calculated by using formula proposed by Kijima, et al. (1990) for twin propeller and twin rudder.

The forces and moment induced the wave are estimated using formula proposed by Umeda and Hashimoto (2002). A correction factor depending on the block coefficient is used on estimating the wave force in surge direction (Ito, et al., 2014). The equation for estimating the wave force in surge and sway direction as well as the wave moment in yaw direction are shown in the equations (5) – (7).

$$X_W = -\alpha\rho g\zeta_W k \cos\chi \int_{AE}^{FE} C_1(x) S(x) e^{-kd(x)/2} \times \sin(k(\xi_G + x \cos\chi)) dx \quad (5)$$

$$\begin{aligned} Y_W = & \rho g\zeta_W k \sin\chi \int_{AE}^{FE} C_1(x) S(x) e^{-kd(x)/2} \times \sin(k(\xi_G + x \cos\chi)) dx + \zeta_W \omega \omega_e \\ & \sin\chi \int_{AE}^{FE} \rho S_y(x) e^{-kd(x)/2} \times \sin(k(\xi_G + x \cos\chi)) dx - \zeta_W \omega u \sin\chi \\ & \times [\rho S_y(x) e^{-kd(x)/2} \cos(k(\xi_G + x \cos\chi))]_{AE}^{FE} \\ & + (1 + a_H) \frac{\rho}{2} A_R f_\alpha \varepsilon_R (1 - w_p) u \sqrt{1 + \kappa_P \frac{8K_T}{\pi J^2} u_{WR}} \end{aligned} \quad (6)$$

$$\begin{aligned} N_W = & \rho g\zeta_W \sin\chi \int_{AE}^{FE} C_1(x) S(x) e^{-kd(x)/2} \times x \sin(k(\xi_G + x \cos\chi)) dx + \zeta_W \omega \omega_e \\ & \times \sin\chi \int_{AE}^{FE} \rho S_y(x) e^{-kd(x)/2} x \sin(k(\xi_G + x \cos\chi)) dx \\ & + \zeta_W \omega u \sin\chi \int_{AE}^{FE} \rho S_y(x) e^{-kd(x)/2} \times \cos(k(\xi_G + x \cos\chi)) dx \\ & - \zeta_W \omega u \sin\chi \\ & \times [\rho S_y(x) e^{-kd(x)/2} x \cos(k(\xi_G + x \cos\chi))]_{AE}^{FE} \\ & + (x_R + a_H x_H) \frac{\rho}{2} A_R f_\alpha \varepsilon_R (1 - w_p) u \sqrt{1 + \kappa_P \frac{8K_T}{\pi J^2} u_{WR}} \end{aligned} \quad (7)$$

Here, α is the correction factor depend on the block coefficient. ζ_w , k , $S(x)$, $d(x)$ are the wave amplitude, wave number, area and draught of section at longitudinal distance x from midship, respectively. The symbols ω , ω_e and $S_y(x)$ indicate the wave frequency, the wave encounter frequency and the added mass of section in sway direction. x_R , x_H , a_H and A_R are the longitudinal position of rudder from midship, the longitudinal position of center of interaction force between hull and rudder, the interaction factor between hull and rudder as well as the rudder area, respectively. The rudder coefficient is indicated by f_α and the effective propeller wake fraction is designated by w_p . ϵ_R , κ_p , J and K_T are the wake ratio between propeller and rudder, the interaction factor between propeller and rudder, the advance coefficient and the thrust coefficient respectively. $C_1(x)$ and v_{WR} are calculated by using the equation (8) and the equation (9), respectively.

$$C_1(x) = \frac{\sin(k \sin \chi \cdot B(x)/2)}{(k \sin \chi \cdot B(x)/2)} \quad (8)$$

$$v_{WR} = \zeta_w \omega \sin \chi \exp(-kz_R) \cos(2\pi \xi_G/\lambda + kx_R \cos \chi) \quad (9)$$

Here, $B(x)$, z_R and λ are the breadth of section, the center of rudder from baseline and wave length, respectively.

The wind forces and moment in surge, sway and yaw direction are calculated using empirical formula proposed by Fujiwara, et al. (2006). The angle of wind attack is determined based on the wind direction and the ship heading angle. The wave angle is assumed to be the same as the wind angle.

Ship data

The subject ship using in the numerical simulation is an Indonesian ro-ro ferry with principle dimension shown in Table 1 and her propeller and rudder geometry are shown in Tabel 2, respectively.

Table 1 Principle dimension of the subject ship

Items	Dimension
Length overall (L_{OA})	36.40 m
Length between perpendicular (L_{BP})	31.50 m
Breadth (B)	8.70 m
Height (H)	2.65 m
Draught (T)	1.65 m
Ship speed (V_S)	10.5 knot
Lateral projected windage area (A_L)	36.40 m ²
Transverse projected windage area (A_F)	93.61 m ²
Lateral projected area of superstructure (A_{OD})	187.21 m ²
Center of windage are from midship (C)	-0.558 m
Vertical center of A_L (H_C)	0.720 m
Vertical center of A_{OD} (H_L)	4.930 m
Height of transverse projected area (H_{BR})	10.73 m

Table 2 Propeller and rudder geometry

Items	Dimension
Number of propeller	2
Propeller blade (Z)	4
Propeller diameter (D_P)	1.10 m
Propeller revolution (n)	8.58 rps
Transverse position propeller (y_P)	± 2.55 m
Long. position propeller (x_P)	15.50 m
Rudder area (A_R)	2.08 m ²
Rudder coefficient (f_Δ)	2.10
Transverse rudder position (y_R)	± 2.55 m
Long. Rudder position (x_R)	15.75 m

3. RESULTS

The numerical results of turning maneuvering simulation for wave height of 0.50 meters and 0.75 meters are shown in Figure 2a for wave length the same as the ship length and in Figure 2b for the wave length of 50.0 meters, respectively. The wind velocity for all wave characteristics is 6.75 m/s (beaufort scale 4). The turning diameter decreases as the wave height increases. The second turning circle moves away from the first one with longer distance for larger wave height. A similiar result is obtained for larger wave length. The distance of turning circles movement becomes smaller when the wave length increases. These results show that the wave height has more significant effect on the ship turning maneuvering for smaller wave length compared with the longer one.

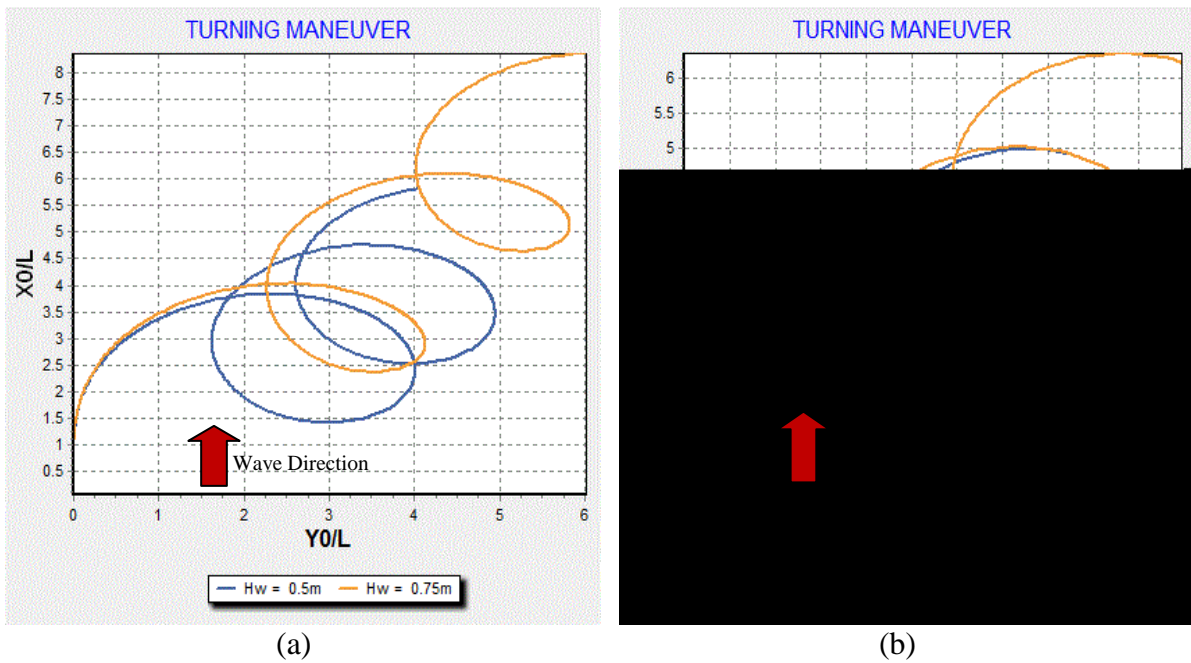


Figure 2 Trajectory of turning circle

The surge and the sway velocities of ship during the turning simulation are shown in Figure 3a for the wave length the same as the ship length with wave height of 0.50 meters and 0.75 meters. For the wave length of 50.0 meters with the same wave heights are shown in Figure 3b. The **yaw rate** for wave length the same as the ship length with the same wave heights are shown in Figure 3c and in Figure 3d for the wave length of 50.0 meters. The surge and the sway velocities oscillate depend on the angle of wave encounter relative to the ship heading angle. The minimum velocities occur in cases of heading wave (the angle of wave encounter is 0.0 degrees) and its maximum in following wave (the angle of wave encounter is 180.0 degrees). An oscillation of surge, sway and yaw motions also occurs in all conditions of wave height and wave length. These are purely affected by the ship position relative to the wave. Oscillation of surge velocity become significant in heading and following waves, while the oscillation of sway velocity becomes significant in cases of beam seas.

Alteration of surge velocity when the ship in following waves and in heading waves is significantly increase as the wave height increases. However, effect of wave height on the alteration of surge velocity decreases in cases of larger wave length. The same trend as the surge velocity alteration is also obtained for the sway velocity. The **yaw rate** are more sensitive to the alteration of angle of wave encounter compared with the surge and sway velocities. This is because the yaw moment exist even in beam seas as result of non-homogenous of hull form between the after part and the forward part. The minimum **yaw rate** will occur in cases of following and heading waves but such condition appears in very short time in case of turning maneuver.

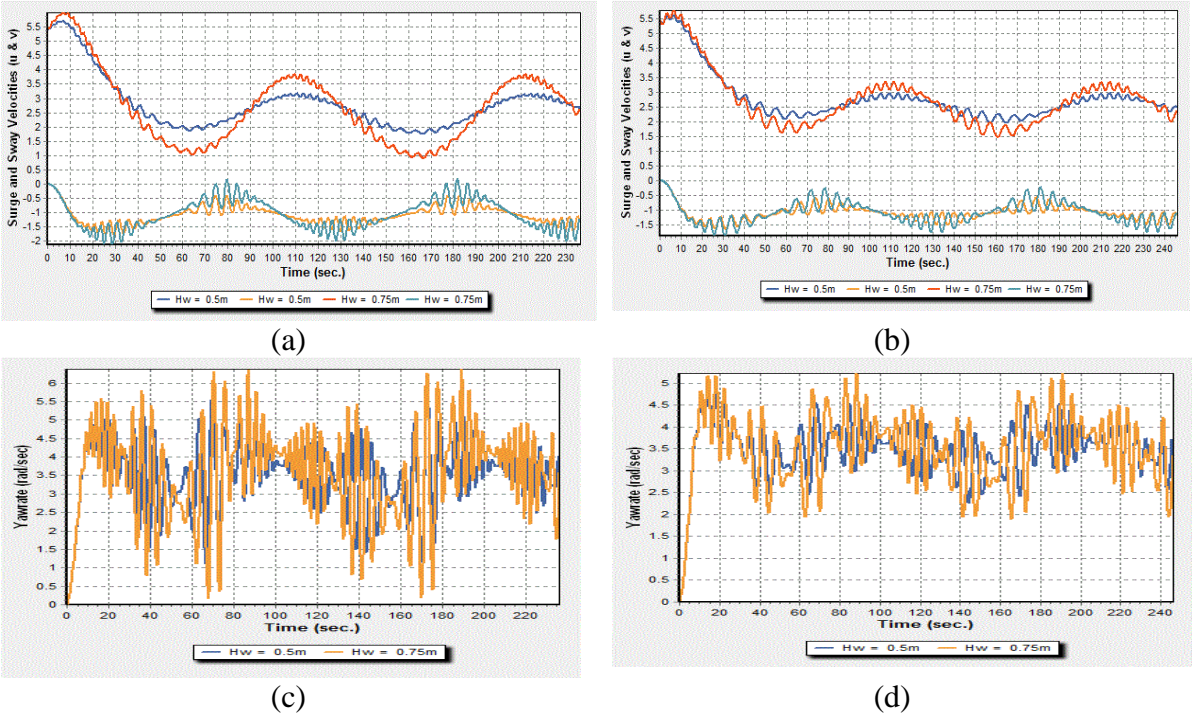


Figure 3 Ship motion during turning maneuver

Figures 4a – 4f show the nondimensional forces and moment in surge, sway and yaw direction with the two different wave height and the two different wave length. The left figures are for the wave length the same as the ship length and the right figures are the forces and moment for the wave length of 50.0 meters. Effect of wave length on force in surge direction is not significant compared with its effect on force in sway direction and on moment in yaw direction. Therefore, the characteristic of turning trajectory significantly change as the wave length increase for the same wave height.

The wave height significantly affect the forces and moment even for wave length of 50.0 meters. However, effect of wave height on the forces and moment tends to decrease as the wave length increases. **Similar** with the sway velocity, the force in sway direction is **negligibly** small in heading and following waves and becomes maximum in beam waves. The same trend is obtained for surge force in angle of wave encounter of 90.0 degrees and 270.0 degrees (beam waves). The minimum value on yaw moment occur in cases of heading and following waves. The yaw moment is still significant in beam wave condition as effect of longitudinal center of buoyancy.

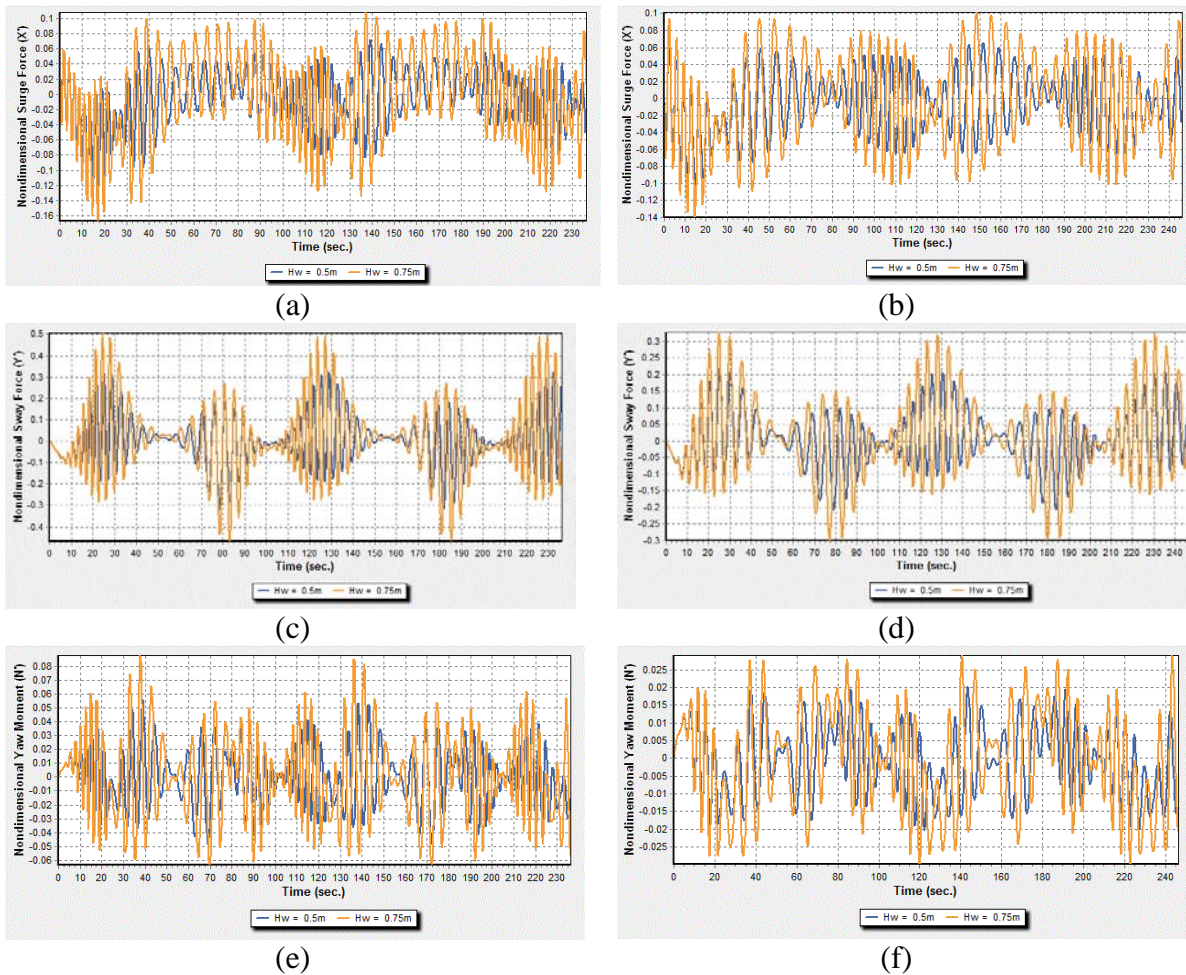


Figure 4 Resultant of forces and moment acting on ship hull during turning maneuver

4. DISCUSSION

The obtained turning trajectory for two different wave height and wave length are similar with the results of previous study (Fang, et al., 2005; Seo & Kim, 2011; Skejck, 2013; Chroni, et al., 2015). The turning circle becomes smaller as the wave height increases for both wave length of the same as the ship length and 50.0 meters. The turning circle for smaller wave length is larger than the larger one. It shows that the drift motion significantly increases when the wave height increases and it tends to decrease as the wave length increases. Figure 3 shows that the surge velocity becomes minimum in beam seas, in which the sway velocity is maximum. The larger yaw moment for larger wave height and smaller wave length will also induce faster turning motion compared with smaller wave height and larger wave length. These turning motion characteristics also induce longer distance of movement between the first turning circle and the second turning circle as shown in Figure 2.

Fang, et al. (2005) shown that both the surge and the sway velocities oscillate depend on the angle of wave encounter relative to the ship heading angle. The same results is obtained in the present study. A more significant amplitude of surge and sway velocities oscillation has also been identified in the transition from the following waves to the beam waves and from the beam waves to the heading waves and so on. This phenomenon did not appear in study conducted by Fang, et al. (2005). A similar results with the present study was obtained by Skjick (2013) for ship turning in irregular waves. This phenomenon may depend on the wave characteristics compared with the ship geometry. It may disappear in cases of large ships compared to the wave height and it may arise for small ship as the subject of present study even for small wave height. Figure 3(a) and Figure 3(b) show that the oscillation due to the transition from the following waves to the beam waves and so on decreases when the wave length increases. It may disappear for smaller wave height and larger wave length.

The initial position of ship relative to the wave does not have significant effect of turning maneuvering of ship in waves. The same results was obtained by Fang, et al. (2005) but they stated that effect of the initial position relative to the wave may be significant for small ships. That effect is not obtained in the present study. The initial position of ship relative the wave surface does not significantly affect the forces and moment induced by the wave during turning maneuver. The initial position makes only changing phase of the forces and moment. Therefore its effect to the turning maneuver becomes negligibly small.

The subject ship cannot perform turning maneuver in wave height of 1.0 meters and the wave length the same as the ship length or smaller. The numerical simulation can be conducted for the wave height of 1.0 meters when the wave length is larger than the ship length. However, the turning circle becomes very small and it seems to be unrealistic in practical point of view. The very small turning circle occurs due to large drift motion with small surge velocity in beam waves condition up to heading waves condition during turning simulation. The large drift motion may occurs due to small draught of the subject ship so that the hydrodynamic damping force in sway direction becomes smaller compared with the ship with larger draught. This had been shown by Chroni, et al. (2015) with wave length of a half of ship length, wave height of 5.50 meters and wind velocity of 19.0 m/s (Beaufort Scale 8). The subject ship used in their simulation was larger than that used in

the present simulation. Therefore, the weather condition to perform sea trial in guidance of International Maritime Organization (IMO) (2002) may not be applied for small ships.

5. CONCLUSION

The mathematical model for predicting turning maneuvering in constant wind and regular wave has been developed by using the 3 DOF of MMG model. A mathematical model to describe the ship position relative to the wave profile as function of ship velocity relative to the wave celerity has been included in the original MMG model. Therefore the mathematical model can be simultaneously solved to obtain maneuvering characteristics. Based on the numerical results for a small Indonesian ro-ro ferry, some conclusion can be remarked as follows:

1. Effect of wave height on ship turning maneuver is more significant in small wave length. This effect decreases as the wave length increases.
2. The sway force and yaw moment of wave significantly decrease when the wave length increases. Alteration of surge force due to increasing the wave length is smaller compared with the sway force and yaw moment. This means that the drift motion may have an important role on ship maneuvering in short waves.
3. The initial position of ship relative to the wave does not have significant effect on ship turning maneuver and its effect can be neglected in case of the present subject ship.

6. ACKNOWLEDGEMENT

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7. REFERENCES

- Carlton, J.S., (2007), Marine Propellers and Propulsion, Second Edition, Elsevier, Ltd., pp. 103 – 106.
- Chroni, D., Liu, S., Plessas, T., Papanikolaou, A., (2015), Simulation of the maneuvering behaviour of ships under the influence of environmental forces. *In: Proceedings of the 16th International Congress of the International Maritime Association of the Mediterranean (IMAM 2015) 2015, Pula, 21 – 24 September, Croatia.*
- Fang, M.C., Luo, J.H., Lee, M.L., (2005), A nonlinear mathematical model for ship turning circle simulation in waves, *Journal of Ship Research, Volume 49, pp. 69 – 79.*
- Fujiwara, T., Ueno, M., Ikeda, Y., (2006), Cruising performance of a large passenger ship in heavy sea. *In: Proceedings of the 16th International Offshore and Polar Engineering Conference 2006, California, 28 May – 2 June, USA.*
- Holtrop, J and Mennen, G.G.J., (1982), An approximate power prediction method, *International Shipbuilding Progress, Volume 29, pp. 166 – 170.*
- IMO, (2002), Maritime Safety Committee on Ship Maneuverability of International Maritime Organization (IMO), MSC &6/23, Resolution MSC 137(36), IMO, London.

- Ito, Y., Umeda, N., Kubo, H., (2014), Hydrodynamic aspects on vulnerability criteria for surf-riding of ships, *Jurnal Teknologi (Science and Engineering)* Volume 66, pp. 127 – 132.
- Kijima, K., Katsuno, T., Nakiri, Y., Furukawa, Y., (1990), On the maneuvering performance of a ship with the parameter of loading condition, *Journal Society of Naval Architects of Japan*, Volume 168, pp. 141 – 148.
- Munif, A. and Umeda, N., (2000), Modelling extreme roll motions and capsizing of a moderate-speed ship in astern waves, *Journal of Society of Naval Architects of Japan*, Volume 187, pp. 51 – 58.
- Paroka, D., Muhammad, A.H., Asri, S., (2015), Steady state equilibrium of ship maneuvering under combined action of wind and wave, *Jurnal Teknologi (Science and Engineering)*, Volume 76, pp. 67 – 75.
- Seo, M.G. and Kim, Y., (2011), Effect of ship motion on ship maneuvering in waves. *In: Proceedings of the 26th International Workshop on Water Waves and Floating Bodies 2011*, Athens, 17 – 20 April, Greece.
- Skejck, R. and Faltinsen, O.M., (2008), A unified seakeeping and maneuvering analysis of ships in regular waves, *Journal of Marine Science and Technology*, Volume 13, pp. 371 – 394.
- Skejck, R., (2013), Ships maneuvering simulations in a seaway – How close are we to reality, *In: Proceedings of the International Workshop on Next Generation Nautical Traffic Models 2013*, Delf, 22 Nopember, Netherlands.
- Umeda, N. and Hashimoto, H., (2002), Qualitative aspects of nonlinear ships motion in following and quartering seas with high forward velocity, *Journal of Marine Science and Technology*, Volume 6, pp. 111 – 121.
- Yoshimura, Y., (2005), Mathematical model for maneuvering ship motion (MMG Model). *In: Proceedings of Workshop on Mathematical Model for Operations Involving Ship – Ship Interaction 2005*, Tokyo, 4 – 5 August, Japan.
- Yoshimura, Y. and Masumoto, Y., (2012), Hydradynamic database and maneuvering prediction method with medium – high speed merchant ships and fishing vessels. *In: Proceedings of MARSIM 2012, International Conference on Marine Simulation and Ship Maneuverability 2012*, Singapore, 23 April, Singapore.
- Zipfel, J.S and Maksoud, M.A., (2011), A numerical model to determine ship maneuvering motion in regular waves, *In: Proceedings of International Conference on Computational Methods in Marine Engineering (MARINE) 2011*, Lisbon, 28 – 30 September, Portugal.



Reviewer's Guide

PART A: Editorial Office Only

SECTION I

Reviewer's Name:	
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Manuscript Number:	IJTech-07-140
Title:	PREDICTION OF SHIP TURNING MANEUVERING IN CONSTANT WIND AND REGULAR WAVES

PART B: Reviewer Only

SECTION II: Comments per Section of Manuscript

General comment:	OK
Introduction:	OK
Methodology:	OK
Results:	OK
Discussion:	OK
Bibliography/References:	OK
Others:	A ship usually perform maneuvering under influence of external forces and moments such as wind, waves and current. Therefore, the maneuvering behaviour of ships under action of the external forces becomes important to understand. This paper discusses turning maneuvering of an Indonesian ro-ro ferry under influence of combined constant wind and regular waves by using MMG model. The ship position relative to the wave through is added to the original MMG model in order to estimate the exciting forces and moment induced by waves. The results of numerical simulation show that effect of wave height on turning ability is more significant in small wave

length and this effect decreases as the wave length increases. Effect of wave length on the sway force and yaw moment is more significant compared with its effect on surge force. The ship initial position relative to the wave through does not have significant effect on turning characteristic and it can be neglected in case of the present subject ship. Overall, the results of the present work compare well with published data.

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Originality:	2
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PREDICTION OF SHIP TURNING MANEUVERING IN CONSTANT WIND AND REGULAR WAVES

IJTech-07-140

ABSTRACT

A ship usually perform maneuvering under influence of external forces and moments such as wind, waves and current. Therefore, the maneuvering behaviour of ships under action of the external forces becomes important to understand. This paper discusses turning maneuvering of an Indonesian ro-ro ferry under influence of combined constant wind and regular waves by using MMG model. The ship position relative to the wave through is added to the original MMG model in order to estimate the exciting forces and moment induced by waves. The results of numerical simulation show that effect of wave height on turning ability is more significant in small wave length and this effect decreases as the wave length increases. Effect of wave length on the sway force and yaw moment is more significant compared with its effect on surge force. The ship initial position relative to the wave through does not have significant effect on turning characteristic and it can be neglected in case of the present subject ship. Overall, the results of the present work compare well with published data.

Keywords: Turning; Maneuvering; Wind; Waves

1. INTRODUCTION

Maneuvering performance of ship in the initial design stage is typically predicted in calm water condition. However, the ships usually maneuver in presence of external forces such as wind, wave and current. Therefore, it is important to understand the maneuvering behaviour of ship in combined action of the environment forces.

Some mathematical models for predicting the maneuvering of a ship in wind and wave have been developed by several authors. Fang, et al. (2005) used a 6 DOF nonlinear mathematical model to simulate turning maneuver in waves by taking into account effect of wave encounter frequency on inertia, damping and linear hydrodynamic derivative of forces and moments acting on ship hull. Similiar approach was used by Zipfel and Maksoud (2011) to determine ship maneuvering motion in regular waves. The frequency-dependent of hydrodynamic coefficients were transfer into time-dependent by using impuls response function. A unified seakeeping and maneuvering problem with second order regular waves was proposed by Skejic and Faltinsen (2008) to analyse seakeeping and maneuvering of a ship in wave. Here, the wave drift force was estimated by using two-time-scale model in order to separate low-frequency motion (maneuvering motion) and high-frequency motion (seakeeping motion). The same method for estimating the wave drift force was used by Seo and Kim (2011) to predict ship maneuvering in waves by using combination of MMG model for ship maneuvering and seakeeping mathematical model. The second order wave force was also used by Chroni, et al. (2015) to investigate effect of environmental forces on ship maneuvering with 4 DOF mathematical model. This second order wave force was also used by Skejic (2013) to simulate ship maneuvering in irregular waves. The two-time-scale method seems to be un-efficient because solution of the seakeeping motion can be obtained after the maneuvering motion has been solved.

The most practical method for predicting maneuvering behaviour of ship in the initial design stage may be the MMG model because empirical formula for estimating the coefficients of hydrodynamic derivative have been developed (Yoshimura & Masumoto, 2012). Even the original MMG model is pure maneuvering motion problem with 3 DOF mathematical model, some researchers included the roll or heeling effect on the original model to be 4 DOF model. Fujiwara, et al. (2006) and Paroka, et al. (2015) used the MMG model to investigate steady state equilibrium of ship maneuvering in wind and wave.

The discrepancy between the MMG model and the previous mentioned methods is the encounter frequency dependency of forces and moment induced by ship hull. In cases of long wave (the wave length is larger than the ship length) some authors neglected the effect of encounter frequency (Munif & Umeda, 2000; Umeda & Hashimoto, 2002) on hydrodynamic forces and moments induced by ship hull but it was taken into account for forces and moments induced by the waves. With long waves, the heave and pitch motion may not be significant as shown by Munif and Umeda (2000). Following this assumption, the MMG model seems to be applicable to predict the turning characteristic of ship in waves. However, it is necessary to add a mathematic equation into the MMG model to describe the ship position relative to the wave. This is important because the forces and the moments induced by the wave depend on the ship position in the wave surface.

This paper discusses regarding turning maneuverability of a small Indonesian ro-ro ferry under combined action of wind and wave by using the modified MMG model. The effect of wave characteristic such as wave height, wave length and the initial position of ship

relative to the wave **was** investigated. For small ships, such wave characteristics may have significant effect on maneuvering performance as indicated by Fang, et al. (2005). The wind velocity is assumed to be constant and to be uncorrelated with the wave characteristic.

2. RESEARCH METHODOLOGY

In order to describe the present mathematical model, two coordinate systems are used as shown in Figure 1. The fixed coordinate system $0-x_0y_0z_0$ is fixed on the calm water surface and **it** is used to describe the coordinate of ship position and wave propagation, respectively. The second coordinate system is $G-xyz$ with its origin on the ship center of gravity, G , and moving with the ship motion. The symbols u , v and r indicate the surge, sway and yaw velocity, respectively. The drift angle is designated by β and δ for the rudder angle. The propeller thrust is indicated by T_j and the heading angle is indicated by ψ . ψ_w is the angle of wave direction which is assumed to be the same as the wind angle.

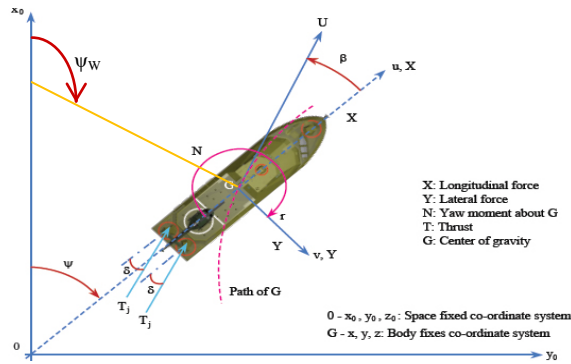


Figure 1 Coordinate system

According to the Newton's second law, the equation of ship maneuvering in combined action of wind and wave **following the MMG model** is written as (Fujiwara, et al, 2006):

$$\ddot{\xi}_G = u \cos \chi - v \sin \chi \quad (1)$$

$$(m + m_x)(\dot{u} - vr) = X_H + X_P + X_R + X_A + X_W \quad (2)$$

$$(m + m_y)(\dot{v} - ur) = Y_H + Y_R + Y_A + Y_W \quad (3)$$

$$(I_{zz} + J_{zz})\dot{r} = N_H + N_R + N_A + N_W - x_G(Y_H + Y_R + Y_A + Y_W) \quad (4)$$

Here, m , m_x and m_y indicate the ship mass, the added mass in surge and the added mass in sway, respectively. \dot{u} , \dot{v} and \dot{r} are the surge, the sway and the yaw accelerations, respectively. The subscripts H, P, R, A and W indicate the hull, the propeller, the rudder, the wind and the wave forces and moments in surge, sway and yaw directions. The equation (1) is added to the **MMG model (equation (2) – (4))** in order to **take into account effect of ship position relative to the wave surface on wave forces and moments. That equation was used by Fang, et al (2005) as well as Umeda and Hashimoto (2002) to estimate wave forces and moments acting on ship hull.** Integration of equation (1) over time results in the relative position of ship center of gravity relative to the wave trough.

The equation (1) – (4) therefore can be solved at the same time without separation between seakeeping and maneuvering motions. The symbol χ in the equation (1) indicates the angle of wave encounter relative to the ship heading angle.

The hull forces and moment in the equation (2) – (4) are empirically estimated by using polynomial regression of the non-dimensional hydrodynamic derivatives (Yoshimura, 2005; Yoshimura & Masumoto, 2012). The ship resistance is estimated by using Holtrop and Mennen method (Holtrop and Mennen, 1982). The propeller thrust is estimated by using the equation proposed by Kijima, et al. (1990). The thrust coefficient is modelled as a quadratic polynomial equation as function of advance coefficient. The coefficients of this polynomial equation are determined based on statistical data of open water test for B series propeller (Carlton, 2007). The rudder forces and moment are calculated by using formula proposed by Kijima, et al. (1990) for twin propeller and twin rudder.

The forces and moment induced the wave are estimated by using formula proposed by Umeda and Hashimoto (2002). A correction factor depending on the block coefficient is used on estimating the wave force in surge direction (Ito, et al., 2014). The equation for estimating the wave force in surge and sway direction as well as the wave moment in yaw direction are shown in the equations (5) – (7).

$$X_W = -\alpha\rho g\zeta_W k \cos\chi \int_{AE}^{FE} C_1(x) S(x) e^{-kd(x)/2} \times \sin(k(\xi_G + x \cos\chi)) dx \quad (5)$$

$$\begin{aligned} Y_W = & \rho g\zeta_W k \sin\chi \int_{AE}^{FE} C_1(x) S(x) e^{-kd(x)/2} \times \sin(k(\xi_G + x \cos\chi)) dx + \zeta_W \omega \omega_e \\ & \sin\chi \int_{AE}^{FE} \rho S_y(x) e^{-kd(x)/2} \times \sin(k(\xi_G + x \cos\chi)) dx - \zeta_W \omega u \sin\chi \\ & \times [\rho S_y(x) e^{-kd(x)/2} \cos(k(\xi_G + x \cos\chi))]_{AE}^{FE} \\ & + (1 + a_H) \frac{\rho}{2} A_R f_\alpha \varepsilon_R (1 - w_p) u \sqrt{1 + \kappa_P \frac{8K_T}{\pi J^2} u_{WR}} \end{aligned} \quad (6)$$

$$\begin{aligned} N_W = & \rho g\zeta_W \sin\chi \int_{AE}^{FE} C_1(x) S(x) e^{-kd(x)/2} \times x \sin(k(\xi_G + x \cos\chi)) dx + \zeta_W \omega \omega_e \\ & \times \sin\chi \int_{AE}^{FE} \rho S_y(x) e^{-kd(x)/2} x \sin(k(\xi_G + x \cos\chi)) dx \\ & + \zeta_W \omega u \sin\chi \int_{AE}^{FE} \rho S_y(x) e^{-kd(x)/2} \times \cos(k(\xi_G + x \cos\chi)) dx \\ & - \zeta_W \omega u \sin\chi \\ & \times [\rho S_y(x) e^{-kd(x)/2} x \cos(k(\xi_G + x \cos\chi))]_{AE}^{FE} \\ & + (x_R + a_H x_H) \frac{\rho}{2} A_R f_\alpha \varepsilon_R (1 - w_p) u \sqrt{1 + \kappa_P \frac{8K_T}{\pi J^2} u_{WR}} \end{aligned} \quad (7)$$

Here, α is the correction factor depend on the block coefficient. ζ_w , k , $S(x)$, $d(x)$ are the wave amplitude, wave number, area and draught of section at longitudinal distance x from midship, respectively. The symbols ω , ω_e and $S_y(x)$ indicate the wave frequency, the wave encounter frequency and the added mass of section in sway direction. x_R , x_H , a_H and A_R are the longitudinal position of rudder from midship, the longitudinal position of center of interaction force between hull and rudder, the interaction factor between hull and rudder as well as the rudder area, respectively. The rudder coefficient is indicated by f_α and the effective propeller wake fraction is designated by w_p . ϵ_R , κ_p , J and K_T are the wake ratio between propeller and rudder, the interaction factor between propeller and rudder, the advance coefficient and the thrust coefficient respectively. $C_1(x)$ and v_{WR} are calculated by using the equation (8) and the equation (9), respectively.

$$C_1(x) = \frac{\sin(k \sin \chi \cdot B(x)/2)}{(k \sin \chi \cdot B(x)/2)} \quad (8)$$

$$v_{WR} = \zeta_w \omega \sin \chi \exp(-kz_R) \cos(2\pi \xi_G/\lambda + kx_R \cos \chi) \quad (9)$$

Here, $B(x)$, z_R and λ are the breadth of section, the center of rudder from baseline and wave length, respectively.

The wind forces and moment in surge, sway and yaw direction are calculated using empirical formula proposed by Fujiwara, et al. (2006). The angle of wind attack is determined based on the wind direction and the ship heading angle. The wave angle is assumed to be the same as the wind angle.

Ship data

The subject ship using in the numerical simulation is an Indonesian ro-ro ferry with principle dimension shown in Table 1 and her propeller and rudder geometry are shown in Tabel 2, respectively.

Table 1 Principle dimension of the subject ship

Items	Dimension
Length overall (L_{OA})	36.40 m
Length between perpendicular (L_{BP})	31.50 m
Breadth (B)	8.70 m
Height (H)	2.65 m
Draught (T)	1.65 m
Ship speed (V_S)	10.5 knot
Lateral projected windage area (A_L)	36.40 m ²
Transverse projected windage area (A_F)	93.61 m ²
Lateral projected area of superstructure (A_{OD})	187.21 m ²
Center of windage are from midship (C)	-0.558 m
Vertical center of A_L (H_C)	0.720 m
Vertical center of A_{OD} (H_L)	4.930 m
Height of transverse projected area (H_{BR})	10.73 m

Table 2 Propeller and rudder geometry

Items	Dimension
Number of propeller	2
Propeller blade (Z)	4
Propeller diameter (D_P)	1.10 m
Propeller revolution (n)	8.58 rps
Transverse position propeller (y_P)	± 2.55 m
Long. position propeller (x_P)	15.50 m
Rudder area (A_R)	2.08 m ²
Rudder coefficient (f_Δ)	2.10
Transverse rudder position (y_R)	± 2.55 m
Long. Rudder position (x_R)	15.75 m

3. RESULTS

The numerical results of turning maneuvering simulation for wave height of 0.50 meters and 0.75 meters are shown in Figure 2a for wave length the same as the ship length and in Figure 2b for the wave length of 50.0 meters, respectively. The wind velocity for all wave characteristics is 6.75 m/s (beaufort scale 4). The turning diameter decreases as the wave height increases. The second turning circle moves away from the first one with longer distance for larger wave height. A similiar result is obtained for larger wave length. The distance of turning circles movement becomes smaller when the wave length increases. These results show that the wave height has more significant effect on the ship turning maneuvering for smaller wave length compared with the longer one.

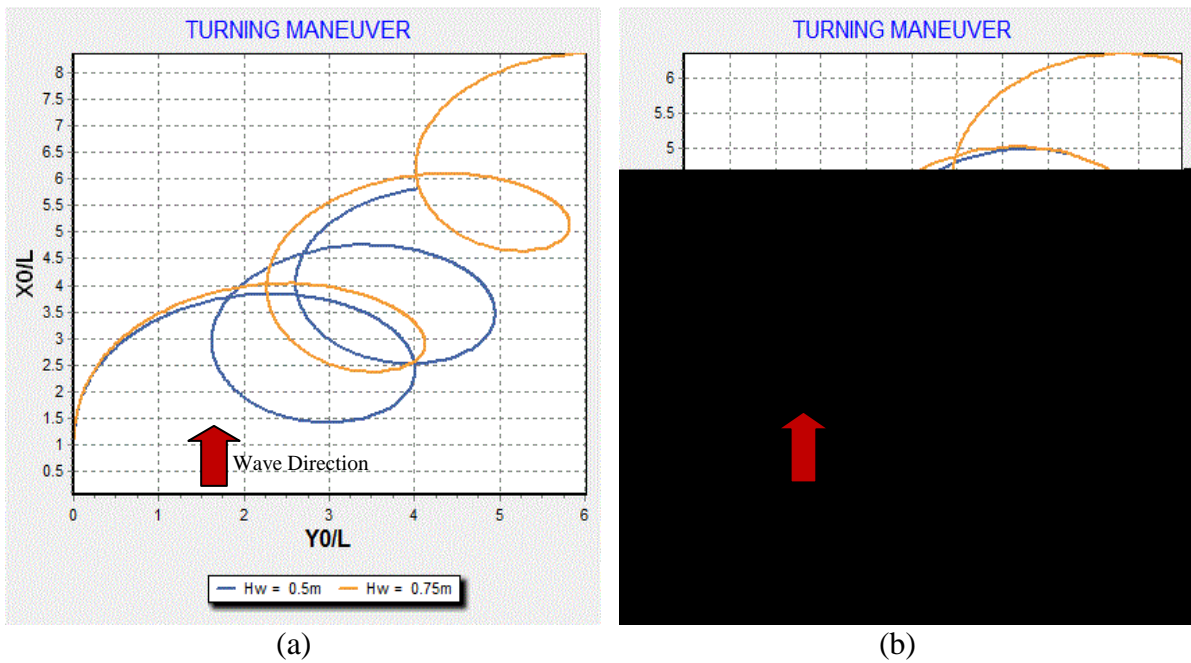


Figure 2 Trajectory of turning circle

The surge and the sway velocities of ship during the turning simulation are shown in Figure 3a for the wave length the same as the ship length with wave height of 0.50 meters and 0.75 meters. For the wave length of 50.0 meters with the same wave heights are shown in Figure 3b. The **yaw rate** for wave length the same as the ship length with the same wave heights are shown in Figure 3c and in Figure 3d for the wave length of 50.0 meters. The surge and the sway velocities oscillate depend on the angle of wave encounter relative to the ship heading angle. The minimum velocities occur in cases of heading wave (the angle of wave encounter is 0.0 degrees) and its maximum in following wave (the angle of wave encounter is 180.0 degrees). The oscillation of surge, sway and yaw motions also occurs in all conditions of wave height and wave length. These are purely affected by the ship position relative to the wave. Oscillation of surge velocity become significant in heading and following waves, while the oscillation of sway velocity becomes significant in cases of beam seas. Therefore the phase between surge and sway motions becomes 90.0 degrees as shown in Figure 3(a) and Figure 3(b).

Alteration of surge velocity when the ship in following waves and in heading waves is significantly increase as the wave height increases. However, effect of wave height on the alteration of surge velocity decreases in cases of larger wave length. The same trend as the surge velocity alteration is also obtained for the sway velocity. The **yaw rate** are more sensitive to the alteration of **wave direction** compared with the surge and sway velocities. This is because the yaw moment exist even in beam seas as result of non-homogenous of hull form between the after part and the forward part. The minimum **yaw rate** will occur in cases of following and heading waves but such condition appears in very short time in case of turning maneuver.

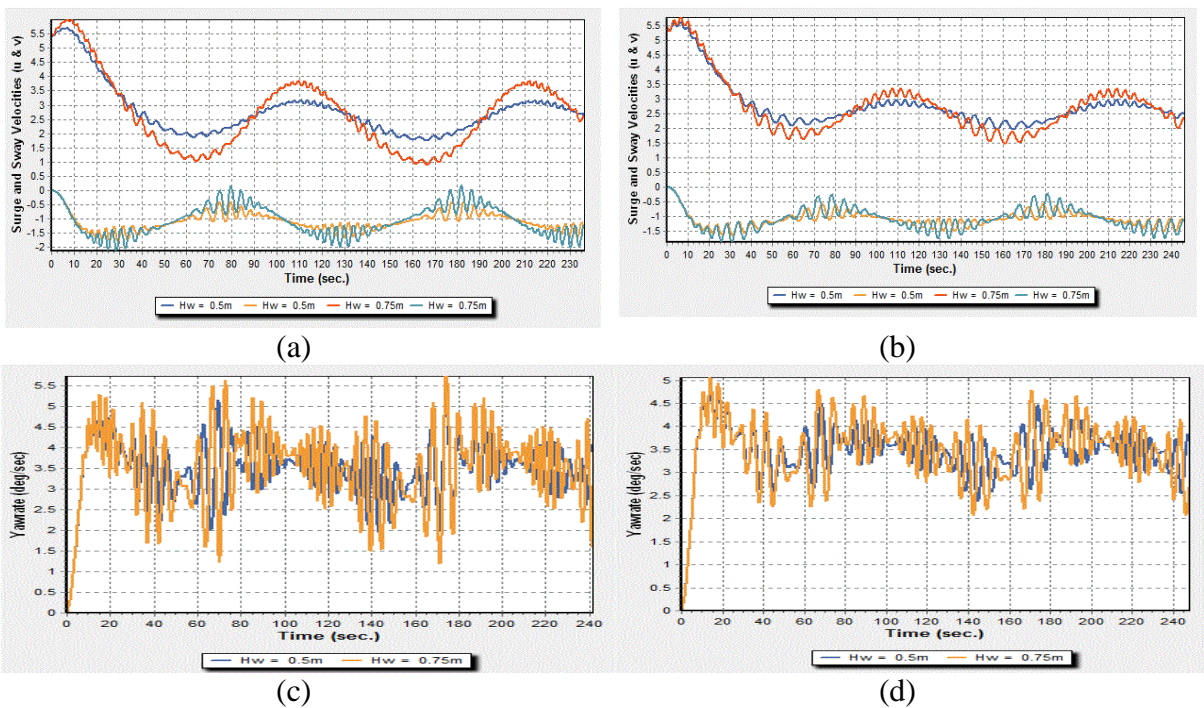


Figure 3 Ship motion during turning maneuver

Figures 4a – 4f show the nondimensional forces and moment in surge, sway and yaw direction with the two different wave height and the two different wave length. The left figures are for the wave length the same as the ship length and the right figures are the forces and moment for the wave length of 50.0 meters. Effect of wave length on force in surge direction is not significant compared with its effect on force in sway direction and on moment in yaw direction. Therefore, the characteristic of turning trajectory significantly change as the wave length increase for the same wave height.

The wave height significantly affect the forces and moment even for wave length of 50.0 meters. However, effect of wave height on the forces and moment tends to decrease as the wave length increases. **Similar** with the sway velocity, the force in sway direction is **negligibly** small in heading and following waves and becomes maximum in beam waves. The same trend is obtained for surge force in angle of wave encounter of 90.0 degrees and 270.0 degrees (beam waves). The minimum value on yaw moment occur in cases of heading and following waves. The yaw moment is still significant in beam wave condition as effect of longitudinal center of buoyancy.

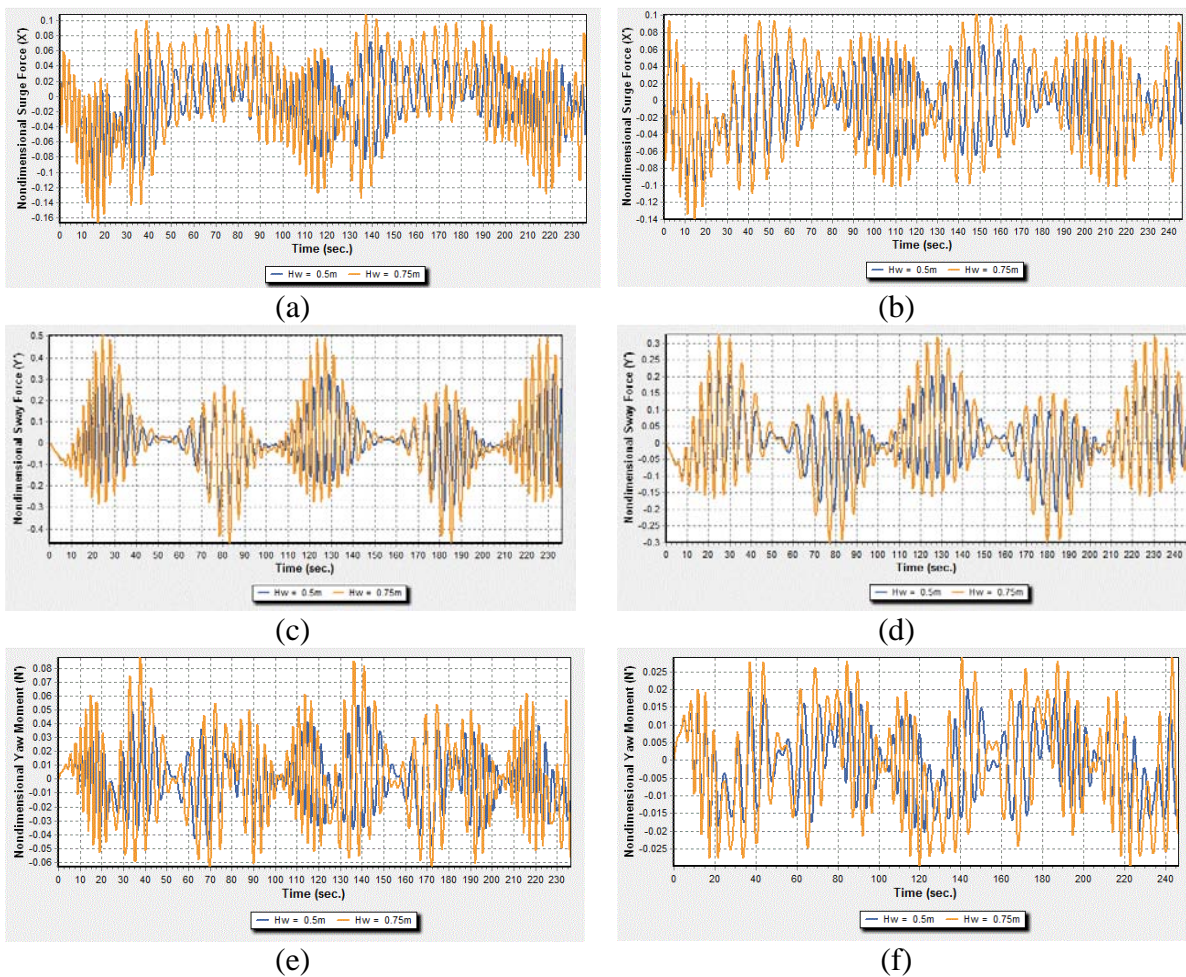


Figure 4 Resultant of forces and moment acting on ship hull during turning maneuver

4. DISCUSSION

The obtained turning trajectory for two different wave height and wave length are similar with the results of previous study (Fang, et al., 2005; Seo & Kim, 2011; Skejck, 2013; Chroni, et al., 2015). The turning circle becomes smaller as the wave height increases for both wave length of the same as the ship length and 50.0 meters. The turning circle for smaller wave length is larger than the larger one. It shows that the drift motion significantly increases when the wave height increases and it tends to decrease as the wave length increases. Figure 3 shows that the surge velocity becomes minimum in beam seas, in which the sway velocity is maximum. **The yaw moment tends to increase when the wave slope increases. As result, the turning motion for large wave slope is faster than that with small wave slope.** These turning motion characteristics also induce longer distance of movement between the first turning circle and the second turning circle as shown in Figure 2.

Fang, et al. (2005) shown that both the surge and the sway velocities **oscillation** depend on the angle of wave encounter relative to the ship heading angle. The same results is obtained in the present study. A more significant amplitude of surge and sway velocities oscillation has also **been** identified in the transition from the following waves to the beam waves and from the beam waves to the heading waves and so on. This phenomenon did not appear in study conducted by Fang, et al. (2005). A similar results with the present study was obtained by Skjick (2013) for ship turning in irregular waves. This phenomenon may depend on the wave characteristics compared with the ship geometry. It may disappear in cases of large ships compared to the wave height and it may arise for small ship as the subject of present study even for small wave height. Figure 3(a) and Figure 3(b) show that the oscillation due to the transition from the following waves to the beam waves and so on decreases when the wave length increases. It may disappears for smaller **wave slope**.

The initial position of ship relative to the wave does not have significant effect of turning maneuvering of ship in waves. The same results was obtained by Fang, et al. (2005) but they stated that effect of the initial position relative to the wave may **be** significant for small ships. That effect **is** not obtained in the present study. The initial position of ship relative the wave surface does not significantly affect the forces and moment induced by the wave during turning maneuver. The initial position makes only changing phase of the forces and moment. Therefore its effect to the turning maneuver becomes negligibly small. The subject ship cannot perform turning maneuver in wave height of 1.0 meters and the wave length the same as the ship length or smaller. The numerical simulation can be conducted for the wave height of 1.0 meters when the wave length is larger than the ship length. However, the turning circle becomes very small and it seems to be unrealistic in practical point of view. The very small turning circle occurs due to large drift motion with small surge velocity in beam waves condition up to heading waves condition during turning simulation. The large drift motion may occur due to small draught of the subject ship so that the hydrodynamic damping force in sway direction becomes smaller compared with the ship with larger draught. This had been shown by Chroni, et al. (2015) with wave length of a half of ship length, wave height of 5.50 meters and wind velocity of 19.0 m/s (Beaufort Scale 8). The subject ship used in their simulation was larger than that used in the present simulation. Therefore, the weather condition to perform sea trial in guidance of International Maritime Organization (IMO) (2002) may not be applied for small ships.

5. CONCLUSION

The mathematical model for predicting turning maneuvering in constant wind and regular wave has been developed by using the 3 DOF of MMG model. A mathematical model to describe the ship position relative to the wave profile as function of **surge and sway velocities as well as heading angle** has been included in the original MMG model. Therefore the mathematical model can be simultaneously solved to obtain maneuvering characteristics. Based on the numerical results for a small Indonesian ro-ro ferry, some conclusion can be remarked as follows:

1. Effect of wave height on ship turning maneuver is more significant in small wave length. This effect decreases as the wave length increases.
2. The sway force and yaw moment of wave significantly decrease when the wave length increases. Alteration of surge force due to increasing the wave length is smaller compared with the sway force and yaw moment. This means that the drift motion may have an important role on ship maneuvering in short waves.
3. The initial position of ship relative to the wave does not have significant effect on ship turning maneuver and its effect can be neglected in case of the present subject ship.

6. ACKNOWLEDGEMENT

This paper is a part of research supported by Hasanuddin University and Directorate General of Higher Education under grand number 1764/UN4.20/PL.09/2015. The authors express their gratitude to the both institution for their support. The authors also express their sincere gratitude to PT. Indonesia Ferry (Persero) for its support to provide ship data used in this paper.

7. REFERENCES

- Carlton, J.S., (2007), Marine Propellers and Propulsion, Second Edition, Elsevier, Ltd., pp. 103 – 106.
- Chroni, D., Liu, S., Plessas, T., Papanikolaou, A., (2015), Simulation of the maneuvering behaviour of ships under the influence of environmental forces. *In: Proceedings of the 16th International Congress of the International Maritime Association of the Mediterranean (IMAM 2015) 2015, Pula, 21 – 24 September, Croatia.*
- Fang, M.C., Luo, J.H., Lee, M.L., (2005), A nonlinear mathematical model for ship turning circle simulation in waves, *Journal of Ship Research, Volume 49, pp. 69 – 79.*
- Fujiwara, T., Ueno, M., Ikeda, Y., (2006), Cruising performance of a large passenger ship in heavy sea. *In: Proceedings of the 16th International Offshore and Polar Engineering Conference 2006, California, 28 May – 2 June, USA.*
- Holtrop, J and Mennen, G.G.J., (1982), An approximate power prediction method, International Shipbuilding Progress, Volume 29, pp. 166 – 170.**
- IMO, (2002), Maritime Safety Committee on Ship Maneuverability of International Maritime Organization (IMO), MSC &6/23, Resolution MSC 137(36), IMO, London.
- Ito, Y., Umeda, N., Kubo, H., (2014), Hydrodynamic aspects on vulnerability criteria for surf-riding of ships, *Jurnal Teknologi (Science and Engineering) Volume 66, pp. 127 – 132.*

- Kijima, K., Katsuno, T., Nakiri, Y., Furukawa, Y., (1990), On the maneuvering performance of a ship with the parameter of loading condition, *Journal Society of Naval Architects of Japan*, Volume 168, pp. 141 – 148.
- Munif, A. and Umeda, N., (2000), Modelling extreme roll motions and capsizing of a moderate-speed ship in astern waves, *Journal of Society of Naval Architects of Japan*, Volume 187, pp. 51 – 58.
- Paroka, D., Muhammad, A.H., Asri, S., (2015), Steady state equilibrium of ship maneuvering under combined action of wind and wave, *Jurnal Teknologi (Science and Engineering)*, Volume 76, pp. 67 – 75.
- Seo, M.G. and Kim, Y., (2011), Effect of ship motion on ship maneuvering in waves. *In: Proceedings of the 26th International Workshop on Water Waves and Floating Bodies 2011*, Athens, 17 – 20 April, Greece.
- Skejick, R. and Faltinsen, O.M., (2008), A unified seakeeping and maneuvering analysis of ships in regular waves, *Journal of Marine Science and Technology*, Volume 13, pp. 371 – 394.
- Skejick, R., (2013), Ships maneuvering simulations in a seaway – How close are we to reality, *In: Proceedings of the International Workshop on Next Generation Nautical Traffic Models 2013*, Delf, 22 Nopember, Netherlands.
- Umeda, N. and Hashimoto, H., (2002), Qualitative aspects of nonlinear ships motion in following and quartering seas with high forward velocity, *Journal of Marine Science and Technology*, Volume 6, pp. 111 – 121.
- Yoshimura, Y., (2005), Mathematical model for maneuvering ship motion (MMG Model). *In: Proceedings of Workshop on Mathematical Model for Operations Involving Ship – Ship Interaction 2005*, Tokyo, 4 – 5 August, Japan.
- Yoshimura, Y. and Masumoto, Y., (2012), Hydradynamic database and maneuvering prediction method with medium – high speed merchant ships and fishing vessels. *In: Proceedings of MARSIM 2012, International Conference on Marine Simulation and Ship Maneuverability 2012*, Singapore, 23 April, Singapore.
- Zipfel, J.S and Maksoud, M.A., (2011), A numerical model to determine ship maneuvering motion in regular waves, *In: Proceedings of International Conference on Computational Methods in Marine Engineering (MARINE) 2011*, Lisbon, 28 – 30 September, Portugal.

List of Changes

Manuscript: PREDICTION OF SHIP TURNING MANEUVERING IN CONSTANT WIND AND REGULAR WAVES

Response and Revision made by Author(s)

Reviewer #2:

No	Comments	Revision/Changes
1		A revision has been made on the thirs paragraph of page 3 regarding the reference for maneuvering equations of MMG model as indicated with blue color
2		The explanation about equation (1) in the page 3 in order the MMG model applicable for investigating wave effect on ship maneuverability has been revised as shown in the last paragraph of page 3 with blue color.
3		
4		
5		
6		

PREDICTION OF SHIP TURNING MANEUVERS IN CONSTANT WIND AND REGULAR WAVES

IJTech-07-140

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ABSTRACT

A ship usually performs maneuvers under the influence of external forces and moments, such as wind, waves, and current. Therefore, it is important to understand the maneuvering behavior of ships under the action of external forces. This paper discusses the turning maneuvers of an Indonesian roro ferry under the combined influence of constant wind and regular waves using the mathematical modelling group (MMG). The ship's position relative to the wave trough is added to the original MMG model to estimate the exciting forces and moment induced by the waves. The results of a numerical simulation show that the effect of wave height on turning ability is more significant for a small wavelength; this effect decreases as the wavelength increases. The effect of wavelength on the sway force and yaw moment is more significant compared with its effect on the surge force. The ship's initial position relative to the wave trough does not have a significant effect on the turning characteristic and it can be neglected for the present study's subject ship. Overall, the results of the present work compare well with published data.

Keywords: Maneuvering; Turning; Waves; Wind

Comment [.1]: Please check that I have not changed your intended meaning.

Comment [Z2]: Yes, the meaning does not change.

Comment [.3]: American English uses a serial comma. I added commas throughout the manuscript.

Comment [Z4]: Ok.

Comment [.5]: Changed to US spelling.

Comment [Z6]: Ok.

Comment [.7]: Please confirm this change.

Comment [Z8]: Ok.

Comment [Z9]: The spelling of MMG has been before the acronym "MMG".

Comment [.10]: Acronyms should be spelled out upon first use, followed by the acronym itself in parentheses.

Comment [.11]: Your intended meaning is not clear. Do you mean wave trough? Please clarify.

Comment [Z12]: Yes, this should be "trough".

Comment [.13]: Should this be wave trough? I am not sure what you mean by wave through.

Comment [Z14]: Yes, it should be "wave trough".

Comment [.15]: Please make sure that the color in the manuscript is all black.

Comment [Z16]: The color has been changed to be black one.

Comment [.17]: Please check the guidelines for the proper formatting of the keywords (capitalization and punctuation).

Comment [Z18]: The keywords has been changed.

1. INTRODUCTION

The maneuvering performance of a ship during the initial design stage is typically predicted in calm water conditions. However, ships usually maneuver in the presence of external forces, such as wind, waves, and current. Therefore, it is important to understand the maneuvering behavior of a ship under the combined actions of the environmental forces.

Some mathematical models for predicting the maneuvering of a ship in conditions of wind and waves have been developed by several authors. Fang et al. (2005) used a 6 degree of freedom (6 DOF) nonlinear mathematical model to simulate a ship's turning maneuver in waves by taking into account the effect of the wave encounter frequency on the inertia, damping, and linear hydrodynamic derivative of the forces and moments acting on the ship's hull. A similar approach was used by Zipfel and Maksoud (2011) to determine a ship's maneuvering motion in regular waves. The frequency-dependent hydrodynamic coefficients were transferred to the time-domain using the impulse response function. A unified seakeeping and maneuvering theory with second-order regular waves was proposed by Skejic and Falinsen (2008) to analyze the behavior of a ship in waves. Here, the wave drift force was estimated using a two-time scale model to separate the low-frequency motion (maneuvering motion) and the high-frequency motion (seakeeping motion). The same method for estimating the wave drift force was used by Seo and Kim (2011) to predict ship maneuvering in waves using a combination between the mathematical modelling group (MMG) and seakeeping mathematical model. The second-order wave force was also used by Chroni et al. (2015) to investigate the effect of environmental forces on ship maneuvering with a 4 degree of freedom (4 DOF) mathematical model. Skejic (2013) also used the second-order wave force to simulate ship maneuvering in irregular waves. However, the two-time scale method seems to be inefficient because the solution to the seakeeping motion can be obtained after the maneuvering motion has been solved.

The most practical method for predicting the maneuvering behavior of a ship in the initial design stage may be the MMG model because empirical formulas for estimating the coefficients of the hydrodynamic derivatives have been developed (Yoshimura & Masumoto, 2012). Even the original MMG model is a pure maneuvering motion problem with a 3 DOF mathematical model; some researchers included the roll or heeling effect using a 4 DOF model. Fujiwara et al. (2006) and Paroka et al. (2015) used the MMG model to investigate the steady state equilibrium of a ship maneuvering in wind and waves. The discrepancy between the MMG model and the previously mentioned methods is the encounter frequency of forces and moments induced by the ship's hull. In cases of long wavelengths in which the length of the wave is larger than the length of the ship, some authors neglected the effect of the encounter frequency on hydrodynamic forces and moments induced by the ship's hull, although it was taken into account for the forces and moments induced by the waves (Munif & Umeda, 2000; Umeda & Hashimoto, 2002). Munif and Umeda (2000) showed that with long waves, the heave and pitch motion may not be significant. Following this assumption, the MMG model seems to be able to predict the turning characteristics of ships in waves. However, it is necessary to add a mathematical equation to the MMG model to describe the ship's position relative to the wave. This is important because the forces and moments induced by the wave depend on the ship's position in the wave surface.

Comment [.19]: Please confirm this definition of the acronym.

Comment [Z20]: "six" has been changed to be "6".

Comment [.21]: Please check that I have not changed your intended meaning.

Comment [Z22]: Yes, the meaning does not change.

Comment [.23]: Please check that I have not changed the intended meaning. Edited to avoid repeating "seakeeping and maneuvering."

Comment [Z24]: Ok, the meaning does not change.

Comment [Z25]: The spelling of MMG has been mentioned just before the acronym "MMG".

Comment [.26]: Acronyms should be spelled out upon first use, followed by the acronym itself in parentheses. Note that acronyms should be defined in both the Abstract and in the text.

Comment [.27]: Your intended meaning is not clear. I am not sure which models were combined. Please clarify.

Comment [Z28]: This sentence has been changed. The meaning is the proposed model was developed ...

Comment [.29]: Should this acronym be spelled out?

Comment [Z30]: The spelling of 4 DOF has been mentioned ...

Comment [.31]: Please check that I have not changed your ...

Comment [Z32]: Yes, the meaning does not change.

Comment [.33]: Should this be long wavelengths?

Comment [Z34]: Here, the meaning of "long waves is the ...

This paper discusses the turning maneuverability of a small Indonesian RoRo ferry under the combined action of wind and waves using the modified MMG model. The effect of the characteristics of the waves, such as wave height, wavelength, and the initial position of the ship relative to the wave, was investigated. For small ships, these wave characteristics may have a significant effect on the maneuvering performance as indicated by Fang et al. (2005). The wind velocity is assumed to be constant and to be uncorrelated with the wave characteristics.

2. RESEARCH METHODOLOGY

To describe the present mathematical model, two coordinate systems are used as shown in Figure 1. The first coordinate system, $O-x_0y_0z_0$, is fixed on the calm water surface and is used to describe the coordinates of the ship's position and wave propagation, respectively. The second coordinate system, $G-xyz$, has its origin on the ship's center of gravity, G , and moves with the ship's motion. The symbols u , v , and r indicate the surge, sway, and yaw velocity, respectively. The drift angle is designated by β , and δ is used for the rudder angle. The propeller thrust is indicated by T_j and the heading angle is indicated by ψ . The angle of the wave direction ψ_W is assumed to be the same as the wind angle.

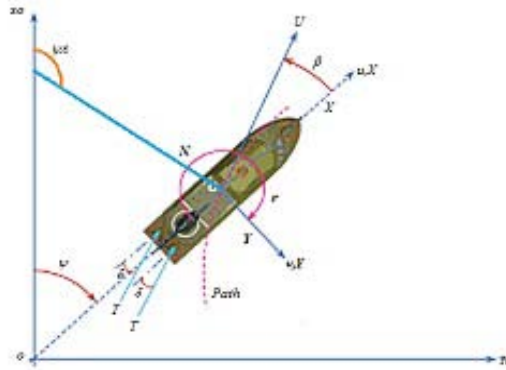


Figure 1 The coordinate systems

According to Newton's second law of motion and following the MMG model, the equation for a ship maneuvering in the combined action of wind and wave according to Fujiwara et al. (2006) is written as:

$$\dot{\xi}_G = u \cos \chi - v \sin \chi \quad (1)$$

$$(m + m_x)(\dot{u} - vr) = X_H + X_P + X_R + X_A + X_W \quad (2)$$

$$(m + m_y)(\dot{v} - ur) = Y_H + Y_R + Y_A + Y_W \quad (3)$$

$$(I_{zz} + J_{zz})\dot{r} = N_H + N_R + N_A + N_W - x_G(Y_H + Y_R + Y_A + Y_W) \quad (4)$$

Comment [.35]: Please confirm this change.

Comment [Z36]: Ok.

Comment [.37]: Should the coordinates be italicized? This also pertains to the G-xyz system below.

Comment [Z38]: The symbols have changed to be italics.

Comment [.39]: Should variables be in italics? This also pertains to u , v , and r , and T_j .

Comment [Z40]: The symbols has been changed to be italics.

Comment [.41]: Should the variables be in italics? Please change coordinate

Comment [Z42]: The variables in the figure have been changed to be italic.

Here, m , m_x , and m_y indicate the ship's mass, the added mass in the surge, and the added mass in the sway, respectively, while \dot{u} , \dot{v} , and \dot{r} are the surge, the sway, and the yaw accelerations, respectively. The subscripts H , P , R , A , and W indicate the hull, propeller, rudder, wind, and the wave forces and moments in the surge, sway, and yaw directions. Equation (1) is added to the MMG model (equations (2) to (4)) to take into account the effect of the ship's position relative to the wave surface on the wave forces and moments. This equation was used by Fang et al. (2005) and Umeda and Hashimoto (2002) to estimate the wave forces and moments acting on a ship's hull. Integration of equation (1) over time results in the relative position of a ship's center of gravity relative to the wave trough. Therefore, equations (1) to (4) can be solved at the same time without separating the seakeeping and maneuvering motions. The symbol χ in equation (1) indicates the angle of the wave encounter relative to the ship heading angle.

The forces and moments of the hull in equations (2) to (4) are empirically estimated using the polynomial regression of the nondimensional hydrodynamic derivatives (Yoshimura, 2005; Yoshimura & Masumoto, 2012). The ship's resistance is estimated using a method developed by Holtrop and Mennen (1982). The propeller thrust is estimated using the equation proposed by Kijima et al. (1990). The thrust coefficient as a function of the advance coefficient are estimated based on statistical data of the open water test for B series propeller (Carlton, 2007). The rudder forces and moments are calculated using a formula proposed by Kijima et al. (1990) for a twin propeller and twin rudder.

The forces and moments induced by the waves are estimated using formula proposed by Umeda and Hashimoto (2002). A correction factor, which depends on the block coefficient, is used to estimate the wave force in the surge direction (Ito et al., 2014). The equation for estimating the wave force in the surge and sway directions, as well as the wave moment in the yaw direction are shown in equations (5) to (7).

$$X_W = -\alpha \rho g \zeta_W k \cos \chi \int_{AE}^{FE} C_1(x) S(x) e^{-kd(x)/2} \times \sin(k(\xi_G + x \cos \chi)) dx \quad (5)$$

$$Y_W = \rho g \zeta_W k \sin \chi \int_{AE}^{FE} C_1(x) S(x) e^{-kd(x)/2} \times \sin(k(\xi_G + x \cos \chi)) dx + \zeta_W \omega \omega_e$$

$$\sin \chi \int_{AE}^{FE} \rho S_y(x) e^{-kd(x)/2} \times \sin(k(\xi_G + x \cos \chi)) dx - \zeta_W \omega u \sin \chi$$

$$\times [\rho S_y(x) e^{-kd(x)/2} \cos(k(\xi_G + x \cos \chi))]_{AE}^{FE} \quad (6)$$

$$+(1 + a_H) \frac{\rho}{2} A_R f_a \varepsilon_R (1 - w_p) u \sqrt{1 + \kappa_P \frac{8K_T}{\pi J^2} v_{WR}}$$

Comment [.43]: Should these variables be italicized (as in the equation)?

Comment [Z44]: The variables have been changed to be italics.

Comment [.45]: Should these letters be italicized (as in the equation)?

Comment [Z46]: The variables have been changed to be italics.

Comment [.47]: Please confirm this change.

Comment [Z48]: Ok. The meaning does not change.

Comment [.49]: It is not clear what equation you are referring to here. Please clarify using the number.

Comment [Z50]: This equation means the equation (1) as mentioned in the previous sentence.

Comment [.51]: Please check that I have not changed the intended meaning.

Comment [Z52]: Our intended meaning is the forces and moment induced by ship's hull due to maneuvering motion.

Comment [.53]: Your intended meaning is not clear. Please clarify.

Comment [Z54]: The sentence has been revised to make the meaning to be clear. The statistical data was obtained from several test of different B series propeller, therefore 'a' before B series is not necessary.

Comment [.55]: Please check that I have not changed the intended meaning.

Comment [Z56]: The meaning does not change but they proposed three formula (eq. 5 to eq. 7). Therefore we change "a formula" to be "formula".

$$\begin{aligned}
N_W = & \rho g \zeta_W \sin \chi \int_{AE}^{FE} C_1(x) S(x) e^{-kd(x)/2} \times x \sin(k(\xi_G + x \cos \chi)) dx + \zeta_W \omega \omega_e \\
& \times \sin \chi \int_{AE}^{FE} \rho S_y(x) e^{-kd(x)/2} x \sin(k(\xi_G + x \cos \chi)) dx \\
& + \zeta_W \omega u \sin \chi \int_{AE}^{FE} \rho S_y(x) e^{-kd(x)/2} \times \cos(k(\xi_G + x \cos \chi)) dx \\
& - \zeta_W \omega u \sin \chi \\
& \times [\rho S_y(x) e^{-kd(x)/2} x \cos(k(\xi_G + x \cos \chi))]_{AE}^{FE} \\
& + (x_R + a_H x_H) \frac{\rho}{2} A_R f_\alpha \varepsilon_R (1 - w_p) u \sqrt{1 + \kappa_p \frac{8K_T}{\pi J^2} v_{WR}}
\end{aligned} \quad (7)$$

Here, α is the correction factor dependent on the block coefficient, and ζ_W , k , $S(x)$, and $d(x)$ are the wave amplitude, wave number, area, and draught of section at a longitudinal distance x from the midship, respectively. The symbols ω , ω_e , and $S_y(x)$ indicate the wave frequency, wave encounter frequency, and added mass of section in the sway direction, while x_R , x_H , a_H , and A_R are the longitudinal position of the rudder from the midship, the longitudinal position of the center of the interaction force between the hull and the rudder, the interaction factor between the hull and the rudder, and a the rudder area, respectively. The rudder coefficient is indicated by f_α and the effective propeller wake fraction is designated by w_p . The symbols ε_R , κ_p , J , and K_T are the wake ratio between propeller and rudder, the interaction factor between propeller and rudder, the advance coefficient, and the thrust coefficient, respectively. $C_1(x)$ and v_{WR} are calculated using equation (8) and equation (9), respectively.

$$C_1(x) = \frac{\sin(k \sin \chi \cdot B(x)/2)}{(k \sin \chi \cdot B(x)/2)} \quad (8)$$

$$v_{WR} = \zeta_W \omega \sin \chi \exp(-kz_R) \cos(2\pi \xi_G/\lambda + kx_R \cos \chi) \quad (9)$$

Here, $B(x)$, z_R , and λ are the breadth of section, the center of the rudder from the baseline, and the wavelength, respectively.

The wind forces and moments in the surge, sway, and yaw directions are calculated using the empirical formula proposed by Fujiwara et al. (2006). The angle of wind attack is determined by the wind direction and the ship heading angle. The wave angle is assumed to be the same as the wind angle.

Ship Data

The ship used in the numerical simulation is an Indonesian ro-ro ferry with the principle dimensions shown in Table 1. The dimensions of the propeller and the rudder are shown in Table 2.

Table 1 Principle dimensions of the subject ship

Items	Dimension
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Comment [.57]: Should this be italicized?

Comment [Z58]: The symbol has been changed to be italic.

Comment [.59]: Should these be italicized (as used in the equation)? This pertains to all variables in this paragraph.

Comment [Z60]: All symbols has been changed to be italics.

Length overall (L_{OA})	36.40 m
Length between perpendicular (L_{BP})	31.50 m
Breadth (B)	8.70 m
Height (H)	2.65 m
Draught (T)	1.65 m
Ship speed (V_S)	10.5 knot
Lateral projected windage area (A_L)	36.40 m ²
Transverse projected windage area (A_F)	93.61 m ²
Lateral projected area of superstructure (A_{OD})	187.21 m ²
Center of windage area from midship (C)	-0.558 m
Vertical center of A_L (H_C)	0.720 m
Vertical center of A_{OD} (H_L)	4.930 m
Height of transverse projected area (H_{BR})	10.73 m

Table 2 Propeller and rudder dimensions

Items	Dimension
Number of propellers	2
Number of propeller blades (Z)	4
Propeller diameter (D_P)	1.10 m
Propeller revolution (n)	8.58 rps
Transverse position propeller (y_P)	± 2.55 m
Longitude position propeller (x_P)	15.50 m
Rudder area (A_R)	2.08 m ²
Rudder coefficient (f_Λ)	2.10
Transverse rudder position (y_R)	± 2.55 m
Longitude rudder position (x_R)	15.75 m

Comment [.61]: Should this be dimensions (as used in the table heading)?

Comment [Z62]: "geometry" has been changed to be "dimensions".

Comment [.63]: Please confirm this change.

Comment [Z64]: Ok.

3. RESULTS

The numerical results of the turning maneuver simulation for a wave height of 0.50 m and 0.75 m are shown for a wavelength that is the same as the ship's length (Figure 2a) and for a wavelength of 50.0 m (Figure 2b). The wind velocity for all wave characteristics is 6.75 m/s (Beaufort scale 4). The turning diameter decreases as the wave height increases. The distance between the first and the second turning circles is longer for a larger wave height. A similar result is obtained for a larger wavelength. The distance of the turning circles movement becomes smaller as the wavelength increases. These results show that the wave height has a more significant effect on the ship turning maneuver for a shorter wavelength compared with a longer wavelength.

Comment [.65]: Your intended meaning is not clear. I am not sure what you mean by *moves away* from the first one with a longer distance. Do you mean that the second turning circle has a longer distance? Please clarify.

Comment [Z66]: The meaning is "distance between the center of the first turning circle and the second turning circle is longer for larger wave height".

Comment [.67]: Do you mean: longer wavelength?

Comment [Z68]: Yes.

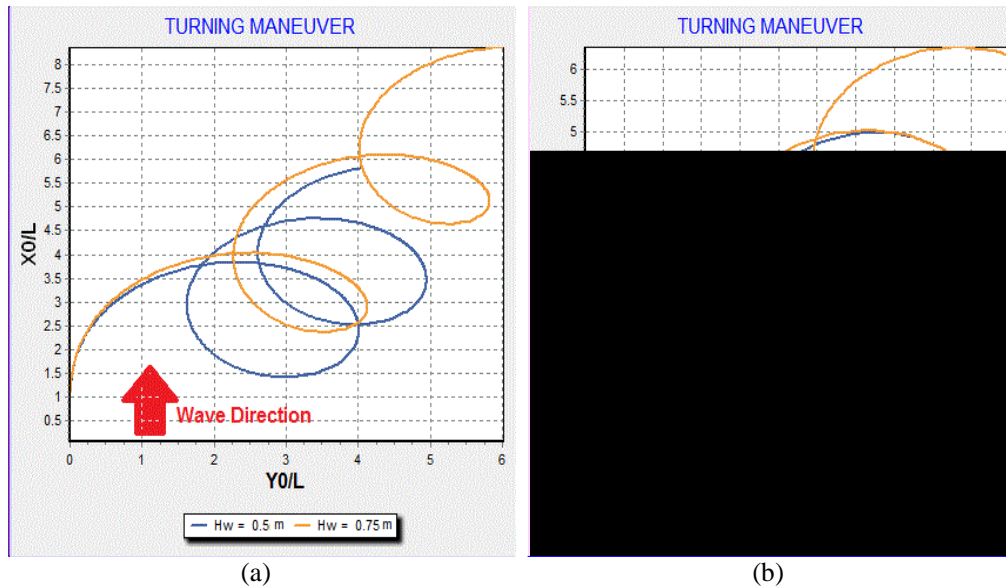


Figure 2 Trajectory of the turning circle: (a) Wavelength is the same as the ship's length and (b) Wave length is 50.00 meters

The surge and sway velocities of the ship during the turning simulation are shown in Figure 3a for a wavelength that is the same as the ship's length for a wave height of 0.50 m and 0.75 m. The results for a wavelength of 50.0 m with the same wave heights are shown in Figure 3b. The yaw rates for a wavelength that is the same as the ship's length for the same wave heights are shown in Figure 3c, while Figure 3d shows the results for a wavelength of 50.0 m. The surge and sway velocities oscillate depending on the angle of the wave encounter relative to the ship heading angle. The minimum velocity occurs when there is a heading wave in which the angle of the wave encounter is 0.0 degrees, while the maximum velocity occurs in a following wave in which the angle of the wave encounter is 180.0 degrees. The oscillation of the surge, sway, and yaw motions also occur in all conditions of wave height and wavelength. These are purely affected by the ship's position relative to the wave. The oscillation of the surge velocity becomes significant in heading and following waves, while the oscillation of the sway velocity becomes significant in beam seas. Therefore, the phase between the surge and sway motions becomes 90.0 degrees as shown in Figures 3(a) and 3(b).

An alteration in surge velocity when the ship is in following waves and heading waves significantly increases as the wave height increases. However, the effect of wave height on the alteration in surge velocity decreases as the wavelengths increase. The same trend is also obtained for the sway velocity. The yaw rate is more sensitive to the alteration in wave direction compared with the surge and sway velocities. This is because the yaw moment exists even in beam seas depend on the position of longitudinal center of gravity. The minimum yaw rate will occur in following and heading waves, although this condition appears in a very short time in case of a turning maneuver.

Comment [.69]: Please insert a space between the number and unit.

Comment [Z70]: The figures have been revised.

Comment [.71]: Should you explain what (a) and (b) signify here?

Comment [Z72]: The figure title has been changed as recommended.

Comment [.73]: Please check that I have not changed the intended meaning.

Comment [Z74]: The meaning does not change.

Comment [.75]: Please check that I have not changed the intended meaning.

Comment [Z76]: Ok.

Comment [.77]: Your intended meaning is not clear. Please clarify.

Comment [Z78]: The sentence has been revised to make the meaning becomes clear.

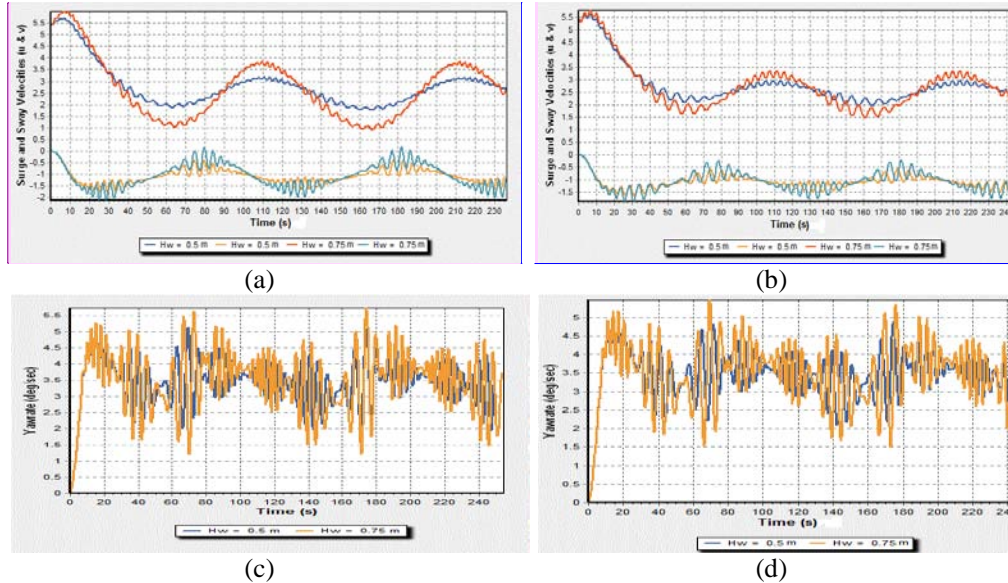


Figure 3 Ship motion during a turning maneuver: (a) Surge and sway velocities for wavelength the same as ship's length, (b) Surge and sway velocities for wave length of 50.00 meters, (c) Yaw rate for wavelength the same as ship's length, (d) Yaw rate for wavelength of 50.00 meters

Figures 4a to 4f show the nondimensional forces and moments in the surge, sway, and yaw directions at two different wave heights and two different wavelengths. The figures on the left are for a wavelength that is the same as the ship's length, and the figures on the right are the forces and moments for a wavelength of 50.0 m. The effect of wavelength on the force in the surge direction is not significant compared with its effect on the force in the sway direction and on the moment in the yaw direction. Therefore, the characteristic of turning trajectory significantly changes as the wavelength increases for the same wave height.

The wave height significantly affects the forces and moments for a wavelength of 50.0 m. However, the effect of wave height on the forces and moments tends to decrease as the wavelength increases. Similar to the sway velocity, the force in the sway direction is negligibly small in heading and following waves, although it reaches its maximum in beam seas. The same trend is obtained for the surge force when the angle of the wave encounter is 90.0 degrees and 270.0 degrees (beam waves). The minimum value of the yaw moment occurs in cases of heading and following waves. The yaw moment is still significant in a beam wave because of the effect of the longitudinal center of buoyancy.

Comment [.79]: The abbreviation for the time unit should be (s).

Comment [Z80]: The time unit has been changed to (s)

Comment [.82]: Perhaps explain (a), (b), (c), and (d) in the caption?

Comment [Z83]: The figures title have been changed as recommended.

Comment [.84]: Please check that I have not changed the intended meaning.

Comment [Z85]: Yes. The meaning does not change.

Comment [.86]: Should this be beam seas? This also pertains to the following sentence.

Comment [Z87]: Yes. It has been changed.

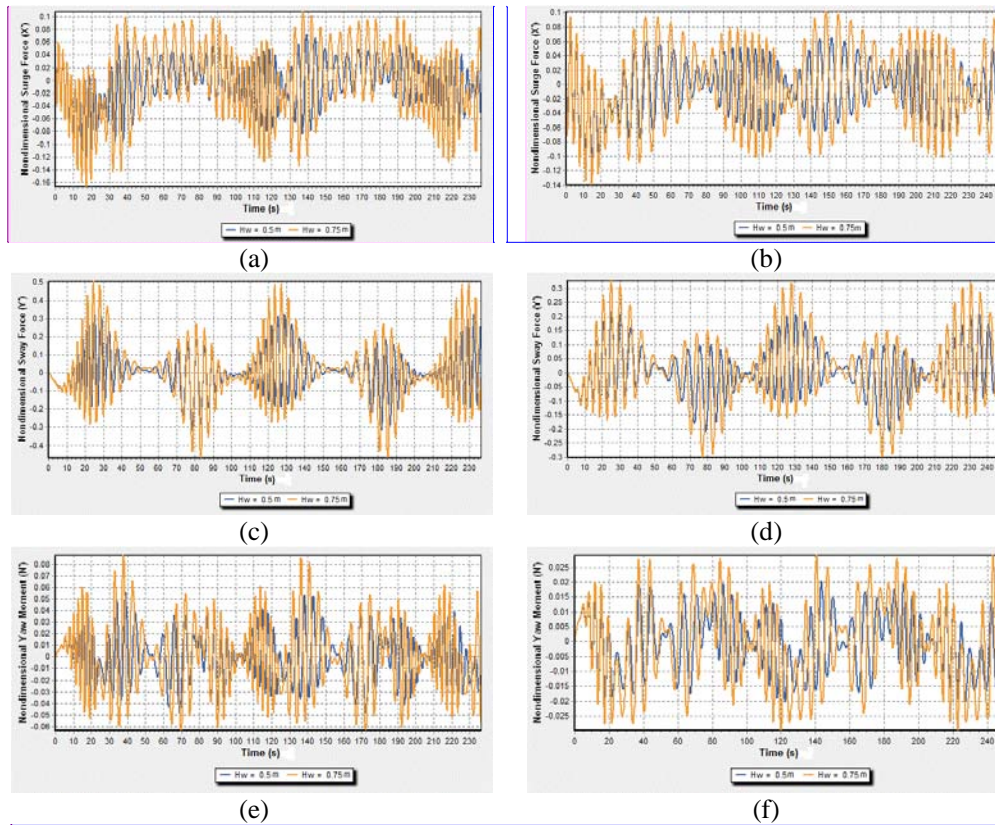


Figure 4 Resultant forces and moments acting on a ship hull during a turning maneuver: (a) Surge force for wavelength the same as the ship's length, (b) Surge force for wavelength of 50.00 meters, (c) Sway force for wavelength the same as the ship's length, (d) Sway force for wavelength of 50.00 meters, (e) Yaw moment for wavelength the same as the ship's length, (f) Yaw moment for wavelength of 50.00 meters

4. DISCUSSION

The obtained turning trajectory for two different wave heights and wavelengths are similar to the results found in previous studies (Fang et al., 2005; Seo & Kim, 2011; Skejck, 2013; Chroni et al., 2015). The turning circle becomes smaller as the wave height increases for both a wavelength that is the same as the ship's length and a wavelength of 50.0 m. The turning circle for a shorter wavelength is larger than for a larger wavelength. This indicates that the drift motion significantly increases when the wave height increases and decreases as the wavelength increases. Figure 3 shows that the surge velocity is minimum in beam seas, which produces a maximum sway velocity. The yaw moment tends to increase when the wave slope increases. As result, the turning motion for a large wave slope is faster than with a small wave slope. These turning motion characteristics also induce a longer distance

Comment [.88]: The abbreviation for the time unit should be (s).

Comment [Z89]: The time unit has been changed to (s)

Comment [.91]: Perhaps explain (a) to (f) in the caption?

Comment [Z92]: The explanation in figures title has been revised.

Comment [.93]: Should this be shorter wavelength and longer wavelength?

Comment [Z94]: Yes. It has been changed.

of movement between the first turning circle and the second turning circle as shown in Figure 2.

Fang et al. (2005) showed that the oscillations of both the surge and sway velocities depend on the angle of the wave encounter relative to the ship heading angle. The same results are obtained in the present study. A more significant amplitude of oscillation of the surge and sway velocities has also been identified in the transition from following waves to beam seas and from beam waves to heading waves and so on. This phenomenon did not appear in a study conducted by Fang et al. (2005). Skjick (2013) had similar results as this study for a ship turning in irregular waves. This phenomenon may depend on the wave characteristics compared with the ship geometry. Thus, it may not occur in cases of large ships compared with the wave height, although it may be seen in small ships even for a small wave height as seen in this study. Figures 3(a) and 3(b) show that the oscillation due to the transition from following waves to beam waves and so on decreases when the wavelength increases. It may disappear for smaller wave slopes.

The initial position of a ship relative to the wave does not have a significant effect on the turning maneuvers of a ship in waves. The same results were obtained by Fang et al. (2005), although they stated that the effect of the initial position relative to the wave may be significant for small ships. This effect is not obtained in the present study. The initial position of a ship relative to the wave surface does not significantly affect the forces and moments induced by the wave during a turning maneuver. The initial position only makes the changing phase of the forces and moments. Therefore, its effect on the turning maneuver becomes negligibly small.

The subject ship cannot perform a turning maneuver in a wave height of 1.0 m when the wavelength is the same as the ship's length or is smaller. The numerical simulation can be conducted for a wave height of 1.0 m when the wavelength is longer than the ship. However, the turning circle becomes very small and it seems to be unrealistic from a practical point of view. The very small turning circle occurs due to the large drift motion with a small surge velocity in beam seas up to heading waves during the turning simulation. The large drift motion may occur due to the small draught of the subject ship so that the hydrodynamic damping force in the sway direction becomes smaller compared with a ship with a larger draught. This was shown by Chroni et al. (2015) using a wavelength that was half the ship's length, a wave height of 5.50 m, and a wind velocity of 19.0 m/s (Beaufort scale 8). The subject ship used in their simulation was larger than that used in the present study. These facts show that the required weather conditions to perform a sea trial of small ships should be smaller than that in the guidance of the International Maritime Organization (IMO, 2002).

5. CONCLUSION

The mathematical model for predicting a ship's turning maneuver in constant wind and regular waves has been developed based on the 3 DOF of the MMG model. In order to directly calculate wave forces and moment, an equation to describe the ship's position relative to the wave profile as a function of the surge and sway velocities, as well as the heading angle has been included in the MMG model. The present mathematical model can be simultaneously solved to obtain the maneuvering characteristics. Based on the

Comment [.95]: Should this be beam seas?

Comment [Z96]: Yes. It has been changed.

Comment [.97]: Do you mean that it may not occur (or be seen)?

Comment [Z98]: It has been changed to be "may not occur".

Comment [.99]: Should this be beam seas?

Comment [Z100]: Yes. It has been changed.

Comment [.101]: I am not sure that I understand the link between the previous sentence and this sentence. Please clarify.

Comment [Z102]: We want to state that the weather condition for maneuvering test of small ships may be smaller than that required in IMO guidance. The sentence has been revised.

Comment [.103]: Your intended meaning is not clear. Please clarify.

Comment [Z104]: The sentence has been revised. We want to state that for estimating wave forces and moment, the ship position relative to the wave surface has to be calculated.

Comment [.105]: Do you mean: the maneuvering and seakeeping characteristics?

Comment [Z106]: We means "maneuvering characteristics" mainly turning ability of ship.

numerical results for a small Indonesian ro-ro ferry, some conclusions can be made as follows:

1. The effect of the wave height on a ship's turning maneuver is more significant for a short wavelength. This effect decreases as the wavelength increases.
2. The sway force and yaw moment of a wave significantly decrease when the wavelength increases. Alteration of the surge force due to an increasing wavelength is smaller compared with the sway force and yaw moment. This means that the drift motion may have an important role on ship maneuvering for short wavelengths.
3. The initial position of a ship relative to the wave does not have a significant effect on the ship's turning maneuver; its effect can be neglected in the subject ship of the present study.

6. ACKNOWLEDGEMENT

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7. REFERENCES

- Carlton, J.S., (2007), Marine Propellers and Propulsion, Second Edition, Elsevier Ltd., Jordan Hill, Oxford, UK, pp. 103-106.
- Chroni, D., Liu, S., Plessas, T., Papanikolaou, A., (2015), Simulation of the maneuvering behaviour of ships under the influence of environmental forces. *In: Proceedings of the 16th International Congress of the International Maritime Association of the Mediterranean (IMAM 2015) 2015*, Pula, 21-24 September, Croatia.
- Fang, M.C., Luo, J.H., Lee, M.L., (2005), A nonlinear mathematical model for ship turning circle simulation in waves, *Journal of Ship Research*, Volume 49, pp. 69-79.
- Fujiwara, T., Ueno, M., Ikeda, Y., (2006), Cruising performance of a large passenger ship in heavy sea. *In: Proceedings of the 16th International Offshore and Polar Engineering Conference 2006*, California, 28 May–2 June, USA.
- Holtrup, J., Mennen, G.G.J., (1982), An approximate power prediction method, *International Shipbuilding Progress*, Volume 29, pp. 166-170.
- IMO, (2002), Maritime Safety Committee on Ship Maneuverability of International Maritime Organization (IMO), MSC &6/23, Resolution MSC 137(36), IMO, London.
- Ito, Y., Umeda, N., Kubo, H., (2014), Hydrodynamic aspects on vulnerability criteria for surf-riding of ships, *Jurnal Teknologi (Science and Engineering)* Volume 66, pp. 127-132.
- Kijima, K., Katsuno, T., Nakiri, Y., Furukawa, Y., (1990), On the maneuvering performance of a ship with the parameter of loading condition, *Journal Society of Naval Architects of Japan*, Volume 168, pp. 141-148.
- Munif, A., Umeda, N., (2000), Modelling extreme roll motions and capsizing of a moderate-speed ship in astern waves, *Journal of Society of Naval Architects of Japan*, Volume 187, pp. 51-58.

Comment [Z108]: Yes. It has been changed.

Comment [.109]: The references were checked according to the [guidelines](#) provided.

Comment [.110]: Please provide the city.

Comment [Z111]: The city has been added in the reference.

- Paroka, D., Muhammad, A.H., Asri, S., (2015), Steady state equilibrium of ship maneuvering under combined action of wind and wave, *Jurnal Teknologi (Science and Engineering)*, Volume 76, pp. 67-75.
- Seo, M.G., Kim, Y., (2011), Effect of ship motion on ship maneuvering in waves. *In: Proceedings of the 26th International Workshop on Water Waves and Floating Bodies 2011*, Athens, 17-20 April, Greece.
- Skejck, R., Faltinsen, O.M., (2008), A unified seakeeping and maneuvering analysis of ships in regular waves, *Journal of Marine Science and Technology*, Volume 13, pp. 371-394.
- Skejck, R., (2013), Ships maneuvering simulations in a seaway – How close are we to reality, *In: Proceedings of the International Workshop on Next Generation Nautical Traffic Models 2013*, Delf, 22 November, Netherlands.
- Umeda, N., Hashimoto, H., (2002), Qualitative aspects of nonlinear ships motion in following and quartering seas with high forward velocity, *Journal of Marine Science and Technology*, Volume 6, pp. 111-121.
- Yoshimura, Y., (2005), Mathematical model for maneuvering ship motion (MMG Model). *In: Proceedings of Workshop on Mathematical Model for Operations Involving Ship – Ship Interaction 2005*, Tokyo, 4-5 August, Japan.
- Yoshimura, Y., Masumoto, Y., (2012), Hydrodynamic database and manoeuvring prediction method with medium-high speed merchant ships and fishing vessels. *In: Proceedings of MARSIM 2012, International Conference on Marine Simulation and Ship Maneuverability 2012*, Singapore, 23 April, Singapore.
- Zipfel, J.S., Maksoud, M.A., (2011), A numerical model to determine ship maneuvering motion in regular waves. *In: Proceedings of the International Conference on Computational Methods in Marine Engineering (MARINE) 2011*, Lisbon, 28–30 September, Portugal.