NUMERICAL SEAKEEPING ANALYSIS OF CONTAINER SHIP IN REGULAR WAVES IN VARIOUS WAVE DIRECTIONS

Van Minh Nguyen, Thi Loan Mai, Thi Thanh Diep Nguyen, Youngho Park
Bon Guk Koo, Hyun Su Ryu and Hyeon Kyu Yoon
Changwon National University, Korea
hkyoon@changwon.ac.kr

Abstract: *Today route simulation plays an important role for ship owners and operators to check the performance of ship sailing under environmental disturbance such as wind, wave and current. In addition, sea waves have a great influence on the ship's structure as well as the seakeeping performance of a ship. It is very important to estimate the correct induced wave force for analyzing seakeeping performance of a ship. In the present study, a numerical seakeeping analysis of a KRISO container ship (KCS) was performed in regular waves in various wave directions. The hydrodynamic interactions between the ship and the regular waves were investigated using Panel Method. The numerical seakeeping analyses were performed in AQWA software. KCS was selected in this study and the numerical analysis of heave and pitch in head sea condition have been compared with the experimental result. The result of the heave and pitch motions of KCS in head sea conditions in the present study have good agreement with the experimental result. The effect of wavelength on characterizing the motion response of a ship in various wave direction was discussed. Particularly, the numerical results in this study can be useful for estimating relative motion and relative velocity of a ship for determining the optimal route avoiding the slamming and deck wetness.*

Keywords: *KRISO container ship (KCS), numerical seakeeping analysis, ship motion in wave.*

Classification numbers: *2.1*

1. Introduction

When a ship sails on the sea, it will be influenced by environmental disturbance such as wind, wave, current, ice. These factors have a great effect on the ship's speed, fuel consumption, safety and operating performance. The concept of ship weather routing has been practiced for a long time ago. Weather routing can be an efficient way of minimizing the fuel cost, and avoiding possible damages to the vessel, cargo and crew. Figure 1 illustrates changes in the number of causes of shipping losses over the decade from 2007 to 2016. Foundered is the main cause of loss accounting for the almost half of all losses. In particular, according to "Safety and Shipping Review 2017", in 2016 Foundered which had been the cause of almost 46% of total losses often driven by bad weather. Obviously, safe routing of a ship plays an important role for ship owners to ensure safe operation of a ship with short passage time or minimum energy under a given weather condition.

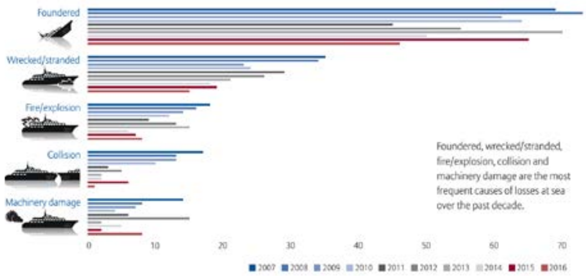


Figure 1. *Cause of total shipping losses.*

The optimal weather route depends on the seakeeping performance of a ship and its performance is highly related to hull form and operating conditions. Slamming and deck wetness are considerable importance in assessing the seakeeping performance of a ship. They can be determined by the magnitude of the relative motion between the hull and the adjacent sea surface (Arjm, 1998). The relative motion and velocity motion can be estimated from Response Amplitude Operator (RAO) of a ship.

The problem of seakeeping analysis of a ship has attracted attention of many researchers in the past. The seakeeping analysis of a ship has been studied based on experiment, potential flow theory and CFD approaches. The first study is Boundary

Element Methods (BEM) which estimated potential flow about arbitrary three-dimensional lifting bodies which was introduced by Hess and Smith (1967). Another numerical approach was introduced by Salvesen et al. (1970) developing the strip theory method for predicting the seakeeping force of a ship. Newman and Sclavounos (1980) proposed the unified theory of ship motions for slender bodies. Zaraphonitis et al. (2011) analysed the seakeeping performance of a medium-speed win hull container ship using Strip theory method. Recently, Simonsen et al. (2013) have investigated the ship motion of KCS in regular head waves. They carried out the experiment in FORCE Technology's towing tank in Denmark. Gasparotti and Rusu (2013) have investigated the seakeeping analysis of a container ship in irregular waves with Perison-Moskowitz wave power density spectrum. They analysed the dynamic response of a container ship in polar diagram and investigated. Malik et al. (2013) carried out the numerical simulations for the prediction of wave forces on underwater vehicle when it operated in beneath the free surface waves using Panel Method.

In the present study, a numerical seakeeping analysis of a KRISO container ship (KCS) in regular waves was investigated using Panel Method. The numerical seakeeping analyses were performed in AQWA software as well as has been compared with the experimental result. The simulation results of the heave and pitch motions of KCS in head sea conditions have good agreement with the experimental result.

2. Mathematical formulation

2.1. Equation of motion

For the dynamic analysis of a ship, it is essential to obtain the added mass, damping and stiffness coefficients and also the forces applied to the body for all of the degrees of freedom. The ship body is assumed as a rigid body, so the ship motion equation in the time domain can be written as follows:

$$(M + A)\ddot{\eta} + B\dot{\eta} + C\eta = F \qquad (1)$$

Where, M is the mass body, A is added mass coefficients, B is damping coefficients, C is stiffness coefficients and F is applied external force.

2.2. Hydrodynamic forces

The applied loads are often determined in term of the amount of pressure applied to the body that can be obtained from Bernoulli's equation as follows:

$$p + \rho\frac{\partial \phi}{\partial t} + \frac{1}{2}\rho\left|\nabla\phi\right|^2 + \rho g z = C \qquad (2)$$

Where, p is the pressure of the fluid, ρ is the density of the fluid, g is the gravitational acceleration, $\phi(x, y, z)$ is a potential function of velocity, C is an arbitrary value which can be assumed equal to zero. For assuming the waves as linear waves, the pressure should be also considered as linear. This can be done by ignoring the hydrostatic term and the second order dynamic effect of waves. Therefore, the force may be calculated by integrating the pressure over the body surface are as follows:

$$F = \iint_S p\hat{n}dS \qquad (3)$$

The potential theory often be used for evaluating the hydrodynamic interaction between the ship and the sea waves. The Laplace equation is solved by considering the boundary conditions of the potential theory. The Laplace governing equation can be written as follows:

$$\nabla^2\phi = \frac{\partial^2\phi}{\partial x^2} + \frac{\partial^2\phi}{\partial y^2} + \frac{\partial^2\phi}{\partial z^2} = 0 \qquad (4)$$

Where, x, y, z, are Cartesian system coordinates. The potential function of a linear wave can be divided into three parts namely: incident wave ϕ_I, diffraction wave ϕ_D, radiation wave ϕ_R.

$$\phi = \phi_I + \phi_D + \phi_R \qquad (5)$$

In Eq. (3), $\hat{n}$ is the normal vector of the surface and if the potential function is written in terms of incident, diffraction and radiation waves.

$$F = \mathrm{Re}\left\{\iint i\rho\omega e^{i\omega t}\hat{n}\left(a\hat{\phi}_I + a\hat{\phi}_D + \hat{x}_n\hat{\phi}_R\right)dS\right\} \quad (6)$$

Equation (6) can be also rewritten as:

$$\begin{aligned} F &= \mathrm{Re}\left\{\hat{F}e^{i\omega t}\right\} \\ &= \mathrm{Re}\left\{a\left(\hat{F}_I + \hat{F}_D\right)e^{i\omega t} + \overline{x}_n\hat{F}_R e^{i\omega t} + F_{HS}\right\} \end{aligned} \quad (7)$$

Where, $\hat{F}$ is amplitude of the total force, $a\hat{F}_I$ is the amplitude of Froude – Krylov force, $a\hat{F}_D$ is the amplitude of diffraction force, $a\left(\hat{F}_I + \hat{F}_D\right)$ is the amplitude of the total force applied to ship hull. The load amplitude of incident, diffraction and radiation waves can be also obtained from:

$$\hat{F}_I = i\omega\rho\iint_S \hat{\phi}_I dS \quad (8)$$

$$\hat{F}_D = i\omega\rho\iint_S \hat{\phi}_D dS \quad (9)$$

$$\hat{F}_R = i\omega\rho\iint_S \hat{\phi}_R dS \quad (10)$$

2.3. Response Amplitude Operators

The harmonic response of the ship to regular wave are commonly to be represented as RAO which are proportional to wave amplitude. The set of linear motion equation with frequency dependent coefficients.

$$[\eta] = H[F] \quad (11)$$

$$H = \left\{-\omega_e^2(M + A) - i\omega_e B + C\right\}^{-1} \quad (12)$$

In Equation (12), H is transfer function which relates input forces to the output response.

3. Numerical computation

3.1. Ship particular

In the present study, a seakeeping analysis of a KRISO container ship (KCS) is performed. The study includes the linear seakeeping analysis coupled heave and pitch motions in regular wave conditions. The numerical seakeeping analyses are carried out with AQWA.

Experiment data for the heave and pitch of KCS in head sea condition have been compared with the numerical analysis. The main characteristic of KCS is in table 1. Three dimensional model of KCS is taken from an available website of SIMMAN. Figure 2 shows the 3D model of KCS in AQWA.

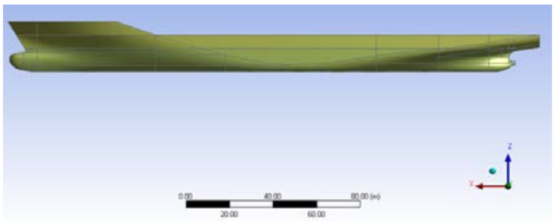


Figure 2. *Three dimensional model of KCS.*

Table 1. *Main particulars of KCS.*

Particulars	Unit	Value
Length of ship, L_{PP}	m	230
Breadth moulded, B	m	32.2
Depth moulded, D	m	19
Draught, D	m	10.8
Block coefficient, C_B	-	0.651
Displacement volume, ∇	m^3	52030
Design speed, V	knots	24
GM	m	0.6
Pitch radius of gyration, k_{yy}	m	57.5

3.2. Simulation condition

Numerical simulation was carried out to the effect of different wavelength in regular waves. Ship speed, wave frequencies have been chosen in order to study on the effect of wavelength on characterizing the motion response of a ship in various wave directions are listed in table 2. The RAO is used to determine how a ship is going to behave when operating in the sea. The hydrodynamic diffraction analysis is used for calculating the RAO for different wave direction. The wave directions are defined as shown in figure 3.

Table 2. *Simulation condition*

Ship speed [knots]	Range of λ / L	Range of wave frequencies [rad/s]
24	0.3~2.0	0.36~0.98

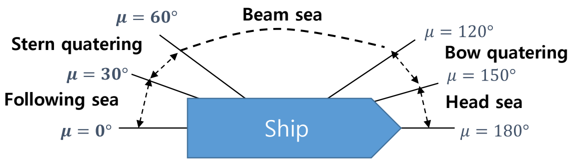


Figure 3. *Definition of incident wave direction.*

3.3. Numerical approach

AQWA is a sub-module in ANSYS software which provide a tool set for investigating the effect of environmental loads on marine structures. The hydrodynamic suite is used for analysing seakeeping of marine application. Figure 4 shows the process of solving the problem of ship motion in AQWA. First, the import of 3D model of KCS was done. After a stage of import geometry, surface mesh is generated in AQWA. Next, analysis setting, definition of wave direction, range of wave frequencies and ship's forward speed were done at stage of pre-processing. And then, a numerical seakeeping analysis of a KRISO container ship (KCS) in regular waves was solved based on Panel method. Finally, the result of ship motion was given at stage of post-processing.

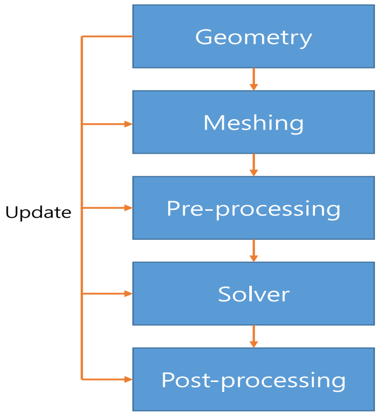


Figure 4. *Flow chart for solving ship motion.*

In addition, the quality of the discrete hull surface by constant panels will affect the accuracy of hydrodynamic properties of analyzing structures. For each individual panel must satisfy with the requirement in this program. Figure 5 shows the generated mesh of the KCS model in AQWA.

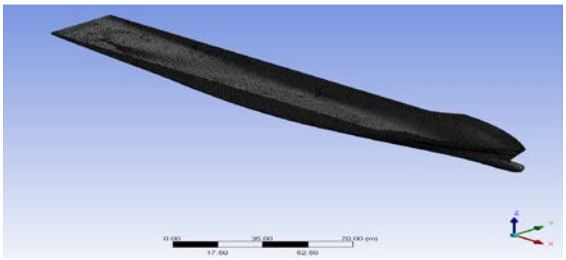


Figure 5*. Mesh generation of KCS.*

The mesh is automatically generated on the bodies in the model and its density based on maximum element size parameters. The larger the maximum element size, the less accurate the results. In this study, the numbers of panel elements and diffracting elements are shown in table 3.

Table 3. *Number of elements of KCS model*

Items	Value	Limitation of AQWA
Number of Elements	11156	40000
Number of Diffracting Elements	7765	30000

4. Result

4.1. Verification of numerical computation

The experimental data for the RAOs heave and pitch of KCS in head sea condition which was conducted in FORCE Technology's towing tank in Denmark (Simonsen, 2013) have been compared with results from the numerical analysis as shown in Figures 6~7. It can be seen from that RAOs of heave and pitch motions in regular wave conditions in the present study (CWNU) are good agreement with the experimental results of RAOs of heave and pitch motion of KCS by Simonsen (2013).

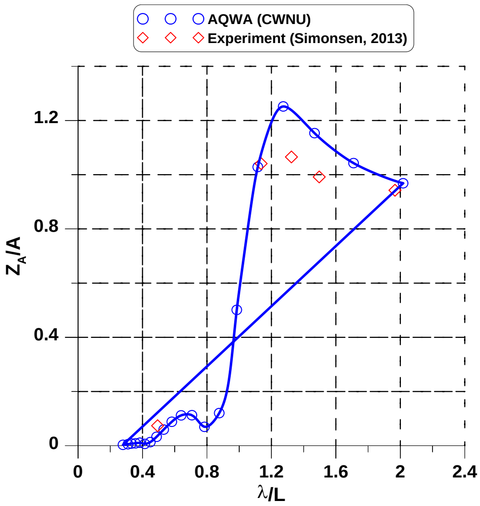


Figure 6. *Heave RAO in head sea.*

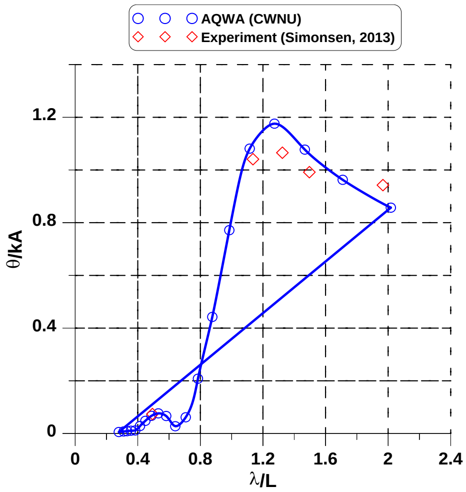


Figure 7. *Pitch RAO in head sea.*

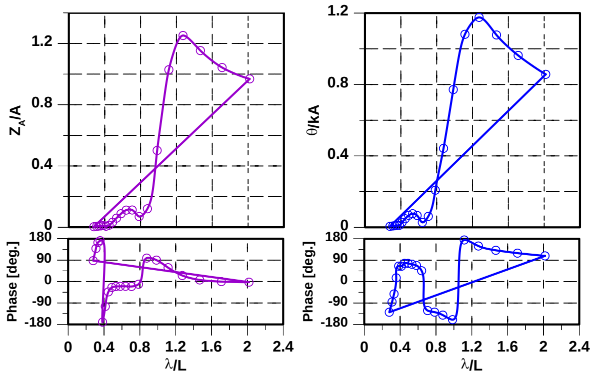
According to Simonsen (2013), if the behavior of the pitching and heaving ship is determined in analogy to a mass-spring-damper system with force motions, two things influence the response of the ship: resonance and the size of the exciting loads.

For this reason, it can be seen from that the maximum heave RAO and maximum pitch RAO occur at the resonance point λ / L = 1.3 in the experiment result and numerical result, respectively.

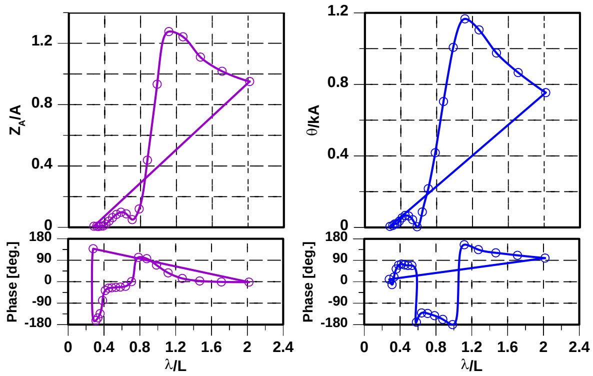
4.2. Analysis of seakeeping performance

The RAO is used to determine how a ship is going to behave when it operates on the sea. The result of heave and pitch motion depends on the ratio of the wavelength over ship length in Froude number Fn = 0.26 as shown in Figure 8. From the simulation result, it can be seen that the maximum heave occurs at the wave crest and large excitation in very long waves results in the large motion.

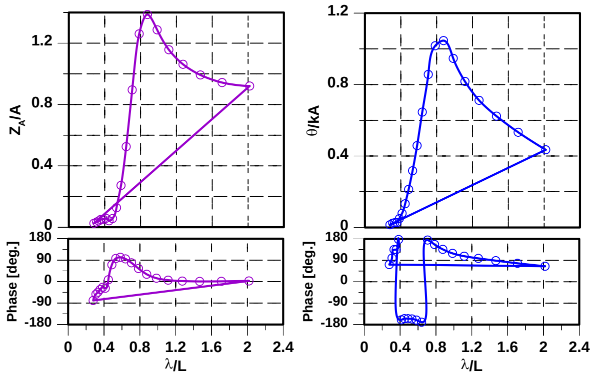
On the other hand, the responses are generally reduced in very high encounter frequencies at the given speed because short wave does not excite the ship so much. In addition, the heave phase is going to zero in very long waves and this indicates the heave motion is synchronized with wave motion.



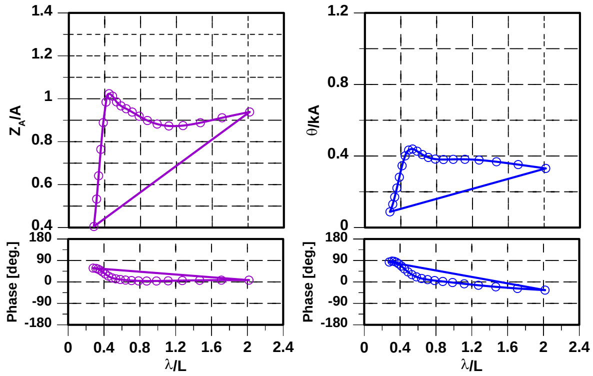
a. $\mu = 180^o$



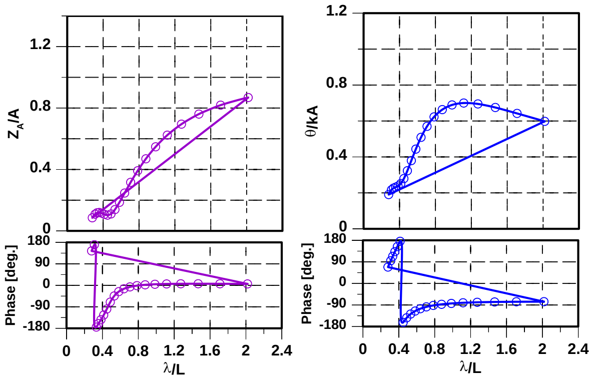
b. $\mu = 150^o$



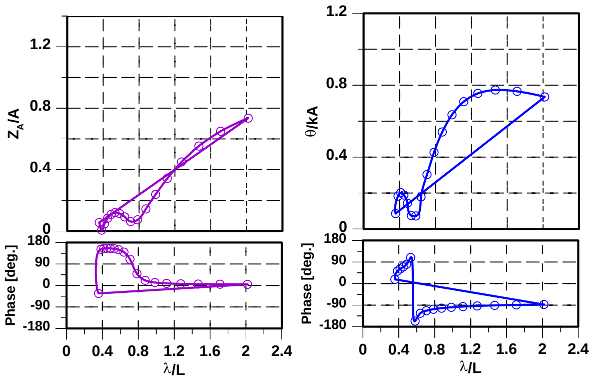
c. $\mu = 120^o$



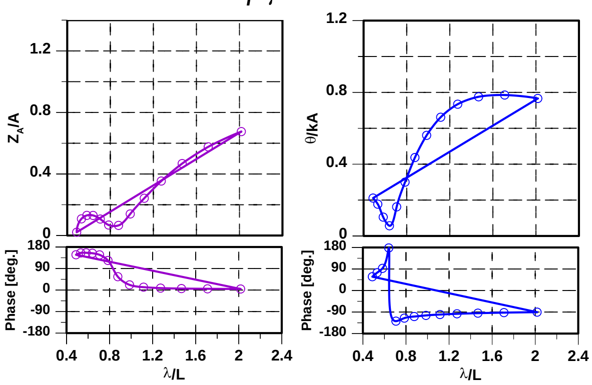
d. $\mu = 90^o$



e. $\mu = 60^o$



f. $\mu = 30^o$



g. $\mu = 0^o$

Figure 8. *Heave and pitch RAO.*

However, the pitch phase has a trend to become 90^o where maximum pitch motion occurs. On the other hand, when 90^o < μ <180^o, the heave response increases as the wave direction becomes μ = 120^o and the wave excitation become synchronized along the entire length of the hull. Particularly, the amplitude of pitch resonance decrease as the wave direction approaches to 90^o. By contrast, when the range of wave direction $0^o < \mu < 90^o$, the heave response and pitch response reduce as the wave direction approaches 0^o and the heave phase is always zero in very long waves indicating the heave is synchronized with wave depression at all wave direction. In addition, the pitch phase is -90^o on wave direction of beam sea. Moreover, in case of following sea, it can be seen that heave phase is close to zero over the most of range of encounter frequencies for which response is significant. It indicates that heave motion is again nearly synchronized with wave motion. On the other hand, pitch phase in following sea is near -90^o over the most of the significant range of encounter frequencies.

4.3. Application for optimal ship route

In order to apply the numerical result at various wave heading angle for optimal ship route, it is necessary to calculate the relative motion and relative velocity at bow area. In the past, there were many empirical formulae for estimating the relative motion from ship response. In this study, relative vertical motion and relative velocity at bow area were calculated from the pitch and heave motion with respect to the center of gravity based on the Ajrm’s method.

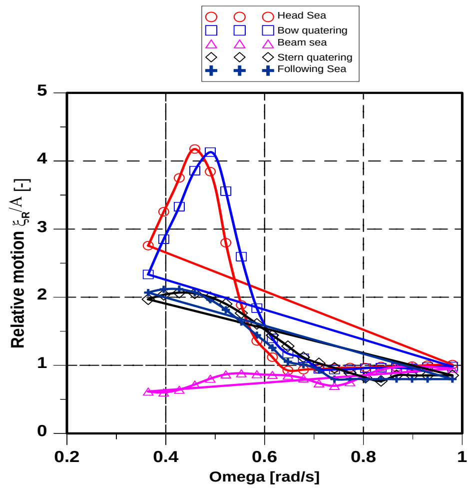


Figure 8. *Relative motion at bow.*

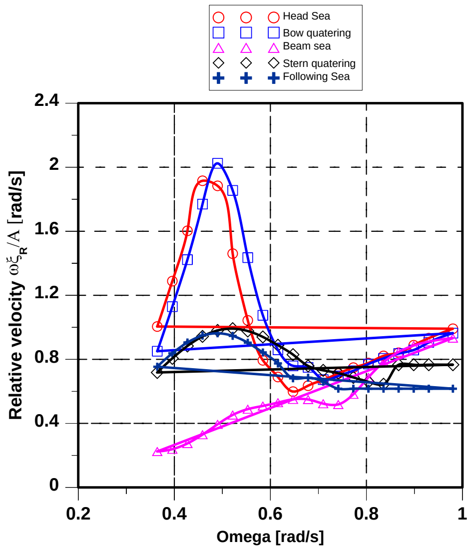


Figure 9. *Relative velocity at bow.*

Figures 8~9 show the relative motion and relative velocity at bow at various wave heading angle which are applied for finding probability of slamming and deck wetness.

5. Conclusion

This study deals with the numerical seakeeping analysis in the waves of the KCS container ship in regular waves. The hydrodynamic interactions between the ship and the linear waves are investigated numerically using Panel Method in AQWA software. The results of the heave and pitch motions of KCS in regular wave conditions in the present study (CWNU) have good agreement with the experimental results of Simonsen (2013). In addition, the effect of wavelength and wave direction have a clear effect on the characterizing the motion response. Heave response and pitch response become small in short wave and the large in a very long wave. Furthermore, the numerical results in this study can be useful in order to predict the slamming and deck wetness for ensuring ship safety❑

References

1] V. M. Nguyen. *Study on the Optimal Weather Routing of a ship considering the Sea State*. Master Thesis. Changwon National University, 2016.

[2] J. L. Hess and A. M. O. Smith. Calculation of potential flow about arbitrary bodies. *Progress in Aerospace Science*, Vol.8, (1967), pp. 1-138.

[3] N. Salvesen, E. O. Tuck and O. M. Faltinsen. Ship motions and sea loads. *Society of Naval Architects and Marine Engineers Transactions*, (1970), pp. 250-287.

[4] G. Zaraphonitis, G. J. Grigoropoulos, D. P. Damala and D. Mourkoyannis. Seakeeping analysis of a medium-speed twin hull container ship. *In Proceeding of 11th International Conference on Fast Sea Transportation FAST 2011*, Hawai, US, (September, 2011), pp. 615-622.

[5] J. N. Newman and P. Sclavounos. The unified theory of ship motions. *In Proceeding of 13th Symposium on Naval Hydrodynamics*, Tokyo, Japan, (October, 1980). pp. 1-25.

[6] C. D. Simonsen, J. F. Otzen, S. Joncquez and F. Stern. EFD and CFD for KCS heaving and pitching in regular head waves. *Journal of Marine Science and Technology*, Vol. 18, (2013), pp. 435-459.

[7] C. Gasparotti and E. Rusu. Seakeeping numerical analysis in irregular waves of a container ship. *Mechanical Testing and Diagnosis*. Vol. 1, (2013), pp. 19-31.

[8] S. A. Malik, P. Guang and L. Yanan. Numerical simulations for the prediction of wave forces on underwater vehicle using 3D Panel Method code. *Journal of Applied Science, Engineering and Technology*, (2013), pp. 5012 – 5021.

[9] L. Arjm. *Seakeeping: ship behavior in rough weather*. Ellis Horwood Ltd, (1998).

[10] Allianz Global Corporate & Specialty. *Safety and Shipping Review 2017*. (2017).

[11] ANSYS. *AQWA theory manual*. (2013).

[12] http://www.simman2008.dk/kcs/container.html

Ngày nhận bài: 18/5/2018
Ngày chuyển phản biện: 22/5/2018
Ngày hoàn thành sửa bài: 12/6/2018
Ngày chấp nhận đăng: 19/6/2018