

Calculations of the Heave and Pitch RAO's for Three Different Ship's Hull Forms

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I_{55}	Longitudinal Inertia
ω_e	Encounter Frequency
γ_5	Encounter Angle of Wave with i Direction
F_{w50}	Pitch Moment: Diffraction + exciting
t	Time

ABSTRACT

The research carried out in this article is to determine the RAO (Response Amplitude Operator) heave and pitch motions of three different ship's hulls forms. Ship is running at the head sea of the regular wave and its responses are obtained by modified strip theory using Maxsurf software. Three different ship's hull forms (Wigley-S60-DDG) are selected in order to predict the results. The obtained results of RAO heave and pitch motions are presented and discussed at various Froude numbers.

KEY WORDS: *Seakeeping; RAO; Heave and Pitch; Hull Forms (Wigley -S60-DDG).*

NOMENCLATURE

a_{ij}	Added Mass Coefficient
m	Ship Mass
\ddot{x}_i	Acceleration in i-Direction
b_{ij}	Damping Coefficients
\dot{x}_i	Velocity in i-Direction
c_{ij}	Restoring Coefficients
x_i	Motion in i-Direction
F_{w30}	Vertical Force: Diffraction + exciting

1.0 INTRODUCTION

Prediction of ship performances in calm and rough waters is one of imperative concerns of naval architects and seakeeping performance is one of the most important aspects of ship design. The hull is designed in most cases need to be optimized.

It's important to know that all process of optimize hull needs to investigate seakeeping performance of vessels and all persons who works on hull optimization, determined seakeeping. Some researchers have considered two or three objective functions for optimizing hull form and some others only one objective functions. Bagheri et al. (2014) work on optimizing the seakeeping performance of ship hull forms using genetic algorithm, Scamardella & Piscopo (2014) use only one objective function in Passenger ship seakeeping optimization by the Overall Motion Sickness Incidence, Gammon (2011) uses three objective functions in Optimization of fishing vessels by multi-objective genetic algorithm, Biliotti et al. (2011) utilize two objective functions for automatic parametric hull form optimization of fast naval vessels, Özüm, S., Şener, B., Yılmaz, H. (2011) investigated the seakeeping qualities of fast ships, Teresa Castiglione (2011) investigate numerical analysis includes evaluation of ship motions, effects of wave steepness on ship response, Grigoropoulos and Chalkias (2010) use utilize two objective functions in Hull-form optimization in calm and rough water, Mousaviraad, Carrica, Stern (2010) developed a harmonic

wave group (HWG) single run seakeeping procedure, by using an unsteady RANS solver, Bunnik et al.(2010) carried out CRS project that conducted a comparative study, like the ITTC Seakeeping workshop and the results from the different approaches have been compared. Zhang et al. (2010) have paper about Time-domain simulations of radiation and diffraction forces that studied large amplitude, time domain and wave bode interactions problems with forward speed and used an exact body boundary condition with linearized free surface boundary conditions. Zhang et al. (2010) also studied seakeeping computations using double body basis flow that free surface boundary conditions are derived based on a double body linearization and the mixed Euler-Lagrange time stepping techniques. Huang et al. (2009) the seakeeping tests and numerical predictions confirmed that even though sloshing impact pressures are nonlinear and stochastic, global tank loads and LNGC motions are deterministic. Bhushan, S. et al (2009) used the VOF scheme for numerical treatment of free surface in seakeeping investigation, Greco et al. (2008) investigate concern the further development of the numerical potential-flow method for seakeeping of a model in regular/irregular wave.

Simonsen et al (2008) carried out a motion analysis for the KCS ship hull in heave and pitch motion in regular head waves, Claus, (2008) proposed a technique to generate a sequence of waves for the simulation of extreme seas for seakeeping tests. Sariöz, Sariöz (2006) proposed a new optimization procedure, based on a nonlinear problem solved by direct search techniques, Grigoropoulos (2004), Saha et al. (2004) employed different types of nonlinear linear programming as optimization techniques, Kukner & Sariöz (1995) optimized the seakeeping qualities of a high speed vessel, using the Lackenby method to generate several hulls, BAILEY, P. A. (2000) The NPL high-speed round bilge displacement hull series, Journee (1992) developed personal computer program based on both the ordinary and the modified strip theory method, Hearn, Hills, Sariöz (1991) Practical seakeeping for design, Besso and Kyozuka (1984) works on ship motion reduction by anti-pitching fins in head seas.

Given the variety of some hull designs used vessels, the extent to which overall design influences motion response is not clear. The objective of this paper is to investigate the extent to which hull design can influence the seakeeping response. In order to make such a comparison a computational method that is valid is required.

2.0 HEAVE AND PITCH MOTIONS

The basic of our calculation are the strip theory that is the standard tool for ship seakeeping computation. Strip theory is a frequency-domain method. This means that the problem is formulated as a function of frequency. This has many advantages, the main one being that computations are speed up considerably. However, the method generally becomes limited to computing the linear vessel response. The vessel is split into a number of transverse sections. Each of these sections is then treated as a two-dimensional section in order to compute its hydrodynamic characteristics. The coefficients for the sections are then integrated along the length of the hull to obtain the global coefficients of the equations of motion of the whole vessel. Finally the coupled equations of motion are solved. As is well

known, strip theory remains a solid basis for seakeeping calculations and competes successfully with newer and more rigorous methods, even at high speeds, when compared with experimental and full-scale results. The ship is considered to be a rigid body floating in an ideal fluid: homogeneous, incompressible, and free of surface tension, irrotational and without viscosity. It is assumed that the problem of the motions of this floating body in waves is linear or can be linearized. For displacement vessels the range of under 0.4, where the heave motion show a resonant response with values of the heave RAO significantly in excess of unity. Whilst the introduction of ride controls has somewhat reduced the severity of motions in some cases, there has been considerable interest in the underlying effect of hull form on the ship motions. As a result of this, only the external loads on the underwater part of the ship are considered and the effect of the above water part is fully neglected.

The heave and pitch equations are coupled so that heave motions are influenced by pitch and vice versa.

$$\text{Heave: } (m + a_{33})\ddot{x}_3 + b_{53}\dot{x}_3 + c_{53}x_3 + a_{35}\ddot{x}_5 + b_{35}\dot{x}_5 + c_{35}x_5 = F_{w3} \sin(\omega_e t + \gamma_3) \quad (1)$$

$$\text{Pitch: } a_{53}\ddot{x}_3 + b_{53}\dot{x}_3 + c_{53}x_3 + (I_{55} + a_{55})\ddot{x}_5 + b_{55}\dot{x}_5 + c_{55}x_5 = F_{w5} \sin(\omega_e + \gamma_5) \quad (2)$$

However, the coupling is usually fairly weak and to a first approximate to the motions of two independent second order spring mass systems. The analogy is not rigorous because the coefficient in the equations is frequency dependent, in contrast to constant coefficients assumed in the classical equations. Nevertheless, we may define approximate natural frequencies for heave and pitch using equation (3):

$$\omega_3 = \sqrt{\frac{c_{33}}{m+a_{33}}}, \quad \omega_5 = \sqrt{\frac{c_{55}}{I_{55}+a_{55}}} \quad (3)$$

Where the heave added mass a_{33} and the pitch added inertia a_{55} are to be evaluated at the respective natural frequencies.

The focus of this paper is the head sea seakeeping response of heave and pitch motions and no attempt is made to evaluate the efficiency of the designs considered with respect to resistance. In this paper, we tried to obtain response amplitude operator of ships motions in oblique waves and the damping factor of roll motion as non-dimensional is considered 0.15 but since the major issue of our calculations is investigation of heave and pitch motions, we preferred to ignore roll motion.

3.0 THREE SHIP'S HULL FORMS

The hull forms selected for this comparative study are Wigley model, S60 model and a modern ship. The main dimensions of these models are shown in Table 1. For simulation of ship motions and analysis we used Maxsurf motion module that is an application which may be used to predict the motion and seakeeping performance of vessels designed using Maxsurf.

The Wigley model is a popular model in ship hydrodynamics experiments. The Wigley Hull model tank test data is available were carried out at the Ship hydromechanics Laboratory of the

Delft University of Technology (DUT). The standard Wigley hull is a mathematical displacement hull form, the geometric surface of which can be defined as:

$$y = \frac{B}{2} \left(1 - \left(\frac{2x}{L} \right)^2 \right) \left(1 - \left(\frac{z}{T} \right)^2 \right) \quad (4)$$

where B is the ship breadth, L is the ship length, T is the ship draft, and $-T \leq z \leq 0$. The Wigley model ($C_m = 0.667$, $L=3m$, $L/B = 10$) have been tested at three forward speeds: $F_n=0.2, 0.3, 0.4$ that shape of this hull form is given in Figure 1. Vertical motions of hull sections are predicted by the coupled strip theory and the Frank method. The hull form seakeeping is carried out at a single Froude number ($F_n = U/\sqrt{gL}$) that is constant for each model and that is 0.3 for the Wigley, where U and L are the speed and the waterline length of the model, respectively.

Table 1: Models dimensions

Parameters	Wigley	S60	DDG51
Midship coeff. (C _m)	0.6667	0.98	0.974
L/B	10	7	5.5
Length [m]	3	122	93.4
Breadth [m]	0.3	17.4	17
Draught [m]	0.1875	6	6.21
Displacement [m ³]	0.078	9605	3450
B/T	1.6	3	2.73
C _B	0.48	0.7	0.577

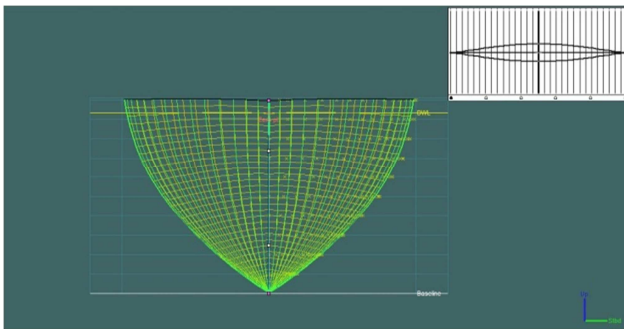


Figure 1: Body plan of the Wigley.

The second hull form is Series 60 model that is one of standard series for merchant ships. The S60 model properties that is discussed in this article are $L=122$ m, $L/B=7$, $CB=0.7$, $B/T=3$, and shown in Figure 2.

The third hull form is DDG. Models scaled by 1:24.824 of that vessel have been constructed and tested by the David Taylor Model Basin (model DTMB5415) and Istituto Nazionale per Studied Esperienze di Architettura Navale (INSEAN, the Italian ship model basin).

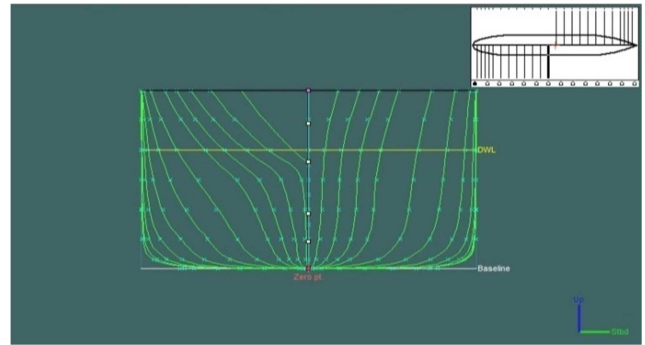


Figure 2: S60 body plan.

Model C.2340; Campana & Peri 2000). ($L=93.4m$, $B=17m$, $CB=0.577$, $T=6.21m$) that there is its other numerical and empirical results. Figure 3 is shown its body plan.

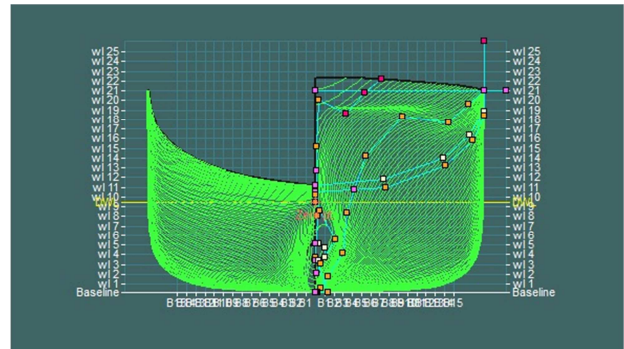


Figure 3: Body plan of the DDG.

4.0 RESULTS AND DISCUSSIONS

4.1 Wigley hull

The Ship hydromechanics laboratory of the Delft University of Technology has published experimental data on hydromechanics coefficients for heave and pitch, vertical motions, wave loads and added resistance in head waves of two Wigley hull forms. The wave is head sea with encounter angle of 180° and wave height of 2 cm for this test. Using main dimensions and equation (4) to calculate offset table then we draw the numerical model. Comparison between numerical results and experimental data at $F_n=0.3$ are shown in Figures 4-7.

As shown in Figures 4 and 5, the peak value of heave and pitch RAOs occur at $\lambda/L=1.2$ and is about 1.7 that means the ship has worst condition of floating. Based on the experimental and numerical charts the computational error rate is about 10%. Now, according to the low error rate of calculation can also be used to assess other environmental condition of vessel.

We can see in predicted charts of seakeeping performance that at low speeds, peak values of heave and pitch reduced and the difference between peak value of heave and pitch increased. At larger angle of attack the peak values of heave and pitch reduced too. Also at higher speeds the peak value occurs at $\lambda/L > 1.2$. In general, the graphs illustrate that Heave and Pitch RAOs will increase with increasing velocity but at higher angle of the wave

hit the ship is inversely related. Also the comparing charts showed the accuracy of experimental test and numerical errors. Figure 8 shows peak values of heave and pitch occur at $\lambda/L=1$ for Froude number 0.2 and the RAO's values reach to unit value at $\lambda/L=3.5$. Max values of heave and pitch are 1.3 and 0.95. Figure 9 shows heave and pitch for Froude number 0.4 that peak values occur at $\lambda/L=1.3$. The Froude number of this condition is for case that the speed is near to reach high speed vessels. Maximum values of heave and pitch are 2.6 and 2.3. The model at this speed will have sever shocks and due to maximum amount of RAO can be seen the ship simply move up and down until λ/L reach about 3 that the ship movement is smoothly. Numerical results of the RAO heave and pitch at various encounter angles that is the angle between wave attack and the ship motion are shown in Figures 10~12.

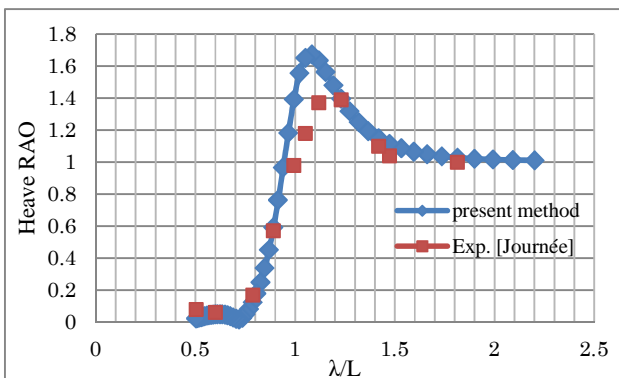


Figure 4: Comparison of the RAO heave for Wigley ($F_n = 0.3$)

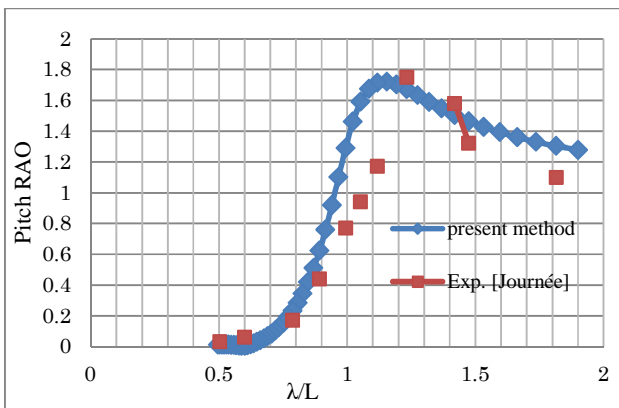


Figure 5: Comparison of the RAO pitch for Wigley ($F_n = 0.3$)

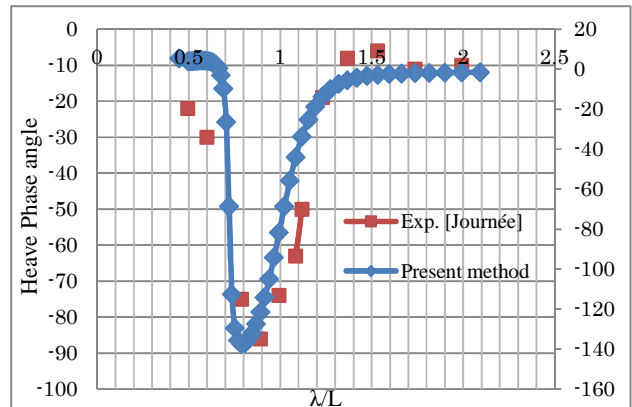


Figure 6: Comparison of the phase heaves for Wigley ($F_n = 0.3$)

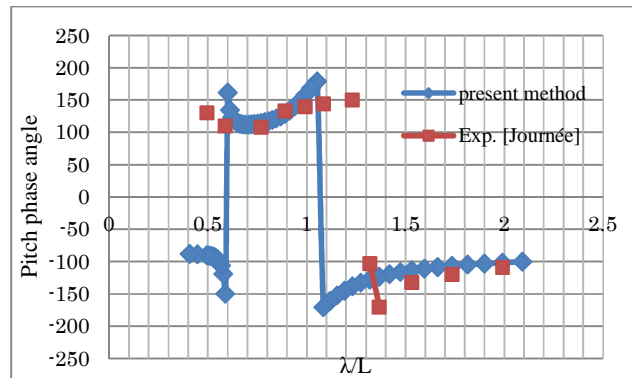


Figure 7: Comparison of the phase pitch for Wigley ($F_n = 0.3$)

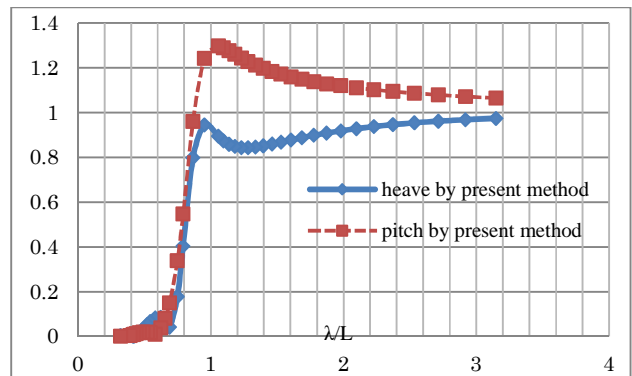


Figure 8: RAO Heave and Pitch for Wigley at ($F_n = 0.2$)

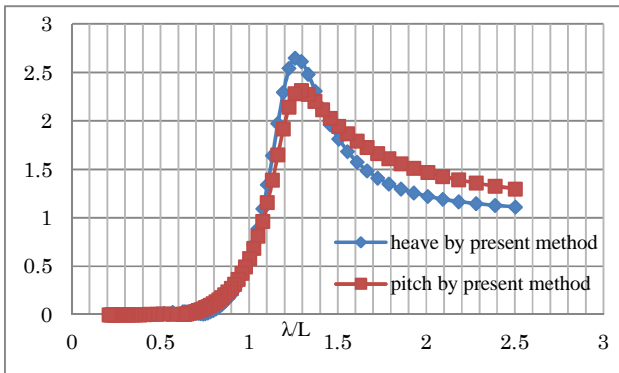


Figure 9: RAO Heave and Pitch for Wigley at ($F_n = 0.4$)

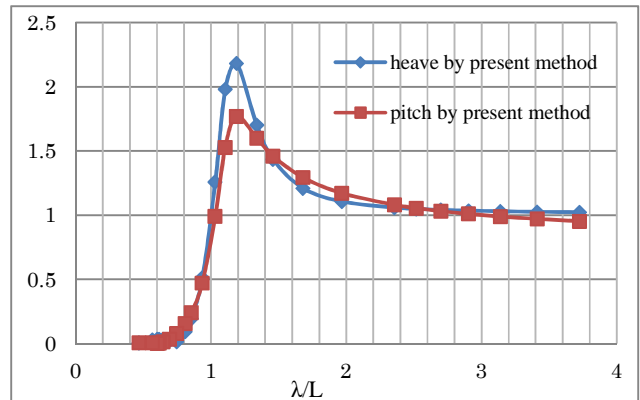


Figure 12: RAO heave and Pitch for Wigley at ($F_n = 0.4$) & ($\mu = 210^\circ$)

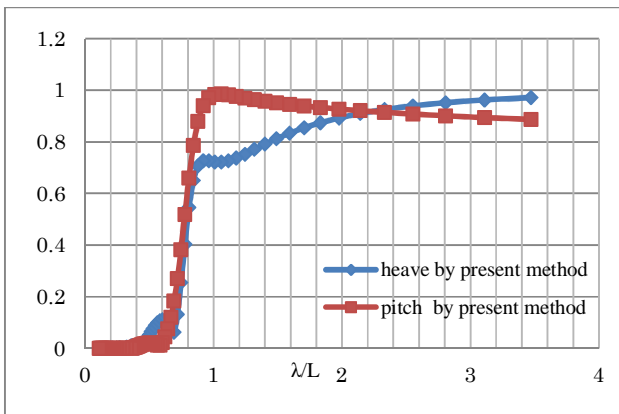


Figure 10: RAO Heave and Pitch for Wigley at ($F_n = 0.2$) & ($\mu = 210^\circ$)

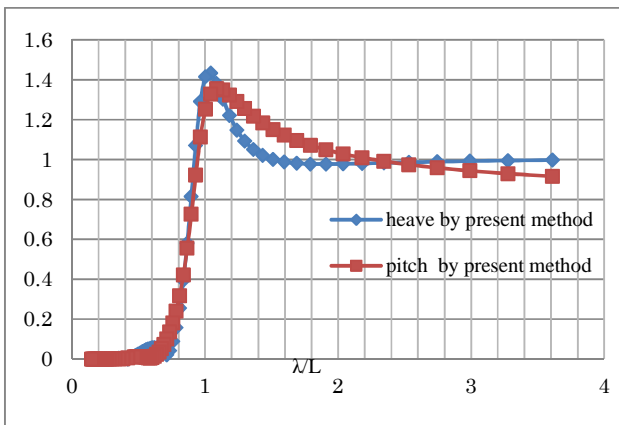


Figure 11: RAO Heave and Pitch for Wigley at ($F_n = 0.3$) & ($\mu = 210^\circ$)

4.2 S60 Hull

Using data for the S60 offset table and its dimensions, we draw our numerical model then compare Bagheri's RAO charts with present method. The wave is type of Param. Bretschneider head sea with encounter angle of 180° . According to charts of Figures 13 and 14, the peak value occurs at $\lambda/L = 1.2$. Figure 15 shows heave and pitch for Froude number 0.3 in head sea that max value of heave RAO is 2.3 and occurs at $\lambda/L = 1.4$, the max value of pitch RAO is 1.45 that occurs at $\lambda/L = 1.4$. Figure 16 shows heave and pitch peak values of Froude number 0.4 occur at $\lambda/L = 1.6$ that is the case when the ship is like a fast ship. For heave, max value is about 2.8 and it's 1.9 for pitch graph. Figure 17 shows heave and pitch RAO at Froude number 0.6 that the ship starts planing. The peak values occur at $\lambda/L = 1.9$ with heave and pitch maximum values of 3.9 and 3, respectively. Increase speed by higher Froude numbers causes peak values occur in further place of chart. In all cases the RAO reach to unit value at λ/L about 3.5. The last mode is shown, can't choose this type of hull as a high speed craft and it's only suitable for displacement vessels.

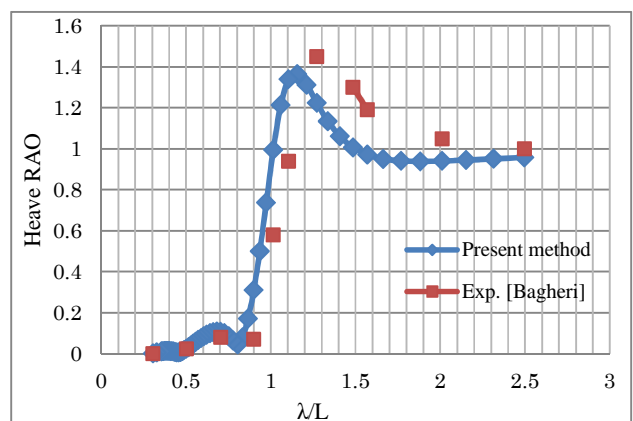


Figure 13: Comparison of the RAO Heave for S60 at ($F_n = 0.2$)

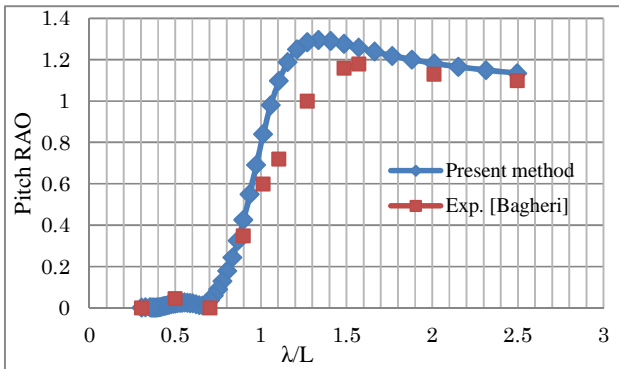


Figure 14: Comparison of the RAO Pitch for S60 at ($F_n = 0.2$)

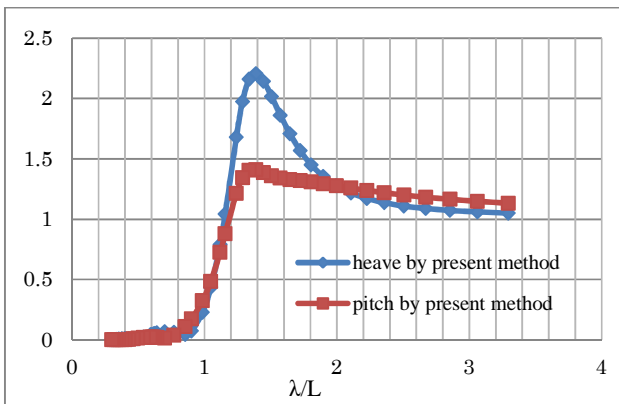


Figure 15: Numerical results of RAO Heave and Pitch for S60 at ($F_n = 0.3$)

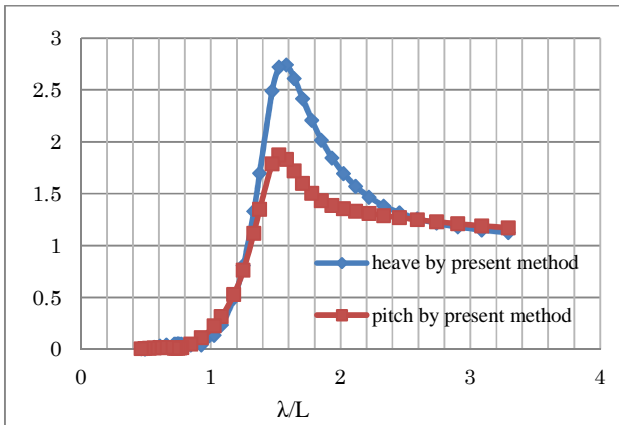


Figure 16: Numerical results of RAO Heave and Pitch for S60 at ($F_n = 0.4$)

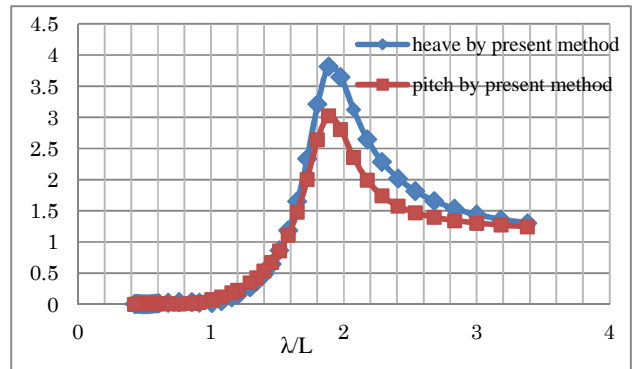


Figure 17: Numerical results of RAO Heave and Pitch for S60 at ($F_n = 0.6$)

4.3 DDG Ship

In this section, we focus on the seakeeping performance of DDG. The wave properties of model test are head sea and rough water with spectrum type ParamBretschneider and significant wave height $H_{1/3}=1\text{m}$ and modal period 10s. Figures 18 and 19 show the comparison of the presents results with other results. The results derived by strip theory using Frank (S-T-F) close-fit method are older than three-dimensional (3-D) panel code by SWAN2-2002, a modern time-domain 3-D Rankine source panel code, and strip theory using Salvesen method using in this paper. The heave graphs show that Frank calculation errors are more than other methods and our present method has error less than 5%. The peak values of heave and pitch charts occurs at λ/L about 1.4. By our negligible error of calculation, we predict modern DDG seakeeping performance for other Froude numbers as well as $F_n=0.3, 0.4$ and 0.7 , in Figures 20, 21 and 22, respectively.

Figure 20 show RAO heave and pitch of Froude number 0.3 with peak values of 1.08 and 1.2 for heave and pitch that these values occur at λ/L about 1.2. At Froude number of 0.4 as shown in Figure 21, the RAO peak values occur at $\lambda/L=1.3$. Seakeeping performance of DDG is more smoothly at $\lambda/L=3.2$. Figure 22 show heave and pitch RAO for Froude number 0.7 that DDG will work like a planing craft and peak values occur at $\lambda/L=1.6$. Maximum values of RAO heave and pitch are 2.2 and 1.5 respectively.

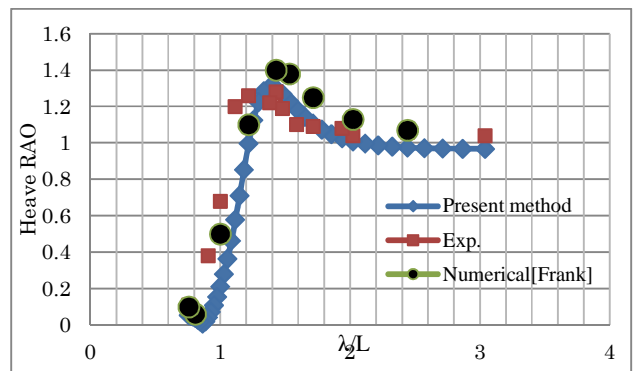


Figure 18: Comparison of the RAO Heave for DDG ($F_n = 0.237$)

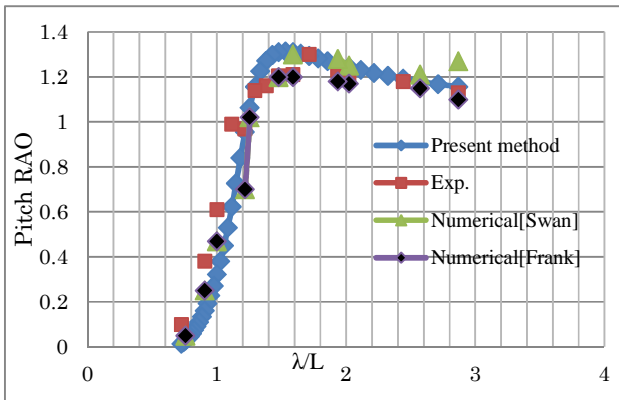


Figure 19: Comparison of the RAO Pitch for DDG ($F_n = 0.237$)

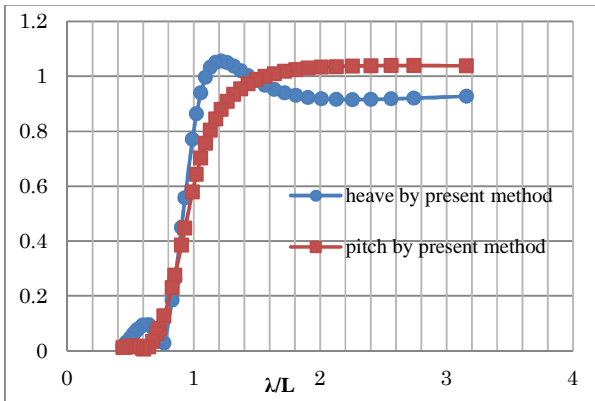


Figure 20: Numerical results of RAO Heave and Pitch for DDG at ($F_n = 0.3$)

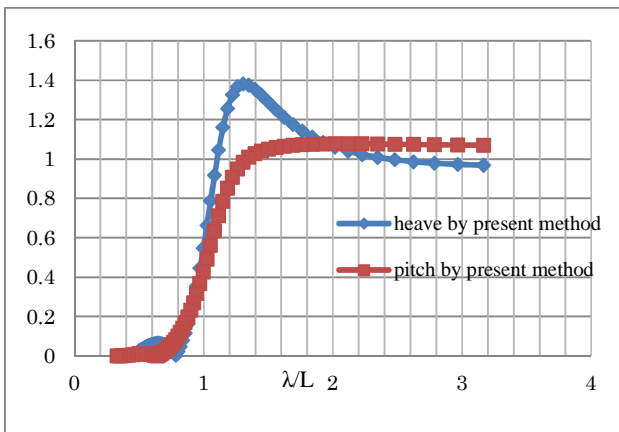


Figure 21 : Numerical results of RAO Heave and Pitch for DDG at ($F_n = 0.4$)

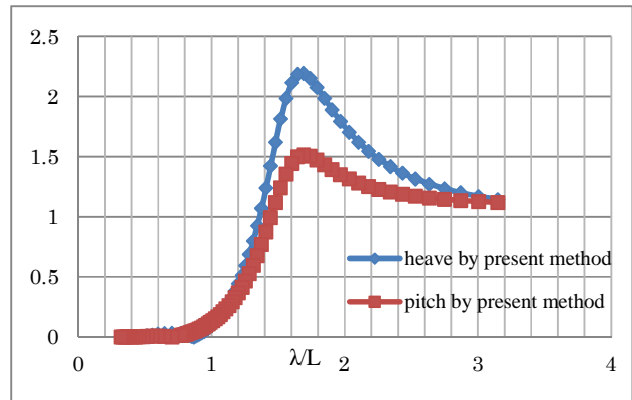


Figure 22: Numerical results of RAO Heave and Pitch for DDG at ($F_n = 0.7$)

5.0 CONCLUSIONS

Calculations of the RAO heave and pitch of the three different ship's hull at various Froude numbers are presented. These three different ships are Wigley, S60 and DDG. Some results are compared with experimental data and seem that the results are satisfactory. Froude number is from 0.2 to 0.7 applied, even at high F_n , the trend of the results are relatively well. Therefore, it is revealed that the present calculations method can estimate properly for the RAO of the ship motions.

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