11th International Workshop on Ship and Marine Hydrodynamics
Hamburg, Germany, September 22-25, 2019

Quick Evaluation of Seakeeping Performance for Ship Hull Form Optimization

Jinkai Wang, Decheng Wan*

State Key Laboratory of Ocean Engineering, School of Naval Architecture, Ocean and Civil Engineering
Shanghai Jiao Tong University, Collaborative Innovation Center for Advanced Ship and Deep-Sea Exploration, Shanghai, China

*Corresponding author: dcwan@sjtu.edu.cn

ABSTRACT

At present, most of the ship hull form optimization designs aim to reduce ship resistance. As the ship speed requirements continue to increase, the ship seakeeping performance is also particularly important. A fast and sensitive seakeeping evaluation program is the basis for ship hull form optimization with the aim of seakeeping performance. In this study, based on the strip theory, Tasai graphics of Lewis section are interpolated to calculate the damping coefficient and additional mass of the two-dimensional slices. Then, based on the Salvesen method, ship heave and pitch coupled motion equations in the wave are used to solve the pitch and heave motion of the ship in different wave directions. Finally, Wigley ship is calculated by the program above, and the evaluation results are compared with the experimental values. The results show that this method can quickly and accurately evaluate the heave and pitch motions of ships, which can greatly shorten the optimization time.

1 INTRODUCTION

With the increasing speed of ships, besides reducing the resistance of ships, maintaining or even improving the seakeeping performance of ships has become an important issue in ship performance on the premise of better rapidity. The ship hull form optimization for better seakeeping performance is to improve the ship seakeeping performance by changing the hull form, or to keep it in a good state when the resistance is reduced by changing the hull form. Fast and accurate evaluation of seakeeping performance is an important part of the optimization of hull lines aiming at seakeeping. The accuracy of evaluation can ensure the correctness of the ship hull form optimization results, and the rapidity of evaluation can save a lot of computing time and resources. Especially in the process of ship form optimization, usually dozens or even hundreds of new sample hull forms have to be evaluated, so a set of fast evaluation methods for ship seakeeping performance are needed, which can greatly shorten the period of ship hull form optimization.

Strip methods based on potential flow theory can accurately and rapidly evaluate the motions of ships in waves, such as pitch, heave and roll, which play an important role in seakeeping. Many scholars use slice method to calculate the motion of ships in waves. In this paper, strip theory is also used in general. When calculating the hydrodynamic coefficient of each slice, Lewis section method based on conformal transformation is adopted. This method can avoid some difficulties in determining the conformal transformation coefficients. At the same time, conformal transformation method and profile fitting method based on source-sink distribution can get relatively accurate results for any actual shape profile, and both methods can be applied to the calculation of ship motions, but Lewis section method is faster than profile fitting method. Therefore, in order to calculate the ship's motion in waves more quickly, the Lewis section method is used to calculate the damping coefficient and additional mass of each two-dimensional section. After obtaining the hydrodynamic coefficients of each section, a simplified coupled equation of pitch and heave motion based on strip theory is adopted, and the frequency response of the ship's pitch and heave motion in regular waves can be obtained by solving the equation.

In this paper, the Tasai graphic of Lewis section method and the simplified coupled equation of pitch and heave motions will be briefly introduced, then the method will be applied to the calculation of the pitch and heave motion of Wigley in waves.

2 THEORY

2.1 Lewis Section Method

A series of pulsating sources satisfying the surface and wave conditions of the object are used to replace the two-dimensional cylinder in heave motion. The average work done by the damping force on the object in a unit time is considered as follows [1]:

$$\frac{1}{2} N_z(x) \omega^2 z_a^2 \tag{1}$$

It is equal to the wave energy per unit time propagating to both sides in oscillation:

$$\frac{1}{2\omega} \rho g^2 \zeta_a^2 \tag{2}$$

So, we can get the following formula:

$$N_z(x) = \frac{1}{\omega^3} \rho g^2 \bar{A}_z^2 \tag{3}$$

Where, $\bar{A}_z = \zeta_a / z_a$ is the ratio of the wave amplitude at infinity to the amplitude of the cylinder's heave motion; ω is the frequency of heave oscillation. The above formula is used to get damping coefficient by calculating wave amplitude of oscillating wave at infinite distance. The additional mass of section can be gotten by following formula:

$$m_z(x) = \frac{1}{8} \rho \pi B^2 C \tag{4}$$

Where, B is the width of section; C is dimensionless hydrodynamic mass.

Japanese scholar Tasai [2], according to the Ursell theory, has made some to get the $\bar{A}_z$ and C values of Lewis section, which depend on the shape of section and oscillation frequency. Two of the graphics are showed as Fig.1

The frequency is expressed in dimensionless form:

$$\xi_T = \frac{\omega^2 T}{g} \tag{5}$$

and the section shape is expressed as follows:

$$H_0 = \frac{B}{2T} \tag{6}$$

$$\sigma = \frac{S}{BT} \tag{7}$$

Where, T is the draft of section; S is the area of section.

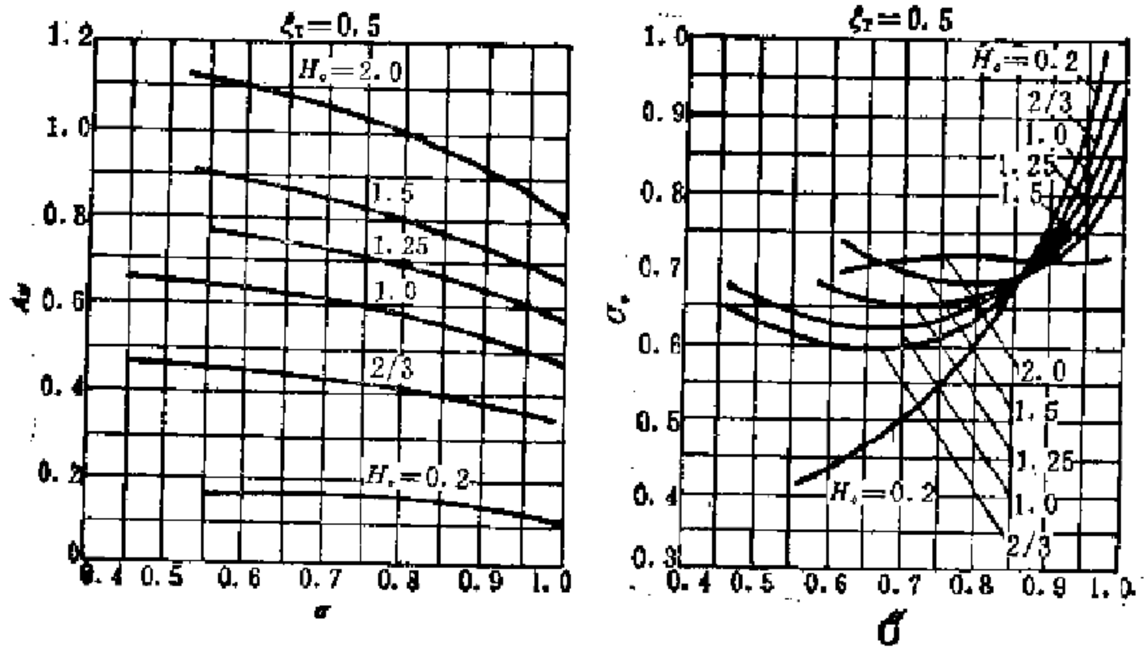


Figure 1: Tasai graphics (ξ_T =0.5) [1].

2.2 Simplified Coupled Equation of Pitch and Heave Motions

When a ship travels at speed U and encounters with regular waves at any angle μ, it often has oscillating motions in six degrees of freedom, in which pitch and heave are coupled. The motion responses of pitching and heaving can be obtained by solving these two degrees of freedom equations together.

$$\left.\begin{aligned}&(m+a_{zz})\ddot{z}+b_{zz}\dot{z}+c_{zz}z+a_{z\theta}\ddot{\theta}+b_{z\theta}\dot{\theta}+c_{z\theta}\theta=F(t)\\&(I_{yy}+a_{\theta\theta})\ddot{\theta}+b_{\theta\theta}\dot{\theta}+c_{\theta\theta}\theta+a_{\theta z}\ddot{z}+b_{\theta z}\dot{z}+c_{\theta z}z=M(t)\end{aligned}\right\} \tag{8}$$

Where, m is the mass of ship; I_{yy} is the inertial moment of ship mass to y-axis; a_{jj} is additional mass or its inertial moment; b_{jj} is damping coefficient relating to linear or angular velocity of motion; c_{jj} is coefficient of restoring force or restoring moment. All of these values depend on ship form, main dimensions, oscillation frequency, ship speed, wavelength and encounter angle.

According to the strip theory, when a ship is in oscillating motion, the fluid around the hull only flows in the tangent plane, which transforms the space problem into a plane problem. Therefore, F and M in Eq. (8) can be expressed by forces and moments distributed along the direction of length [3]:

$$\left.\begin{aligned}F&=\int_L F(x)dx\\M&=-\int_L F(x)xdx\end{aligned}\right\} \tag{9}$$

Where, $F(x)$ is the vertical force acting on a cross section; x is the coordinate position in the direction of length.

The force on the cross section at x is composed of hydrostatic force, damping force and inertial force:

$$F(x) = -2\rho g y_m (z - x\theta - \zeta_x^*) \\ - N_z(x)(\dot{z} - x\dot{\theta} + U\theta - \zeta_x^*) \\ - \frac{d}{dt}\left[m_z(x)(\dot{z} - x\dot{\theta} + U\theta - \zeta_x^*) \right] \tag{10}$$

Where, y_m is the half width of waterline; ζ_x^* is a modified waveform coordinate considering the difference between the dynamic pressure gradient and the static pressure gradient in waves, and it can be expressed as follows:

$$\left.\begin{aligned} \zeta_x^* &= \zeta_a \cos\left(\frac{2\pi x}{\lambda} + \omega_e t\right) e^{-kT^*} \\ T^* &= -\frac{1}{k} \ln\left(1 - \frac{k}{y_w} \int_{-T}^{0} y e^{kz} dz\right) \end{aligned}\right\} \tag{11}$$

By substituting Eq. (9) and Eq. (10) into Eq. (8) and collating and comparing the two ends, the coefficients of the coupled equations of pitch and heave can be obtained, and the differential equations of z and θ can be obtained. The module of the frequency response function of heave and pitch can be obtained by solving the equations by numerical or analytical methods.

3 APPLICATION

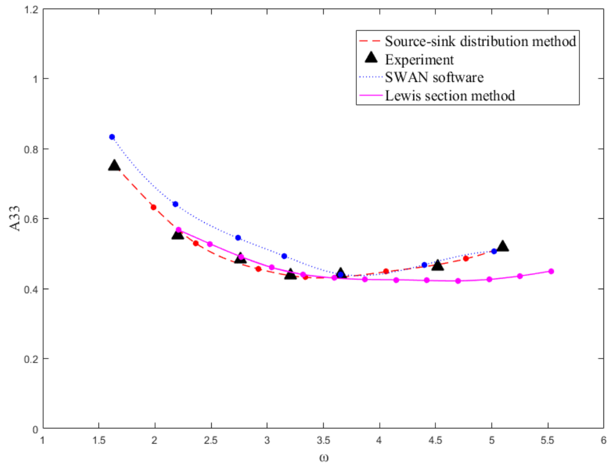
In this study, based on above theory, a set of evaluation program is written, and Wigley is calculated as an example. Seventeen sections are taken in the direction of length, and the pitch and heave motions of the ship in head sea regular waves at Fr=0.3 are calculated. The main dimensions of the ship are shown in table 1.

Table 1: The main dimensions of Wigley

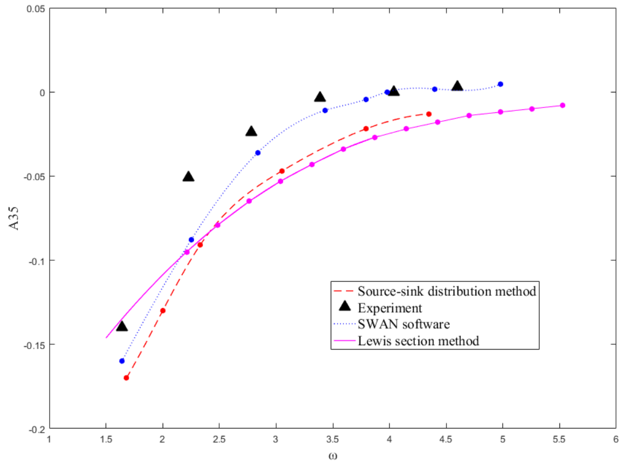
Length	**Width**	**Draft**	**Displacement**	**Speed**
3.0m	0.3m	0.1875m	0.0946m^3	1.627m/s

Firstly, heaving, pitching and their coupling hydrodynamic coefficients of Wigley under different encounter frequencies are calculated by the evaluation program. The results are compared with the experimental values, SWAN software calculations and the results obtained by source-sink distribution method [5].

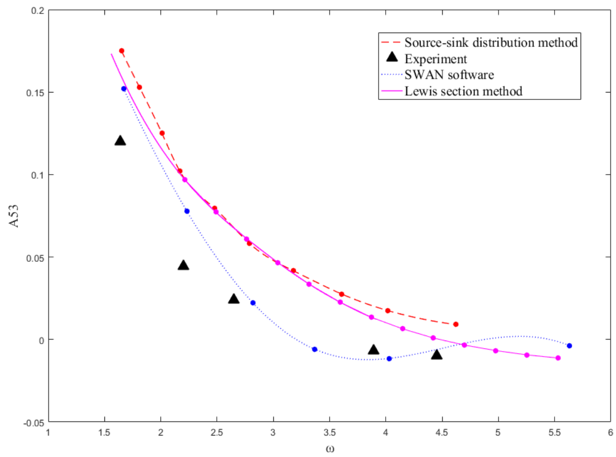
As we can see in Fig.2, the general trend of the additional mass calculated by Lewis section method is basically consistent with the experimental results. The coefficient A33 obtained by Lewis section method is basically consistent with the experimental values at low frequencies and has a small error at high frequencies. The coefficient A35 is smaller than the experimental values, while the coefficient A53 is larger than the experimental values, and both of them are close to the calculation results of source-sink distribution method. The coefficient A55 is basically consistent with the experiment values and is better than the results gotten by source-sink distribution method.



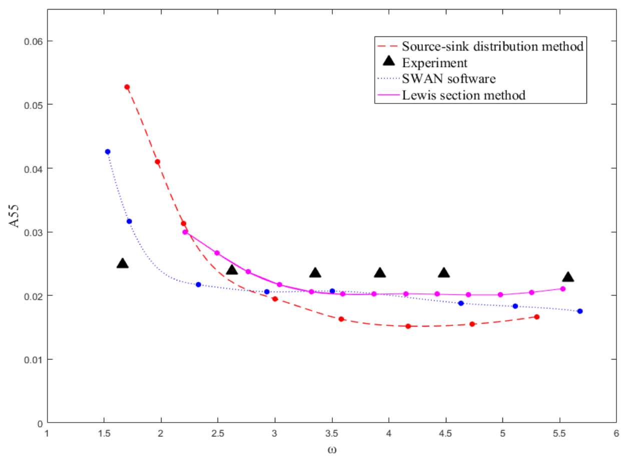
(a) Additional mass of heave.



(b) Additional mass of pitch coupled heave.



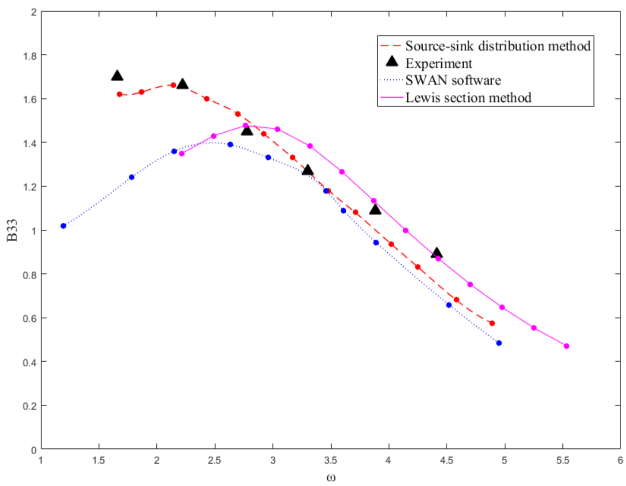
(c) Additional mass of heave coupled pitch.



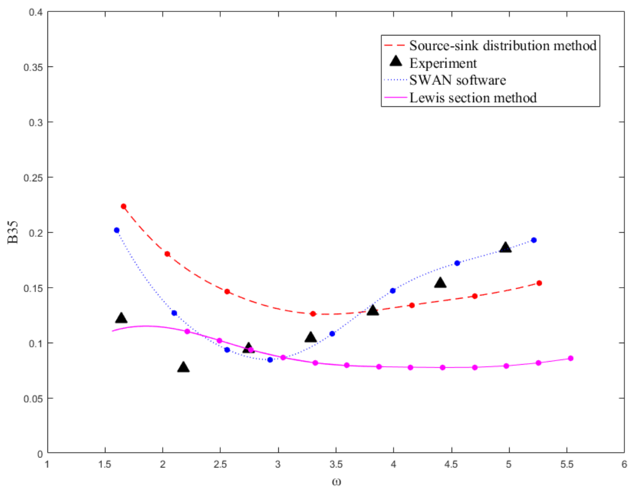
(d) Additional mass of pitch.

Figure 2: Comparisons of addition mass.

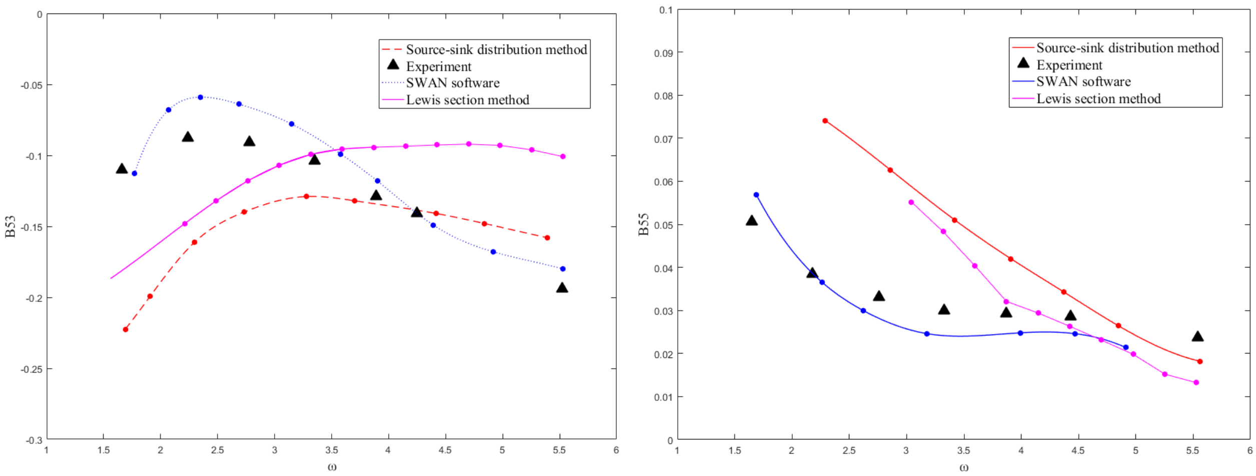
Fig.3 shows that the general trend of coefficient B33 calculated by Lewis section method is basically consistent with the experimental results. The coefficient B35 is smaller than the experimental values at high frequencies, while the coefficient A53 is larger than the experimental values at low frequencies. There is a difference in the trend of coefficient B53 between Lewis section method and experimental values, but their values are relatively close.



(a) Damping coefficient of heave.



(b) Damping coefficient of pitch coupled heave.



(c) Damping coefficient of heave coupled pitch. (d) Damping coefficient of pitch.

Figure 3: Comparisons of damping coefficient.

Some discrepancies between experimental data and the results of the presented method are visible, but when they are used as coefficients to solve the equation, the discrepancies do not strongly affect the results ,

The hydrodynamic coefficients and encounter frequencies in the above figures are dimensionless. The formulas of dimensionless are as follows [6].

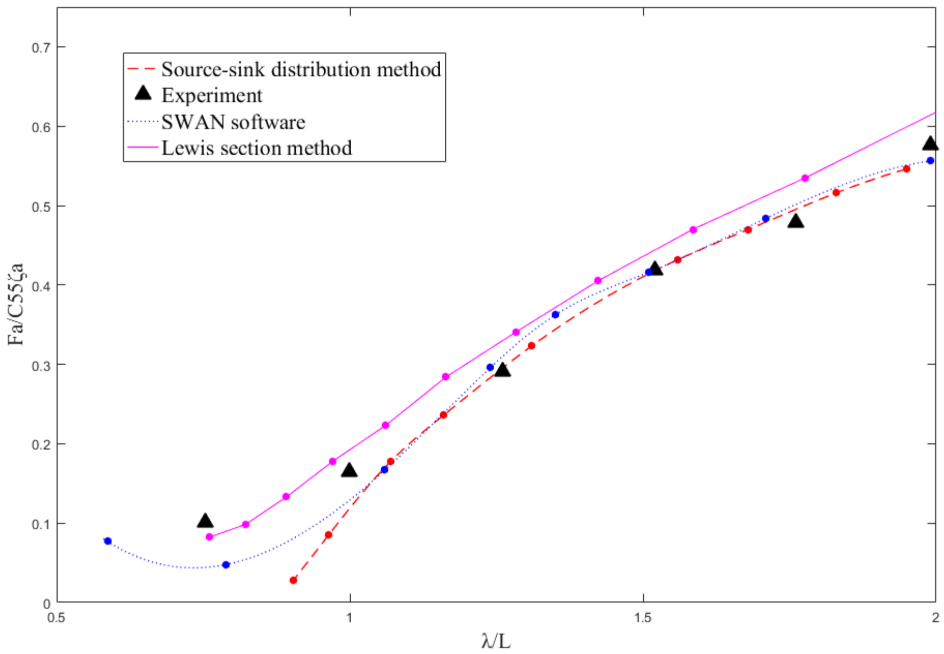
$$\begin{cases} A_{ij} = \dfrac{a_{ij}}{\rho \nabla L^{(m_i+n_j)}} \\ B_{ij} = \dfrac{b_{ij}}{\rho \nabla L^{(m_i+n_j)}} \sqrt{L/g} \end{cases} \quad where, \;\; m_i = \begin{cases} 0 & i=3 \\ 1 & i=5 \end{cases} \;\; n_j = \begin{cases} 0 & j=3 \\ 1 & j=5 \end{cases} \tag{12}$$

$$\omega = \varpi \sqrt{L/g} \tag{13}$$

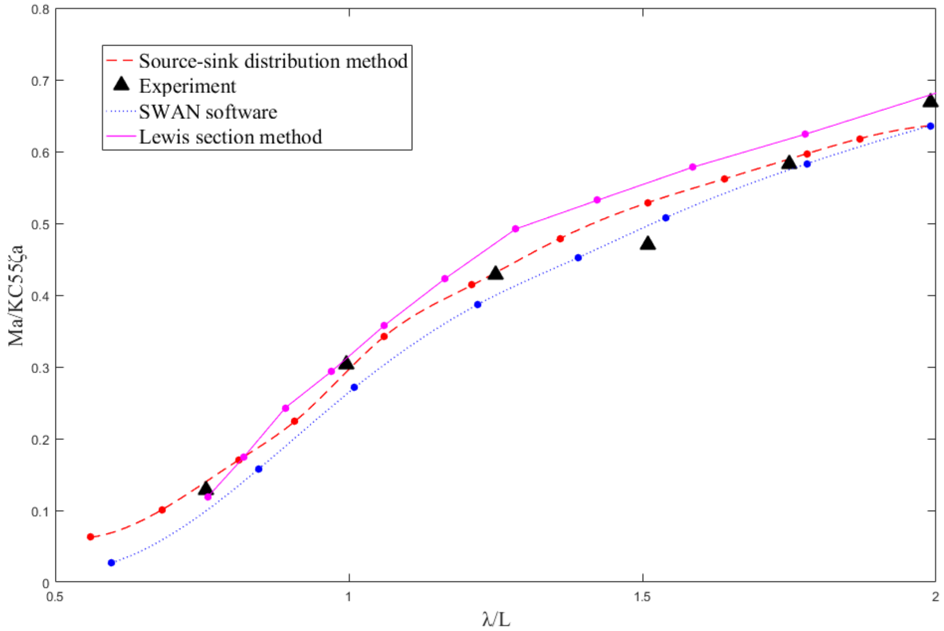
Next, the evaluation program based on Lewis section method is used to calculate the disturbance force and moment caused by waves, and the amplitude response curve of wave force and moment are gotten, which are shown in Fig. 4. The amplitude responses of wave forces and wave moments are dimensionless, and the coefficient C_{55} is defined as:

$$C_{55} = \rho g \nabla h_y = \rho g [J_y + (zB - zG)\nabla] \tag{14}$$

Where, h_y is the longitudinal metacentric height; J_y is the moment of inertia to y axis; z_B is vertical coordinate of buoyancy; z_G is vertical coordinate of center of gravity.



(a) Amplitude response curve of wave force.



(b) Amplitude response curve of wave moment

Figure 4: Comparisons of wave force and moment.

Fig. 4 shows that the general trend of wave force amplitude and wave moment amplitude calculated by Lewis section method are consistent with the experimental results. When the wave frequency is larger, the wave force amplitude is closer to the experimental value, while when the wave frequency is smaller, it is slightly larger than the experimental value, and the results obtained by source-sink fitting method and three-dimensional method are closer to the experimental value.

According to the calculation of hydrodynamic coefficients, wave forces and wave moments, it can be seen that the numerical results keep the same trend as the experimental results, and the values are similar and within acceptable range. Some coefficients are even better than the three-dimensional method and source-sink distribution method, and the calculation time is very short, which can be applied to the rapid calculation of ship seakeeping performance.

4 CONCLUSION

In order to further shorten the calculation time of ship seakeeping evaluation and shorten the optimization period of ship hull form, the Lewis section method is used to calculate the hydrodynamic coefficients of each section, and the Tasai graphic is introduced to assist the calculation. The hydrodynamic coefficients of each section can be quickly obtained. Then the strip method is used to calculate the pitch and heave hydrodynamic coefficients, wave forces and wave moments of Wigley. From the calculation results, it can be seen that the Lewis section method can give the numerical results which are close to the experimental results. In some coefficients, it is even better than the source-sink distribution method and three-dimensional method, and greatly shortens the evaluation time. Of course, the calculation of Wigley hull form is not enough to illustrate the wide applicability of Lewis section method. Next, other hull forms will be calculated to further verify the validity of the Lewis section method.

ACKNOWLEDGEMENTS

This work is supported by the National Natural Science Foundation of China (51879159, 51490675, 11432009, 51579145), Chang Jiang Scholars Program (T2014099), Shanghai Excellent Academic Leaders Program (17XD1402300), Program for Professor of Special Appointment (Eastern Scholar) at Shanghai Institutions of Higher Learning (2013022), Innovative Special Project of Numerical Tank of Ministry of Industry and Information Technology of China (2016-23/09) and Lloyd’s Register Foundation for doctoral student, to which the authors are most grateful.

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