Influence of the Steady Flow in Seakeeping of a Blunt Ship through the Free-Surface Condition

Hidetsugu IWASHITA
Engineering Systems, Hiroshima University
Kagamiyama 1-4-1, Higashi-Hiroshima 739, JAPAN

Introduction

The accurate estimation of the wave pressure locally acting on a ship in a seaway is an imprtant topic for the practical ship design besides general estimations of total hydrodynamic forces and/or ship motions. In the last workshop [1] we presented some numerical results based on the 3-D Green function method (GFM) and investigated numerically the influence of the steady flow in seakeeping, especially in the wave pressure on a blunt ship (HSVA tanker). There we obtained a conclusion that the influence of the steady Kelvin-wave field through the body boundary condition seems not so remarkable in the local wave pressure distributions against our experimental data for a blunt VLCC [2] , where the experimental wave pressure indicates considerably larger value than the theoretical estimation of the GFM at the bow part although some numerical improvements are observed by taking into account the steady Kelvin-wave field instead of the double-body flow through the body boundary condition. Then it is suspected that another influence of the steady flow through the free-surface condition might affect more strongly the local wave pressure especially at the bow part.

In this paper we develop a Rankine panel method (RPM), which was originally presented by Jensen [3] and Ando [4] for the steady wave-making problem and extended to the unsteady problem by Bertram [5], mixing a numerical technique to make the method effective even for the blunt ship. The numerical method developed here is applied to a blunt VLCC advancing in oblique short waves. Numerical results are compared with the experiments and another numerical results of GFM or strip theory, and the influence of the steady flow in the wave pressure through the free-surface condition is discussed.

Formulation

We consider a ship advancing at constant forward speed U in oblique regular waves encountered at angle χ, Fig.1. The ship motion $\xi_j e^{i\omega_e t}(j = 1 \sim 6)$ around its equilibrium position and the wave amplitude A of the incident wave are assumed to be small. ω_0 is the circular frequency and K the wave number of the incident wave. The encounter circular frequency is $\omega_e(= \omega_0 - KU\cos\chi)$. The linear theory is employed for this problem assuming ideal (potential) flow.

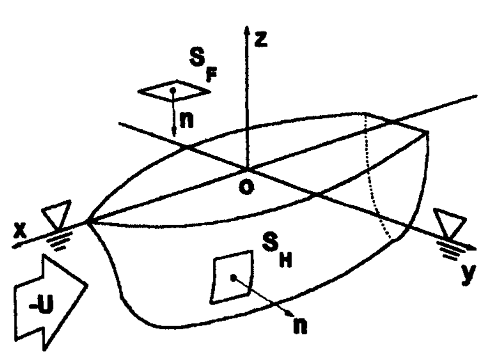

Fig. 1 Coordinate system

The velocity potential Ψ governed by Laplace's equation can be expressed as

$$\Psi(x,y,z;t) = U[\Phi(x,y,z) + \varphi(x,y,z)] + \Re[\phi(x,y,z)e^{i\omega_e t}] \tag{1}$$

where

$$\phi = \frac{gA}{\omega_0}(\phi_0 + \phi_7) + i\omega_e \sum_{j=1}^{6} \xi_j \phi_j \,, \quad \phi_0 = ie^{Kz - iK(x\cos\chi + y\sin\chi)} \tag{2}$$

Φ means the double-body flow, φ the steady wave field and ϕ the unsteady wave field. Assuming small disturbance due to the ship, we can linearize the free-surface conditions for φ and ϕ in several forms. In this paper we adopted the following free-surface conditions derived by Yasukawa [6] and corresponding body boundary conditions. For φ it becomes

$$\frac{1}{2K_0}\nabla\Phi\cdot\nabla(\nabla\Phi\cdot\nabla\Phi)+\frac{1}{K_0}\nabla\Phi\cdot\nabla(\nabla\Phi\cdot\nabla\varphi)+\frac{1}{2K_0}\nabla(\nabla\Phi\cdot\nabla\Phi)\cdot\nabla\varphi+\frac{\partial\varphi}{\partial z}=0 \quad \text{on } z=0 \quad (3)$$

$$\frac{\partial\varphi}{\partial n}=0 \quad \text{on } S_H \quad (4)$$

and for ϕ_j

$$-K_e\phi_j+2i\tau\nabla\Phi\cdot\nabla\phi_j+\frac{1}{K_0}\nabla\Phi\cdot\nabla(\nabla\Phi\cdot\nabla\phi_j)+\frac{1}{2K_0}\nabla(\nabla\Phi\cdot\nabla\Phi)\cdot\nabla\phi_j+\frac{\partial\phi_j}{\partial z}=0 \quad \text{on } z=0 \quad (5)$$

$$\frac{\partial\phi_j}{\partial n}=n_j+\frac{U}{i\omega_e}m_j \quad (j=1\sim 6), \quad \frac{\partial\phi_7}{\partial n}=-\frac{\partial\phi_0}{\partial n} \quad \text{on } S_H \quad (6)$$

where

$$(n_1,n_2,n_3)=\boldsymbol{n}, \qquad (m_1,m_2,m_3)=-(\boldsymbol{n}\cdot\nabla)\boldsymbol{V},$$
$$(n_4,n_5,n_6)=\boldsymbol{r}\times\boldsymbol{n}, \quad (m_4,m_5,m_6)=-(\boldsymbol{n}\cdot\nabla)(\boldsymbol{r}\times\boldsymbol{V}),$$

$\boldsymbol{r}=(x,y,z)$, $\boldsymbol{V}=\nabla\Phi$, $K_0=g/U^2$, $K_e=\omega_e^2/g$ and $\tau=U\omega_e/g$. m_j in eq.(6) derived by Timman & Newman [7] is an influence term from the steady flow to the unsteady flow on the body surface. Eq.(3) coincides with the Dawson's free-surface condition in the steady problem [8] and eq.(5) is a corresponding form in the unsteady problem.

If we put $\Phi=-x$, $\partial\varphi/\partial n=n_x$ and $\boldsymbol{V}=\nabla[-x+\varphi]$, the formulation (3) $\sim$ (6) leads to the Neumann-Kelvin formulation which is applied to the GFM.

Numerical methods

The RPM applied in this study is a collocation method developed by Jensen [3] and Ando [4] for the steady problem and extended to the unsteady problem by Bertram [5]. The radiation condition is satisfied by shifting the collocation point one panel upward on the free surface. Recently Eguchi [9] and Nakatake [10] proposed its extended computation method which is quite robust and stable even for the blunt ship in the steady problem. We solve our problem applying this method to the unsteady problem.

The steady and unsteady potentials, φ and ϕ_j, are both expressed by the source distributions on the body surface S_H and the free surface S_F as follows:

$$\left.\begin{matrix}\varphi(P)\\ \phi_j(P)\end{matrix}\right\}=-\iint_{S_H+S_F}\left\{\begin{matrix}\sigma_s(Q)\\ \sigma_j(Q)\end{matrix}\right\}G(P,Q)\,dS \quad (7)$$

where

$$G(P,Q)=\begin{cases}(1/r+1/r')/4\pi & \text{for } Q \text{ on } S_H\\ 1/4\pi r & \text{for } Q \text{ on } S_F\end{cases}, \quad \left.\begin{matrix}r\\ r'\end{matrix}\right\}=\sqrt{(x-x')^2+(y-y')^2+(z\mp z')^2}$$

The body surface and the free-surface are discretized into the finite number of constant panels, and numerical solutions for steady and unsteady problems are obtained such that a corresponding set of the free-surface condition and the body boundary condition are satisfied at collocation points. The collocation points on S_H coincides with the geometric center of each panel and those on S_F are shifted one panel upward in order to force the radiation condition numerically. This numerical radiation condition is valid only for $\tau>1/4$ in the unsteady problem where the waves do not propagate to the forward direction of the ship. Fig. 2 and 3 illustrate the computation grids on S_H and S_F. For the panels inside the waterline on S_F, source distributions are forced to be zero, or those panels are totally removed from the computation domain [9], [10].

The GFM is also attempted in this study for the blunt VLCC. The free surface and body boundary conditions for the steady and unsteady problems are reduced to the well known Neumann-Kelvin formulation as noted in the previous section. The computation domain is restricted only on S_H by introducing the Green function which satisfys the free-surface condition and the radiation condition analytically. Instead of this advantage we need to evaluate this complicated function accurately. The special algorithm presented by Iwashita & Ohkusu [11] is employed for evaluating this Green function, and the direct method incorporated with the spline element [2] is adopted for solving the boundary value problem. Although the influence of the non-uniform steady flow cannot be taken into account through the free-surface condition, the Kelvin wave field can affect through the body boundary condition, m_j.

Numerical results

Fig. 4 shows the perspective view of the steady wave around the VLCC obtained by the present RPM with conditions (3) and (4). Fig. 5 is its 2-D profile along the ship-side. A large steady bow wave is simulated well compared with a picture of experiment, Fig. 6.

Fig. 7 and 8 show the comparison of m_3 distribution on the ship surface evaluated from Φ and $-x + \varphi$. The former is used in the computation of the RPM and the later is in the GFM. The wavy distribution can be observed in Fig.8.

Fig. 9 illustrates the diffraction wave around the VLCC at $F_n = 0.2$, $\lambda/L = 0.5$ and $\chi = 180$ deg. So called k_2-wave system is simulated remarkably in the figure.

Fig.10 is a wave pressure distribution on VLCC at ordinate 9. The present RPM estimates the wave pressure well among other computations by reflecting the influence of the steady flow around blunt bow part.

Further calculations are now in progress and the results will be presented in the workshop.

References

[1] Iwashita, H., Bertram, V.: *Numerical Study on the Influence of the Steady Flow in Seakeeping*, 12th WWWFB, Marseille (1997)

[2] Iwashita, H., Ito, A., Okada, T., Ohkusu, M., Takaki, M., Mizoguchi, S.: *Wave Forces Acting on a Blunt Ship with Forward Speed in Oblique Sea (3rd Report)*, J. Soc. Naval Arch. Japan 176 (1994) (in Japanese)

[3] Jensen, G., Mi, Z.-X., Söding, H.: *Rankine Source Methods for Numerical Solutions of the Steady Wave Resistance Problem*, 16th Symp. on Nav. Hydrodyn., Berkeley(1986)

[4] Ando, J., Nakatake K.: *A Method to Calculate Wave Flow by Rankine Source*, Transactions of The West-Japan Soc. of Naval Arch. No. 75(1988) (in Japanese)

[5] Bertram, V.: *Fulfilling Open-Boundary and Radiation Condition in Free-Surface Problems Using Rankine Sources*, Ship Technology Research, Vol. 37/2(1990)

[6] Yasukawa, H.: *A Rankine Panel Method to Calculate Unsteady Ship Hydrodynamic Forces*, J. Soc. Naval Arch. Japan 168 (1990)

[7] Timman, R., Newman, J.N.: *The Coupled Damping Coefficients of a Symmetric ship*, JSR 5/4 (1962)

[8] Dawson, C. W.: *A Practical Computer Method for Solving Ship Wave Problems*, 2nd Int. Conf. on Numerical Ship Hydrodynamics, Berkeley(1977)

[9] Eguchi, T.: *Numerical Analysis of Rankine Source Collocation Method for the Steady Wave Making Resistance Problem*, J. Soc. Naval Arch. Japan 177 (1995) (in Japanese)

[10] Nakatake K., Ando, J.: *A Method to Calculate Wave Flow around a Wide Ship*, Transactions of The West-Japan Soc. of Naval Arch. No. 90(1995) (in japanese)

[11] Iwashita, H., Ohkusu, M.: Hydrodynamic Forces on a Ship Moving with Forward Speed in Waves, J. Soc. Naval Arch. Japan 166 (1989) (in Japanese)

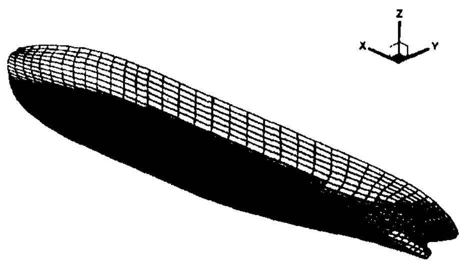

Fig. 2 Hull form and computation grids of VLCC (1200 panels)

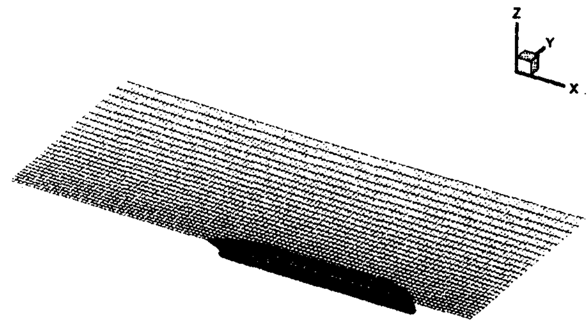

Fig. 3 Computation grids on S_H and S_F (600 and 2666 panels on half)

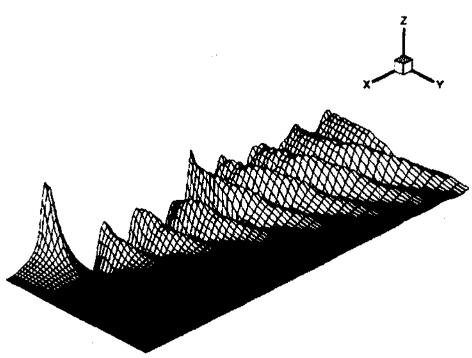

Fig. 4 Perspective view of the steady wave at $F_n = 0.2$

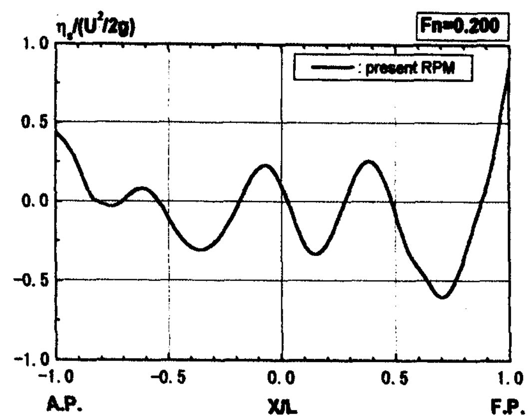

Fig. 5 Computed steady wave along ship-side at $F_n = 0.2$

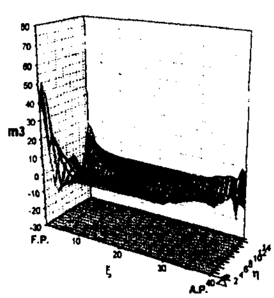

Fig. 7 m_3 distribution on S_H (double-body flow)

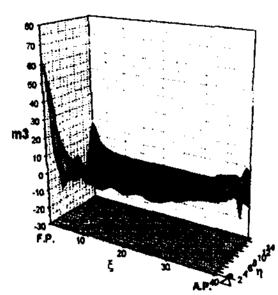

Fig. 8 m_3 distribution on S_H (Kelvin wave flow)

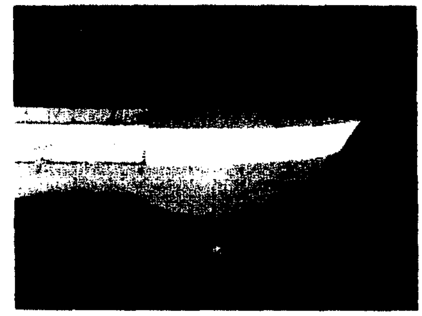

Fig. 6 Picture of the steady wave along ship-side at $F_n = 0.2$

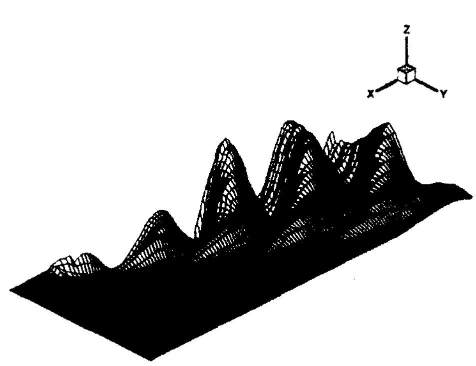

Fig. 9 Perspective view of the diffraction wave at $t = 0$ ($F_n = 0.2$, $\lambda/L = 0.5$, $\chi = 180$ deg.)

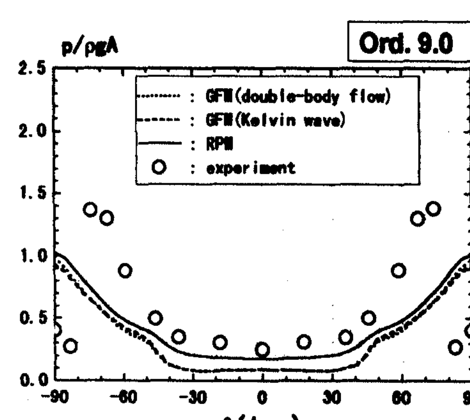

Fig.10 Wave pressure distribution at ord.9 ($F_n = 0.2$, $\lambda/L = 0.5$, $\chi = 180$ deg.)