Diffraction Waves of a Blunt Ship with Forward Speed Taking account of the Steady Nonlinear Wave Field

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Introduction

Nowadays, the forcus of the seakeeping computations is changing from the ordinal prediction of the global forces and/or ship motions to more accurate prediction of the local wave field represented by the wave pressure on the ship, for the purpose of the global structural analysis based on FEM. *Iwashita et al. (1994)* systematically investigated about the wave pressure distribution on a blunt VLCC advancing in oblique short waves and showed its negligible discrepancies between experiments and theoretical computations based on the linear theory. Consecutively the influence of the steady flow in seakeeping computations has been studied by *Iwashita & Bertram (1997)*, *Iwashita et al.(1998)* and so on. It has been made clear up to now that the estimation accuracy of the wave pressure is improved in some quantity by taking into account the influence of the steady non-uniform flow in both the free surface and body surface conditions, but its improvement is not still sufficient against our expection. More accurate estimation may be expected only by fully taking into account the steady Kelvin-wave field beyound the framework of the linear theory.

In this paper we perform the computation of a diffraction wave around a blunt ship with forward speed fully capturing the steady Kelvin-wave field. The steady problem is solved so that the full nonlinear free-surface condition is satisfied and the boundary conditions of the unsteady problem are satisfied on the exact steady free-surface and wetted surface on the body. A Rankine panel method (RPM) presented by *Jensen et al.(1986)* and *Bertram (1990)* is applied extending the method to be robust for the blunt ship. Numerical resuts are compared with experiments and the influence of the steady Kelvin-wave field in diffraction wave field 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 is restricted at 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.

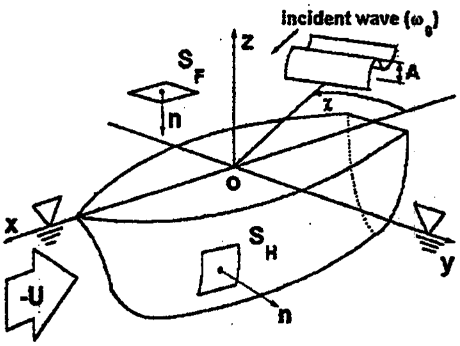


Fig. 1 Coordinate system

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

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

where

$$\phi = \frac{gA}{\omega_0}(\phi_0 + \phi_7), \quad \phi_0 = ie^{Kz - iK(x\cos\chi + y\sin\chi)} \tag{2}$$

Φ means the steady wave field and ϕ the unsteady wave field which consists of the incident wave ϕ_0 and the diffraction wave ϕ_7. The steady wave field is solved so that

$$\frac{1}{2}\overline{\nabla}\Phi\cdot\overline{\nabla}(\nabla\Phi)^2 + K_0\frac{\partial\Phi}{\partial z} = 0 \quad \text{on } z = \zeta_* = \frac{1}{2K_0}[1-(\nabla\Phi)^2] \tag{3}$$

$$\frac{\partial \Phi}{\partial n} = 0 \quad \text{on } S_H \tag{4}$$

are satisfied, where $\overline{\nabla}$ denotes the two-dimensional Laplacian with respect to x and y. S_H means the wetted surface and $K_0 = g/U^2$. A RPM developed by *Jensen et al. (1986)* is used to solve this problem numerically. The nonlinear free-surface condition is satisfied by the iteration scheme, and the radiation condition by shifting the collocation points one panel upward.

Assuming small disturbance of the incident wave due to the ship, we can linearize the free-surface condition for ϕ_7 around the steady free-surface $z = \zeta_s$. The final form can be written as follows (*Newman (1978)*, *Bertram (1990)*):

$$-K_e\phi_7 + i\tau[\nabla\Phi\cdot\nabla\phi_7 + \overline{\nabla}\Phi\cdot\overline{\nabla}\phi_7] + \frac{1}{K_0}\left[\overline{\nabla}\Phi\cdot\overline{\nabla}(\nabla\Phi\cdot\nabla\phi_7) + \overline{\nabla}\phi_7\cdot\overline{\nabla}(\frac{1}{2}(\nabla\Phi)^2)\right] + \frac{\partial\phi_7}{\partial z}$$
$$-\frac{\frac{\partial}{\partial z}\left[\frac{1}{2}\overline{\nabla}\Phi\cdot\overline{\nabla}(\nabla\Phi)^2 + K_0\frac{\partial\Phi}{\partial z}\right]}{K_0 + \nabla\Phi\cdot\nabla\frac{\partial\Phi}{\partial z}}\left(i\tau + \frac{1}{K_0}\nabla\Phi\cdot\nabla\right)\phi_7 = 0 \quad \text{on } z = \zeta_s \tag{5}$$

$$\frac{\partial\phi_7}{\partial n} = -\frac{\partial\phi_0}{\partial n} \quad \text{on } S_H \tag{6}$$

where $K_e = \omega_e^2/g$ and $\tau = U\omega_e/g$. Once Φ and ϕ_7 are determined, the diffraction wave $\Re[\zeta_7 e^{i\omega_e t}]$ is calculated by

$$\zeta_7 = \frac{-i\tau/\nu}{1 + \frac{1}{K_0}\nabla\Phi\cdot\nabla\frac{\partial\Phi}{\partial z}}\left(1 + \frac{1}{iK_0\tau}\nabla\Phi\cdot\nabla\right)\phi_7 \quad \text{on } z = \zeta_s \tag{7}$$

If we express the double-body flow by φ and put $\Phi = \varphi + \phi_s$, eqs.(3) and (5) lead to the doubel-body flow formulations such as

$$\frac{1}{2K_0}\overline{\nabla}\varphi\cdot\overline{\nabla}(\overline{\nabla}\varphi\cdot\overline{\nabla}\varphi) + \frac{1}{K_0}\overline{\nabla}\varphi\cdot\overline{\nabla}(\overline{\nabla}\varphi\cdot\overline{\nabla}\phi_s) + \frac{1}{2K_0}\overline{\nabla}(\overline{\nabla}\varphi\cdot\overline{\nabla}\varphi)\cdot\overline{\nabla}\phi_s + \frac{\partial\phi_s}{\partial z} = 0 \quad \text{on } z = 0 \tag{8}$$

$$-K_e\phi_7 + 2i\tau\overline{\nabla}\varphi\cdot\overline{\nabla}\phi_7 + \frac{1}{K_0}\overline{\nabla}\varphi\cdot\overline{\nabla}(\overline{\nabla}\varphi\cdot\overline{\nabla}\phi_7) + \frac{1}{2K_0}\overline{\nabla}(\overline{\nabla}\varphi\cdot\overline{\nabla}\varphi)\cdot\overline{\nabla}\phi_7 + \frac{\partial\phi_7}{\partial z} = 0 \quad \text{on } z = 0 \tag{9}$$

and if simply $\varphi = -x + \phi_s$, it becomes the uniform-flow formulation.

Numerical methods

The RPM applied in this study is a collocation method developed by *Jensen et al. (1986)* and *Ando (1988)* for the steady problem and extended to the unsteady problem by *Bertram (1990)*. The radiation condition is satisfied by shifting the collocation point one panel upward on the free surface. *Iwashita (1998)* extended the method to be robust even for the blunt ship by employing the method of *Eguchi (1995)* and *Nakatake et al.(1995)*. We solve our problem applying this method in this paper.

The steady and unsteady potentials, Φ and ϕ_7, are both expressed by the source distributions on the body surface S_H and the free surface S_F. 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 when 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.

Results

Numerical computations are performed for a Series-60 ($C_b = 0.8$) model in ballast-load condition ($B/d = 5.9412$). Besides the formulation described above, the double-body flow formulation and the uniform-flow formulation are also attempted for the comparison. Those numerical results are compared with corresponding experiments presented by *Ohkusu & Wen (1996)* and the influence of the steady wave field is discussed.

Fig.4 shows the diffraction waves along the transverse line at ordinate 9, 8, 7 and 6. Notwithstanding the double-body formulation seems to improve the computation results slightly, the remarkable discrepancy between computed and measured results can be still observed especially near the bow part and it decreases as the distance from the bow increases. At ordinate 9 the computed result underestimates the experiment about 50 % in magnitude and this result consistent with the result that we have obtained for the wave pressure, *Iwashita et al. (1993, 1994)*. This suggests the significant influence of the steady wave field.

Further calculations based on the present formulation are now in progress and the results will be presented in the workshop.

References

ANDO, J., NAKATAKE K. (1988), *A Method to Calculate Wave Flow by Rankine Source*, Transactions of The West-Japan Soc. of Naval Arch. No. 75 (in Japanese)

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

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

IWASHITA, H., BERTRAM, V. (1997), *Numerical Study on the Influence of the Steady Flow in Seakeeping*, 12th WWWFB, Marseille (1997)

IWASHITA, H. (1998), *Influence of the Steady Flow in Seakeeping of a Blunt Ship through the Free-Surface Condition* 13th WWWFB, The Netherlands (1998)

IWASHITA, H., ITO A. (1998), *Seakeeping Computations of a Blunt Ship Capturing the Influence of the Steady Flow*, Ship Technology Research, Vol. 45/4

IWASHITA, H., ITO, A., OKADA, T., OHKUSU, M., TAKAKI, M., MIZOGUCHI, S. (1993), *Wave Forces Acting on a Blunt Ship with Forward Speed in Oblique Sea (2nd Report)*, J. Soc. Naval Arch. Japan, Vol. 173 (in Japanese)

IWASHITA, H., ITO, A., OKADA, T., OHKUSU, M., TAKAKI, M., MIZOGUCHI, S. (1994), *Wave Forces Acting on a Blunt Ship with Forward Speed in Oblique Sea (3rd Report)*, J. Soc. Naval Arch. Japan, Vol. 176 (in Japanese)

JENSEN, G., MI, Z.-X., SÖDING, H. (1986), *Rankine Source Methods for Numerical Solutions of the Steady Wave Resistance Problem*, 16th Symp. on Nav. Hydrodyn., Berkeley

NAKATAKE, K., ANDO, J. (1995), *A Method to Calculate Wave Flow around a Wide Ship*, Transactions of The West-Japan Soc. of Naval Arch. No. 90 (in japanese)

NEWMAN, J. N. (1978), *The Theory of Ship Motions*, Advances in Applied Mechanics 18.

OHKUSU, M., WEN, G. C. (1996), *Radiation and Diffraction Waves of a Ship at Forward Speed*, Proc. 21st Symp. Naval Hydro. , Trondheim

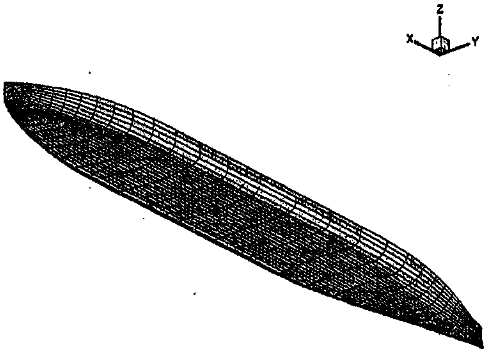


Fig.2 Series-60 in ballast-load condition
($C_b = 0.8$, $B/d = 5.9412$)

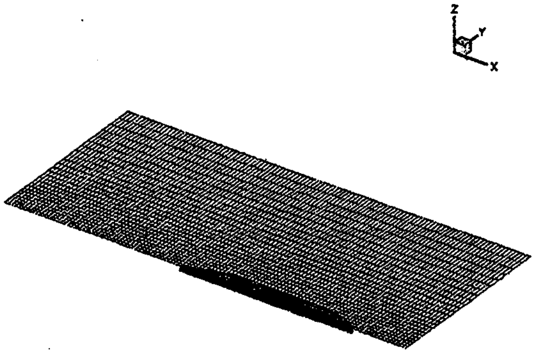
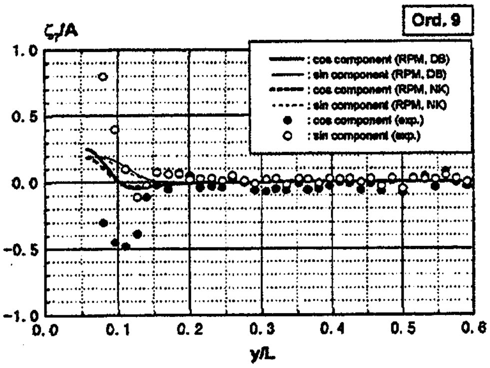
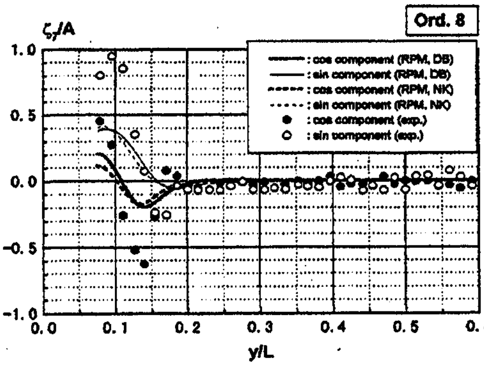


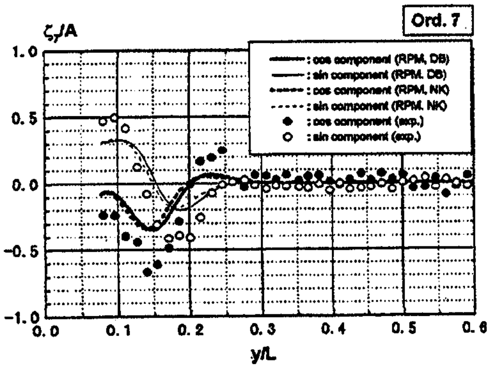
Fig.3 Computation grids ($N_H = 448$, $N_F = 2683$)



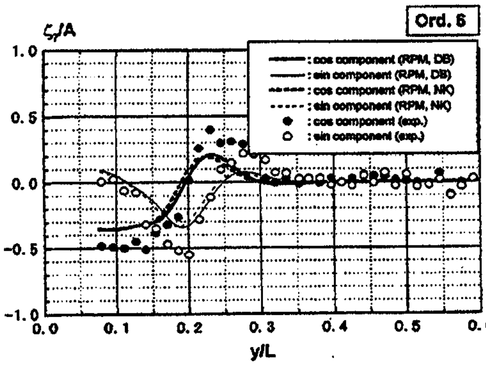
(a) Ord. 9



(b) Ord. 8



(c) Ord. 7



(d) Ord. 6

Fig.4 Diffraction wave distributions along transvers line in ballast-load condition
($F_n = 0.2$, $\lambda/L = 0.5$, $\chi = 180$ deg.)