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ON UNSTEADY WAVES GENERATED BY A BLUNT SHIP WITH FORWARD SPEED

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INTRODUCTION

Now plenty of studies on the seakeeping problem of ships based on the potential theories are performed by applying the Rankine panel methods (RPMs) in frequency domain and/or recently in the time domain to capture the nonlinear effects. Most of reports have treated slender ships and suggested some improvements of the estimation accuracy at least for the slender ships and for the global hydrodynamic forces and ship motions. However it has not been made so clear whether or not the methods are effective also for the blunt ships and for the estimation of local forces.

Iwashita et al.(1993) highlighted the wave pressure distribution locally acting on a blunt ship and found a significant discrepancy between computed and measured wave pressure at the bow part. Their consecutive studies show that this discrepancy can not be reduced so much even if the influence of the steady flow is taken into account more accurately, *Iwashita & Ito (1998)*. *Iwashita (1999)* adopted a diffraction wave instead of the wave pressure itself and applied one of the most sophisticated RPMs to another kind of blunt ship and compared the computed diffraction wave with measured one. Notwithstanding the computation method applied there could take account of the influence of the fully nonlinear steady wave field, the theoretical computation underestimated experiment more than 50% as well as previous wave pressure.

In this paper we perform a systematic experiment for a Series-60 ($C_b = 0.8$) and measure not only the hydrodynamic forces but also radiation and diffraction waves at a same time, in order to provide the experimental data to all the researchers concerned with. The conventional hydrodynamic forces correspond to global forces and unsteady waves represent the local physical values in the wave field around the ship. Numerical calculations by strip method, Green function method (GFM) and RPM are also carried out and obtained results are compared with experiments. Then we discuss how those computation methods can predict experiments.

FORMULATION

We consider a ship advancing at constant forward speed U in oblique regular waves encountered at angle χ, Fig.1. The ship motions $\Re[\xi_j e^{i\omega_e t}](j = 1 \sim 6)$ 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.

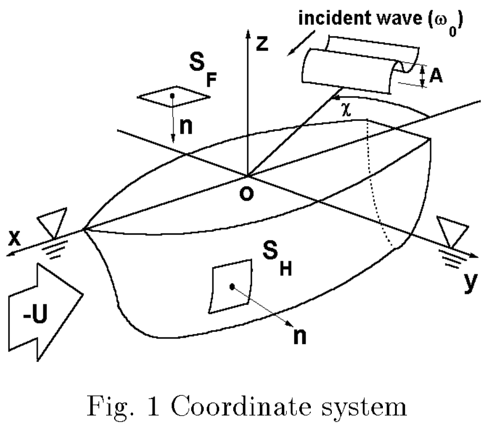

Fig. 1 Coordinate system

The total velocity potential Ψ of the fluid governed by Laplace's equation can be expressed as

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

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 steady wave field and ϕ the unsteady wave field which consists of the incident wave ϕ_0, the diffraction wave ϕ_7 and the radiation wave $\phi_j (j = 1 \sim 6)$. The kinematic and dynamic boundary conditions to be satisfied on the exact free surface $z = \zeta(x, y; t)$ yields

$$\frac{\partial^2 \Psi}{\partial t^2} + 2\nabla\Psi \cdot \nabla\frac{\partial\Psi}{\partial t} + \nabla\Psi \cdot \nabla(\frac{1}{2}(\nabla\Psi)^2) + g\frac{\partial\Psi}{\partial z} = 0 \quad \text{on } z = \zeta \tag{3}$$

By substituting (1) into (3), the problem can be decomposed into the steady and the unsteady problems.

Then the steady wave field is solved so that

$$\frac{1}{2}\nabla\Phi \cdot \nabla(\nabla\Phi)^2 + K_0\frac{\partial\Phi}{\partial z} = 0 \quad \text{on } z = \zeta_s = \frac{1}{2K_0}[1 - (\nabla\Phi)^2]\,, \quad K_0 = g/U^2 \tag{4}$$

is satisfied on the exact steady free surface $z = \zeta_s(x, y)$ and $\partial\Phi/\partial n = 0$ on the body surface S_H. A RPM developed by *Jensen et al.(1986)* is used to solve this problem numerically. The nonlinear free surface condition (4) is satisfied by iteration scheme and the radiation condition by shifting the collocation points one panel upward.

Assuming small amplitude of the incident wave and ship motions, we can linearize the free surface condition for ϕ_j around the steady free surface $z = \zeta_s(x, y)$ obtained by solving the previous steady problem. The final form can be written with corresponding body boundary condition as follows (*Newman (1978)*, *Bertram (1990)*):

$$-K_e\phi_j + i2\tau\nabla\Phi \cdot \nabla\phi_j + \frac{1}{K_0}\Big[\nabla\Phi \cdot \nabla(\nabla\Phi \cdot \nabla\phi_j) + \nabla\phi_j \cdot \nabla(\frac{1}{2}(\nabla\Phi)^2)\Big] + \frac{\partial\phi_j}{\partial z}$$
$$-\frac{\dfrac{\partial}{\partial z}\Big[\dfrac{1}{2}\nabla\Phi \cdot \nabla(\nabla\Phi)^2 + K_0\dfrac{\partial\Phi}{\partial z}\Big]}{K_0 + \nabla\Phi \cdot \nabla\dfrac{\partial\Phi}{\partial z}}\Big(i\tau + \frac{1}{K_0}\nabla\Phi \cdot \nabla\Big)\phi_j = 0 \quad \text{on } z = \zeta_s \tag{5}$$

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

where $K_e = \omega_e^2/g$, $\tau = U\omega_e/g$ and

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

m_j and $\boldsymbol{V}(= \nabla\Phi)$ in (5) and (6) are evaluated by using the steady nonlinear wave field, Φ.

Once ϕ_j is obtained, the unsteady pressure $\Re[pe^{i\omega_e t}]$ is given as follows (*Timman & Newman (1962)*):

$$p = -\rho(i\omega_e + U\boldsymbol{V} \cdot \nabla)\phi - \rho\frac{U^2}{2}\sum_{j=1}^{6}\xi_j(\boldsymbol{\beta}_j \cdot \nabla)(\boldsymbol{V} \cdot \boldsymbol{V})\,, \quad \boldsymbol{\beta}_j = \begin{cases} \boldsymbol{e}_j & (j = 1, 2, 3) \\ \boldsymbol{e}_{j-3} \times \boldsymbol{r} & (j = 4, 5, 6) \end{cases} \tag{7}$$

$\boldsymbol{e}_j(j = 1, 2, 3)$ are the unit vectors of x, y, z axes. The added mass & damping coefficients and wave exciting forces are computed by substituting the first and the second term of (2) into (7) respectively and integrating the pressure over the ship surface.

The radiation and diffraction waves $\Re[\zeta_j e^{i\omega_e t}]$ are calculated by

$$\begin{Bmatrix} \zeta_j/\xi_j \\ \zeta_7/A \end{Bmatrix} = \frac{1}{1 + \dfrac{1}{K_0}\nabla\Phi \cdot \nabla\dfrac{\partial\Phi}{\partial z}}\Big(1 + \frac{1}{iK_0\tau}\nabla\Phi \cdot \nabla\Big)\begin{Bmatrix} K_e\phi_j \\ (-i\tau/\nu)\phi_7 \end{Bmatrix} \quad \text{on } z = \zeta_s \tag{8}$$

where $\nu = U\omega_0/g$. The influence of the steady flow is introduced through the terms multiplied by $1/K_0$.

EXPERIMENT AND NUMERICAL METHODS

The experiment was carried out for Series-60 model of $C_b = 0.8$ at RIAM, Kyushu University. The length of the model is $L = 2$m. Added mass & damping coefficients, wave exciting forces and both of radiation wave (due to heave and pitch motion) and diffraction wave were measured. Unsteady waves were measured by Multifold Method developed by *Ohkusu (1977)*.

In the numerical calculation based on RPM, both the steady and unsteady potentials, Φ and ϕ_j, are 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. From the practical point of view, it has been confirmed that this numerical radiation condition is valid only for $\tau > 0.5$ where waves do not propagate to the forward direction of the ship. Not only the RPM but also the GFM and the strip method are also applied and compared.

RESULTS

Fig.2 illustrates the ship hull form and a computation grid of Series-60 of $C_b = 0.8$. Using 660 panels on S_H and additional 1840 panels on S_F, the steady problem is solved at first. Fig.3 shows the obtained steady wave distribution along a longitudinal axis near the ship. The fully nonlinear calculateion predicts the experiment in good accuracy along the ship-side, but it overestimates transverse wave behind the ship. The difference can be considered to be caused by the viscous effect.

By using the solution of the steady problem the unsteady problem is solved consecutively. Figs.4 and 5 are examples of obtained hydrodynamic forces and ship motions. The present calculation can improve the estimation accuracy of the heave motion by taking account of the influence of fully nonlinear steady wave field. Figs.6 and 7 show the unsteady wave fields. The present calculation can not predict unsteady wave with large amplitude in vicinity of the bow. The discrepancy will not be caused by the nonlinear effect because the experiment shows the first term of Fourier series of obtained experimental data.

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

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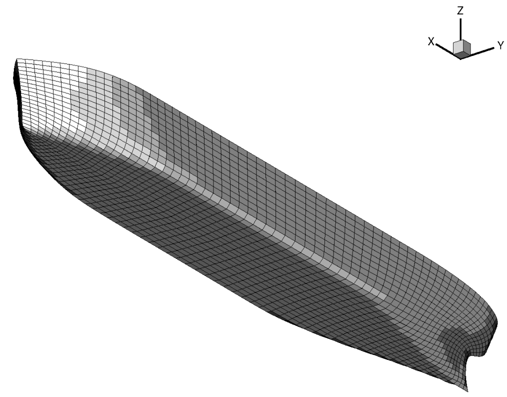

Fig.2 Perspective view of Series-60 ($C_b = 0.8$)

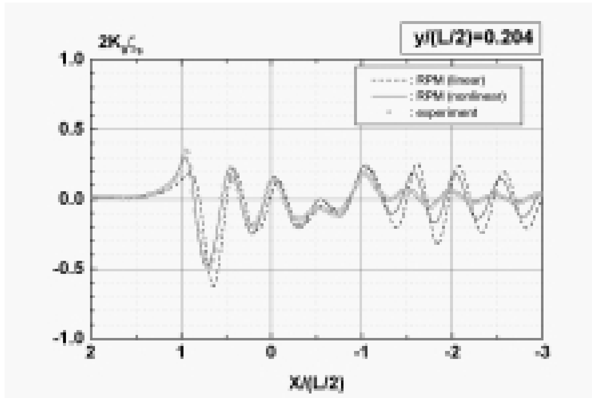

Fig.3 Steady wave distribution along longitudinal axis at $F_n = 0.2$

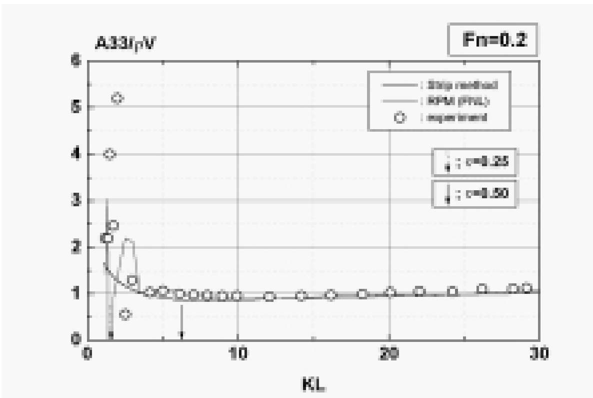

Fig.4 Added mass coefficient for heave

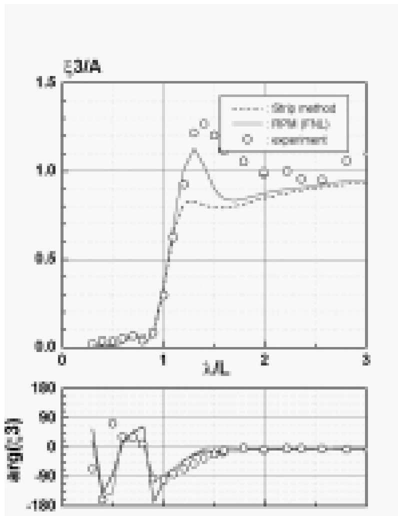

Fig.5 Heave motion at $F_n = 0.2$, $\chi = 180$ degs.

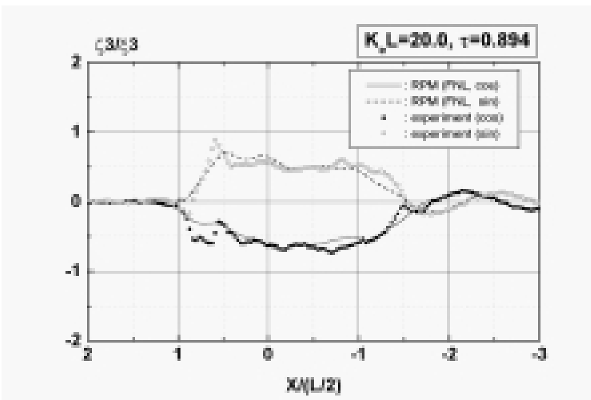

Fig.6 Heave radiation wave at $F_n = 0.2$

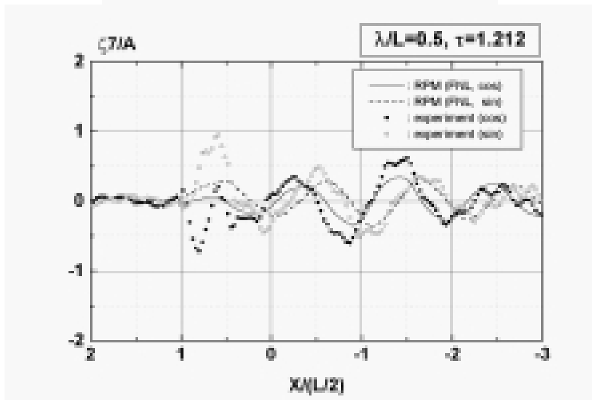

Fig.7 Diffraction wave at $F_n = 0.2$, $\chi = 180$ degs.