Wave Forces Acting on a Blunt Ship Advancing in Oblique Short Waves

by Hidetsugu IWASHITA*, Akio ITO**, Tetsuo OKADA***, Makoto OHKUSU****, Mikio TAKAKI*, Sumitoshi MIZOGUCHI**

* Department of Engineering Systems, Hiroshima University
Kagamiyama 1-4-1, Higashi-Hiroshima 724, Japan
** Ship and Marine Technology Department, Research Instisute,
Ishikawajima-Harima Heave Industries Co., Ltd.
Shin-Nakagawa-Cho 1, Isogo-Ku, Yokohama 235, Japan
*** Advanced Analysis Technology Department, Shipbuilding & Offshore,
Ishikawajima-Harima Heave Industries Co., Ltd.
Toyosu 2-Chome 1-1, Koto-Ku, Tokyo 135, Japan
**** Research Institute for Applied Mechanics, Kyushu University
Kasuga-City, Fukuoka 816, Japan

Introduction

Results of numerical and experimental study on the wave forces acting on a blunt ship advancing in oblique short waves are presented in this paper. We have been continuously investigated about this theme in these three years, and already published two papers as a result [1,2]. The main purpose of that study was to investigate the efficiencies of the 3-D panel method for predicting wave forces acting on a blunt ship especially in oblique short waves, and to make the 3-D panel method robust and practical scheme for that prediction. In order to achive the purpose, a lot of numerical calculations and experiments were performed not only for the wave forces such as wave exciting forces and second order steady forces but also for the wave pressure on the ship surface. These plenty of calculations, experiments and detail comparison between them confirmed that 3-D panel method is generally useful to predict the wave forces comparatively in long waves, while in short waves it does not give such accurate solutions as be in good agreement with experiments even if the large number of panels is used.

Many calculations due to 3-D panel method have been presented by many researchers up to now [3,4,5], and another new predicting schemes such as Rankine panel method have been also developed recently [6,7,8]. Most of those numerical results, although, are for the slender ship or for the long wave case unfortunately. It will be difficult to confirm that enough investigations as to the predicting scheme of wave forces acting on the blunt ship advancing in short waves have been done, or that robust and practical method for that purpose has been established already.

We are now performing the new numerical caluculations based on the newly formulated 3-D panel method, and those results will be presented with detail experimental results in this paper. The aforementioned discrepancies between calculations and experiments in oblique short waves will be solved by this new calculations.

Formulation

We consider a ship advancing at constant forward speed U in regular waves encountering with angle χ, and take the coordinate system illustrated in Fig.1. The circular frequency, wave number and wave amplitude of incident wave are ω_0,K and A respectively, and encounter circular frequency is $\omega_e(=\omega_0 - KU\cos\chi)$. The linear theory is employed for this problem assuming incompressible, inviscid and irrotational fluid.

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

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

where

$$\phi = \frac{gA}{\omega_0}(\phi_0 + \phi_7) + i\omega_e \sum_{j=1}^{6} \xi_j \phi_j \tag{2}$$

$$\phi_0 = ie^{Kz - iK(x\cos\chi + y\sin\chi)} \tag{3}$$

ϕ_s is the steady velocity potential independent of time , and ϕ is the unsteady velocity potential including the incident wave potential ϕ_0, the radiation potentials $\phi_j\,(j = 1 \sim 6)$ and the diffraction potential ϕ_7. ξ_j indicates the complex amplitude of ship motion in j-th direction.

The unsteady disturbance potential $\phi_j\,(j = 1 \sim 7)$ must supply the following free-surface boundary condition and body boundary condition.

$$\left(i\omega_e - U\frac{\partial}{\partial x}\right)^2 \phi_j + \mu\left(i\omega_e - U\frac{\partial}{\partial x}\right)\phi_j + g\frac{\partial \phi_j}{\partial z} = 0 \quad z = 0 \tag{4}$$

$$\frac{\partial \phi_j}{\partial n} = n_j + \frac{U}{i\omega_e} m_j \quad (j = 1 \sim 6) \quad , \quad \frac{\partial \phi_7}{\partial n} = -\frac{\partial \phi_0}{\partial n} \quad \text{on } S_H \tag{5}$$

where

$(n_1, n_2, n_3) = \boldsymbol{n}$; inward normal , $(n_4, n_5, n_6) = \boldsymbol{r} \times \boldsymbol{n}$,
$(m_1, m_2, m_3) = -(\boldsymbol{n} \cdot \nabla)\boldsymbol{V}$, $(m_4, m_5, m_6) = -(\boldsymbol{n} \cdot \nabla)(\boldsymbol{r} \times \boldsymbol{V})$,
$\boldsymbol{V} = \nabla(-x + \phi_s)$, $\boldsymbol{r} = (x, y, z)$

m_j in eq.(5), which shows the effect of the steady flow field on the ship surface, tends to be estimated approximately assuming that the free surface is not disturbed by the ship's forward translation.

Application of the Green's second identity for the closed region surrounded by S_H, S_F and artificial surface located at the infinity leads to the integral expression of ϕ_j as follows:

$$\begin{aligned}\phi_j(P) = &-\iint_{S_H} \left[\frac{\partial \phi_j(Q)}{\partial n} - \phi_j(Q)\frac{\partial}{\partial n}\right] G(P,Q)\, dS \\ &+ \frac{1}{K_0}\oint_{C_H} \left[\frac{\partial \phi_j(Q)}{\partial x'} - \phi_j(Q)\frac{\partial}{\partial x'} - 2i\tau K_0 \phi_j(Q)\right] G(P,Q)\, dy'\end{aligned} \tag{6}$$

where $P \equiv (x, y, z)$,$Q \equiv (x', y', z')$ show the field point and source point respectively. $G(P,Q)$ denotes the Green function which satisfies the free-surface condition (4) and the radiation condition at infinity, and can be evaluated accurately by means of Ohkusu & Iwashita's method [9,10].

In order to solve the integral equation derived from eq.(6), we express the body shape and the potential distribution on it by means of the spline function. After discretizing the body surface into N elements, the arbitraly point on it can be expressed as

$$x(\xi,\eta) = \sum_{j=1}^{N} \alpha_j B_j(\xi,\eta), \quad y(\xi,\eta) = \sum_{j=1}^{N} \beta_j B_j(\xi,\eta), \quad z(\xi,\eta) = \sum_{j=1}^{N} \gamma_j B_j(\xi,\eta) \tag{7}$$

where ξ and η are the local coordinats situated on the body surface, and $B_j(\xi,\eta)$ is the two dimensional spline function. The spline coefficients α_j,β_j and γ_j are determined from the coordinates of the collocation points on N elements. The transformation of the velocity fields between gloval and local coordinate systems are

$$\begin{bmatrix} \partial\phi_j/\partial x \\ \partial\phi_j/\partial y \\ \partial\phi_j/\partial z \end{bmatrix} = \begin{bmatrix} \partial\boldsymbol{r}/\partial\xi \\ \partial\boldsymbol{r}/\partial\eta \\ \partial\boldsymbol{r}/\partial\zeta \end{bmatrix}^{-1} \begin{bmatrix} \partial\phi_j/\partial\xi \\ \partial\phi_j/\partial\eta \\ \partial\phi_j/\partial\zeta \end{bmatrix} \tag{8}$$

where ζ-axis is taken to be vertical to both ξ and η axes, and the partial derivatives of x,y and z with respect to ζ are evaluated by

$$\frac{\partial \boldsymbol{r}}{\partial \zeta} = \frac{\partial \boldsymbol{r}}{\partial \xi} \times \frac{\partial \boldsymbol{r}}{\partial \eta}$$

The similar expression as the geometrical expression of the body shape shown in eq.(7) is employed also for the potential distribution on the body surface such as

$$\phi_j(\xi,\eta) = \sum_{i=1}^{N} \lambda_i B_i(\xi,\eta) \tag{9}$$

λ_j is the unknown spline coefficients. By using this expression of the potential distribution, we can express its derivatives in terms of the derivatives of the spline function.

The discretized integral equation to be solved follows from eq.(6) and (9) in the form

$$\begin{aligned}
&\sum_{j=1}^{N}\Bigg[\sum_{l=1}^{N}\Bigg(-\hat{B}(l,j)\iint_{\Delta S(l)} \hat{G}_n(k,l)\,dS \\
&\qquad -\frac{1}{K_0}\Big\{[C_{11}(l)\hat{B}_\xi(l,j)+C_{12}(l)\hat{B}_\eta(l,j)]\oint_{\Delta C(l)} \hat{G}(k,l)\,dy' \\
&\qquad -\hat{B}(l,j)\oint_{\Delta C(l)}[\hat{G}_{x'}(k,l)+2iK_0\tau\hat{G}(k,l)]\,dy'\Big\}\Bigg)\Bigg]\lambda_j \\
&= -\sum_{l=1}^{N}\phi_{jn}(l)\Big[\iint_{\Delta S(l)}\hat{G}(k,l)\,dS - \frac{1}{K_0}C_{13}(l)\oint_{\Delta C(l)}\hat{G}(k,l)\,dy'\Big] \quad (k = 1 \sim N)
\end{aligned} \tag{10}$$

$\hat{B}(i,j)$ indicates $B_j(\xi_i,\eta_i)$, and $\hat{B}_\xi(i,j)$,$\hat{B}_\eta(i,j)$ are its partial derivatives with respect to ξ and η respectively. $\hat{G}(k,l)$ and $\hat{G}_n(k,l)$ are the Green function and its normal derivative, which are evaluated at the k-th collocation point as the contribution from l-th element. $C_{11}(l)$,$C_{12}(l)$ and $C_{13}(l)$ denote the elements of the matrix in eq.(8). In this formulation, ϕ_j and $\partial\phi_j/\partial x$ are assumed to be constants over the elements which touch with the free surface, and the calculation of the kernel for each elements is carried out following the manner of the constant panel. Eq.(10) is solved numerically with respect to the unknown spline coefficients λ_j submitting boundary conditions into $\phi_{jn}(l)$, that is, the normal derivative of the velocity potential.

Once the coefficients λ_j have been determined, the velocity potential and velocity fields may be easily calculated by means of eq.(9). The calculations for other phisical values such as linearized unsteady pressure and wave forces are strightforward following well known formulations based on the linear theory.

Numerical Results

Two kinds of calculations are performed and compared. One is the calculation based on the formulation presented in this paper. Another one is the calculation based on the formulation due to the source distribution, which is well known and alternative expression of the velocity potential (6). For the calculations based on the later formulation, no interpolating function such as spline function related above is used and only the manner of the constant panel is applied.

Fig.2 and 4 show the panel distribution of the blunt ship ($L/B = 5$) and calculated wave exciting force for surge respectively, which have been already reported in [1]. Calculations are carried out following the formulation due to the source distribution. The large discrepancies are observed between numerical and experimental results for the case with forward speed.

Fig.5 is the present results calculated for the half-submerged prolate spheroid ($L/B = 5$) illustrated in Fig.3. It is confirmed that the present formulation gives reasonable results compared with another formulation based on the source distribution. The differencies between two formulations may be caused by such phenomenon as the irregular frequency which is possible for the formulation due to the source distribution. The similar resonable results can be expected even for the real ship in Fig.2. We are now trying to apply the present scheme to the real blunt ship, and several results will be appear until the workshop.

References

[1] 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, Journal of the Society of Naval Architects of Japan, Vol.171(1992), pp.109–123.

[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 (2nd Report), Journal of the Society of Naval Architects of Japan, Vol.173(1993), pp.195–208.

[3] Chang,M.S. : Computations of Three-Dimensional Ship Motions with Forward Speed, Proc. 2nd Int. Conf. Num. Ship Hydrody., Berkeley (1977).

[4] Kobayashi,M. : On the Hydrodynamic Forces and Moments Acting on a Three Dimensional Body with a Constant Forward Speed, Journal of the Society of Naval Architects of Japan, Vol.150(1981), pp.175–189.

[5] Inglis,R.B. and Price,W.G. : Three-Dimensional Ship Motion Theory ; Comparison between Theoretical Predictions and Experimental Data of the Hydrodynamic Coefficients with Forward Speed, Trans. RINA(1981).

[6] Sclavounos,P.D., Nakos,D.E. : Stability Analysis of Panel Method for Free–Surface Flows with Forward Speed, 17th Symp. on Naval Hydrodynamics. The Hague(1988),pp.173–193.

[7] Takagi,K. : An application of Rankine Source Method for Unsteady Free Surface Flows, Journal of the Kansai Society of Naval Architects, No.213(1990), pp.21–29.

[8] Yasukawa,H. : A Rankine Panel Method to Calculate Unsteady Ship Hydrodynamic Forces, Journal of the Society of Naval Architects of Japan, Vol.168(1990), pp.131–140.

[9] Ohkusu,M., Iwashita,H. : Evaluation of the Green Function for Ship Motions at Forward Speed and Application to Radiation and Diffraction Problems, 4th International Workshop on Water Waves and Floating Bodies, Norway(1989).

[10] Iwashita,H., Ohkusu,M. : Hydrodynamic Forces on a Ship Moving with Forward Speed in Waves, Journal of the Society of Naval Architects of Japan, Vol.166(1989), pp.187–206.

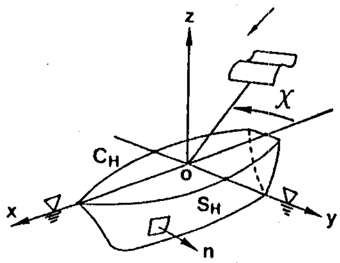

Fig.1 Coordinate system

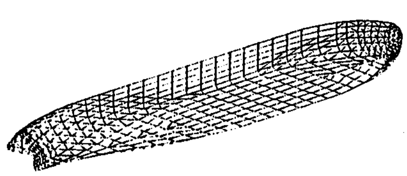
Fig.2 Panel distribution on the blunt ship ($N = 994$)

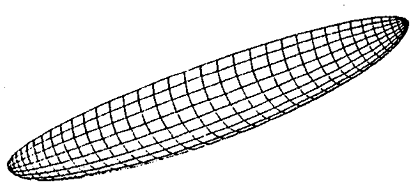
Fig.3 Pnel distribution on the half-submerged prolate spheroid ($N = 480$)

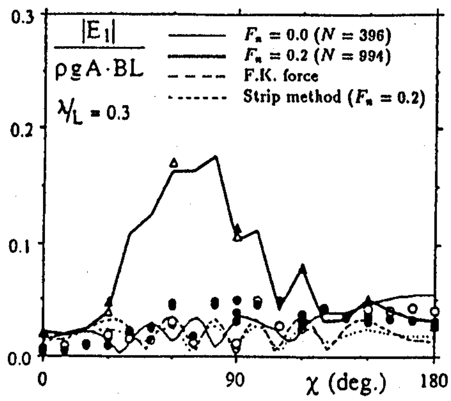

Fig.4 Wave exciting force for surge in obluque short waves ($\lambda/L = 0.3$, blunt ship)

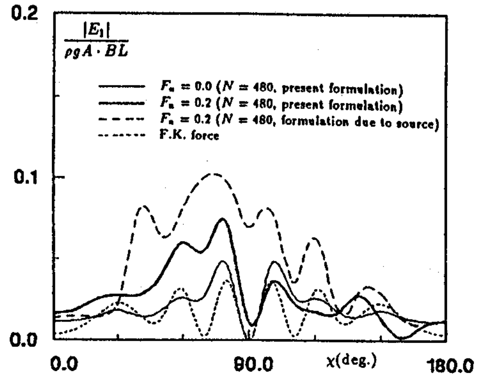

Fig.5 Wave exciting force for surge in obluque short waves ($\lambda/L = 0.3$, half-submerged prolate spheroid)

DISCUSSION

Newman J.N.: 1) What kind of spline basis functions did you use?
2) How did you evaluate the integrals over each panel?

Iwashita H.: 1) Cubic B-spline is used. Although another kind of B-spline such as 5-th order B-spline was also tried, we could not find out any advantages comparing Cubic B-spline.
2) The following scheme is used for evaluating

$$J \equiv \int_{a_1}^{b_1} \int_{a_2}^{b_2} f(x_1, x_2) dx_1 dx_2$$

- for the normal function $f(x_1, x_2)$
  Clenshaw-Curtis method
- for the function $f(x_1, x_2)$ which has the singularity
  Integral transformation + Clenshaw-Curtis method + shift of the field point of $O(10^{-10})$

$$J = \frac{(b_1 - a_1)(b_2 - a_2)}{4} \times \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} f(x_1, x_2) \frac{1.5 \cosh t_1}{\cosh^2(1.5 \sinh t_1)} \frac{1.5 \cosh t_2}{\cosh^2(1.5 \sinh t_2)} dt_1 dt_2$$

$$\left. \begin{aligned} x_1 &= [(b_1 - a_1) \tanh(1.5 \sinh t_1) + (b_1 + a_1)]/2 \\ x_2 &= [(b_2 - a_2) \tanh(1.5 \sinh t_2) + (b_2 + a_2)]/2 \end{aligned} \right\}$$

Kim M.H.: According to your numerical results, there is big discrepancy between the constant panel result and the high-order element result. Is it a generic numerical problem of the constant panel method for this particular application? Or can you have better agreement by simply increasing the number of constant panels?

Iwashita H.: The discrepancy between upper part and lower part of the figure which I presented doesn't have any relation with the approximation order of the element at all. This discrepancy is caused by the different type of the integral equation. If we solve the integral equation with respect to ϕ assuming constant panel (0-th order) approximation, we can get a similar solution to that obtained by the assumption of higher-order approximation, provided the number of panel is enough (at least more than 100 elements).