Wave Forces on a Ship Running in Quartering Waves

D.L. Huang and Z.Zhong

Dalian University of Technology, China

1. Introduction

When a ship running in following or quartering waves, the encounter frequency between ship and wave becomes very low, but not be zero. In this case, to predict waves forces acting on the ship by use of the strip theory is recognized to be not available in the strict sense. Regarding the basic background of present problem, to ignore the influence of encounter frequency on wave forces seems to be also not appropriate. The object of present work is to take account the influences of forward velocity and encounter frequency simultaneously in predicting waves exiting froces of a ship in such a environment, and try to develop a 3–D theoretical method for this purpose.

By assumming that the ship is slender and the incident waves are sinusoidal and of small amplitude, the wave field around the ship can be divided into two regions, i.e. the far field and the near field. In the far field the flow is considered to be generated by sources of oscillatory strenght distributed on the center line of ship. The flow in near field can be considered to be two dimensional. By matching the velocity potentials in the two fields, the expression of diffraction wave potential can be determined and therefore, hydrodynamic pressure and resulting wave forces on the ship can be obtained. In order to simplify computation procedure, a modified numerical method for calculating 3–D velocity potential of source of oscillatory strength with constant forward velocity is proposed here.

2. Mathematical Model of Problem

A translating reference frame (0–xyz) is defined to be fixed to the mean position of the ship with z–axis upward and z=0 is the undisturbed water surface. Ship is running with constant speed U in the positive x–direction. Since the encounter frequency, ω, is very low that the influence of oscilating motions of ship is ignored in present problem. The diffraction wave potential, $\varphi_D e^{i\omega t}$, satisfyies following equations

$$\begin{aligned} &\nabla^2 \varphi_D = 0 \\ &(i\omega - U\frac{\partial}{\partial x})^2 \varphi_D + g\frac{\partial \varphi_D}{\partial z} = 0, \qquad \text{on } z=0 \\ &\frac{\partial \varphi_D}{\partial n} = -\frac{\partial \varphi_I}{\partial n}, \qquad \text{on hull surface} \end{aligned} \tag{1}$$

In the far field, diffraction wave potential can be considered to be the sum of that induced by sources of oscillatory strength distributed along the center line of ship, and satisfies the first two equations of (1). According to the assumption of slender ship, the diffraction wave potential in near field should satisfies equations:

$$\begin{aligned}
&\frac{\partial^2 \varphi_D}{\partial y^2} + \frac{\partial^2 \varphi_D}{\partial z^2} = 0 \\
&\frac{\partial \varphi_D}{\partial z} = 0, \qquad \text{on } z = 0 \\
&\frac{\partial \varphi_D}{\partial N} = -\frac{\partial \varphi_D}{\partial N}, \qquad \text{on hull surface}
\end{aligned} \tag{2}$$

and takes the from

$$\begin{aligned}
\varphi_D = &\frac{\sigma(x)}{\pi} lnR + F(x) + \sum_{n=1}^{\infty} \left[P_{2n}(x)cos2n\theta / R^{2n}\right. \\
&\left. + P_{2n-1}(x)sin(2n-1)\theta / R^{2n-1}\right] \\
R = &(y^2 + z^2)^{1/2}, \qquad \theta = tan^{-1}(y/z)
\end{aligned} \tag{3}$$

By matching φ_D in far field with the near field expression (3), the function F(x) can be determined immediately as

$$\begin{aligned}
F(x) &= \frac{1}{2\pi} \int_{L/2}^{L/2} [ln2|x-\xi|Sgn(x-\xi) + H(x,00,\xi,00)] \frac{d\sigma}{d\xi} d\xi \\
H(x,y,z,\xi,\eta,\zeta) &= \frac{g}{\pi} \int_0^{\pi} d\theta \int_0^{\infty} \frac{k e^{k(z+\zeta) + ik[(x-\xi)cos\theta + (y-\eta)sin\theta]}}{yk - (\omega + Ukcos\theta)^2} dk
\end{aligned} \tag{4}$$

In order to determine the coefficiets in (3), it is found to be appropriate to express the ship section contour with a mapping function of generized Lewis form.

3. Numerical computation of source of oscillatory strength with constant forward velocity.

It is obviously impotant to find a effective numerical method of calculating moving pulsating source potential. Based upon preceding reserches on numerical computation of Green's function, a numerical method is developed for this purpose by exploiting the analytiacal feature of exponential integral and using some numerical integrating formulas. The potential of a source located at the point $Q(\xi,\eta,\zeta)$ of oscillatory strength with constant moving velocity, U, can be reformed as

$$G_3(P,Q)=\frac{1}{r}-\frac{1}{r_1}+H(P,Q), \qquad P=P(x,y,z)$$

$$H(P,Q)=\frac{1}{\pi}\sum_{i,j=1}^{2}\int_0^{\pi}d\theta\int_0^{\infty}\frac{(-1)^{i-1}k_i e^{k_i\alpha_j}}{\sqrt{1-r\tau\cos\theta}\ (k-k_i)}dk, \qquad \tau=\omega U/g$$

$$=N(P,Q)+W(P,Q)$$

$$N(P,Q)=\frac{1}{\pi}\sum_{i,j=1}^{2}(-1)^{i-1}\int_0^{\pi}\frac{k_i d\theta}{\sqrt{1-4\tau\cos\theta}}e^{k_i\alpha_j}E_1(k_i\alpha_j)$$

$$N(P,Q)=i\sum_{i,j=1}^{2}(-1)^{i-1}\int_0^{\pi}\frac{k_i d\theta}{\sqrt{1-4\tau\cos\theta}}e^{k_i\alpha_j}h_{ij}$$

where $\alpha_j=(z+\zeta)+(x-\xi)\cos\theta+(-1)^{j-1}(y-\eta)\sin\theta$, k_i $(i=1-4)$ are the four singularities. $E_1(z)$ is exponential integral, h_{ij} is the monitor factor equaling to 1 or 0 that depends on α_j and $k_i\alpha_j$. N(P,Q) and W(P,Q) can be interpreted as the nearfield disturbance and the far field disturbance, respectively. Some particular forms of the source potential can be derived from (5) for certain special cases. For example, for the case of very low frequency $\omega\to 0$, $k_1=U^2(1-2\cos\theta)/g$, $k_2=0$, we have

$$N(P,Q)=\frac{2}{\pi}\sum_{j=1}^{2}\int_0^{\pi}[e^{k_1\alpha_j}E(k_1\alpha_j)]d\theta, \quad W(P,Q)=4i\sum_{j=1}^{2}\int_0^{\pi}h_{ij}e^{k_i\alpha_j}d\theta \tag{6}$$

The integration respect to θ can be performed by using Lobatto rule with some transforms of the integrand. In order to ensure the numerical stability of integration in the region near $\pi/2$, certain derivations and procedures are introduced. It should point out that this method can satisfy the requirements of computation of present problem.

4. Wave Forces

The wave field around the ship is constructed by incident wave, diffraction wave and the steady wave made by ship running in calm water. Considering the object of present study, the pressure caused by steady wave alone is then ognored. The linearized hydrodynamic pressure on a hull section is

$$P=-\rho e^{i\omega t}[i\omega\varphi_I-U\frac{\partial\varphi_D}{\partial x}+\frac{\partial\varphi_s}{\partial y}\cdot\frac{\partial(\varphi_I+\varphi_D)}{\partial y}+\frac{\partial\varphi_s}{\partial z}\cdot\frac{\partial(\varphi_I+\partial_D)}{\partial z}] \tag{7}$$

where, φ_I and φ_s are the velovity potentials of incident wave and steady ship wave, respectively. The first term of pressure is due to incident wave alone, the second term is diffraction pressure, the rest are caused by the interactions between steady ship wave and other two waves. The form of steady ship wave potential given by Tuck in 1964(JSR, Vol.8, No.1,2) are employed for evaluating the pressure components in present study.

By integrating the pressure along section contour, three hydrodynamic forces on the section, i.e. swaying force, heaving force and rolling moment, can be obtained. To integrate further these forces along the ship length, we have the resulting wave forces. The Japanese fishing boat "Taishomaru" is applied here in numerical study. Fig1 and Fig2 give the swaying force on sections and the resulting yawing moment, respectively.

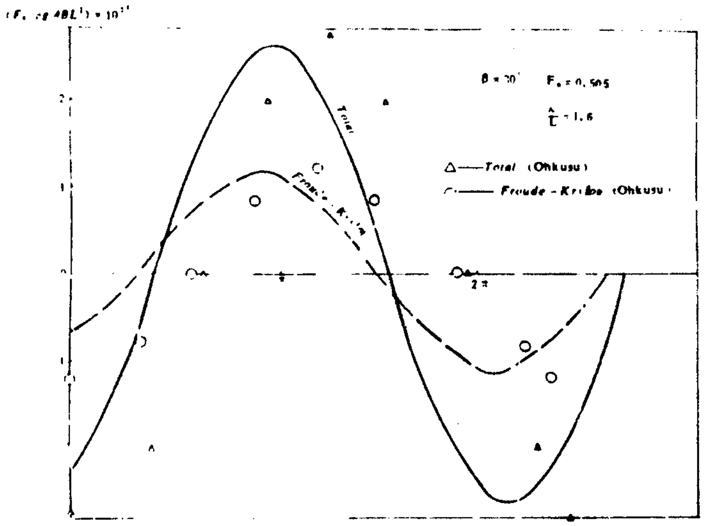

Fig. 1 Swaying force on section $\beta=30^{\circ}$

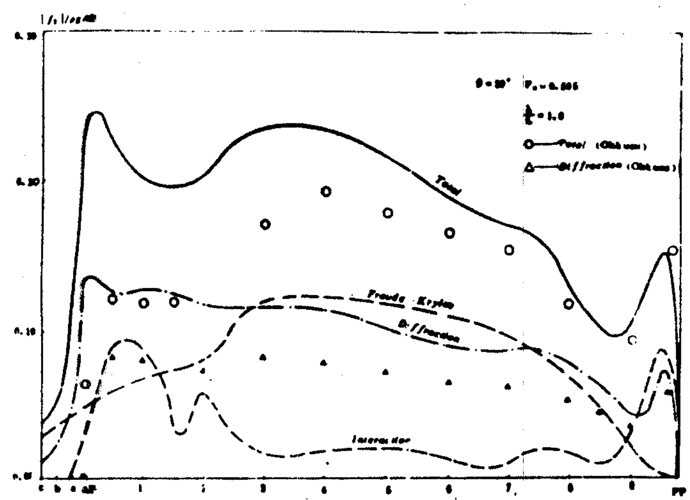

Fig. 2 Yawing moment relative to the distance between hollow and midship $\beta=30^{\circ}$

By numerical studies, the following conclusions can be drawn:

1) The diffraction pressure has the same order as that of Froude-Krylov pressure;

2) The pressure caused by the interaction between steady wave making and incident as well as diffraction waves is of higher order than Froude-Krylov pressure. However, it can't be ignored in computation of total wave forces.

3) There are obvious discrepencies between the data given by present study and that by Ohkusu. The reason may be that though the encounter frequency is taken to be low here, it is not zero.

Newman: Why are the force curves (especially Froude-Krylov) not exactly sinusoidal functions of the phase if the theory is linear?

Huang & Zhong: The force curves represent the forces in relation to the location of a water trough. Since the hull is not exactly symmetric with respect to its midship section, the force is not exactly sinusoidal.

Yeung: Your results seem to differ substantially from Ohkusu's work (not cited in the abstract). Was his steady-forward motion potential also based on Tuck's slender body theory? If so, why the large discrepancies?

Huang & Zhong: In his derivation of the diffraction potential in the far field, M. Ohkusu sets the encounter frequency to be exactly zero. This allows him to use the steady wave making potential to represent the diffraction potential in the far-field. In our work the encounter frequency is considered small, but not zero, so we use the velocity potential due to a distribution of a sources of oscillating strength along the ship's center line. For this reason, although the steady wave making potential used in the two papers is the same, the diffraction pressures are quite different.