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Elangovan, Muniyandy

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PREDICTION OF DIFFRACTION WAVE FOR A BLUNT SHIP WITH FORWARD SPEED

Muniyandy ELANGOVAN.[1]

Abstract: *Seakeeping analysis based on potential theory has been used to predict the hydrodynamics forces, exciting forces, motions and wave pattern. In this paper, author made effort to study the bluntness effect by comparing two ship model diffraction waves and calculated diffraction wave is compared with experimental data. Series 60 (Cb=0.6) & (Cb=0.8) have been taken for the analysis and the exciting forces and diffraction wave are calculated.*

Keywords: *format; conference; headings; details.*

INTRODUCTION

The accurate estimation of the hydrodynamic forces and ship motions of a ship advancing in a seaway has been an important topic in practical ship design. It is the requirements for the ship structure analysis by finite element methods (FEM) where the pressure force is needed rather than total force. Potential theory is followed here for the formulation of problem where fluid is assumed to be invisicid, incompressible and the flow is irrotational (Bertram 1990, Sclavounos 1990, Yasukawa 1990, Takagi 1990, Iwashita 1993, Elangovan 2006). The increasing accessibility of computers high capacity led to the development of three-dimensional theories that removed some of the deficiencies of strip theory. The choice of the elementary singularities leads to the classification of these methods into the Green function method (GFM) and the Rankine panel method (RPM). In hydrodynamic problems, in addition to the Laplace's equation, the free surface condition, the body boundary condition and the radiation condition must be satisfied. In Green function method, the radiation condition will be satisfied analytically.

In RPM, the radiation condition must be satisfied numerically and this numerical radiation can be implemented in different method. The typical one is the finite difference method originated in (Dawson 1977). The upward differential operator is used to evaluate the partial derivative of the velocity potential on the free surface and the radiation condition which proves non-radiating waves in front of a ship is satisfied. (Sclavounos & Nakos 1977) introduced the B-Spline function to express the potential distribution on the free surface and satisfied the radiation condition by adding a non wave condition at the leading edge of the computation domain of the free surface. The alternative method is (Jensen's 1986) method is called collocation method and this is limited for $\tau > 0.25$where no waves propagate in front of the ship. Mainly, for the fast ship, estimation of seakeeping quality is important because the encounter frequency relatively

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[1] Surveyor, Hydrodynamics and Stability Group, R&D, Indian Register of Shipping, Mumbai – 400 072, INDIA, Email: m.elangovan@irclass.org

increases due to the high forward speed and this leads to the large acceleration induced by the ship motions and large wave pressures acting on the hull. For fast ships, the strip theory has been broadly applied to their seakeeping estimations from the practical point of view. Presently, application for the fast ships has been proceeding (Elangovan 2008). Present analysis, standard series 60 hull has been taken and the analysis is done for Froude numbers =0.2.

MATHEMATICAL FORMULATION

We consider a symmetrical ship sailing with a constant velocity (*U*) in oblique regular waves encountered at an angle χ. The ship motion $\xi_j=e\text{^}(i\omega_e t)$ $(j=1\text{˜}6)$ is restricted at its equilibrium position and the wave amplitude (*A)* of the incident wave assumed to be small. $\omega 0$ is the circular frequency and *K* the wave number of the incident wave. Right hand coordinate system is followed to define the mathematical formulation and the forward speed is in the negative X direction (Iwashita, 1998). Figure 1 shows the coordinate system of the problem, direction of the wave, forward speed and the free surface. Normal of the surface is facing the fluid domain. The encounter frequency is $\omega_e(=\omega_0 - KU\cos\chi)$. The linear theory is employed for this problem assuming ideal (potential) flow.

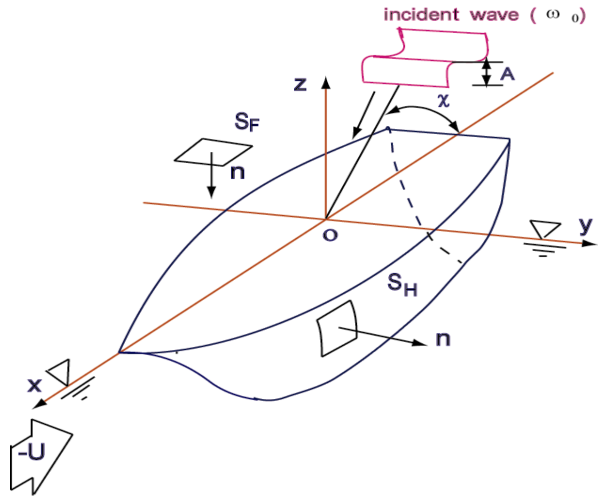


Fig. 1. Coordinate System

The total potential is decomposed into steady flow potential, which is time independent, and unsteady potential, which is time dependent. In unsteady potential, it is further classified as diffraction potential, which is partially time dependent and radiation potential, which is time dependent. The total velocity potential Ψ is governed by the Laplace's equation and can be written as

$$\Psi(\vec{x};t) = \Psi_s(\vec{x}) + \Psi_t(\vec{x};t) \tag{1}$$

$$\Psi(\vec{x};t) = U\left[\Phi(\vec{x}) + \varphi(\vec{x})\right] + \Re\left[\phi(\vec{x})e^{i\omega_e t}\right]$$

where

$\Phi = -x + \Phi^D$; $\phi = \dfrac{gA}{\omega_0}(\phi_0 + \phi_7) + i\omega_e \sum_{j=1}^{6} \xi_j \phi_j$;

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

Φ mean 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, basic flow is double body flow which better than uniform flow. In this formulation, if we put $\Phi = -x$, $\partial\phi/\partial n = n_1$ and $\vec{V} = \nabla[-x + \varphi]$, the formulation lead to Neumann-Kelvin formulation.

BOUNDARY VALUE PROBLEM

It is necessary to formulate the physical model into mathematical models to implement the physical boundary condition in mathematical form. In addition to Laplace equation, the body boundary condition and the free surface boundary condition must be included. Finally, the radiation condition must be satisfied on the free surface.

Body boundary condition states that the fluid does not penetrate the hull surface and the velocity of the hull and the fluid particle will be same that location. The boundary condition will be derived at the instantaneous wave elevation. Free surface condition is the combination of two conditions. First one is that dynamic boundary condition which comes from the Bernoulli's equation and second one is kinematics boundary condition.

Dynamic boundary condition states that the pressure at the free surface is equal to the atmospheric pressure. Kinematics boundary condition states that the fluid moves in vertical direction, and it remains in the same location. A free surface will not get break in the flow.

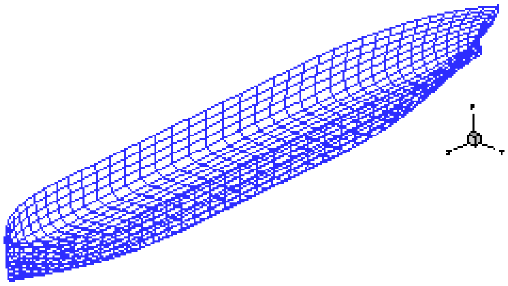


Fig. 2. Discretized Grid System – Series 60 (*cb*=0.8)

These boundary conditions are derived in the exact free surface i.e., $z=\eta$. It is to be simplified by linearising to the mean water level at $z=0$. In this paper we adopted the following free surface condition derived (Yasukawa 1990) and corresponding body boundary conditions shall be written as

for φ

$$\frac{1}{2k0}\overline{\nabla}\overline{\Phi}.\overline{\nabla}(\overline{\nabla}\overline{\Phi}.\overline{\nabla}\overline{\Phi})+\frac{1}{k0}\overline{\nabla}\overline{\Phi}.\overline{\nabla}(\overline{\nabla}\overline{\Phi}.\overline{\nabla}\varphi) + \frac{1}{2k0}\overline{\nabla}(\overline{\nabla}\overline{\Phi}.\overline{\nabla}\overline{\Phi}).\overline{\nabla}\varphi+\frac{\partial\varphi}{\partial z}=0 \quad \text{on} \quad z=0 \qquad (2)$$

for ϕ_7

$$-Ke\phi_7+2i\tau\overline{\nabla}\overline{\Phi}.\overline{\nabla}\phi_7+\frac{1}{k0}\overline{\nabla}\overline{\Phi}.\overline{\nabla}(\overline{\nabla}\overline{\Phi}.\overline{\nabla}\phi_7) + \frac{1}{2k0}\overline{\nabla}(\overline{\nabla}\overline{\Phi}.\overline{\nabla}\overline{\Phi}).\overline{\nabla}\phi_7+\frac{\partial\phi_7}{\partial z}=0 \quad \text{on} \quad z=0 \qquad (3)$$

Hull boundary condition is derived, and it is written as :

$$\frac{\partial\phi_7}{\partial n}=-\frac{\partial\phi_0}{\partial n} \qquad \text{on } S_H \qquad (4)$$

$\vec{r}=(x,y,z),\ \vec{V}=\nabla\Phi,\ \vec{r}=(x,y,z),\ K_0=g/U^2,\ K_e=\omega_e{}^2/g$ and $\tau=U\omega_e/g$. m_j in eqn. (4) is derived by Timman & Newman (Timman & Newman 1990) is an influence term from the steady flow to the unsteady flow on the body surface.

NUMERICAL METHOD

Discretized hull and free surfaces are shown in figure 4, hull has 400 panels and the free surface has 2184 panels. In the formulation half of the elements are considered because symmetry is considered in the formulation which can reduce the computational time. The collocation method in the Rankine Panel Method is applied to solve the boundary value problems (Takaki, 1998 and Iwashita, 1998). 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

$$\left.\begin{matrix}\varphi(P)\\ \phi_7(P)\end{matrix}\right\}=-\iint_{S_H+S_F}\left\{\begin{matrix}\sigma_s(Q)\\ \sigma_7(Q)\end{matrix}\right\}G(P,Q)dS \qquad (5)$$

where

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

$P=(x,y,z)$ and $Q=(x',y',z')$ show the flied point and the source point, and $G(P,Q)$ is a Green function satisfying the Laplace equation in the fluid domain. When P is on the boundary surface, above equation leads to the following integral equation with respect to $\sigma_s(Q)$ or $\sigma_j(Q)$.

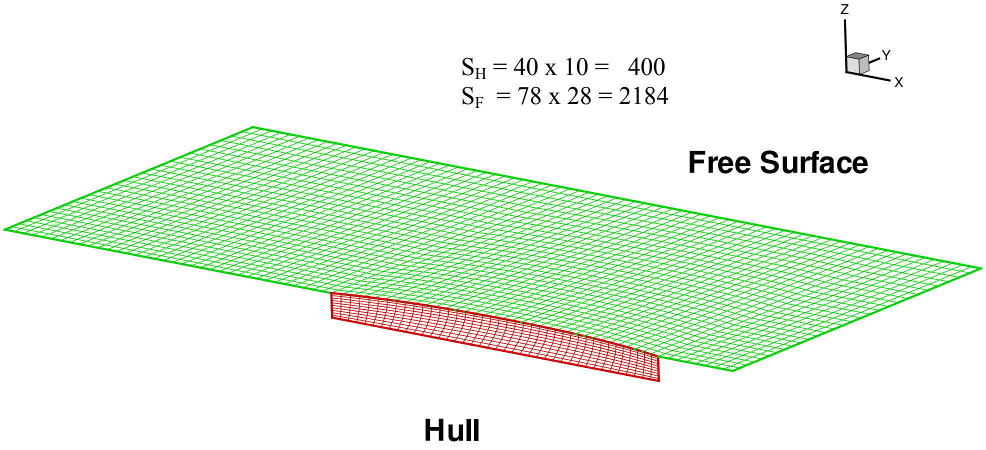


Fig. 3. Discretized Hull and Free Surface for Computation

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 SH coincide with geometric centre of each panel and those on SF are shifted one panel upward in order to force the radiation condition numerically. This numerical radiation condition is valid only $\tau > 0.25$ in the unsteady problem where the waves do not propagate to the forward direction of the ship.

EXCITING FORCES AND DIFFRACTION WAVE

Exciting forces are calculated from the incident wave potential and diffraction potential. This is used in solving the motion equation.

$$\frac{E_j}{\rho g A} = -i\frac{\tau}{\nu}\iint_{S_H}\left(1+\frac{1}{ik_0\tau}\vec{V}.\vec{\nabla}\right)(\phi_0+\phi_7)n_j\,dS \qquad (j=1\sim6) \qquad (6)$$

Diffraction wave is calculated by the derived equation

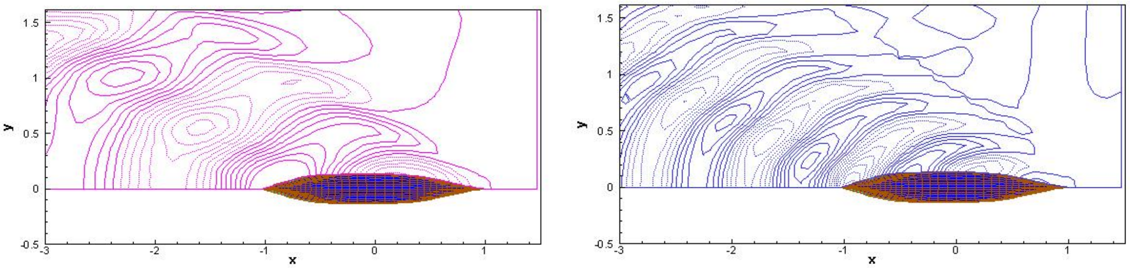
$$\left.\begin{matrix}\dfrac{\zeta_j}{\xi_j}\\[2mm] \dfrac{\zeta_7}{A}\end{matrix}\right\} = \left(1+\frac{1}{ik_0\tau}\vec{V}\Phi.\vec{\nabla}\right)\left\{\begin{matrix}K_e\phi_j\\ (-i\tau/\upsilon)\phi_7\end{matrix}\right\} \qquad \text{on} \quad z=0 \qquad (7)$$

NUMERICAL RESULTS

Figure 3 shows the computation grid used in the present calculations. Because of the symmetry with respect to *xz* plane, the computation domain is reduced to half ($y > 0$). The free surface extended upto one ship length and for the forward ¼ ship length is considered. Calculations are carried out taking the steady double body flow as base flow. The forward speed effects are generally introduced through the body boundary condition and the free surface boundary condition. RPM can capture both effects accurately with significant three dimensional effects.

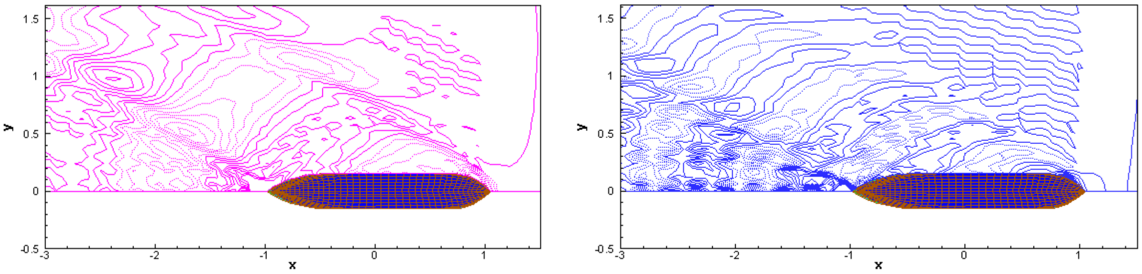
Tow hull has been taken for the analysis i.e, series 60 *cb*=0.6 and *cb*=0.8. Series 60 (*cb*=0.6) hull diffraction wave has been estimated and it is shwon in figure 4. Figure 4(a) has been taken for λ/L=1.0 and figure 4(b)is for λ/L=0.5. The wave pattern around the hull shows that behind has no disturbance due to wave and it is not disturbed. Series 60 (*cb*=0.8) hull diffraction wave has been estimated and it is shwon in figure 5. Figure 5(a) has been taken for λ/L=1.0 and figure 5(b)is for λ/L=0.5. The wave pattern around behind the hull shows that wave pattern is not very smooth when compare to the *cb*=0.6. This may be reason that bluntness can bring such a different.

Diffraction wave in transverse direction has been plotted for series 60 *cb* =0.8 and it compared with experimental data (Hiroshima University Research Report), refer figure 6. Though pattern seems to be good but the amplitude is not matching well. It is concluded that diffraction wave calculation shall be improved.



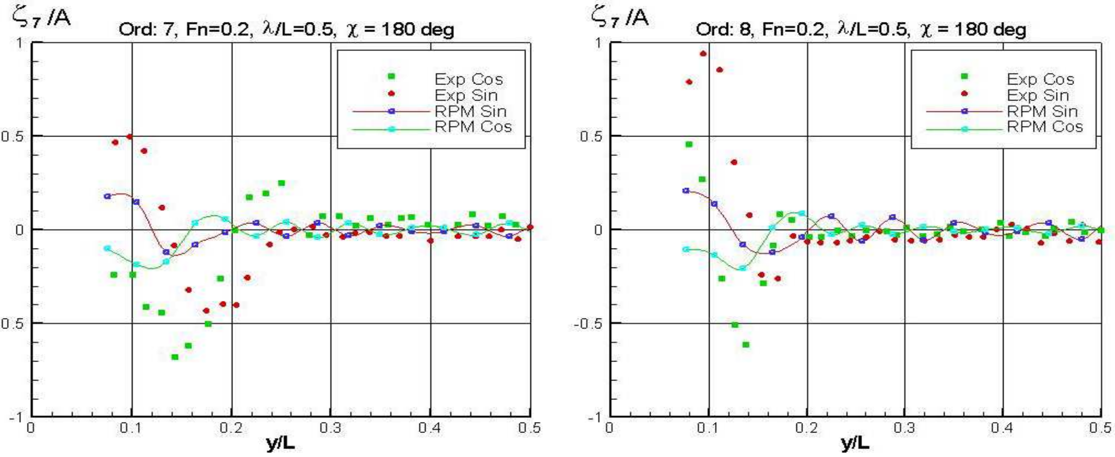
(a) **(b)**

Fig. 4. Diffraction wave, Series 60 (*cb*=0.6), Fn=0.2 (a) λ/L=1.0 (a) λ/L=0.5



(a) **(b)**

Fig. 5. Diffraction wave, Series 60 (*cb*=0.8), Fn=0.2 (a) λ/L=1.0 (a) λ/L=0.5



(a) **(b)**

Fig. 6. Diffraction wave, Transverse direction, Series 60 (*cb*=0.8) (a) Ord:7 (b) Ord:8

CONCLUSIONS

Rankine panel method formulation has been derived and code has been developed. Series 60 *cb*=0.6 and *cb*=0.8 has been analyzed for diffraction wave and compared for bluntness effect on wave. Series 60 (*cb*=0.8) diffraction wave has been compared with experimental data and the difference is quite a large. It is concluded that diffraction wave shall be improved by taking the exact free surface with steady wave.

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