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COMPUTATION OF SHIP RESPONSES IN WAVES USING PANEL METHOD

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Abstract

Hydrodynamic coefficients, Forces / Moments and Motions of a ship moving with a mean forward speed in six degrees of freedom are computed using Panel Method. In this study, an existing numerical model without speed consideration was modified by incorporating the speed parameters. Appropriate Green function was used to calculate the concern velocity potential. The accuracy of the developed numerical code employing the Panel Method has been validated by comparing the result with known/published results of a series 60 ship available in the literature. Based on the results presented in the paper, it can be concluded that the developed model is able to predict the responses of the ship with forward speed effect.

Keywords: Motions, Green function, 3D Source distribution.

NOMENCLATURE:

A_{kj}	:	Added mass coefficient	R'	:	Distance between a field point and the image of a singular point above z = 0
B_{kj}	:	Damping coefficient	t	:	Time
C_{kj}	:	Restoring Force coefficient	τ	:	Brard's parameter $= \dfrac{\omega_e U}{g}$
F_n	:	Froude Number = $U/\sqrt{(gL)}$	x, y, z	:	Coordinate system, with x forward, y starboard and z upward, coordinate of a field point
F_j	:	Force on hull in the j-th direction	λ	:	Wave length
g	:	Acceleration due to gravity	X_j	:	Motion amplitude in j-th mode
G	:	Green Function	ξ, η, ζ	:	x-, y-, z- coordinate of a singularity point
h	:	Depth of water	ζ_a	:	Wave amplitude = h/2
k	:	Wave Number = $2\pi/\lambda$	$\zeta(x,y;t)$	:	Free surface elevation
L	:	Ship Length	χ	:	Wave heading, $\chi = 0^\circ$ => following seas
m_j	:	Forward speed components of body boundary condition for the Neumann – Kelvin problem	ρ	:	Water density
n	:	Unit normal vector out of the fluid = (n_1, n_2, n_3)	σ	:	Source density

P	:	Pressure	ϕ	:	Perturbation velocity potential
$\boldsymbol{r}$	:	Position vector from the origin to a point on the hull	Φ	:	Total velocity potential
$\boldsymbol{r} \times \boldsymbol{n}$	:	Moments of the unit normals for the rotational motions = (n_4 n_5, n_6)	ω	:	Wave frequency
R	:	Distance between a field Point and a singular point	ω_e	:	Frequency of encounter = $\omega - \frac{\omega^2 \overline{U}}{g} \cos \chi$

1. Introduction:

During the last decade, advancements in computer technology have made possible the development of new classes of three-dimensional numerical tools for analyzing problems in Naval Architecture. Early attempts to model ships in potential flow focused on variations of slender body and strip theory to study simplified body geometries and free surface conditions. As computing power increased, so did the development of three-dimensional methods. Of these, considerable attention has been received by boundary element or panel methods. Panel methods attempt to solve the Laplace equation in the fluid domain by distributing sources and dipoles on the body and, in some methods, on the free surface. These surfaces are divided into panels, each one associated with a source and dipole distribution of unknown strength. The boundary conditions to be applied to the problem are often linearised and they determine either the potential or the normal velocity on each panel. Green's theorem relates the source and dipole distribution strength to the potential and normal velocity on each panel. Having solved for the unknown source and dipole strengths, Green Function may be used to find the potential at any point in the fluid domain. Hydrodynamic forces are found from pressure integration and are used with Newton's Law to determine motions.

As mentioned above, in the past, wave forces and responses of a floating body were often calculated by any two-dimensional strip theory method viz. Salvesen *et al.* (1970), Vugts (1971). Strip theories describe the hydrodynamic properties of each section by using Lewis forms, which means accurate shape of the body in concern is not accounted. On the other hand, in 3-D source distribution panel method mesh size i.e. the number of panels plays a vital role to represent the shape of the body more accurately. In principle, large number of panels can ensure more accuracy of shape of the body and hence accuracy of the results. But in the past, large memory size of electronic computer was not easily available to handle large number of meshes. With the advancement of computer technology, nowadays enough memory can handle large number of panels easily. So it is now very easy to make computations with varying sizes of meshes. Some researches have been done on floating bodies by 3-D source distribution method without forward speed and these are Faltinsen & Michelsen (1975), Hogben & Standing (1975) and Garrison (1978) but a very few works on 3-D source distribution method with forward speed have been done and notably by Inglis and Price (1980, 1981, 1981). These works have been carried out by taking the large panels due to the limitation of the computing facility. Hence the main objective of this research work is to apply the 3-D source method for computation of the wave forces on floating bodies and motions with forward speed effect by taking large number of panels to obtain good results.

Panel methods are very efficient for sea-keeping calculations. But for the problem with forward speed, a lot of numerical and theoretical difficulties appear. For long time, only frequency encounter approximation limited to thin ships with the zero speed diffraction-radiation Green function or Rankine methods available for high values of Brard's parameter $\tau = w_e U/g$ have been used. Recently, using either Steepest Descent Method (Iwashita and Okhusu (1989), Brument (1998), Maury (2001)), Super Green Function Method (Chen and Noblesse (1998)) or Simpson Adaptative Method (Ba Guiband ,1995) , Nontakaew *et al.* (1997)), progresses in the calculations of the Green's function have been performed. Many researchers have worked on the speed effect of moving bodies. Since 3D approaches generally require large high-speed computers, some researchers (Chapman (1975, 1976), Yeung and Kim (1981), Yamasaki and Fujino (1985), Faltinsen and Zhao (1991)) developed two and one-half dimensional approach to solve the ship motion problems. Some researchers (viz. Wang, 1999) have used this approach for slender bodies where relaxed radiation conditions with numerical correcting terms are imposed on the open boundaries in the finite fluid domain.

In the past the assumption of infinite depth was common to most of the published works in ship hydrodynamics (Garrison , 1974). On the other hand 3D-source distribution technique in most published works has been outlined only for zero forward speed (Faltinsen and Michelsen, (1974), Garrison C. J (1974)). In this paper 3D-source distribution technique has been employed with effect of forward speed to predict the hydrodynamic coefficients, forces and motions of a ship in six degrees of freedom. Also depth of water assumed to be finite and linear wave theory has been employed in the numerical scheme.

2. Mathematical model:

2.1 Governing Equations

Consider a three-dimensional body of arbitrary shape in water of uniform depth. The amplitude of motions as well as of the incident waves are supposed to be small, while the fluid is assumed to be inviscid and irrotational. For the steady state condition, the total velocity potential, Φ, with effect of forward speed U of ship may be expressed as,

$$\Phi(x, y, z; t) = [-Ux + \phi_S(x, y, z)] + \phi_T(x, y, z)e^{-i\omega_e t}$$

(1)

Where first part is steady contribution with U and the second part is time dependent ones.

Components of time dependent potential ϕ_T (x, y, z; t) are**:**

(1) Incident wave potential: ϕ_0 (x, y, z; t)

(2) Diffraction potential: ϕ_7 (x, y, z; t)

(3) Radiation potential: ϕ_j (x, y, z; t)

In periodic form:

$$\phi_0 = \phi_0 e^{-i\omega_e t}$$

$$\phi_7 = \phi_7 e^{-i\omega_e t}$$

$$\phi_j = \sum_{j=1}^{6} \phi_j e^{-i\omega_e t}$$

That means ϕ_T is divided into (2+6) components.

2.2 Incident wave potential

In the case of long crested, harmonic progressive waves the incident potential for finite depth (h) is defined as. *(Islam, M.R. et.al. 2003)*:

$$\phi_0 = \frac{-ig\zeta_a}{\omega}\frac{\cosh[k(z+h)]}{\cosh kh}e^{ik(x\cos\chi + y\sin\chi)}$$

in which :
h = water depth
g = acceleration of gravity
k = wave number
χ = angle between incident waves and X axis

The individual potentials should satisfy the Laplace equation in the fluid domain, i.e.: $\nabla^2\phi=0$. There are different solutions for above Laplace equation and the boundary conditions of the problem specify the suitable solution for each problem. However, there is no analytical solution for ϕ_7 and ϕ_j, so the problem should be solved numerically. According to the 3-D source method, the potentials ϕ_7 and ϕ_j can be expressed in terms of well-known Green functions. Noted that, Green function inherently satisfies the free surface, bottom and radiation conditions. As a result, boundary conditions are reduced only to wetted surfaces of the bodies. So, the wetted surfaces should be divided into panels to transform integral equations to a system of algebraic equations to determine unknown source density over each panel as discussed in section 2.4.

2.3 Boundary Conditions

The boundary conditions to be satisfied by the potential functions are listed below:

i) The linearised free surface condition: $\left[\left(i\omega_e - U\dfrac{\partial}{\partial x}\right) + g\dfrac{\partial}{\partial z}\right]\phi_T = 0$ on z = 0 (Faltinsen,1990)

ii) The sea bottom condition: $\dfrac{\partial\phi}{\partial z} = 0$ on z = -h (Faltinsen,1990)

iii) The body boundary condition (Inglis and Price, 1981, Islam M. R. *et al*, 2003):

$$\frac{\partial\phi_0}{\partial n} + \frac{\partial\phi_7}{\partial n} = 0 \quad \text{on the body surface}$$

$$\frac{\partial\phi_j}{\partial n} = i\omega_e n_j + \bar{m}_j \quad \text{on the body surface}$$

In which n_j is the direction cosine on the surface of the body in the j-th mode of motion.

2.4 Treatment for Boundary Conditions

Fig. 1 represents an arbitrary shape body surface for which, total potential Φ = uniform stream potential + disturbance potential due to the body $= \phi_\infty + \phi$.

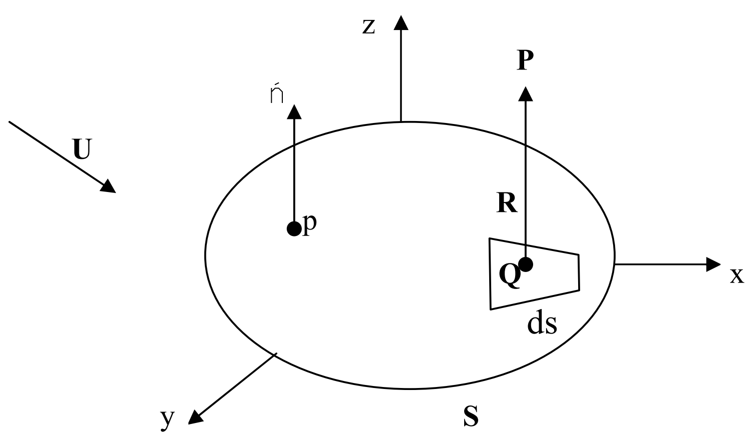

Fig. 1: Arbitrary shape body surface

Again, the potential at a point P(x, y, z) in space due to a unit point source located at a point Q on the surface S is $\dfrac{1}{R(P,Q)}$, where R (P, Q) is the distance between the points P and Q. Accordingly, the disturbance potential at point P due to a source distribution σ(Q) on the surface S is $\phi(x,y,z) = \dfrac{1}{4\pi}\iint_S \dfrac{\sigma(Q)}{R(P,Q)}ds$. The $\phi(x,y,z)$ automatically satisfies Laplace equation and ϕ tends to zero at $x^2 + y^2 + z^2$ tends to infinite for any function **σ**, simply because the point source potential $\dfrac{1}{R(P,Q)}$ satisfies these conditions. The function **σ** must be determined from the normal derivative boundary condition on the ship surface. But to apply this condition evaluation of the limit of the normal derivative of the above integral at a point p on the surface S is approached. The derivatives of the integral become singular as the surface S is approached i.e. P moves to p, and the evaluation of the limits of the derivatives of the integrand in above equation requires some care. The limit of the normal

derivative consists of two terms. One is simply the normal derivative of the integral above evaluated on the surface; i.e. at P = p. The other term arises from the limiting process. Physically, this latter term, which equals -2πσ(p), is the contribution to the normal derivative at p of the portion of the surface S in the immediate neighborhood, while the integral term is the contribution of the remainder of S.
Thus,

$$\frac{\partial\phi}{\partial n}\Big|_S = \frac{1}{4\pi}\times(-2\pi\sigma(p)) + \frac{1}{4\pi}\iint_S \sigma(Q)\frac{\partial}{\partial n}\left(\frac{1}{R(p,Q)}\right)ds$$

Or, $\frac{\partial\phi}{\partial n}\Big|_S = -\frac{1}{2}\sigma(p) + \frac{1}{4\pi}\iint_S \sigma(Q)\frac{\partial}{\partial n}(G(p,Q))ds$

Inserting this into the normal derivative boundary conditions the integral equations for σ is obtained.

That is, for radiation potentials, $\frac{\partial\phi_j}{\partial n}\Big|_S = -\frac{1}{2}\sigma_j(p) + \frac{1}{4\pi}\iint_S \sigma_j(Q)\frac{\partial}{\partial n}(G(p,Q))ds = i\omega_e n_j + \overline{U}m_j$ for j = 1, 2,......6

and for diffraction potential, $\frac{\partial\phi_7}{\partial n}\Big|_S = -\frac{1}{2}\sigma_7(p) + \frac{1}{4\pi}\iint_S \sigma_7(Q)\frac{\partial}{\partial n}(G(p,Q))ds$

In general form:

$$-\frac{1}{2}\sigma_j(p) + \frac{1}{4\pi}\iint_S \sigma_j(Q)\frac{\partial}{\partial n}(G(p,Q))ds = -\frac{\partial\phi_j}{\partial n} \quad \text{for } j = 1,2,....7$$

(2)

The term $\frac{1}{2}\sigma_j(p)$ considers the contribution of the Green Function at the source location P = p, where Green Function and its derivatives are not defined. Since $\frac{\partial G}{\partial n}$ is complex, and does not permit a solution in closed form, a numerical approach is required to solve the equations. In this approach the wetted surface of the body is divided into a finite number of small rectangular or triangular elements (Facets / Panels) capable of representing a curved surface and avoiding 'leakage' gaps. The source strength distribution is taken to be uniform over each element with the boundary condition being satisfied at the center of the panel. Dividing into N elements replaces the integral equations by seven systems of N linear equations, from which the desired source strength σ_j (p) can be determined. With a numerical approximation, the normal derivative of the Green Function are transformed into,

$$-\frac{1}{2}\sigma_{jm} + \sum_{n=1}^{N}\alpha_{mn}\sigma_{jn} = 2(i\omega_e n_{jm} + \overline{U}m_j) \text{ or } -2\frac{\partial\phi_{jm}}{\partial n}$$

where, $\alpha_{mn} = \frac{1}{2\pi}\int_{\Delta S_n}\frac{\partial}{\partial n}G_{mn}ds_n$

Here, ΔS_n refers to the respective surface element, and the coordinates of the control points are normally chosen in the center of the elements. Note that the body boundary condition is only satisfied at the control points.

In matrix form: $[\alpha_{mn} - I][\sigma_{jm}]_n = 2[i\omega_e n_{jm} + \overline{U}m_{jm}]_n \quad , \; -2\left[\frac{\partial\phi}{\partial n}\right]_n$ and from this the solution matrix for the source strength is obtained as,

$$[\sigma_{jm}]_n = 2[i\omega_e n_{jm} + \overline{U}m_{jm}]_n \times [\alpha_{mn} - I]^{-1} \quad , \; -2\left[\frac{\partial\phi}{\partial n}\right]_n \times [\alpha_{mn} - I]^{-1}.$$

After evaluation of all source strength, the diffraction potential and the local function of body motions follow from:

$\varphi_7(x) = \sigma_{7n}\beta_{mn}$ and $\varphi_j(x) = \sigma_{jn}\beta_{mn}$ for $j = 1,2,...6$

where, $\beta_{mn} = \frac{1}{4\pi}\int_{\Delta S_n}\frac{\partial}{\partial n}G_{mn}ds_n$

Here, x = (x_m , y_m , z_m) are the coordinates of the center (control points) of the elements.

2.5 Hydrodynamic Coefficients and Forces

After getting the velocity potentials, the hydrodynamic pressure at any point on the body can be obtained from the linearised Bernoulli's equation and can be written as:

$\frac{\partial \Phi}{\partial t} + \frac{1}{2}(\nabla \Phi)^2 + \frac{P}{\rho} + gz = 0$ and by linear potential theory total velocity potential is divided into

$\Phi = -Ux + \phi_s + \phi$

Where $\phi = \phi_0 e^{-i\omega_e t} + \phi_7 e^{-i\omega_e t} + \sum_{j=1}^{6} -i\omega_e X_j \phi_j$

Now after putting the value of Φ in the Bernoulli's equation, the following expression is obtained,

$$-\frac{P}{\rho} = \frac{\partial \Phi}{\partial t} + \frac{1}{2}\{\nabla(-Ux + \phi_s)\}^2 + \nabla(-Ux + \phi_s).\nabla\phi + \frac{1}{2}(\nabla\phi)^2 + gz$$

From which,

$$-\frac{P}{\rho} = \frac{\partial \Phi}{\partial t} + \frac{1}{2}\left[\{\nabla(-Ux)\}^2 + 2\nabla(-Ux)\nabla\phi_s + \{\nabla\phi_s\}^2\right] + \nabla(-Ux)\nabla\phi + \nabla\phi_s\nabla\phi + \frac{1}{2}(\nabla\phi)^2 + gz$$

Or, $-\frac{P}{\rho} = -i\omega_e\phi + \frac{1}{2}\left[\{-iU\}^2 + 2.iU.i\frac{\partial\phi_s}{\partial x} + \left\{i\frac{\partial\phi_s}{\partial x}\right\}^2\right] + \{-iU\}.i\frac{\partial\phi}{\partial x} + i\frac{\partial\phi_s}{\partial x}.i\frac{\partial\phi}{\partial x} + \frac{1}{2}(i\frac{\partial\phi}{\partial x})^2 + gz$

After simplification by neglecting higher order terms, hydrostatic part(s) as well as steady force, we get,

$$-\frac{P}{\rho} = -i\omega_e\phi + U\frac{\partial\phi}{\partial x}$$

Or, $P = \rho(i\omega_e\phi - U\frac{\partial\phi}{\partial x})$

(3)

Hence, on integration the radiation force, F_j (due to radiation potential ϕ_j i.e. motions of the ship) becomes,

$$F_j = \int_{S_B} Pnds = \rho\int_{S_B}\left(i\omega_e\phi_j - U\frac{\partial\phi_j}{\partial x}\right)nds$$

Hence,

$$F_{kj} = \rho\int_{S_B}\left(i\omega_e(-i\omega_e X_j\phi_j) - U(-i\omega_e X_j)\frac{\partial\phi_j}{\partial x}\right)n_k ds$$

where, F_{kj} denotes the k-th component of wave exciting forces or moments from the j-th component of motion.

Putting $\phi_j = \phi_{jc} + i\phi_{js}$ we get,

$$F_{kj} = \rho\int_{S_B}\left[\omega_e^2 X_j(\phi_{jc} + i\phi_{js}) + i\omega_e U X_j\frac{\partial}{\partial x}(\phi_{jc} + i\phi_{js})\right]n_k ds \quad (4)$$

Separating real and imaginary parts:

Real part of $F_{kj} = \rho\int_{S_B}\left[\omega_e^2 X_j\phi_{jc} - \omega_e U X_j\frac{\partial\phi_{js}}{\partial x}\right]n_k ds$

Imaginary part of $F_{kj} = \rho\int_{S_B}\left[\omega_e^2 X_j\phi_{js} + \omega_e U X_j\frac{\partial\phi_{jc}}{\partial x}\right]$

Hence, comparing with the equation (7) of motion, the added mass and damping co-efficient becomes,

$$A_{kj} = -\rho[\int_s(\phi_{jc} - \frac{\overline{U}}{\omega_e}\frac{\partial\phi_{js}}{\partial x})n_k ds]$$

(5)

$$B_{kj} = -\rho\omega_e[\int_s(\phi_{js} + \frac{\overline{U}}{\omega_e}\frac{\partial\phi_{jc}}{\partial x})n_k ds]$$

2.6 Motions

2.6.1Coordinate System

Two right hand coordinate systems , one is fixed to the body (X, Y, Z) of the ship, and another fixed to the space (X_0, Y_0, Z_0) have been introduced (**Fig. 2**). The ship is assumed to have X-Z plane as a plane of symmetry. Here, U denotes ship speed and X_1, X_2, X_3, X_4, X_5, X_6 denote the ship motions, namely surge, sway, heave, roll, pitch and yaw.

2.6.2 Equation of Motions

The response of a ship to waves in the frequency domain is generally described by means of a mass-spring system. Assuming a linear system in 6 degrees of freedom, such analysis represents the equation of motions as:

$$\sum_{j=1}^{6}\left(M_{kj}+A_{kj}\right)\ddot{X}_j+B_{kj}\dot{X}_j+C_{kj}X_j=F_k \qquad \text{Where } k = 1, 2, 3 \ldots 6 \tag{6}$$

For periodic expression $X_j = X_j^{0} e^{-i\omega_e t}$ and $F_k = F_k^{0} e^{-i\omega_e t}$ equation (6) becomes:

$$\left[\sum_{j=1}^{6}-\omega_e^{2}\left(M_{kj}+A_{kj}\right)-i\omega_e B_{kj}+C_{kj}\right]X_j^{0}=F_k^{0} \tag{7}$$

Hence for the solution of the matrix of the motions amplitudes, we have:

$$X_j^{0}=F_k^{0}\times\left[\sum_{j=1}^{6}-\omega_e^{2}\left(M_{kj}+A_{kj}\right)-i\omega_e B_{kj}+C_{kj}\right]^{-1} \tag{8}$$

Where,

X_j	:	Amplitude of the periodic motions of the floating body (ship).
M_{kj}	:	Body inertia matrix including moments of inertia for rotational modes.
A_{kj}	:	Added mass coefficients matrix.
B_{kj}	:	Damping coefficients matrix.
C_{kj}	:	Hydrodynamic and static inertia restoring matrix.
F_k	:	Wave exciting Forces and Moments.
F_k^{0}	:	Amplitudes of Wave exciting Forces and Moments.

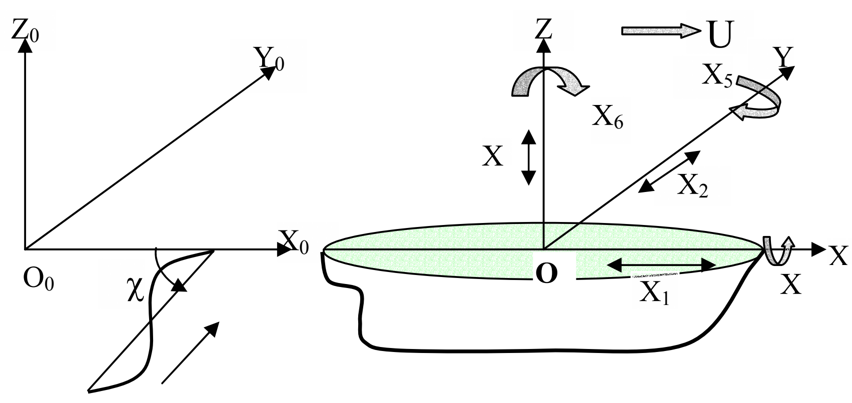

***Fig.* 2: Coordinate System**

Noted that wave encountering frequency (ω_e) is introduced here in place of circular wave frequency (ω) to incorporate the effect of forward speed.

3. Wave Conditions and the Ship Particulars:

The calculations have been carried out for a Tanker with a water depth of 260 meter. The particulars of the Tanker are given in **Table**-I. The under water part of the Tanker has been divided into 280 panels. The mesh arrangement is seen in the **Fig.** 3**.**

Table-I: Principal particulars of the Tanker

▪ Length, L	265.47 m
▪ Breadth, B	46.00 m
▪ Depth, D	28.80 m
▪ Draft, T	11.00 m
▪ Displacement, ∇	96630.00 m^3
▪ Block Coefficient, C_b	0.715
▪ Center of gravity above base line, KB	15.60 m
▪ Metacentric Height, GM	5.10 m
▪ Transverse radius of gyration, Kxx	14.20 m
▪ Longitudinal radius of gyration, Kyy	69.20 m

4. Validation:

The numerical program developed for this research work has been validated by calculating and comparing results for a series 60 parent ship of block coefficient 0.70 with some available experimental data obtained by Gerritsma and Beukelman (1966) as well as some computed data of Inglis and Price (1981). The 432 panels mesh arrangement of the parent ship is shown in the **Fig.** 4. The comparison has been presented in **Fig.** 5 to 7 for surge, heave and pitch motions in head sea condition. From the figures, it is seen that the agreement between the present computational results and the results obtained by Gerritsma and computed by Inglis and Price are quite satisfactory, though the computed results shows a sudden jump at encountering frequency range 0.90 to 1.0. But for this range experimental and computed results are not available. Again the sudden jump may be the effect of resonance frequency results from the small viscous damping neglected in present work.

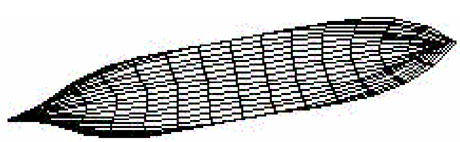

Fig. 3: 3D Mesh arrangement of the Tanker (280 panels)

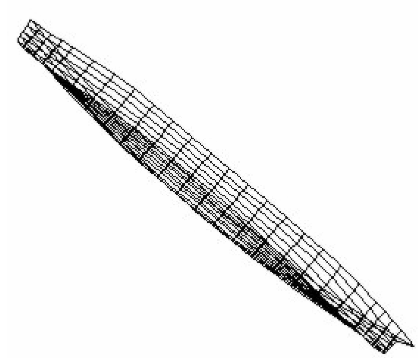

Fig. 4: 3D mesh arrangement of Series 60 Parent ship (C_b=0.7, 432 panels)

5. Results and Discussions:

The numerical computational results of the scheme outlined above are presented in Fig**.** 8 to Fig. 22. The non-dimensionalized added-mass, damping coefficients, Hydrodynamic Forces and Moments as well as motions at various Froude Number have been plotted against encountering frequency. The symbols ζ_a and κ represent wave amplitude and wave number respectively. Fig. 8 represents added mass, Fig. 9, 10 represent damping coefficients. From Fig. 8, it is seen that at different Froude number the peaks are different as the frequency of encounter also different for different Froude number. It is also observed that at higher frequencies the added mass gradually decreases and it is obvious as at higher frequencies motions are less.

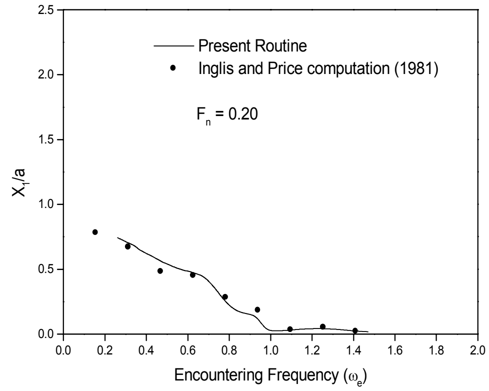

Fig. 5 Validation of Surge Motions (Head Sea)

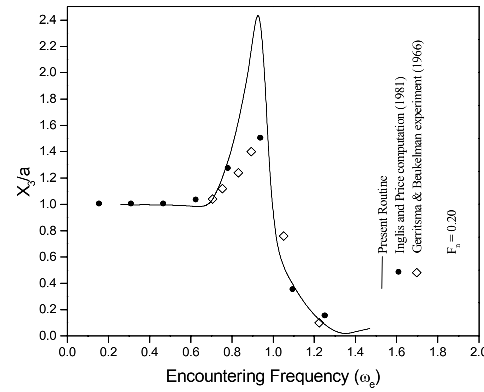

Fig. 6 Validation of Heave Motions (Head Sea)

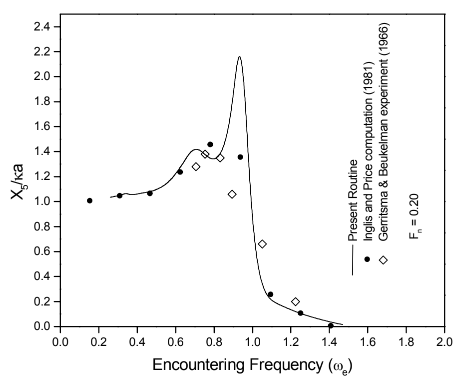

Fig. 7: Validation of Pitch Motions (Head Sea)

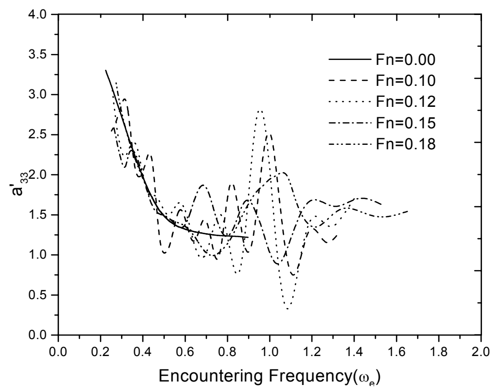

Fig. 8: Non-Dimensional added-mass in heave at various Froude numbers (Head Sea)

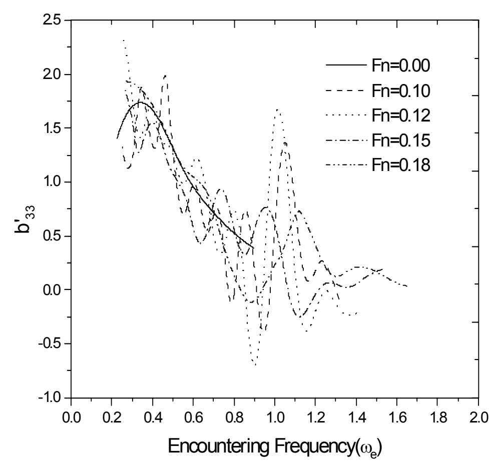

Fig. 9: Non-Dimensional damping coefficient in heave at various Froude numbers (Head Sea)

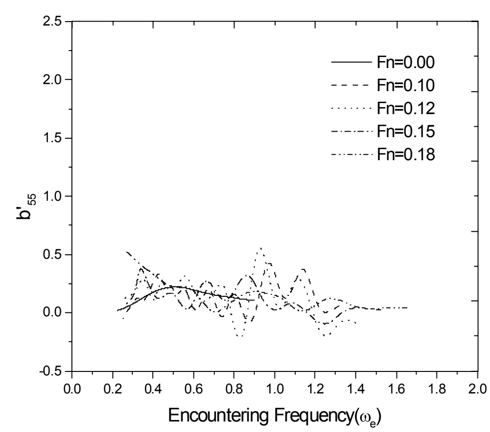

Fig. 10: Non-Dimensional damping coefficient in pitch at various Froude numbers (Head Sea)

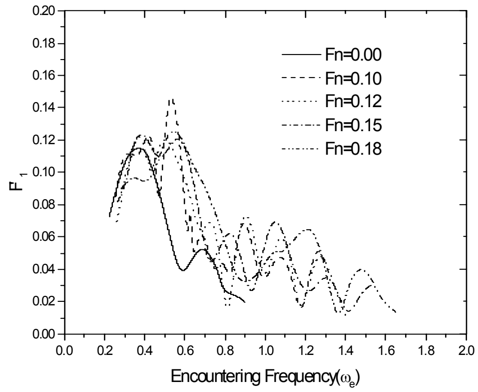

Fig. 11: Non-dimensional surge exciting force at various Froude numbers (Head Sea)

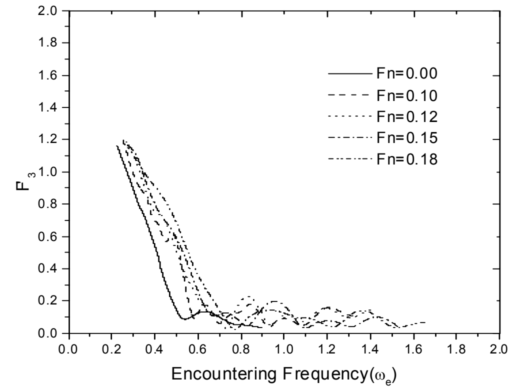

Fig. 12: Non-dimensional heave exciting force at various Froude numbers (Head Sea)

Fig. 11-13 represent hydrodynamic forces and moments. From these figures it is clear that with the increasing of speed the hydrodynamic forces also increases. Fig. 14, 16, 18 represent amplitudes of surge, heave and pitch for head sea condition and Fig. 15, 17, 19 and 20-22 represent amplitudes of motions in 6 degrees of freedom for quarter sea condition. From these figures, it appears that at the higher frequency range motions tend to approach zero as respective forces or moments tend so. It is also seen that the motion increases with the increase of Froude number up to certain extent and at further increase of Froude number the motion decreases. The effect of forward speed is seen to be more significant on surge, heave and pitch motions and least significant on roll motion. Sudden jumps of graphs especially for non-zero Froude Numbers may be the effect of resonance frequency results from respective small damping. The very large response in the case of roll motions may be the effect of resonance frequency alike and due to non-consideration of the viscous roll damping.

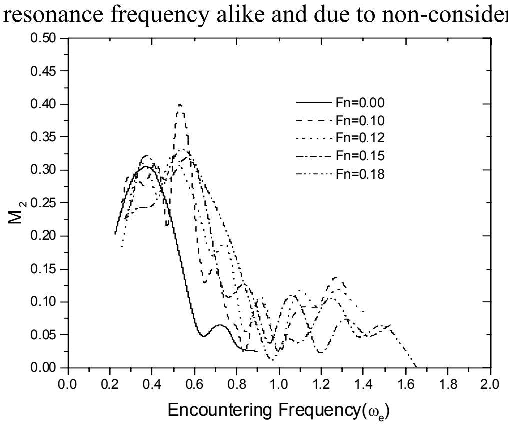

Fig. 13: Non-dimensional pitch moments at various Froude numbers (Head Sea)

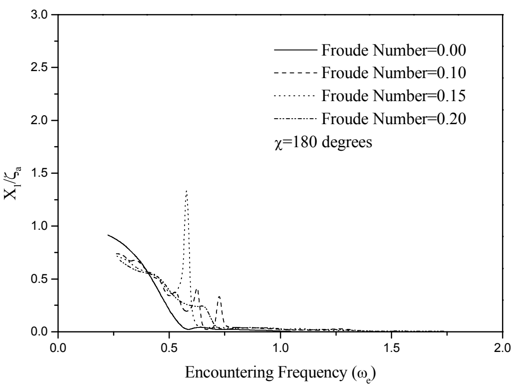

Fig. 14: Surge Amplitude (head sea)

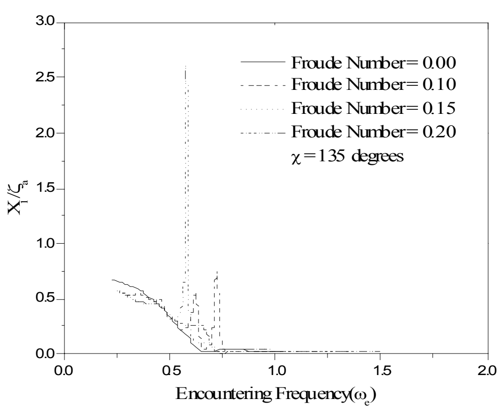

Fig. 15: Surge Amplitude (quarter sea)

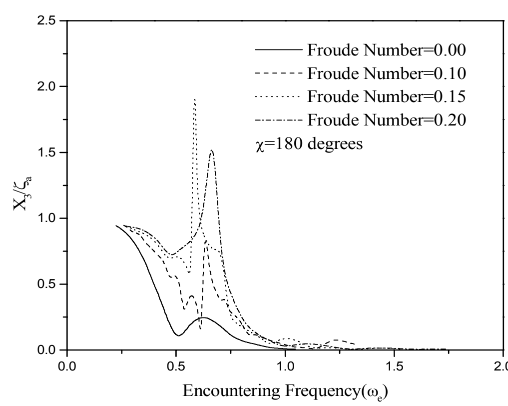

Fig. 16: Heave Amplitude (head sea)

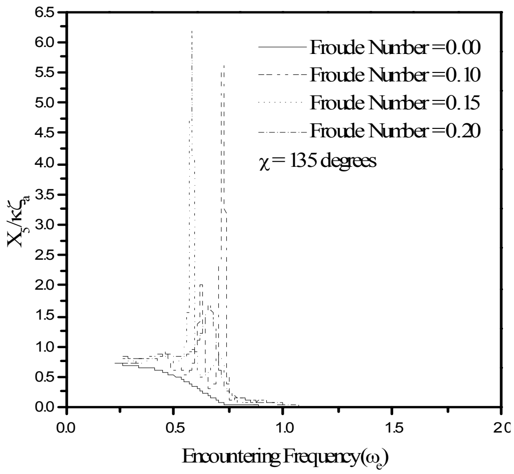

Fig. 19: Pitch Amplitude (quarter sea)

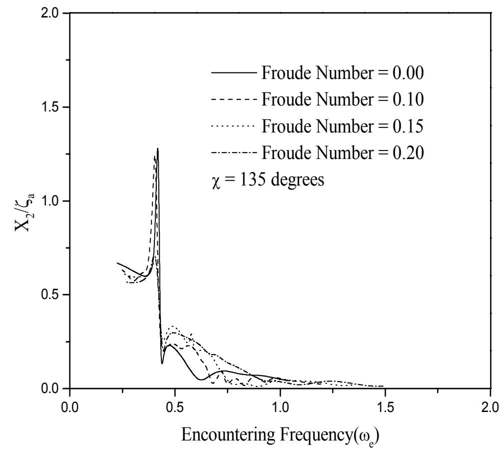

Fig. 20: Sway Amplitude (quarter sea)

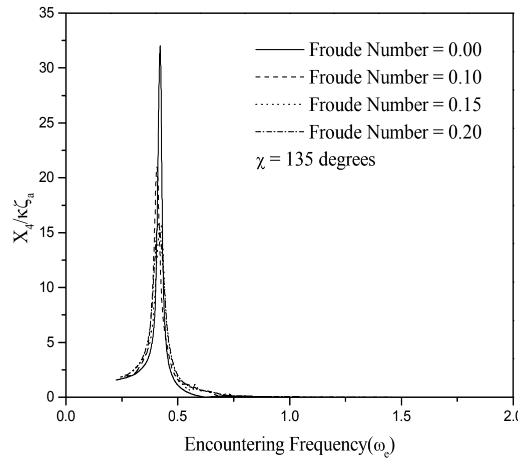

Fig. 21: Roll Amplitude (quarter sea)

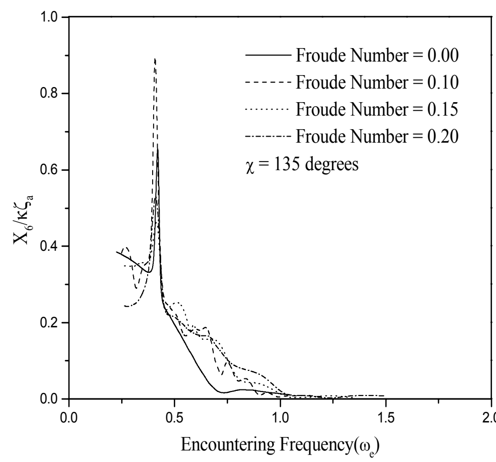

Fig. 22: Yaw Amplitude (Quarter Sea)

6. Conclusion:

1. From above discussion it may be concluded that the numerical model developed can be applied for the computation of response of a ship or other floating bodies in six degrees of freedom with quite satisfactory accuracy.
2. As such the model may be useful in prediction of seakeeping performance of ships or other floating bodies in a seaway.
3. The output of the model may be used to study maneuvering or powering problem(s) also. Some extension of the model may help in such study simultaneously.

References

Ba, M. and Guilbaud, M (1995): A Fast method of evaluation for the translating and pulsating Green's function. Ship Technology Research, 42, 2 68-80.

Brumet, A. (1998) : Evaluation numerique de la fonction de Green de la tenue a la mer. These de Doctorat, Ecole Centrale de Nantes.

Chapman, K.B (1975): Numerical Solutions for Hydrodynamic Forces on a Surface Piercing Plate Oscillating in Yaw and Sway. 1st Intl. Conf. on Numerical Ship Hydrodynamics, Maryland, USA, pp333-350.

Chen, X.B. and Noblesse, F, (1998): Super Green Function. Proc., 22nd Symposium on Naval Hydrodynamics, Washington, 860-874.

Faltinsen, O. M. & Michelsen, F. C (1975): Motions of Large Structures in Waves at zero Froude number',

International Symposium on the Dynamics of Marine Vehicles and Structures in Waves, Mechanical Engineering, Published in London, pp 99-114.
Faltinsen, O. M. and Michelsen, F. C. (1974): Motions of Large Structures in Waves at Zero Froude Number, The Dynamics of Marine Vehicles and Structures in Waves, Paper No. 11, The Institution of Mechanical Engineers.
Faltinsen, O.M. (1990): Sea Loads on ships and offshore structures, Cambridge University Press, pp.109, 123.
Garrison, C. J. (1974): Dynamic response of Floating Bodies, Proc. Offshore Technology conference, Paper No. OTC 2067.
Garrison, C. J. (1978): Hydrodynamic Loading of Large Offshore Structures', Three Dimensional Source Distribution methods', Numerical Methods in Offshore Engineering, pp87-140.
Gerritsma, J. and Beukelman, W. (1966): Comparison of calculated and measured heaving and pitching motions of a series 60, C_B=0.7 ship model in regular longitudinal waves. Technische Hogeschool Delft, Report No. 139.
Gunther Clauss, Eike Lehmann and Carsten Ostergaard (1988): Offshore Structures Vol-I Conceptual Design and Hydromechanics.
Hogben, N. and Standing R. G. (1975): Wave Loads on Large Bodies', International Symposium on the Dynamics of Marine Vehicles and Structures in Waves, Mechanical Engineering, Published in London, pp 273-192.
Inglis, R. B. and Price, W. G. (1980): Calculation of the Velocity Potential of a Translating, Pulsating Source, RINA.
Inglis, R. B. and Price, W. G. (1981): A Three Dimensional Ship Motion Theory: Calculation of Wave Loading and Responses with Forward Speed, RINA.
Inglis, R. B. and Price, W. G. (1981): A Three Dimensional Ship Motion Theory-Comparison between Theoretical predictions and Experimental Data of the Hydrodynamic Coefficients with Forward Speed, RINA.
Islam, M. N., Islam, M. R. and Baree, M. S. (2004): Prediction of Ship Motions with effect of Forward Speed, Proc. 2nd BSME-ASME International Conference on Thermal Engineering, pp757-762.
Islam, M. R., Baree, M. S. and Islam, M. N., (2003) : Hydrodynamic Forces with effect of Forward Speed on Floating Bodies by 3D Source Method', Sports Dynamics Discovery and Application – the Proc. Book of International Congress on Sports Dynamics-2003, Melbourne, pp261-269.
Iwashita, H. and Okhusu, M. (1989): Hydrodynamic Forces on a Ship Moving at Forward Speed in Waves, J.S.N.A. Japan, 166, 87-109.
Maury, C., 'Etude du probleme de tenue a la mer avec vitesse d'avance quelconque par une methode de singularittes de Kelvin. These de Doctorat, Eclole Centrale de Nantes.
Nontakaew, U. *et al.* (1997): Solving a radiation problem with forward speed using a lifting surface method with a Green's Function. Aerospace Science and Technology, 8, 533-543.
Salvesen, N., Tuck, E. O. And Faltinsen, O. (1970): Ship Motions and Sea Loads, SNAME, Vol.78, pp 250-287.
Vugts, J. H. (1971): The Hydrodynamic Forces and Ship Motions in Oblique Waves, Research Center, TNO for Shipbuilding, Delft Report No. 1505.
Wang Chun-Tsung (1999): Vertical Motions of Slender Bodies with Forward Speed, Proc. Natl. Sci. Counc. ROC (A), vol. 23, No.1, pp. 31-44.