The Computation of the Second-Order Hydrodynamic Forces on a Slender Ship in Waves

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1 Introduction

The accurate prediction of the mean and slow-drift force on a ship is necessary for the reliable simulation of slow-drift response and design of a positioning system. The slow-drift problem, in particular, becomes important for the ship with no forward speed, like a drilling ship or shuttle tanker. In contrast to a floating off-shore platform, the ship is a slender body. Therefore, slender-body theory is applicable to reduce the effort which comes from full 3-dimensional discretization. In the present study, strip and unified theory are applied to predict the second-order mean drift forces and moment and wave drift damping coefficient.

2 Application of Slender-Body Theory

Consider a ship at zero-forward speed in regular monochromatic waves. When the ship is slender, slender-body theory allows an accurate linear solution for the radiation and diffraction problems. Especially, unified theory provides excellent accuracy for not only diffraction problem but also the heave and pitch radiation problem. For the transverse motions, strip theory is adequate.

2.1 Strip Theory with NIIRID

NIIRID[1] is a computer code developed at MIT for the computation of the radiation and diffraction forces on a 2-dimensional section. This code adopts the 2-dimensional wave source potential as the Green function, and provides the complete linear solution of the radiation and diffraction problems. In this study, NIIRID is integrated into a strip theory code based on the Salvesen, Tuck and Faltinsen(STF) method[2].

2.2 Unified Theory

Newman[3], Sclavounos[4] developed an excellent slender-body theory which carries out the solution of the zero-speed seakeeping problem in the frequency domain. Unified theory adds a 3-dimensional correction to the sectional solution of strip theory. In this theory, the radiation potential is obtained by the superposition of the strip theory solution(particular solution) and the longitudinal wave interaction(homogeneous solution). The diffraction potential has an analogous form which can be related to the radiation solution in not very short waves. The most important task in unified theory is to solve the integral equations for the three-dimensional sectional strength, q_j. For example, the integral equation for the radiation problem is

$$q_j(x) - \frac{1}{2i\pi}(\frac{\sigma_j}{\bar{\sigma}_j} + 1)L(q_j) = \sigma_j(x) \qquad j = 3(\text{heave}), 5(\text{pitch}) \tag{1}$$

with

$$\begin{aligned} L(q_j) &= q_j(x)\,(\gamma + \pi i) + \int_L d\xi\,\{\frac{1}{2} + sgn(x-\xi)\,ln(2\nu|x-\xi|)\,\frac{d}{d\xi}q_j(\xi) \\ &\quad -\frac{\pi\nu}{4}\,(Y_o(|\nu(x-\xi)|) + 2iJ_o(|\nu(x-\xi)|) + H_o(|\nu(x-\xi)|))\,q_j(\xi)\} \end{aligned} \tag{2}$$

where σ_j is the two-dimensional strength obtained from strip theory. All other notations are the same with Ref.4. The added mass, a_{ij}, and damping coefficient, b_{ij}, can be derived from the equation,

$$\omega^2 a_{ij} - i\omega b_{ij} = -i\omega\rho \int\int n_i\psi_j ds - i\omega\rho \int\int n_i \frac{q_j - \sigma_j}{\sigma_j + \bar{\sigma}_j}(\psi_j + \bar{\psi}_j)ds \tag{3}$$

where ψ_j is the strip theory potential. The wave exciting forces and moments can be obtained from the Haskind relation. The far-field formula derived by Sclavounos(1985) has been adopted in the present study.

$$X_i = \frac{i\rho g A}{2\omega} \int_L q_j(x) e^{i\nu x\cos\beta} dx \tag{4}$$

where A is the wave amplitude and β is the heading angle of the wave relative to the ship axis.

2.3 Mean Drift Forces and Moment

Maruo(1960) derived a far-field formula for the surge and sway mean forces,

$$\bar{F}_{x,y} = \frac{\rho\nu^2}{8\pi}\int_0^{2\pi} |H(\theta)|^2 \left\{ \begin{array}{c} (\cos\theta + \cos\beta) \\ (\sin\theta + \sin\beta) \end{array} \right\} d\theta \tag{5}$$

The far-field equation for mean yaw moment was derived by Newman(1967),

$$\bar{M}_z = -\frac{\rho\nu}{8\pi} Im \int_0^{2\pi} \bar{H}(\theta)\frac{\partial H}{\partial\theta}(\theta)d\theta - \frac{1}{2\nu L}\,Im\{\frac{\partial H}{\partial\theta}(\pi + \beta)\} \tag{6}$$

where $H(\theta)$ is the Kochin function. In the present study, the following form of the Kochin function is found to generate the most accurate results for the drift forces and moment[5].

$$H(\theta) = \int_L \sum_{j=0}^{7} \sigma_j^*(x) e^{-i\nu x\cos\theta} dx \tag{7}$$

where the sectional source strength (heave & pitch) or horizontal dipole moment (roll, sway & yaw) are defined as follows

$$\sigma_j^*(x) = \int_{C_m(l)} \left[\frac{\partial}{\partial n}\phi_j(x_m, y, z) - \phi_j(x_m, y, z)\frac{\partial}{\partial n}\right] e^{\nu(z - iy\sin\beta)} dl \tag{8}$$

where $C_m(l)$ denotes the ship section at station $x = x_m$.

2.4 Wave Drift Damping

The drift damping is also an important quantity in the slow-drift oscillation problem. Aranha[6] suggested a formula for the wave drift damping which is adopted in the present study although there is some doubt about its accuracy in the radiation problem.

3 Computational Results

Fig.1 shows the added mass and damping coefficient of the heave motion and Fig.2 shows the heave and pitch RAO. Both are for the Series $60(C_B = 0.7)$ hull. As expected, unified theory is in very good agreement with WAMIT. Fig.3 shows the pitch component of the Kochin function. The accurate computation of the Kochin function is the key to the drift force computation. Some minor discrepancy with WAMIT's is found, and the accumulation of this discrepancy produces the difference of the total drift force and moment. However, the agreement is generally favorable. Fig.4 shows the mean drift force for the surge of a parabolic hull with beam/length=0.15. The longitudinal drift force is more important than others since the ship will change her position to be parallel to the wave direction. This figure shows the effect of the number of stations in unified theory. Fig.5 shows the lateral mean force on the Series 60 hull. Since the fore and aft body of this hull is not symmetric, the longitudinal component doesn't vanish. Sway, roll, and yaw components contribute to the second-order quantities in headings other than head seas. Fig.6 shows the wave drift damping coefficients. Aranha's formula is applied to the mean forces obtained by strip theory, unified theory and WAMIT. The primary difference of these curves is the difference of the slopes of mean forces with respect to the wave heading angle and wave frequency.

4 Acknowledgement

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References

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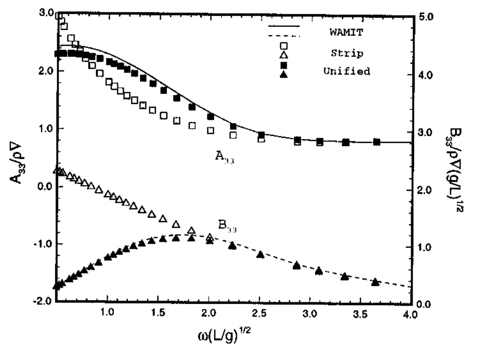

Figure 1: Added-Mass and Damping Coefficient : Heave, Series 60($C_B = 0.7$) Hull

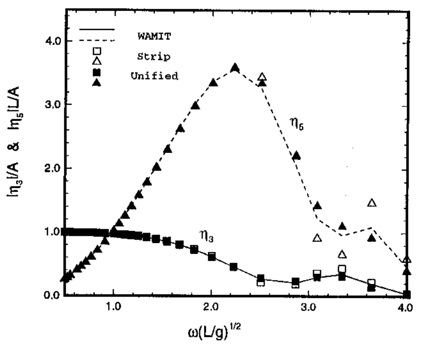

Figure 2: Heave and Pitch RAO : Series 60($C_B =$ 0.7) Hull, Head Sea

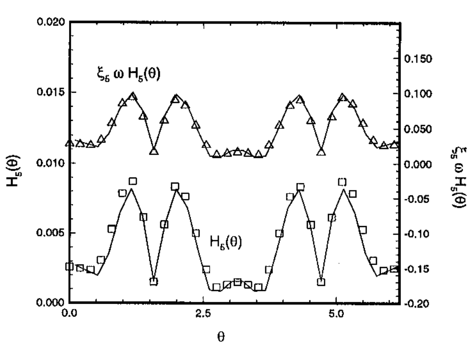

Figure 3: The Pitch Component of the Kochin Function : Series 60($C_B = 0.7$) Hull, $\omega(L/g)^{1/2} =$ 3.34, Head Sea

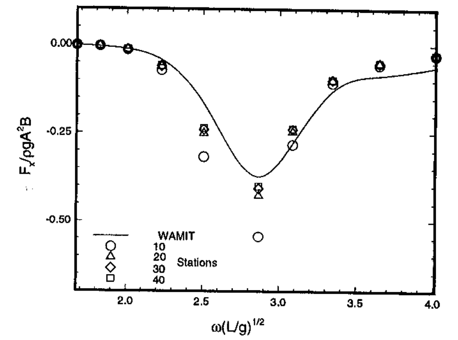

Figure 4: The Convergence of Drift Force : Parabolic Hull($B/L = 0.15$), Head Sea

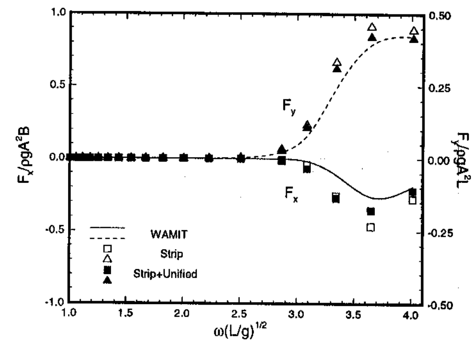

Figure 5: The Drift Forces : Series 60($C_B = 0.7$) Hull, Beam Sea

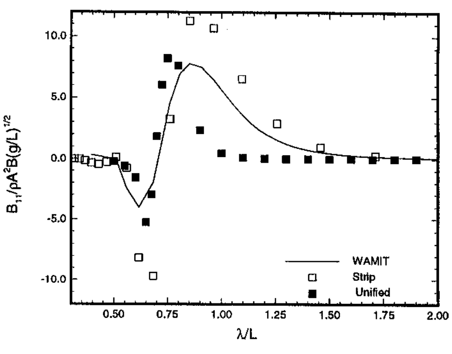

Figure 6: The Wave Drift Damping : Parabolic Hull($B/L = 0.15$), Head Sea, Surge-Surge Component