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Side Wall Effect of Towing Tank on Measured Unsteady Waves in Low Frequency Range

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1. INTRODUCTION

Several kinds of numerical method to estimate hydrodynamic forces and motions of ships advancing in waves have been developed up to now. Typical examples, for instance, will be the Green function method and the Rankine panel method in the three dimensional methods. Especially the Rankine panel method may be the main current of the most recent studies from the reason that it enables to apply more exact free surface condition and to apply the numerical radiation condition even for the low frequency range when the method is extended to the time domain. In those methods, the Rankine source is used as the kernel function of the integral equation. Therefore adequate numerical techniques must be introduced for satisfying the radiation condition and some techniques have been proposed already. The validation of the numerical accuracy due to those teqniques, however, have not been attempted enoughly for the low frequency range. This comes from few experimental data because of the difficulty of the experiment in the low frequency range.

On the other hand, it is suggested that the comparison of the numerical results with experiments on the hydrodynamic forces and motions is not sufficient for the validation of the computation codes based on advanced and complicated methods proposed nowadays(*Iwashita et al. (1993,1998)*). Actually it is very few to see the remarkable advantage of such advanced methods against the strip method if we adopt those physical values for an index of validation. The local physical value such as pressures should be used to make clear the advantage of advanced methods.

From these backgrounds, *Iwashita et al.(1993,1998)* carried out a systematic experiment for a blunt VLCC and measured not only the hydrodynamic forces but also the wave pressure acting on the ship advancing in oblique waves. In the experiment the low frequency range where the reduced frequency τ takes smaller value than 0.25 appears depending on the attack angle of the incident wave. Experiments were compared with some kinds of computations and the importance of the comparison on the wave pressure has been pointed out in the paper. Similar experiments has been performed in some companies in Japan. However most of the hull form is confidential. We therefore can not utilize their experimental data for the validation of our computation codes. One of the reason why companies hesitate to present their experimental data may be related to the expensive cost and much time to get experimental data especially on the wave pressure. This may be settled if the local physical value can be measured more easily and cheaply.

Iwashita (1998,1999) carried out the experiment for popular hull forms, Series-60 ($C_b = 0.6$ and 0.8), in order to get data which everybody can use. The unsteady waves measured by *Ohkusu's method (1977)* were adopted as the local physical value and plenty of wave patterns were obtained through the experiments carried out in 1999 and 2000. The unsteady wave pattern physically means the unsteady pressure distribution on the free surface and its measurement is not so difficult and expensive. In the experiment, so called k_2 wave system which propagates from the ship to the forward direction and k_1 wave system which propagates from down stream toward the ship have been observed for $\tau = 0.23$. A k_1 wave with large amplitude which propagates from down stream toward the ship and disappears at bow region has been also observed for $\tau = 0.28$. These are very interesting phenomena in the low frequency range arround $\tau = 0.25$. In order to utilize those measured unsteady waves for the validation of the computation codes, measured data itself must be validated on the effect of the side wall of the towing tank which will be involved in the obtained data.

In this study the side wall effect of the towing tank on measured unsteady waves is investigated by simulating the actual experiment numerically. The thin ship theory is applied in the time domain and the radiation problem is solved corresponding to the experiment. The numerical result obtained considering side wall effect is compared with the result obtained excluding side wall effect, and the effect of the side wall is made clear.

2. FORMULATION

The problem is simplified restricting our interest only in the radiation problem since both radiation and diffraction wave systems generated by the ship takes the same pattern as understood by the asymptotic theory. Then we consider a thin ship advancing at arbitrary forward speed $U(t)$ and oscillating with cirlular frequency ω_e in the towing tank. The space fixed coordinate system is taken allocating its origin at beach side of the tank. The ship motions are restricted in heave and pitch modes corresponding to the experiment and we express them by $\xi_3(t)$ and $\xi_5(t)$. The linear theory is employed for this problem assuming ideal potential flow.

The velocity potential $\phi(x, y, z; t)$ of the fluid must satisfy the following initial and boundary conditions (*Lin & Yue (1990)*):

$$\text{[L]} \quad \nabla^2\phi = 0 \qquad \text{in } V(t) \text{ for } t > \tau \tag{1}$$

$$\text{[F]} \quad \Big(\frac{\partial^2}{\partial t^2} + g\frac{\partial}{\partial z}\Big)\phi = 0 \qquad \text{on } z = 0 \text{ for } t > \tau \tag{2}$$

$$\text{[H]} \quad \frac{\partial \phi}{\partial n} = V_n \qquad \text{on } S_H \text{ for } t > \tau \tag{3}$$

$$\text{[W]} \quad \frac{\partial \phi}{\partial n} = 0 \qquad \text{on } S_W \text{ for } t > \tau \tag{4}$$

$$\text{[I]} \quad \phi = \frac{\partial \phi}{\partial t} = 0 \qquad \text{on } z = 0 \text{ for } t = \tau \tag{5}$$

S_H and S_W denote the ship surface and the side wall of the towing tank respectively. When we assume a thin ship which body shape is expressed by $F(x, y, z) = y - f(x, z) = 0$, the body boundary condition (3) can be simplified as

$$\frac{\partial \phi}{\partial y} = \Big\{-[U(t) + z\,\xi_5(t)]f_x - [\xi_3(t) - x\,\xi_5(t)]f_z\Big\}/\sqrt{1 + f_x^2 + f_z^2} \tag{6}$$

Applying the Green's second identity to the fluid domain, we obtain the following two sets of equation:

$$\sigma(P; t) = 2\Big\{-[U(t) + z\,\xi_5(t)]f_x - [\xi_3(t) - x\,\xi_5(t)]f_z\Big\}/\sqrt{1 + f_x^2 + f_z^2} \quad \text{for } P \text{ on } S_H \tag{7}$$

$$\begin{aligned}\frac{\partial \phi(P; t)}{\partial n_P} =& -\iint_{S_H(t)} \sigma(Q; t)\frac{\partial G_0(P, Q)}{\partial n_P}\, dS_Q \\ &- \int_0^t \Big\{\iint_{S_H(\tau)} \sigma(Q; \tau)\frac{\partial G_T(P, Q; t - \tau)}{\partial n_P}\, dS_Q\Big\}\, d\tau \\ &+ \frac{\sigma_W(P; t)}{2} - \iint_{S_W(t)} \sigma_W(Q; t)\frac{\partial G_0(P, Q)}{\partial n_P}\, dS_Q \\ &- \int_0^t \Big\{\iint_{S_W(\tau)} \sigma_W(Q; \tau)\frac{\partial G_T(P, Q; t - \tau)}{\partial n_P}\, dS_Q\Big\}\, d\tau \quad \text{for } P \text{ on } S_W\end{aligned} \tag{8}$$

where P and Q show the field point and the source point respectively. G_0 and G_T are the impulse response functions defined by

$$G_0(P, Q) = \frac{1}{4\pi}\Big(\frac{1}{r} - \frac{1}{r'}\Big), \quad G_T(P, Q; t - \tau) = \frac{1}{2\pi}\int_0^\infty \sqrt{gk}\sin(\sqrt{gk}(t - \tau))e^{k(z+z')}J_0(kR)\, dk \tag{9}$$

$$\left.\begin{matrix} r \\ r' \end{matrix}\right\} = \sqrt{R^2 + (y - y')^2 + (z \mp z')^2}, \quad R = \sqrt{(x - x')^2 + (y - y')^2} \tag{10}$$

We need not to solve the integral equation to determine the source distribution on S_H since it is determined explicitly by eq.(7).

If the source distribution is determined on the side wall for every time step, the wave elevation $\zeta(P;t)$ is evaluated by

$$
\begin{aligned}
-g\zeta(P;t) =& -\int_0^t \Big\{ \iint_{S_H(\tau)} \sigma(Q;\tau) \frac{\partial G_T(P,Q;t-\tau)}{\partial t} \, dS_Q \Big\} \, d\tau \\
& -\int_0^t \Big\{ \iint_{S_W(\tau)} \sigma_W(Q;\tau) \frac{\partial G_T(P,Q;t-\tau)}{\partial t} \, dS_Q \Big\} \, d\tau \quad \text{on } z=0
\end{aligned}
\tag{11}
$$

The forward speed $U(t)$ and motions $\xi_3(t)$, $\xi_5(t)$ are arbitrary functions in the present study. Therefore the kernel functions G_0 and G_T must be calculated for all P and Q at each time step.

3. NUMERICAL CALCULATION

The numerical calculation is carried out simulating the actual measurement of radiation waves experimented at RIAM in Kyushu University by the author. The towing tank ($L \times B \times D = 65\text{m} \times 5\text{m} \times 7\text{m}$) is descretized into the finite number of elements, and the forward speed $U(t)$ and motions $\xi_3(t)$, $\xi_5(t)$ are given refering measured results.

Computations are performed mainly for $\tau = 0.23$ and $\tau = 0.28$. For $\tau = 0.23$, k_2 wave system and k_1 wave system progressing in forward direction has been observed remarkably in the experiment, Figs.1,3. For $\tau = 0.28$ the wave progressing in forward direction with large amplitude and disappearing in front of the ship has been observed, Figs.2,4. Present numerical simulations are compared with those results, and we validate how the side wall of the towing tank affects the measured results and whether the measured results are reliable or not. If it is confirmed that the side wall effect is not so significant, we can utilize measured radiation waves for the validation of arbitrary numerical methods in the low frequency range.

4. SAMPLE OF RESULTS

Figs.5 and 6 show the wave elevation due to the point source advancing at forward speed $U(t)$ and pulsating as a function $\sigma(t)$. $U(t)$ and $\sigma(t)$ are given by $U(t) = U_0(1 - e^{-dt})$ and $\sigma(t) = (1 - e^{-ct})(a + b\cos\omega_e t)$. Constants are $a = 0.0(\text{m}^3/\text{s})$, $b = 1.0(\text{m}^3/\text{s})$, $c = d = 2.0$, $U_0 = 0.886(\text{m/s})$, $\omega_e = 2.55(1/\text{s})$ in this example. The point source is located at $Q = (x'(t), 0, -2)$ and starts from $x'(0) = 5.0(\text{m})$. The wave elevation is computed along the longitudinal axis of $y = 0.2(\text{m})$.

Figures show that the present computation ('TD' in figures) near the source point converges to the result of the frequency domain ('FD') around $t > 30$. The correponding results considering side wall effect are illustrated in Figs.7 and 8. The wave refrection from the side wall can be seen by comparing them with Figs.5 and 6.

Further calculations for the thin ship and for other conditions are now in progress, and all the results will be presented in the workshop.

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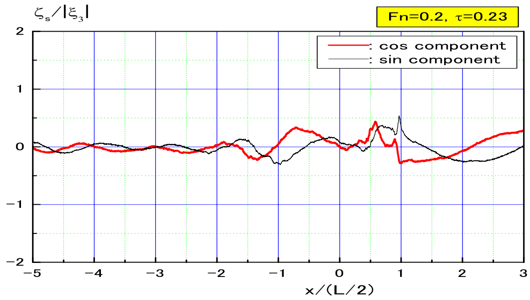

Fig.1 Heave radiation wave for Series-60 ($C_b = 0.8$) measured at $y/(B/2) = 1.32$, $F_n = 0.2$, $\tau = 0.23$

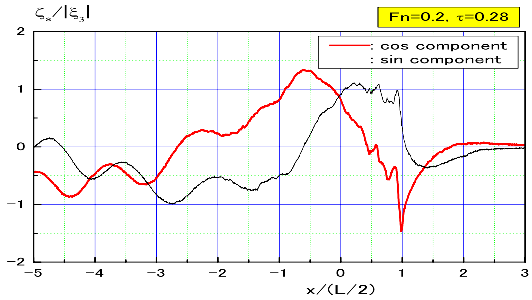

Fig.2 Heave radiation wave for Series-60 ($C_b = 0.8$) measured at $y/(B/2) = 1.32$, $F_n = 0.2$, $\tau = 0.28$

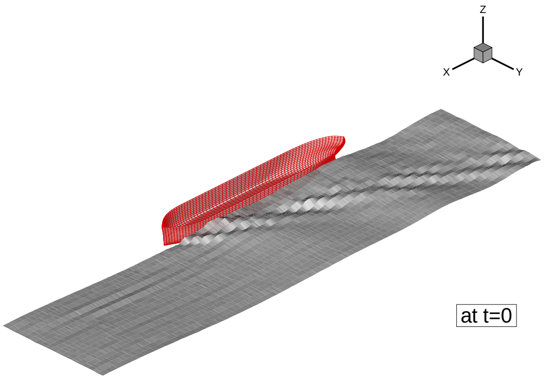

Fig.3 Perspective view of heave radiation wave for Series-60 ($C_b = 0.8$) measured at $F_n = 0.2$, $\tau = 0.23$

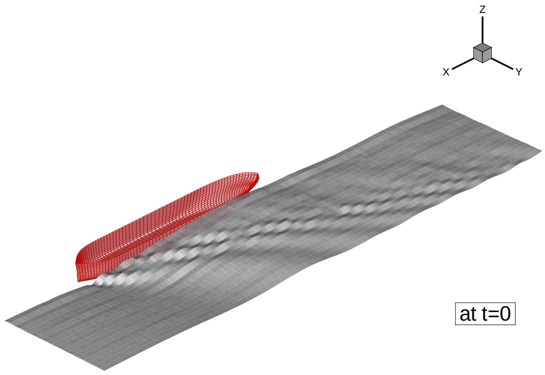

Fig.4 Perspective view of heave radiation wave for Series-60 ($C_b = 0.8$) measured at $F_n = 0.2$, $\tau = 0.28$

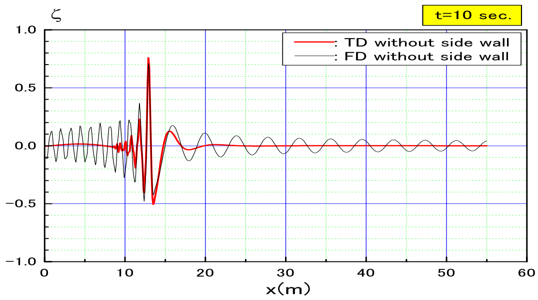

Fig.5 Unsteady wave generated by a point source at $y = 0.2$, $t = 10$ sec. (corresponding to $F_n = 0.2$, $\tau = 0.23$)

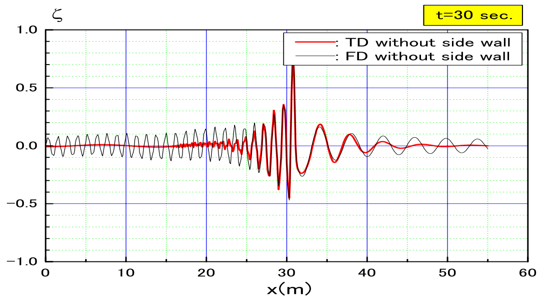

Fig.6 Unsteady wave generated by a point source at $y = 0.2$, $t = 30$ sec. (corresponding to $F_n = 0.2$, $\tau = 0.23$)

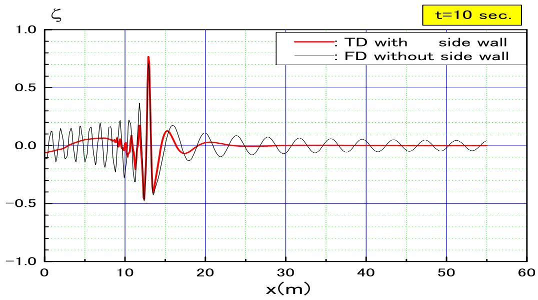

Fig.7 Unsteady wave generated by a point source in the tank at $y = 0.2$, $t = 10$ sec. (corresponding to $F_n = 0.2$, $\tau = 0.23$)

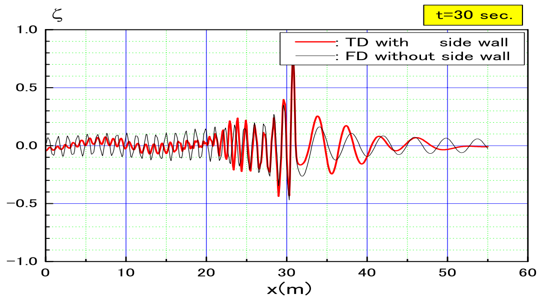

Fig.8 Unsteady wave generated by a point source in the tank at $y = 0.2$, $t = 30$ sec. (corresponding to $F_n = 0.2$, $\tau = 0.23$)