# Unsteady Wash Generated by a High Speed Vessel

Hironori YASUKAWA, *Nagasaki Experimental Tank, Mitsubishi Heavy Industries**

## Introduction

The unsteady wash generated by a high speed vessel with decelerated motion in a channel is numerically investigated. This situation may be similar to that the vessel reduces the speed in the channel. Then, the Kelvin waves generated by the vessel progress straight and propagate in the channel. We carried out computations of the wash using a time domain panel method including the attitude change of the vessel. Several studies with respect to the time domain method have been carried out, for instance, by Maskew (1991), Beck et al.(1993), Li and Chwang(1997) and Yasukawa(1999, 2000). However, there is no analysis of the unsteady wash including the effect of the attitude change so far as we know. The time domain method and the computed results for the unsteady wash will be introduced.

## Basic Equations

Let us consider the shallow channel of the water depth $h$. The vessel is assumed to move in center of the channel with the speed $U(t)$ which varies as the function of time $t$. The coordinate system fixed in the space is employed. The $x$-axis is defined as direction from the ship stern to the bow, $y$-axis to port and $z$-axis vertically upward. The $x-y$ plane is the still water surface.

The perturbation velocity potential due to the vessel moving in the channel is defined as $\phi(x,y,z,t)$. Then, $\phi$ has to fulfill the following boundary conditions as:

$$\frac{\partial\phi}{\partial t} = -g\zeta - \frac{\partial^2\phi}{\partial t\partial z}\zeta - \frac{1}{2}\left\{\left(\frac{\partial\phi}{\partial x}\right)^2 + \left(\frac{\partial\phi}{\partial y}\right)^2 + \left(\frac{\partial\phi}{\partial z}\right)^2\right\} \quad \text{on } z=0 \tag{1}$$

$$\frac{\partial\zeta}{\partial t} = \frac{\partial\phi}{\partial z} + \frac{\partial^2\phi}{\partial z^2}\zeta - \frac{\partial\phi}{\partial x}\frac{\partial\zeta}{\partial x} - \frac{\partial\phi}{\partial y}\frac{\partial\zeta}{\partial y} \quad \text{on } z=0 \tag{2}$$

$$\frac{\partial\phi}{\partial n} = \left(U(t)\cos\theta - \dot{\xi}_3\sin\theta + \dot{\theta}z_H\right)n_x + \left(U(t)\sin\theta + \dot{\xi}_3\cos\theta - \dot{\theta}x_H\right)n_z \quad \text{on } S_H \tag{3}$$

$$\frac{\partial\phi}{\partial n} = 0 \quad \text{on } S_W, \qquad \frac{\partial\phi}{\partial z} = 0 \quad \text{on } z=-h \tag{4}$$

The 2nd order non-linear free surface conditions expanded with respect to $\zeta$, which means the wave height, around $z=0$ are employed, eqs.(1) and (2). Eq.(3) is hull surface condition, and has to be satisfied on actual wetted surface $S_H$. In eq.(3), $\xi_3$ and $\theta$ denote dynamic sinkage and trim respectively, $x_H$ and $z_H$ the coordinate of hull surface, and $n_x$ and $n_z$ the component of outward normal vector. Eq.(4) is the boundary conditions on the channel wall $S_W$ and the sea bottom $z=-h$.

Velocity potential $\phi$ is represented using source strength $\sigma$ as follows:

$$\phi(P) = \iint_{S_H+S_F+S_W} \sigma(Q)G(P;Q)dS \tag{5}$$

where

$$G(P;Q) = \frac{1}{\sqrt{(x-x_1)^2+(y-y_1)^2+(z-z_1)^2}} + \frac{1}{\sqrt{(x-x_1)^2+(y-y_1)^2+(z+z_1+h)^2}} \tag{6}$$

*5-717-1 Fukahori-Machi, Nagasaki 851-0392, JAPAN, email: yasukawa@ngsrdc.mhi.co.jp

Here, $P = (x, y, z)$ is a field point and $Q = (x_1, y_1, z_1)$ the source point. $S_F$ denotes the still water surface ($z = 0$). The 2nd term of the right hand side of eq.(6) is the additional term to fulfill the bottom surface condition.

## Numerical Scheme

Numerical scheme to solve the boundary value problem is as follows:

1. Accelerations of dynamic sinkage and trim ($\ddot{\xi}_3^{k+1}, \ddot{\theta}^{k+1}$), and time derivatives of wave height and velocity potential on free-surface ($\zeta_t^{k+1}$, $\phi_t^{k+1}$) respectively at $(k+1)$-th time step are assumed using values at $k$-th step. Here suffix $t$ represents time derivation.

2. According to Newmark's $\beta$ method, the velocities and displacements of the sinkage and trim at $(k+1)$-th step are estimated as (herein, only $\dot{\xi}_3^{k+1}$ and $\xi_3^{k+1}$ are written.):

$$\dot{\xi}_3^{k+1} = \dot{\xi}_3^k + \Delta t \left( \ddot{\xi}_3^k + \ddot{\xi}_3^{k+1} \right) /2 \tag{7}$$

$$\xi_3^{k+1} = \xi_3^k + \Delta t \ \dot{\xi}_3^k + \frac{(\Delta t)^2}{2} \ddot{\xi}_3^k + \beta (\Delta t)^2 (\ddot{\xi}_3^{k+1} - \ddot{\xi}_3^k) \tag{8}$$

   where $\Delta t$ is time increment, and $\beta$ the acceleration factor.

3. Based on the given ship speed and the sinkage and trim estimated in Step 2, ship hull and free-surface panels are arranged.

4. According to Newmark's $\beta$ method, wave height and velocity potential on free-surface at $(k+1)$-th step are estimated as:

$$\zeta^{k+1} = \zeta^k + \Delta t \left( \zeta_t^k + \zeta_t^{k+1} \right) /2, \quad \phi^{k+1} = \phi^k + \Delta t \left( \phi_t^k + \phi_t^{k+1} \right) /2 \tag{9}$$

5. Influence functions are calculated with respect to free-surface, ship hull and channel wall surfaces to make a matrix for determining all source strengths. Basic equations for the sources are discretized using constant panels.

6. Solving the base matrix by SOR method, source strengths on free-surface, hull and tank wall surfaces are obtained.

7. $\phi_t^{k+1}$ and $\zeta_t^{k+1}$ are calculated using eqs.(1) and (2). Then, velocity components on free-surface are analytically calculated. The derivatives of $\zeta$ with respect to $x$ and $y$ are obtained numerically using finite different technique.

8. Hydrodynamic forces acting on hull are calculated by Bernoulli's equation. Obtaining the hydrodynamic forces, $\ddot{\xi}_3$ and $\ddot{\theta}$ are calculated from the motion equations of the ship.

9. The $\ddot{\xi}_3, \ddot{\theta}$, $\zeta_t$ and $\phi_t$ obtained in step 7 and 8 are compared with those assumed in step 1. When the difference between both is sufficiently small, $\ddot{\xi}_3, \ddot{\theta}$, $\zeta_t$ and $\phi_t$ are regarded as reaching to the convergence. Otherwise, returning to step 2, calculations are continued using $\ddot{\xi}_3, \ddot{\theta}$, $\zeta_t$ and $\phi_t$ obtained in step 7 and 8 until obtaining converged solution through this iteration.

10. $k$ is set one time step ahead and return to step 1.

## Computed Results

Computations of the wash are carried out for a high speed vessel with $L/B$=7.50, $B/d$=4.58 and $C_b$=0.45, where $L, B, d$ and $C_b$ are ship length, breadth, draft and block coefficient respectively. $L$ is assumed to be 1.0m in the computations. This vessel has a transom stern. In actual computations, we put round stern panels to the stern end to avoid the unexpected higher stern waves. The additional panels are dealt with as inexistent panels for calculation of the forces acting on the hull.

Fig.1 shows the propagation of the waves generated by the vessel in the channel from -2.35 to 4.35 for non-dimensional time $T$. $T = 0$ is corresponding to the stop time of the vessel after the deceleration. The assumed speed change is shown in Fig.2. Froude number based on the constant speed $U_0$ before the deceleration and the ship length $F_n$ is 0.519. As the region of the channel, 24.5$L$ for the length, 2.2$L$ for the half breadth and 2.2$L$ for water depth are assumed in this case. Then, Froude number based on the water depth $F_h$ becomes 0.350. The breadth and the depth are the same size as the towing tank of Nagasaki R & D center, MHI. In the computation, 4,000 panels for free surface, 480 panels for the vessel and 2,400 panels for the channel walls are used. Time interval 0.02s is in the computation.

Typical Kelvin wave pattern is observed at $T$=-2.35. At $T$=0.35, we can see that shifting of the waves generated by the vessel strats just after the vessel stopped. Further, the waves reflected by the channel walls are remarkably observed at the rear region of the vessel. At $T$=2.35 and 4.35, the bow-shape waves observed in front of the vessel propagate up stream. Thus, propagation process of the unsteady wash generated by the high speed vessel in the channel is realistically demonstrated.

To obtain the verification data, the model test was carried out in the towing tank. Fig.2 shows the comparison of time histories of the ship motions (sinkage and trim) and wave heights at 3 positions fixed at the tank. The positions are $(x/L, y/L)$= (1.79, 0.5), (1.79, 0.643) and (1.79, 0.786) where $x$ is longitudinal distance between fore peak of the stationary vessel and the wave height sensor and $y$ the lateral distance from the tank center line. Behavior of the motions which occur due to the passage of the waves, arrival time of the wash and the wave period in the computation agree well those in the experiment.

In the workshop, we will present further results computed in shallow waters.

## References

Beck, R.F., Cao, Y., and Lee, T.-H. (1993): *Fully Nonlinear Water Wave Computations using the the Desingularized Method*, 6th International Conference on Numerical Ship Hydrodynamics, Iowa City.

Li, D. and Chwang, T. (1997): *Time Domain Analysis of Ship-Generated Waves in Harbour using a Fast Hierarchical Method*, 7th International Offshore and Polar Engineering Conference, Honolulu.

Maskew, B. (1991): *A Nonliner Numerical Method for Transient Wave/Hull Problems on Arbitrary Vessel*, SNAME Trans., Vol.99.

Yasukawa, H. (1999): *Unsteady Wash Computation for a High Speed Vessel*, Numerical Towing Tank Symp.(NuTTS'99), Rome.

Yasukawa, H. (2000): *Nonlinear Time Domain Analysis of Ship Motions in Regular Head Waves*, Numerical Towing Tank Symp.(NuTTS'00), Tjärnö.

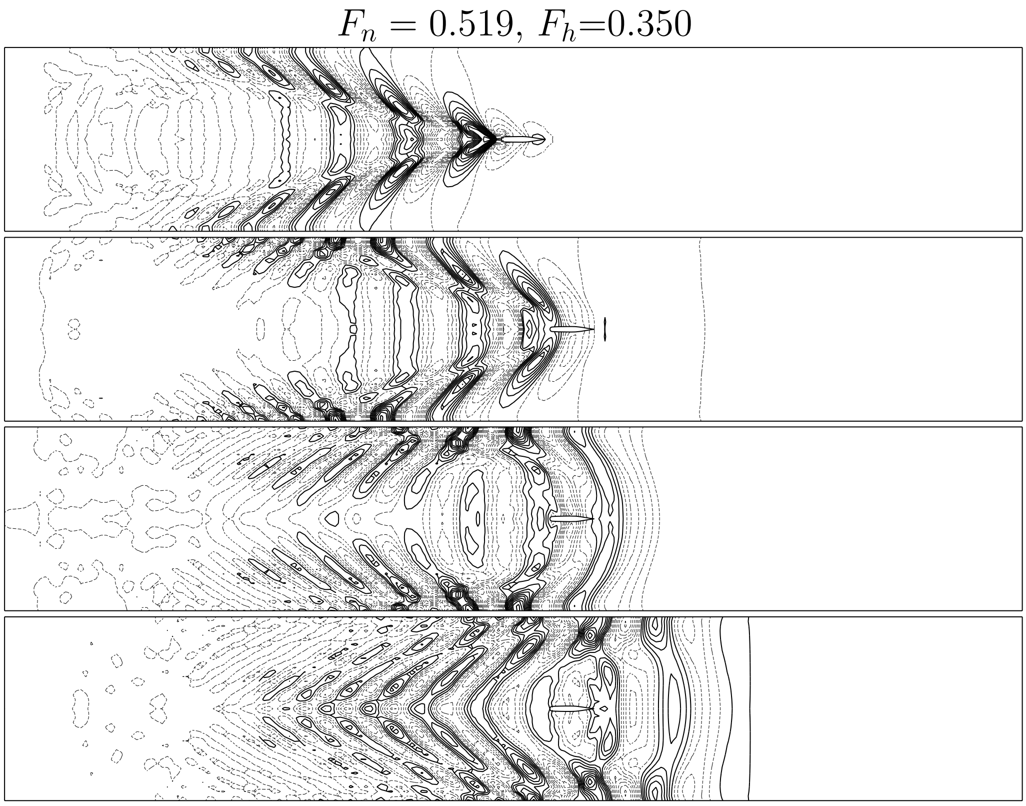


Fig.1: Propagation of the unsteady wash generated by a high speed vessel. The results are of $T$ = -2.35, 0.35, 2.35 and 4.35 from the top.

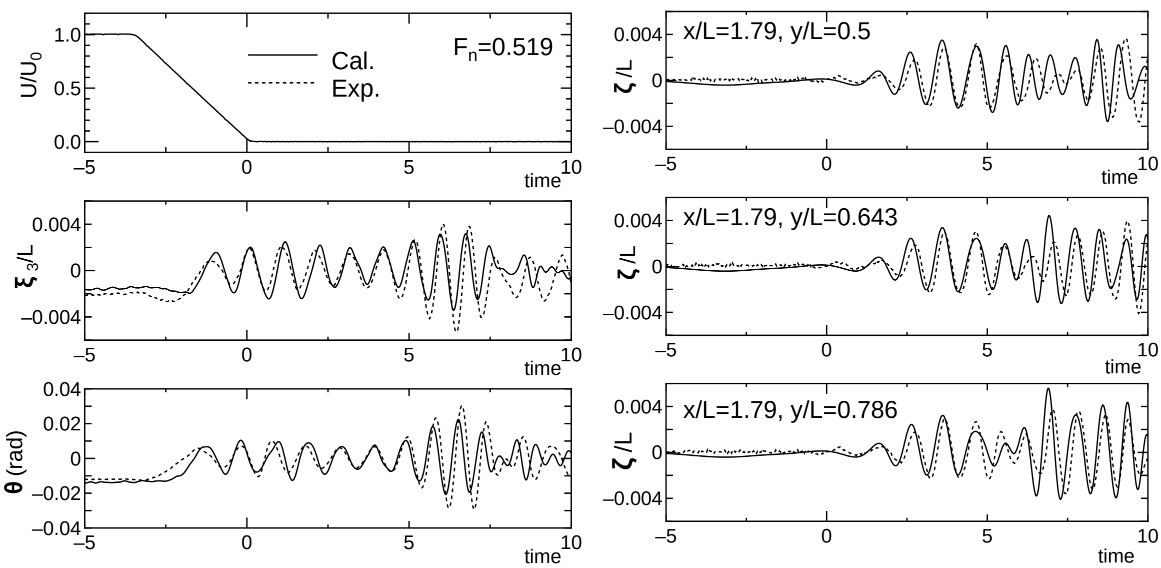


Fig.2: Change of ship speed and comparison of time histories of the motions (sinkage and trim) and wave heights at 3 positions fixed at the tank