Numerical Simulation of the Free-surface Flow around a Floating Body

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It is important to verify the flow and free-surface characteristics around piercing bodies. The wave breaking phenomena on the free-surface and vortex distribution in the vicinity of a floating body, and also the interaction of these hasn't yet come to knowledge.

Miyata[1] et al. simulated the flow field around a 2-D floated rectangular body by Finite Difference Method (FDM) on the staggered rectangular grid system. The simulated results show reasonable agreement with the experimental data. The nonlinear behaviour in front of the body and wave-breaking phenomena are simulated by the marker segments moved by Lagrangian technique.

Yeung et al.[2] investigated the flow characteristics of bow waves. There is a critical flow velocity at which the bow wave-breaking takes place. At this critical flow velocity, the bow wave develops a periodic oscillation. This oscillation appears to be due to the balance between the rate at which fluid is being entrained into the separated region and the rate at which it is existing in quiescent condition.

Mori[3,4] suggested the sub-breaking waves as a free-surface turbulent flow which is transited from the laminar to turbulent flow. By the direct observation of free-surface and the analysis of measured data, it was clarified that the sub-breaking waves are neither overturning nor spilling motions.

In the present paper, the Navier-Stokes equations and the continuity equation are directly solved by the FDM for the simulation of the disturbed free-surface and the viscous flow around a 2-D rectangular piercing body. In the critical flow velocity region, the instability analysis of free-surface flow is applied to detect the sub-breaking waves in front of the body.

The critical condition for the appearance of sub-breaking waves was proposed by Mori[3,4] as follows ;

$$\frac{U}{M}\frac{\partial M}{h\partial S} - \frac{\partial U}{h\partial S} - \frac{1}{n_z}U\frac{\partial n_z}{h\partial S} > 0 \tag{1}$$

where, $M = (\kappa U^2 - n_z g)n_z$
U, W : velocity components on stream line coordinate
κ : curvature of wave elevation

Near the wave crest, it is assumed $n_z \doteq 1$, $\frac{\partial}{h\partial S} \doteq \frac{\partial}{\partial x}$ and Eqn(1) changes as follow ;

$$\frac{U^2}{M}\frac{\partial}{\partial x}\left(\frac{M}{U}\right) > 0 \tag{2}$$

where, $$M = \kappa U^2 - g$$

M is always negative in this paper. If the gradient of M/U with respect to the incident flow direction shows negative gradient, the flow field near the free-surface can be unstable.

Fig. 1 shows the coordinate system. All of the length parameters and the velocity components are non-dimensionalized by the draft and uniform velocity, respectively.

Fig. 2 shows the grid system used in this calculation.

Fig. 3 shows the calculated wave elevation and the general accordance with experiment[1] is good.

Fig. 4 shows the contour maps of vorticity. It is shown that hollow regions of the stern waves are located above the center of vortex. This means that the wave pattern of the rear side of a body is greatly affected by the viscous flow with vortex motions.

Fig. 5 shows the M/U distribution when the steady state is reached. Because the velocity components near the body are potentially reduced, abrupt negative gradient is seen in the range of $-2.0 \leq x \leq -1.0$. In this range, the decision of the critical state of the free-surface flow by the present instability analysis seems unsuitable. Anyway, there is no sign of the appearance of sub-breaking waves at $x \leq -2.0$ which is confirmed by Miyata[1].

Although the basic flow is steady, the critical condition for the appearance of the sub-breaking waves is applied to the unsteady flow field. Fig. 6 shows the M/U distribution at T=15 when the flow field is still accelerated. Negative gradient with respect to x axis is shown, and it means the sub-breaking waves can be appeared.

The numerical simulation of the flow field around a 2-D floating body is performed. The simulated results are reasonable and critical condition shows some prospective view. The computation with high Froude number where sub-breaking takes place is near future work.

[REFERENCES]

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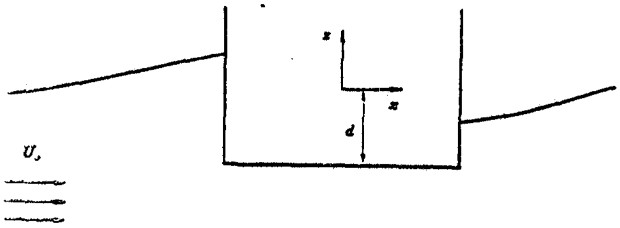

Fig. 1 Coordinate System

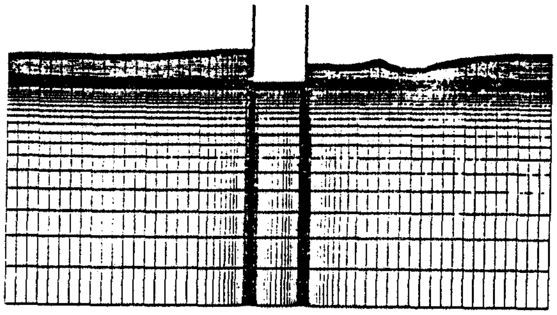

Fig. 2 Mesh System ($Rn=10^4$, $Fn=0.75$, $T=27$)

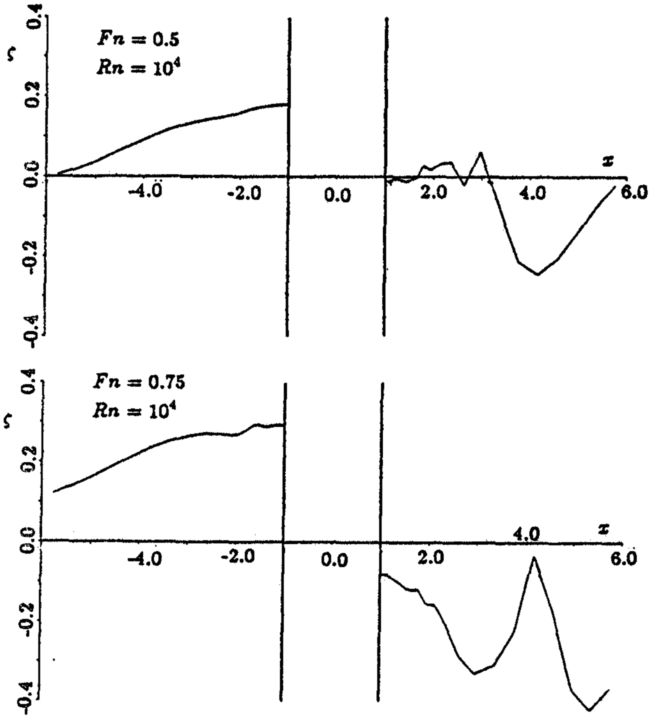

Fig. 3 Calculated wave elevation (T=27)

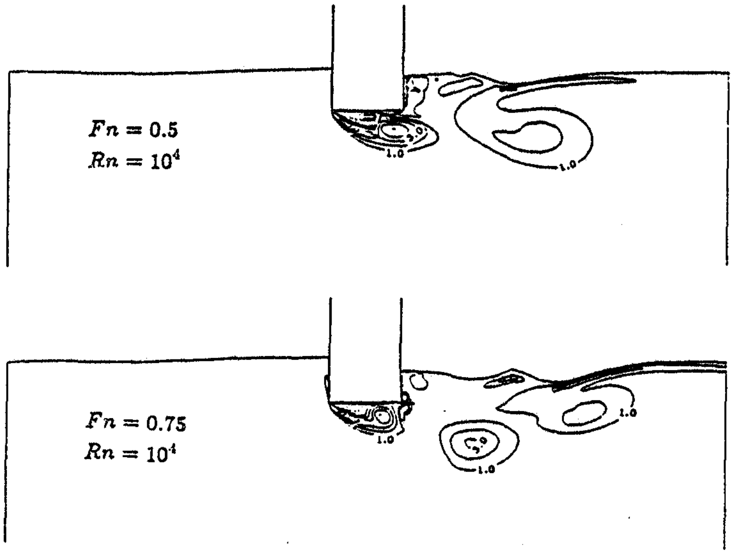

Fig. 4 Contour maps of vorticity (T=27)

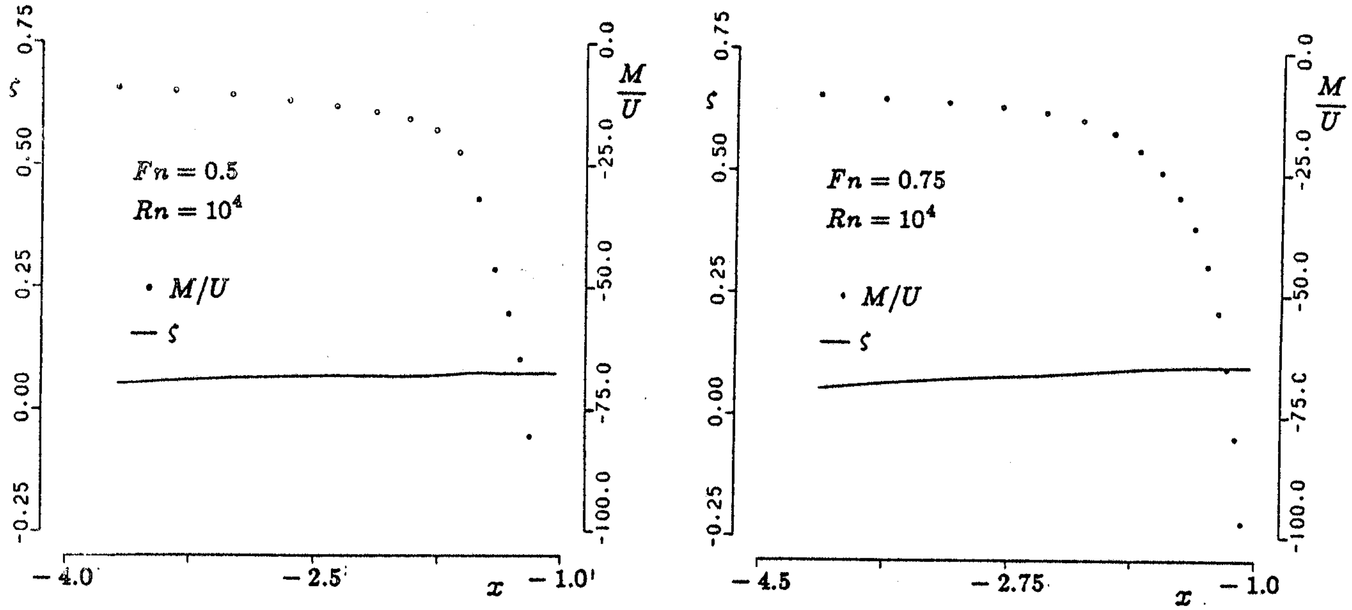

Fig. 5 Distribution of M/U (T=27)

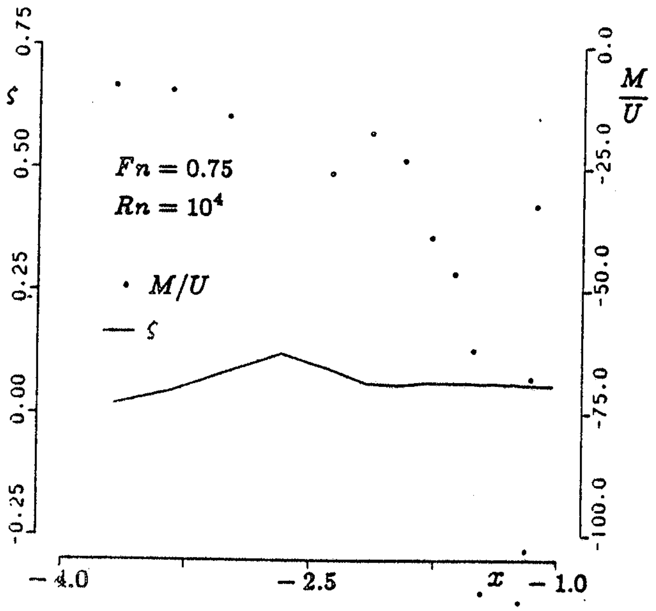

Fig. 6 Distribution of M/U (T=15)