SLAMMING ON THE WETDECK OF MULTIHULLS

Odd Faltinsen, Norwegian Institute of Technology,
Trondheim, Norway

and

Rong Zhao, Marintek, Trondheim, Norway

Incident head sea longcrested waves are assumed. The instant of slamming is found by monitoring the relative vertical motion ζ_R between the wetdeck and the waves. When the slamming occurs, there is set up an additional flow field that is described by a velocity potential ϕ. The boundary value problem for ϕ is described in Fig. 1. V_R is the relative normal velocity between the wetdeck and the waves. The (x,y,z) coordinate system is the global coordinate system used to describe the wave induced motions of the vessel. The local coordinate system (X,Z) is changing with time. V_R is approximated by $V_1 + V_2X$ over the wetted deck surface. The velocity potential on the body surface can be written as

$$\phi = (V_1 + 0.5\, V_2 X)\sqrt{\ell^2(t) - X^2} \tag{1}$$

This solution will match with a local jet flow solution at $X = \pm \ell(t)$. This is similar as Armand & Cointe (1986) and Cointe (1991) did in studying water entry of two dimensional bodies. The outer expansion of the local jet flow solution can be found from Wagner's analyses (1932). We find from the matching

$$4\,\frac{dc}{dt}\sqrt{\frac{\delta}{\pi}} = -(V_1 + 0.5\, V_2\ell)\sqrt{2\ell} \tag{2}$$

where δ is the thickness of the jet in Wagner's solution. $\ell(t)$ and c(t) are found by solving the integral equation

$$\int_0^t \left[-\frac{V_1|X|}{\sqrt{X^2-\ell^2}} + V_1 \quad V_2X - 0.5 sgnX\, V_2 \left[\sqrt{X^2-\ell^2} + \frac{X^2}{\sqrt{X^2-\ell^2}} \right] \right] dt = \zeta_R(x,t) \tag{3}$$

where t = 0 is the initial time of contact between the waves and the wetdeck. For each time t equation (3) will be satisfied for two x-values. This determines $\ell(t)$ and c(t). The integral equation is solved numerically and is a generalization of an integral equation set up by Wagner (1932) in studying water entry of two-dimensional bodies.

Composite solutions for the pressure p are presented. For $0 \le X \le \ell(t)$ we can write this to lowest order as

$$p - p_o = -\rho\,(V_1 + 0.5\,V_2X)\left[\frac{\ell(t)\dfrac{dl}{dt} + X\left(-\dfrac{dl}{dt} + \dfrac{dc}{dt}\right)}{\sqrt{\ell^2(t) - X^2}} - \frac{\ell\,\dfrac{dc}{dt}}{\sqrt{2\ell\,(c - x)}}\right] \tag{4}$$

$$- \rho 0.5 V_2\left(-\frac{dc}{dt} + \frac{dl}{dt}\right)\sqrt{\ell^2(t) - X^2} + p_{jet}$$

where p_{jet} is the pressure according to the local jet flow solution given by Wagner (1932), ρ is the mass density of the water and p_o is the atmospheric pressure. p_{jet} approaches the second term in equation (4) when c-x is large, and the first term in equation (4) approaches the second term when c-x goes to zero.

The analytical formulation has been validated by applying the same approach to water entry of a wedge with constant vertical velocity V. Dobrovol'skaya (1969) has derived a similarity solution for this problem in terms of an integral equation. Dobrovol'skaya (1969) solved the integral equation for deadrise angles $\alpha \ge 30°$. Zhao & Faltinsen (1992) provided new numerical similarity results for deadrise angles between 4° and 81°.

Fig. 2 shows an example of numerical pressure results for water entry of a wedge with deadrise angle 4°. There is very good agreement between the similarity solution, the asymptotic method and the nonlinear boundary element method. The nonlinear boundary element method uses a jet flow approximation and is described in detail by Zhao & Faltinsen (1992). The asymptotic method is application of a formula similar to equation (4). Fig. 2 shows also results by Watanabe's (1986) asymptotic method. Watanabe did not match his solution with Wagner's solution. A different local flow analysis was used in the jet flow area. He also included velocity square terms in Bernoullis equation in the outer flow domain outside the jet flow area. This is a higher order term in the present approach. Fig. 2 shows that Watanabe's method gives different results that the asymptotic method outlined in this abstract.

Numerical results for slamming on the wetdeck of a multihull will be presented and discussed. Comparisons will be made with the nonlinear boundary element method described by Zhao & Faltinsen (1992). The advantages of using the asymptotic method relative to the nonlinear boundary element method to this problem is that it requires negligible CPU-time and is robust numerically.

Fig. 3 shows an example on numerical predictions of pressure by means of the asymptotic method. The studied problem is a horizontal flat plate that is impacting regular sinusoidal waves propagating along the positive x-axis with phase velocity c. The wave elevation is given as

$$\zeta = \zeta_a \cos(\omega t - kx) \tag{5}$$

where ζ_a is the wave amplitude, ω = circular frequency of oscillation and k is the wave number. The flat plate has a constant downward velocity V =4 m/s. Results for three different time instants are presented. t = 0 corresponds to the time when the flat plate hits the wave crest. It is seen that the pressure is asymmetric about x = ct and that the largest pressure occurs for a positive value of x - ct at each time instant. The maximum pressure will depend on the wave slope and the relative vertical velocity between the plate and the waves.

References

Armand J.L., Cointe, R., 1986, Hydrodynamic impact analysis of a cylinder, Proc. Fifth Int. Offshore Mech. and Arctic Engng. Symp. (OMAE), Tokyo, Japan, Vol. 1, pp. 609-34. New York, The American Society of Mechanical Engineering.

Cointe, R. 1991, Free surface flows close to a surface-piercing body, Mathematical approaches in hydrodynamics, Editor: T. Miloh, SIAM.

Dobrovol'skaya, Z.N., 1969, On some problems of similarity flow of fluid with a free surface, J. Fluid Mech., Vol. 36, part 4, pp. 805-829.

Wagner, H., 1932, Über Stoss- und Gleitvergänge an der Oberfläche von Flüssigkeiten, Zeitschr. f. Angewandte Mathematik und Mechanik, 12,4, 192-235.

Watanabe, T., 1986, Analytical expression of hydrodynamic impact pressure by matched asymptotic expansion technique, Transactions of the West-Japan Society of Naval Architects, No. 71.

Zhao, R., Faltinsen, O., 1992, Water entry of two-dimensional bodies, To be published.

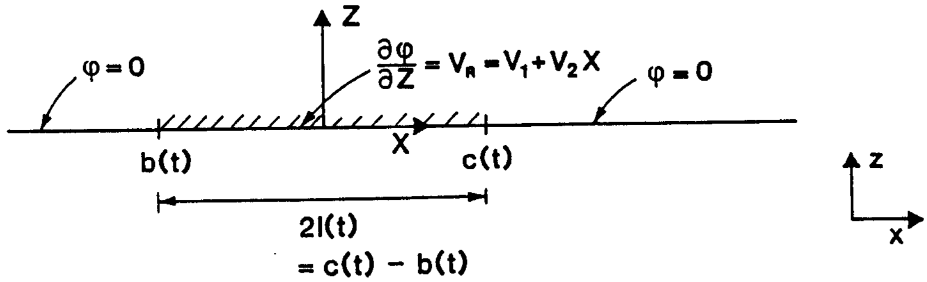

Fig.1 Definitions of the coordinate systems and illustration of the boundary value problem.

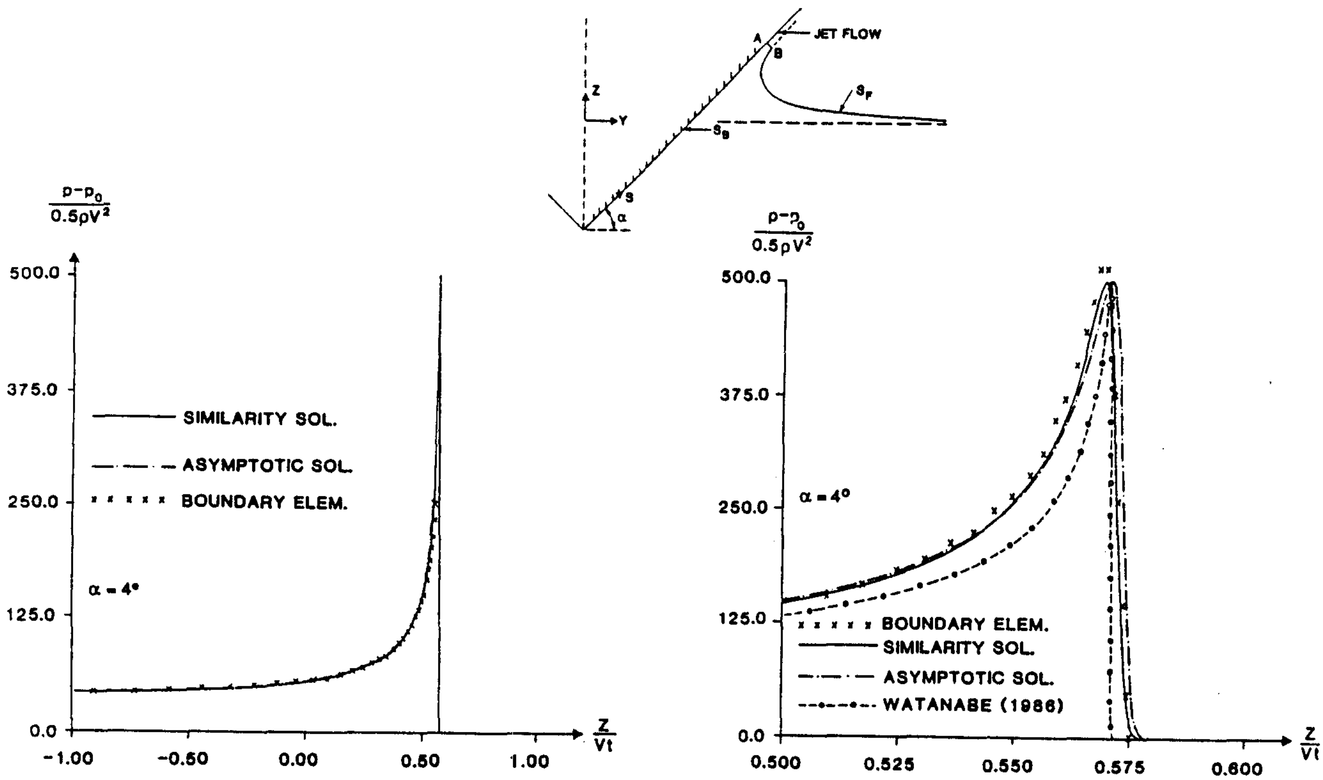

Fig.2 Predictions of pressure distribution during water entry of a wedge with constant vertical velocity V. α = deadrise angle.

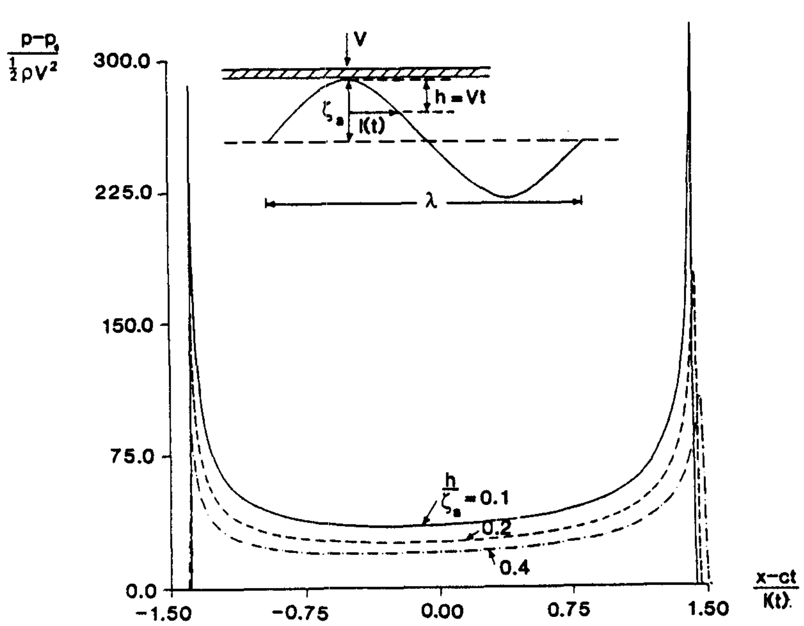

Fig.3 Pressure distribution caused by a horizontal flat plate impacting on regular sinusoidal waves. V = 4 m/s. ζ_a = 1.5m. The wave length λ = 50m.

DISCUSSION

GREENHOW: The authors are to be congratulated on producing practical and accurate solutions for the wedge entry problem for arbitrary deadrise angles. This represents very real progress on a problem which has occupied some great mathematician for the last 60 years!

Also of interest is the *exit* problem. Analytical difficulties arise because the problem is gravity dependent, resulting in the usual and more difficult, free surface conditions: numerical difficulties are associated with the treatment of the intersection points, especially at low deadrise angles. Nevertheless the problem may be important for the ship motions, especially to predict the velocities of bow re-entry, and hence slamming forces (proportional to kV^2)