(Abstract for the 9th Int. Workshop on Water Waves and Floating Bodies, April 1994)

Calculation of Breaking Wave Impact on a Wall

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Predicting impact effect of breaking waves on ships and offshore structures, particularly, the impact pressures, has been a challenging subject to engineers and marine hydrodynamists. Experimental study by Chen & Melville (1988) indicates that the impact pressure produced by a breaking wave on a wall is of impulsive nature and its peak value is as high as $(3 \sim 10)\rho C^2$ (C is the phase speed of the wave, and ρ the density of liquid), and that the trapped air during impact plays an important role in inducing high impact pressures. Numerical studies by Vinje & Brevig (1981), Cooker & Peregrine (1992) show that peak impact pressures on structures due to a wave impact are on the order of $(1 \sim 10)\rho gh$ (g is gravity acceleration and h the depth of the flow). In the previous workshop presentations, Tanizawa & Yue (1991, 1992) considered the cases of a breaking wave striking a vertical wall with and without air trapping. However, the calculations were unable to give a converged result on the impact pressures because of a non-physical truncation of the tip of the breaker at the initial stage of the impact. As a result, no definite estimation on the impact pressures could be given from the previous studies. To resolve this problem the key issue is to develop a physically robust and numerically effective method to deal with, particularly, the initial stage of the impact process.

The present study takes a new approach to simulate the the initial stage of the wave impact on a vertical wall by implementing a similarity solution for a liquid wedge impact problem into a boundary integral scheme within the framework of incompressible hydrodynamics. The effect of the trapped air between the interior breaking wave and the wall is included and modeled with a polytropic law. With this method, a consistent and converged prediction on the impact pressures can be achieved and other fluid dynamics effects associated the impact can be investigated.

In the flow system we consider, the characteristic length, time and pressure scales are chosen as h, $(h/g)^{\frac{1}{2}}$, and ρgh, respectively. The important parameters that control the flow are the non-dimensional length of the tank, L/h, initial velocity of the wave maker, $U/(gh)^{\frac{1}{2}}$ and air pressure $P_{air}/\rho gh$. The results presented in this paper are for the case of $L/h = 5.6$, $U/(gh)^{\frac{1}{2}} = 0.7$ and $P_{air}/\rho gh = 15$. The dependence of the fluid behavior on the parameters will be discussed at the Workshop.

Once the tip of the plunging breaker touches the wall, the initial stage of the impact starts. This process represents a sudden transition of the tip of the plunger from a previously converging jet into a diverging jet within a very short time period. During this period the effect of the trapped air is negligible because there is little change of the volume enclosed by the interior free surface. The key issue here is how to calculate the converging-diverging transition process of the plunger at the initial stage of the impact. To avoid the numerical difficulties encountered in our previous study, a similarity solution for the oblique impact of an asymmetrical liquid wedge on a wall is developed. This is an extension of the work by Borisova, Koriavov & Moiseev (1959) for the cases of a normal impact of a symmetrical solid wedge on a liquid surface. The solution depends on three geometrical parameters, α_1, α_2 and α, which are respectively, the two angles measured from the normal of the wall to the two edges of the wedge and the angle of attack of a uniform velocity V in the wedge. The spatial and temporal variables in the physical plane (x, y, t) are transformed into two similarity variables in the plane $(x/Vt,\ y/Vt)$. The free surface profiles of the wedge in the similarity plane are assumed to be linear functions away from the wall and exponential functions near the wall. The coefficients of these functions are determined by the boundary conditions at infinity and on the wall as well as the conservation of mass and momentum of the fluid. Fig. 1 shows that our calculation for the free surface profile and the impact pressure on the wall for a 22.2° wedge normal impact problem agrees quite well with existing similarity solutions (Cumberbatch, 1960).

The next step in the simulation is to map the similarity solution into the physical plane. The parameters α_1, α_2, α, velocity V as defined above are determined with the information on the breaking plunger, and the time period from the initial instant when the jet tip touches the wall to the instant when a finite portion of the jet "passes through" the wall is also calculated. Given these parameters, the similarity solution converted into the physical plane provides all fluid information in the time period from the initial impact to the instant when the similarity solution is matched to the numerical solution. To continue the numerical simulation the similarity solution has to be matched to the solution of the breaking wave. Since the behavior of the plunging breaker adjacent to the wall can be reasonably approximated as a liquid wedge, it is expected that the wedge profile determined by the values of α, V, etc. on the plunger can be smoothly matched to the plunger profile. It is also noted that although the velocity potential and stream function of the wedge at the matching points differ from those of the plunger, the local velocities near the matching region in the wedge and in the wave are approximately the same. Taking the values of the velocity potential and the stream function on the wave as the boundary values and integrating the velocity field gives a smooth distribution in both velocity potential and stream function along the matched free surfaces. Thus, the numerical calculation can proceed after the initial impact.

Following the initial stage of the impact, the motion of the spreading jet and the effect of the trapped air are considered. As the liquid jet spreads along the wall it is divided into two branches, one moving upwards against gravity and the other moving downwards. The motion of the interior surface and downward spreading jet changes the volume they enclose with the wall. As a result, the trapped air starts to play a role based on a polytropic gas law. It is found that the upward-moving spreading jet becomes thinner and thinner and Taylor instabilities eventually develop along the free surface as the upward motion slows. Considering the fact that the jet is very thin away from the central impact zone, cutting a portion of the thin jet will not cause too much change in impact pressure but help to stablize the calculation. It is also found that the downward-moving spreading jet tends to re-enter the pool of the fluid opposite to it. The cutting strategy is also applied to this jet to avoid the re-entry. One of the physical reasoning for this treatment is that in a real impact situation, the tip region of a spreading jet is actually a spray region, therefore, cutting the jet tip has an effect as if the portion of fluid that has being cut became spray whose effect on the impact process were neglected. With this treatment, the calculation of the free surface profiles at different time instant are presented in Fig. 2, the corresponding pressure distribution along the wall is given in Fig. 3, and the impact force at the impact zone is also show in Fig. 4 as a function of time.

It should be pointed out that if the downward-moving spreading jet is allowed to re-enter the pool of fluid opposite to it, the numerical scheme need to be modified. This is because the re-entry of the jet induces a jet-liquid impact process, transforming the fluid domain into a doublely-connected region and circulation is created. However, since the re-entrant jet is very thin, as it penetrates into the receiving fluid, the vortex sheet effect along the interface of the two impacting fluids can be negligible and the modification of the scheme can be simplified by superimposing a point vortex flow with a given circulation on a vortex-free flow field. This treatment has been implemented and the results will be presented at the Workshop.

From our preliminary simulations, some typical features associated with wave impact phenomena have been identified. For instance, the impact force on the wall and maximum impact pressures are indeed impulsive in nature and their rising and falling period is comparable to experimental measurements and their peak values are on the same order as those obtained by the previous investigators. The entrapped air directly affects the impact pressure distribution and tends to increase the pressure as it is being compressed and to decrease as it is re-expending. The entrapped air also tends to push the free surfaces up near the impact zone and shift the impact zone up against gravity. The converging jet near the tip of the breaking wave before impact is smoothly transformed into a diverging jet after the initial impact. As the jet spreads both upwards and downwards along the wall, the upper branch becomes unstable and the lower branch tends to re-enter the fluid below, then a jet-liquid impact or jet penetration process may take place.

References

Borisova, E.P, Koriavov, P.P and Moiseev, N.N., 1959, Plane and axially symmetrical similarity problems of penetration and of stream impact, *J. of Appl. Math. and Mech.,* Vol. 23, No. 2, pp. 490-507.

Chen, E.S. and Melville, W.K., 1988, Deep-water plunging wave pressure on a vertical plane wall. *Proc. R. Soc. Lond.* A 417, pp. 95-131.

Cooker, M.J. and Peregrine, D.H., 1992, Wave impact pressure and its effect upon bodies lying on the sea bed. *Coastal Eng.* 18, pp. 205-229.

Cumberbatch, E., 1960, The impact of a water wedge of a wall, *J. Fluid Mech.* 7, pp. 353-374.

Tanizawa, K and Yue, D.K.P., 1991 and 1992, Numerical computation of plunging wave impact loads on a vertical wall. *Proc. 6th and 7th Intl. Workshop on Water Waves and Floating Bodies.*

Vinje, T. and Brevig, P., 1981, Numerical calculation of forces from breaking waves. *Proc. of Int. Syp. on Hydro. in Ocean Eng.*, Trondheim, Norway.

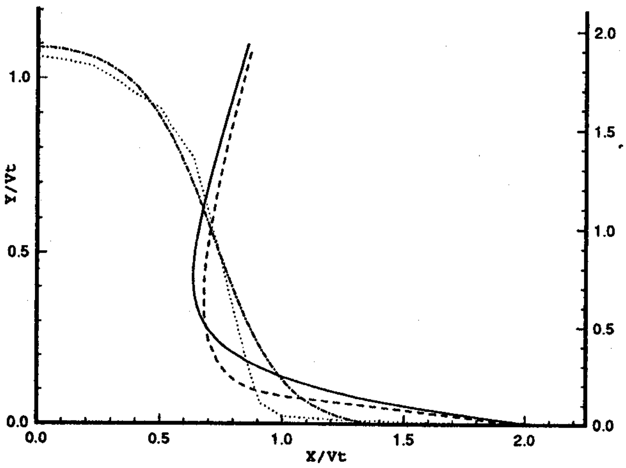

Figure 1: Similarity solutions of a 22° wedge impact on a wall. Free surfaces (the left y-axis): present result (solid line) and Cumberbatch (1960) (dashed line). Pressures (the right y-axis): present result (dash-dotted line) and Cumberbatch (1960) (dotted line)

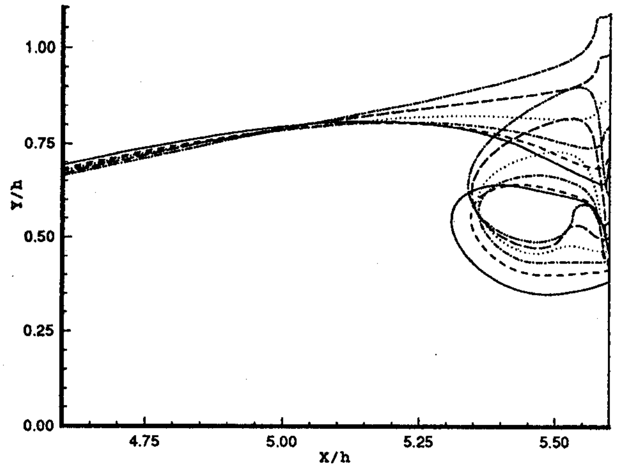

Figure 2: Free surface profiles at $t(g/h)^{\frac{1}{2}}$ =4.35 (solid), 4.37 (dashed), 4.39 (dashdotted), 4.41 (dotted), 4.43 (longdashed), 4.45 (dash-double dotted).

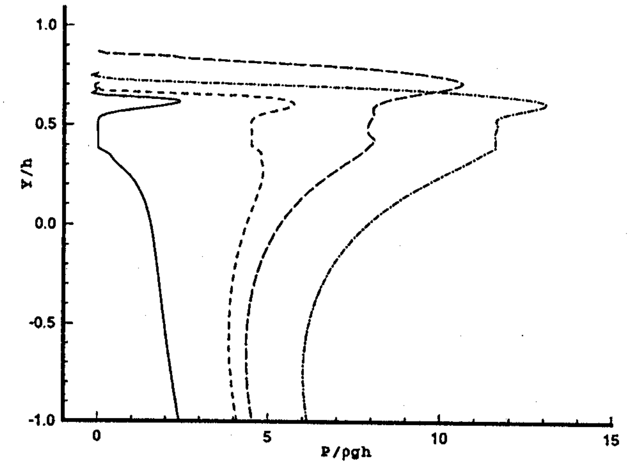

Figure 3: Pressure distribution on the wall versus time at $t(g/h)^{\frac{1}{2}}$ =4.35 (solid), 4.36 (dashed), 4.38 (dashdotted) and 4.40 (long-dashed).

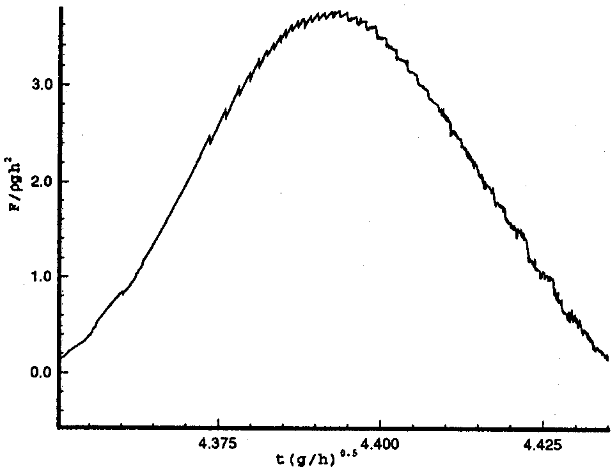

Figure 4: Impact force along the impact zone on the wall versus time.

DISCUSSION

Palm E.: For the air you use a polytropic equation according to the talk. Do you refer to adiabatic processes, or to processes with mean exchange of heat with the surroundings?

Tanizawa & Yue: We use a plytropic law with constant $\gamma = 1.4$ which corresponds to adiabatic conditions with no heat exchange. Physically, this is a reasonable model since the time scales involved are very small.