Aspects of violent water wave impacts

S.Kalliadasis, D.H.Peregrine & M.E.Topliss
School of Mathematics, University Walk, Bristol BS8 1TW, England
e-mail: d.h.peregrine@bristol.ac.uk

Summary

In irrotational flow studies of breaking waves approaching a wall, Cooker & Peregrine (1990a) discovered a violent motion, they call "flip-through", with extreme pressures and water accelerations, that is fully described by smooth irrotational flow and yet matches the highest pressures recorded from wave impacts. We report on further studies of violent flows, both with irrotational computations and simpler models.

In most practical breaking wave impacts some air is trapped between the wave and body. As the amount of trapped air goes to zero there is another approach to very violent conditions. If the water impacts in a relatively confined space, pressure-impulse methods indicate that there can be a marked increase in the severity of wave impact. Examples include box and cylinder shapes. Penetration of impacts into cracks and slots, or below a deck, is known to produce severe conditions. A pseudo-steady model of such an impact provides some insight.

Introduction.

Our studies of wave impact have been mainly in the context of waves hitting walls or within containers, however, they do provide results that are relevant to other impacts between floating or fixed bodies and water. Computations of extreme pressures when almost breaking waves meet a wall, but no actual impact occurs were a suprise. The water level at the wall accelerates upward so fast that although the eye might "see" an impact the actual transition between a wave face parallel to, and approaching, a wall and a violent upward jet of water can happen smoothly in a "flip-through" motion described Cooker & Peregrine (1990a, 1992 and in preparation). More recent computations have yielded water accelerations higher than 60000g, the maximum pressure being more than $25(\frac{1}{2}\rho U^2)$, where U is the approach velocity of the water. However, the higher the pressure, the smaller the surface on which it acts.

These results motivated a simpler approach using the well established concept of pressure impulse. This gives an integrated view of the impact, or flip-through, but enables simple calculations giving an overview of features that affect impacts, e.g. the actual shape of the wave is not very important. Illustrations are given below.

The region of very high pressure at the base of the incipient, and developed, jet up the wall is relatively small, and Cooker has shown that it can be modelled by a steady flow in a frame of reference moving up the wall (Cooker & Peregrine, in preparation). This can be justified by the very short time that most fluid particles spend in that region. A similar pseudo-steady flow can be used to model flow when water impacts on a wall beneath a deck which forms a 2D slot that rapidly fills with water and extensive high pressures can arise.

Trapped air in wave impact.

Air can be trapped in two ways, either as a coherent air pocket, such as occurs when a wave meeting a wall has a significant overhanging jet, see figure 1, or as bubbles distributed within the water. In both cases there is a substantial influence on impact pressures since air is so much more compressible than water. Tanizawa & Yue (1992) presented some examples of irrotational-flow computations that are continued after closure of an air pocket and give the initial part of the pressure oscillations that often result in these cases. Hattori, Arami & Yui (1994) present a range of experimental data. They show, in figure 27, a trend towards higher pressures as the size of air pocket decreases. This can be seen more dramatically in figure 1 where the same incident wave, over a horizontal bed, is shown meeting a wall placed at two different positions. It seems likely that with careful choice of wall position the most severe wave impact will be on the borderline between flip-through and a minute pocket of trapped air. More investigation is needed.

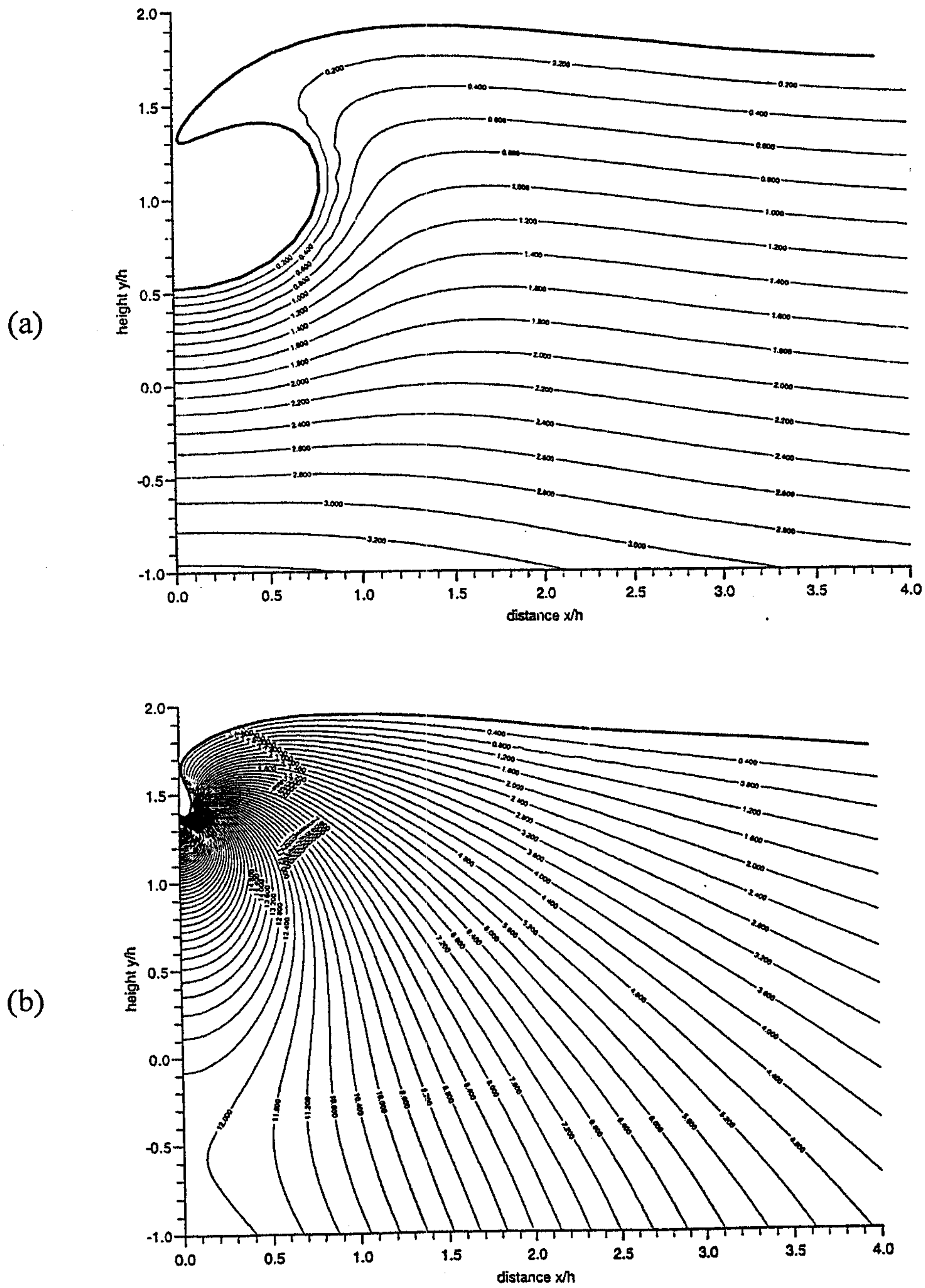

Figure 1. The pressure contours at impact for the same breaking wave meeting a wall:
The wall in (b) is 2 units closer to the breaking point than in (a).
Note contour intervals in (b) are twice those in (a).

A more general discussion of the effect of trapped air can be found in Peregrine (1994), Topliss & Peregrine (1994) and Topliss (1994). The main effect of distributed bubbles is that they cause the velocity of sound to be enormously reduced within their region of existence, so the bubbly body of water acts in a manner very similar to that of the trapped air pocket.

Pressure-impulse examples in containers.

Pressure impulse satisfies Laplace's equation in the liquid domain with relatively simple boundary conditions on the rigid and free boundaries (Cooker & Peregrine 1990b, 1992, 1995). Thus for convenient shapes it is easy to find analytic solutions, e.g. in Fourier expansions. Rectangles are quite straightforward and some experimental waves do have simple horizontal crests a they hit a wall. These solutions show that the pressure impulse distribution on the wall is insensitive to any shape variation that is not within the water depth of the wall. If another boundary is brought closer than this then the pressure impulse increases, especially on the lower part of the wall. Another shape that is important for contained fluids is a circular cylinder. By choosing the free surface shape to be a circle meeting the cylinder at right angles a Fourier solution may be found (Topliss, 1994). Figure 2 shows the contours of pressure impulse for three examples with different levels of fill, for exactly the same extent, and velocity, of impact.

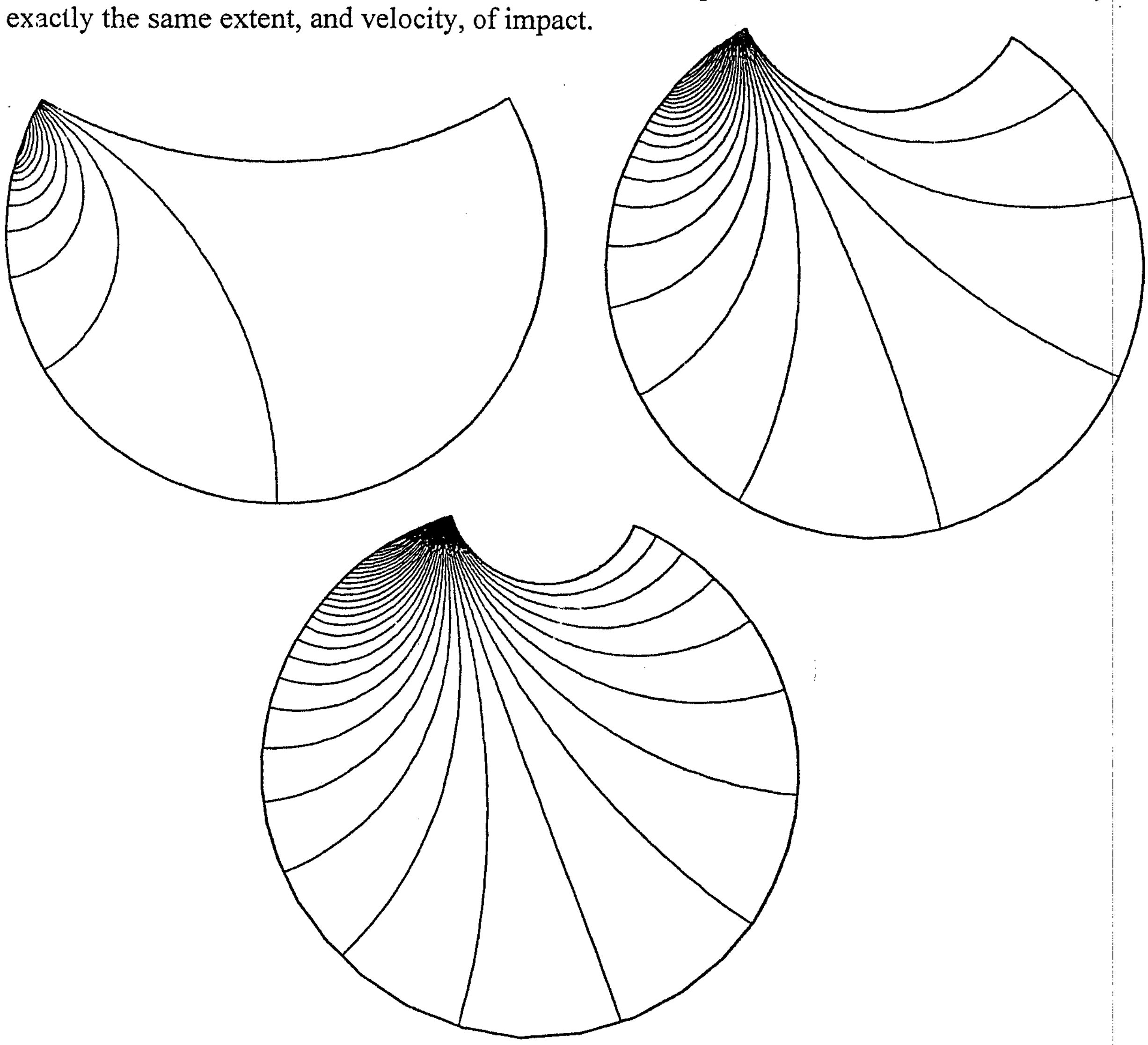

Figure 2. Contours of pressure impulse for the same impact at different fill levels.

Impact at the end of a horizontal slot

Consider a rectangular plug of water flowing along between two horizontal planes, and then meeting the closed end of the slot. There is then an impact such as can be described by the methods already mentioned. However the water very rapidly reaches the top of the slot and starts filling it. If the water filling the slot came to rest then the speed of filling and approximate pressures would be easy to estimate. However, some of the inflowing water can form an outward jet along the top of the slot. The acceleration that this water has as it turns round is substantial and requires a significant pressure acting in the filled part of the slot. By moving with the point of water turn around a steady flow problem can be set up as sketched in figure 3. Gravity is unimportant on the sort of time scale that occurs in these violent water motions so we now have a classical free-streamline problem. The results give the excess pressure when the clearance between the incoming water and the upper boundary is known.

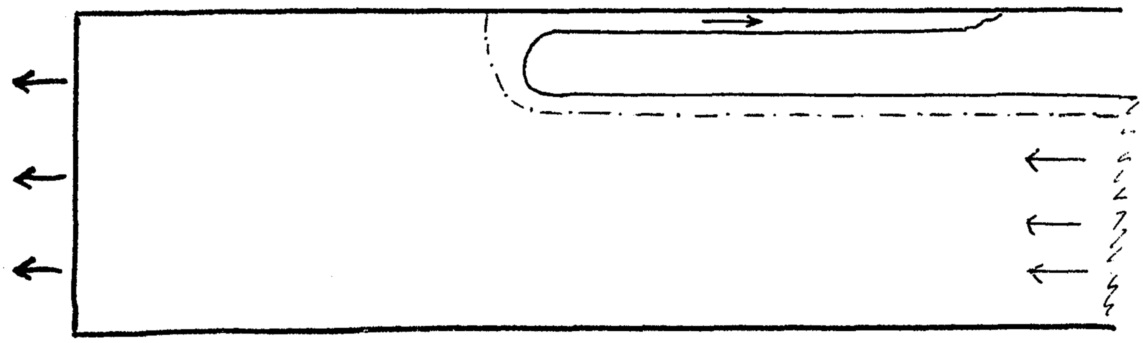

Figure 3. Sketch of quasi-steady problem for impact in a slot.

References

M.J.Cooker & D.H.Peregrine (1990a) Computations of violent motion due to waves breaking against a wall. *Proc.22nd Internat.Conf.Coastal Engng. Delft. A.S.C.E.* **1**, 164-176.

M.J.Cooker & D.H.Peregrine (1990b) A model for breaking wave impact pressures. *Proc.22nd Internat. Conf. Coastal Engng. Delft. A.S.C.E.* **2** 1473-1486.

M.J.Cooker, & D.H.Peregrine (1992) Wave impact pressure and its effect upon bodies lying on the bed. *Coastal Engineering.* **18**, 205-229.

M.J.Cooker, & D.H.Peregrine (1995) Pressure-impulse theory for liquid impact problems. (submitted for publication).

M.J.Cooker, & D.H.Peregrine (in preparation). Computations of water wave impact on a wall and flip-through.

M.Hattori, A.Arami & T.Yui (1994) Impact pressure on vertical walls under breaking waves of various types. *Coastal Engng.* **20**, 79-114.

D.H.Peregrine (1994) Pressure on breakwaters: a forward look. *Proc. Internat. Wkshp. on Wave Barriers in Deep Waters.* Port and Harbour Research Institute, Yokosuka, Japan pp553-571, discussion pp572-573.

D.H.Peregrine & M.E.Topliss, (1994) The pressure field due to steep water waves incident on a vertical wall. *Proc.23nd Internat. Conf. Coastal Engng. Kobe. A.S.C.E.* (in press).

K.Tanizawa, & D.K.P.Yue, (1992) Numerical computation of plunging wave impact loads on a vertical wall. Part 2. The air pocket. *Proc. 7th International Workshop on Water Waves and Floating Bodies*, pp269-274.

M.E.Topliss, (1994) *Water wave impact on structures.* Ph.D. Dissertation, Bristol Univ.