COMPUTATIONS OF WAVES BREAKING AGAINST A VERTICAL WALL

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SUMMARY

Numerical computations of steep overturning water waves meeting a vertical wall are described. For waves with vertical faces, quoted from experiments as giving the most severe impacts on a wall, we find that impact does not occur. Instead there is extremely violent water motion as the water surface at the wall "flips through" past the wave crest with high velocity and acceleration.

INTRODUCTION

We are studying shallow-water waves which are commencing to break as they meet a vertical wall. This is an example relevant to coastal structures for which numerous experiments have been reported. Reports from visual and movie observations indicate that the most severe impacts occur when an incident wave hits the wall with a near vertical face. Subsequent motion sends water to a great height. Examples of experimental reports are Bagnold (1939), Nagai (1960), Mitsuyasu (1962) and Partenscky (1988).

The water wave motion is modelled by an accurate and efficient boundary-integral method for irrotational flow which has evolved from that described by Dold & Peregrine (1986) for a periodic wave domain, and is closely related to that used by Tanaka, Dold, Lewy and Peregrine (1987) to study the instability of solitary waves.

There is a wide range of possible incident waves. We have chosen to study relatively large and substantial waves for two reasons. Firstly, experimental, and prototype, structures often have a relatively steep slope of the bed reaching out to deeper water. Such a rapid shoaling leads to much larger breakers than on a gently sloping beach. Secondly, as breaking progresses the numerical method is limited because the surface curvature becomes too large to resolve adequately: the evolution of larger waves can be followed further.

COMPUTATIONAL EXAMPLES

The wave we choose to illustrate in this work starts as a long wave of elevation with water depth increasing smoothly from 1.0 to 2.5 as we pass from $x = -\infty$ to $x = +\infty$. (We use units in which the initial depth, the acceleration due to gravity and the water density are all unity.) Finite-amplitude shallow-water theory indicates such waves steepen, and the full potential theory solution, of which the later stages are shown in figure 1, demonstrates that the wave overturns and breaks. Figure 1 shows a computation for an unbounded region of water, that is, the wave is unimpeded by any obstruction. We simulate a vertical wall by using symmetrical initial conditions corresponding to two such waves propagating towards each other. The "wall" is the line of symmetry which in figures 2 and 3 lies at $X = 0$. The centre of the initial wave profile lies at X_0, corresponding to placing a wall at $-X_0$ in figure 1.

Figure 2 shows the case $X_0 = 8.5$ where the wave overturns before meeting the wall. The final profile can be used to give a good estimate of the velocity with which the overturning jet hits the wall, and of the volume of trapped air. This is the type of result we expected initially.

Figure 3 shows the case $X_0 = 8$ in which the wave starts to overturn but is prevented from forming a jet by the rise of water near the wall. This rising water accelerates the near vertical face of the wave to velocities around 5 at the final time illustrated. However, these velocities are too small to permit impact because the water in the trough at the wall has been violently accelerated upward, by as much as 3000g, and has a velocity greater than 20. Although we have not been able to follow this flow any further it is clear that a jet of water will travel upwards causing water to reach a height of at least 200 times the initial depth (in the absence of air resistance). The peak pressure on the wall is 36 and lies just below the water-line. It is still rising fast at the last time computed. The total force on the wall is 44 and should be compared with an initial hydrostatic force of $\frac{1}{2}$.

The pressure distribution beneath the $X_0 = 8$ wave at the final time for which it is reliably computed, is shown in figure 4. Two features are apparent. The peak pressure causing the violent acceleration up the wall, and the wide spread of the substantial pressures greater than twice the hydrostatic head. For example the pressure at the corner between the wall and the bed is greater than 10. Both of these features also appear in calculations of impulsive pressures due to impact (Cooker and Peregrine, this meeting). The usual experimental arrangement of pressure measurements on the wall is unlikely to distinguish between an impact and the violent "flip through" that we have revealed.

In order to follow through to see the clear formation of a vertical jet we illustrate a much weaker example in figure 5. This is for $X_0 = 5.5$. Even so the maximum vertical acceleration is greater than 45g and the jet can rise to more than 20.

DISCUSSION

After these computations it is no longer clear that the most violent impact of a wave on a wall is that when the wave surface and wall are parallel. The intense converging flow illustrated here, for $X_0 = 8$ might well yield the most severe conditions. In some ways it is reminiscent of the collapse of a vapour filled cavity. As in that case the upper limit of pressures, for the optimum wall and wave arrangement, is likely to depend either on jet formation disrupting the near cylindrical symmetry as in figure 3, or compressibility effects. In practical examples wall roughness may be as important.

We see no reason to consider a vertical wall as a special case and expect similar "flip through" behaviour on steeply sloping beaches, overhanging walls and in the slamming of ship hulls.

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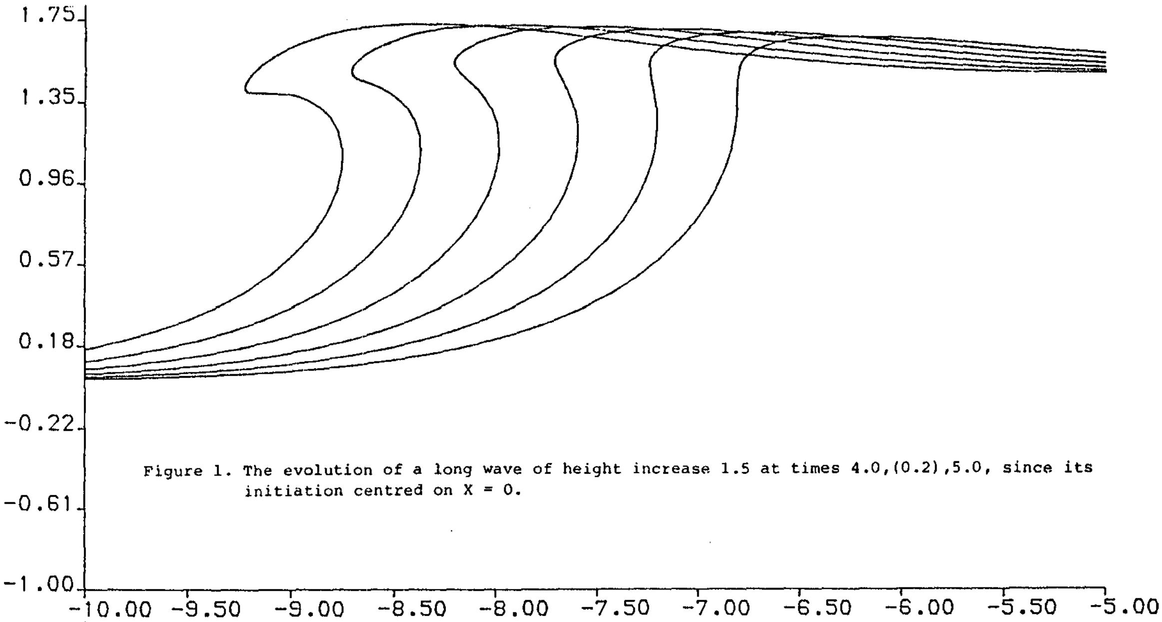

Figure 1. The evolution of a long wave of height increase 1.5 at times 4.0,(0.2),5.0, since its initiation centred on X = 0.

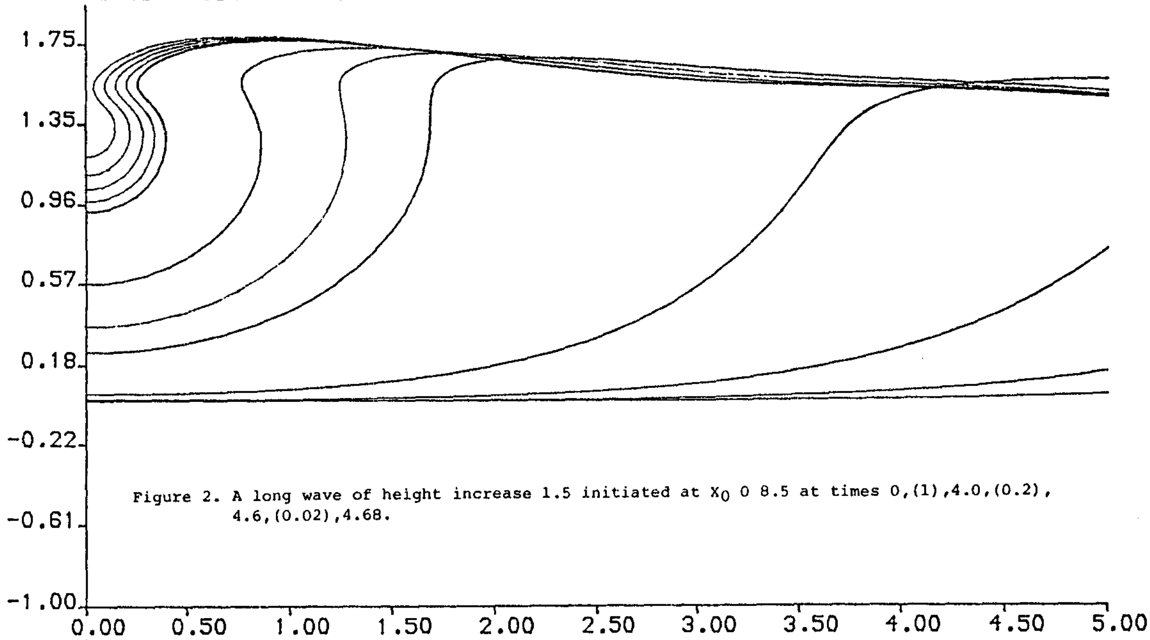

Figure 2. A long wave of height increase 1.5 initiated at X_0 0 8.5 at times 0,(1),4.0,(0.2), 4.6,(0.02),4.68.

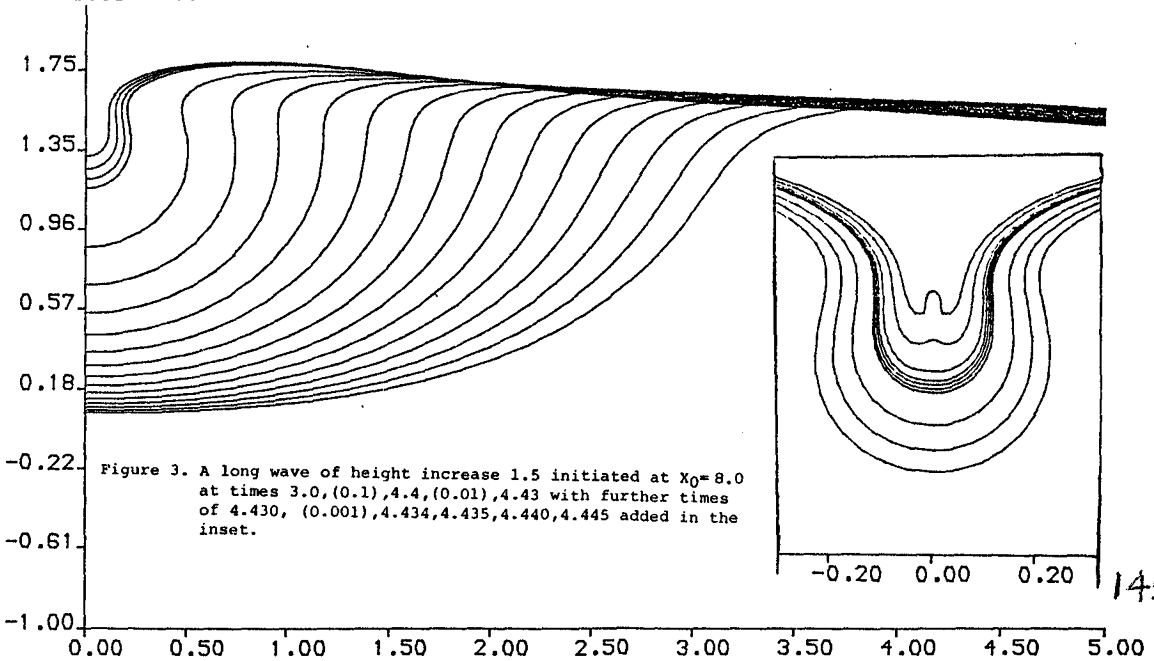

Figure 3. A long wave of height increase 1.5 initiated at X_0= 8.0 at times 3.0,(0.1),4.4,(0.01),4.43 with further times of 4.430, (0.001),4.434,4.435,4.440,4.445 added in the inset.

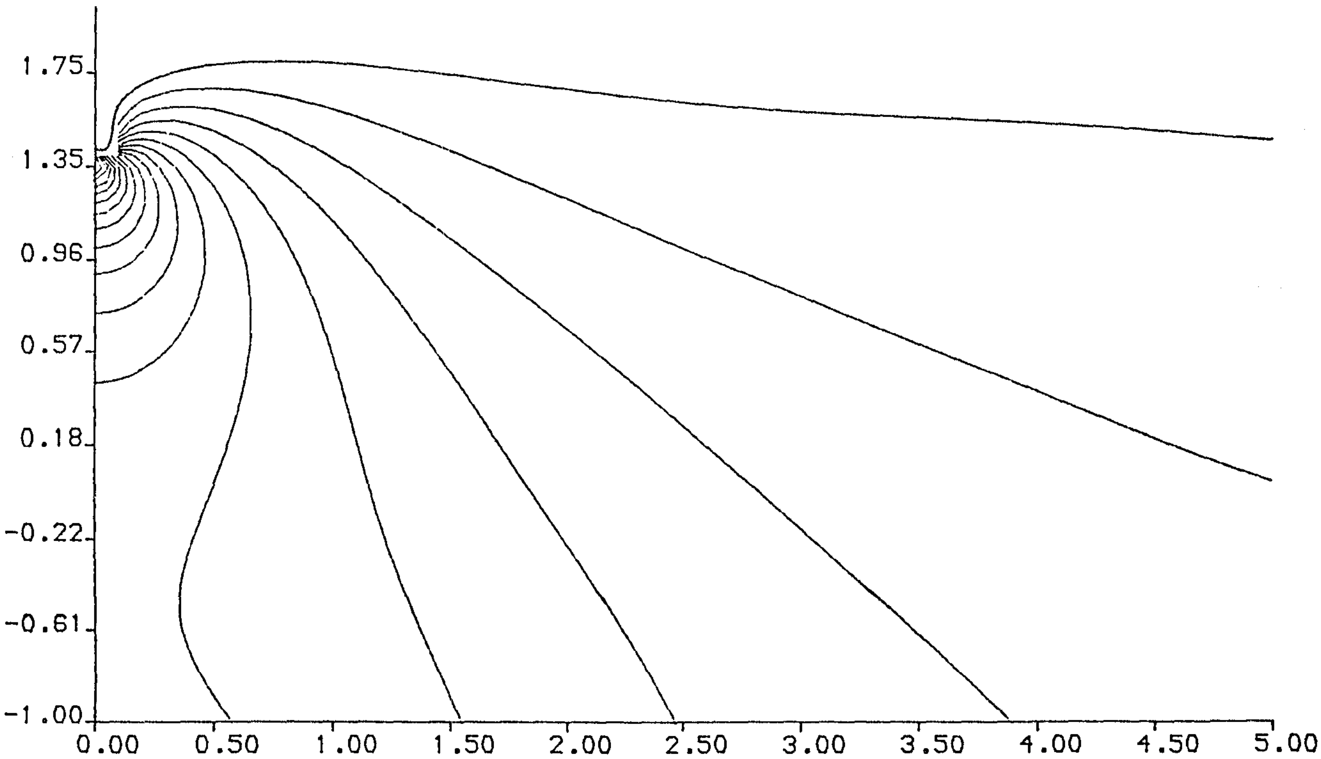

Figure 4. Pressure contours under the wave shown in figure 3 at time 4.440. Contour interval 2g. Maximum pressure 36.4.

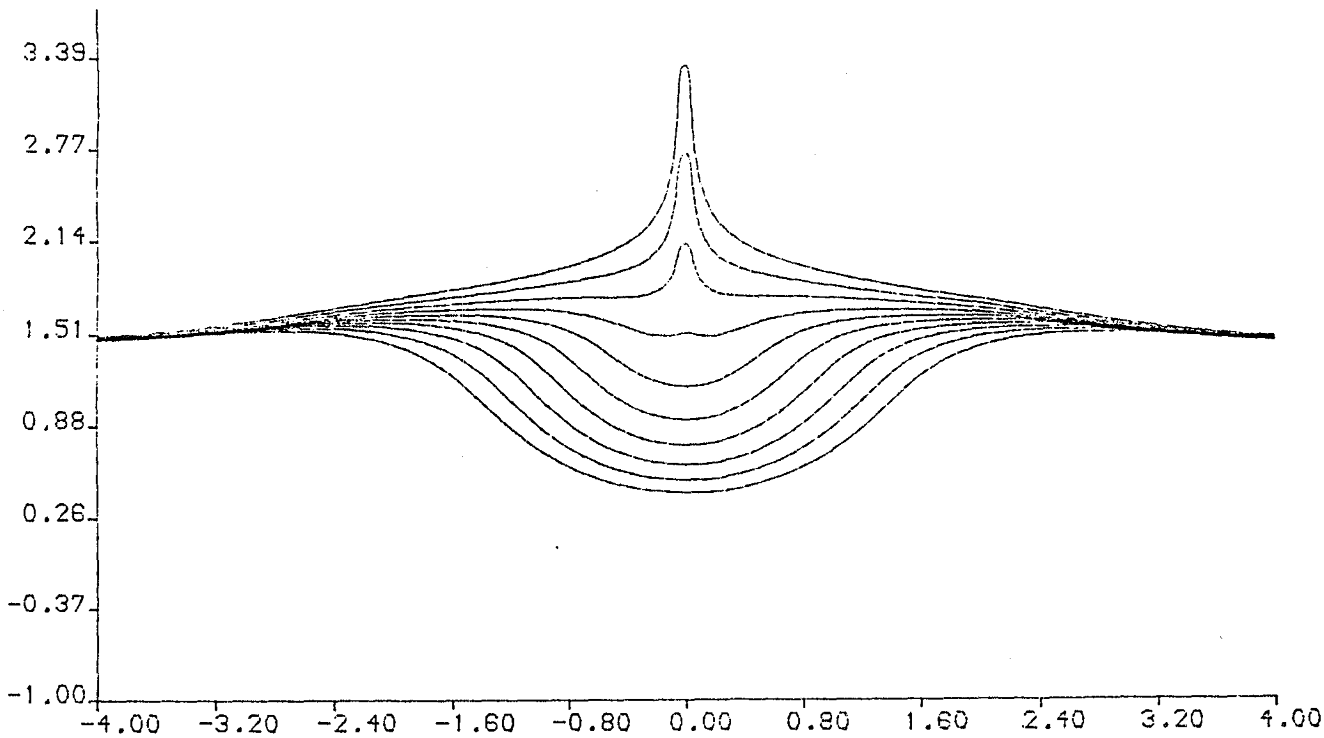

Figure 5. A long wave of height increase 1.5 initiated at $X_0 = 5.5$ at times 2.5,(0.1),3.4.

DISCUSSION

Newman: What is the relevant regime in practice — the intuitive impact/cushion phenomenon or this one?

Peregrine: The full range of regimes occurs in practice. The interesting question is which gives the most severe pressures? I suspect the 'flip through' mode as being most severe. In the direct impact case, it seems very unlikely that the overturning jet will attain a velocity of more than about $5(gh)^{1/2}$. However, one can imagine waves like the computed example with $x_0 = 8$ which 'focus' to an even smaller region before giving birth to a smaller but more violent upwards jet. Thus, there is no clear upper limit to the velocity of the upward jet or to the acceleration and pressures which produce it.

Schultz: Is it clear from the experimental literature that the wall jet regime (of the type that you can model here) is more hazardous than the slamming of overturning waves?

Peregrine: No. There are very few detailed observations of water motion with a time resolution of the order of a millisecond.

Sclavounos: Are there any practical limitations of the numerical scheme, such as time-stepping *vs.* panel size in the jet region where the rate of change of the flow is very rapid?

Peregrine: Time stepping is performed with a Taylor series method. Time steps are chosen to keep the fourth and fifth terms of the series below a chosen tolerance. We have run with different tolerances. In the most severe case illustrated, final values of Δt were less than 10^{-4} and the shortest distance between points was 0.003.

Korsmeyer: Have you tried to solve the problem using a gridded wall onto which the free-surface grid strikes? Presumably this is what one would have to do in three dimensions rather than employing symmetry.

Peregrine: No. We shall be studying sloping walls soon, but we do not require grid points on impermeable walls.

Greenhow: How important is the previous wave's downwash?

Peregrine: The horizontal velocity at the wall remains zero. Our computation corresponds to starting integration at a trough when seaward motion has ceased.