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# Experiments and Computations of Solitary Wave Action on a Submerged Obstacle.

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This work is part of a research programme on waves which encounter coastal structures. Here we consider unsteady waves in two-dimensional, irrotational, inviscid flows. We have used the boundary integral method developed by Dold and Peregrine (1986), which we have modified to tackle wave propagation over irregular beds. At the last Workshop we reported computations of the interaction between solitary waves and semi-circular submerged obstacles (Cooker and Peregrine [1988]), as shown in Figure 1. Here we report some experimental results which bear out our earlier numerical work.

We used the wave tank at Santander University in Spain, which is 70m long and 2m wide. It is equipped with a piston-type wave maker suitable for generating solitary waves of height up to about 0.51h, where h the depth, varied from 25.5 to 34.0cm. The depth was varied in order to change the relative size of the cylinder from 0.6h to 0.8h. Wave gauges were placed in the vicinity of the obstacle and the surface elevation was recorded as a function of time. A video record was also made.

Amongst other features the computer predictions show that waves of height between 0.3 and 0.6 (on a depth of unity), when passing over obstacles of radius between 0.7 and 0.9, the tail of the transmitted waves steepen and often break *backwards* onto the cylinder.

Figure 2 shows a comparison between computations and experimental measurements made by gauges near the backward breaker. (Figure 3 shows the gauge positions and *computed* profiles.) The agreement is good, and this is true of the other predicted phenomena. For instance the numerical results show that solitary waves decrease in amplitude as they approach the obstacle, and at the same time, a new crest grows on the other side of the obstacle. This new crest becomes the transmitted wave. The video clearly shows this crest exchange.

In those cases where the transmitted wave breaks forward, experiments and computations agree as to the time and position of breaking. It is worth noting that in all cases where the solitary waves break they do so *beyond* the obstacle.

The video recorded the wave behaviour close to the breakwater and has allowed us to look at the surface motion beyond the time at which our computations stop (It is not possible at present to compute beyond the initial wave overturning.) Figure 4 is a sequence of tracings from the TV screen which shows the surface steepening of a backward breaker. The incident wave crest moves from right to left. The backward breaker is seen to move from left to right, against the left side of the obstacle. As it moves the wave partly breaks, and continues back across the cylinder. This is peculiar, because clearly reflection has occurred in the uniform region behind the obstacle.

In the limited range of wave heights and obstacle radii of the experiments our computations give encouraging agreement. Although our computations give a complete description of the hydrodynamics there is much left to explain:

(i) Why is there a second crest when the wave is near the cylinder ?

(ii) Why do all breaking waves break beyond the cylinder ?

(iii) Why is it that in the uniform region beyond the cylinder, there are waves of reflection ?

The incident wave induces an unsteady current over the obstacle. We solve the problem of a steady current $U_0$ passing over the same obstacle, where $U_0$ is chosen so that a flux passes over the obstacle similar to that induced by the wave. Different disturbances develop downstream which are like those observed for the solitary waves. For example, the steady flow can induce a depression over the obstacle of comparable size to the dip between the two crests, seen during crest-exchange. The flow can also induce a backward breaking wave, similar to that caused by the solitary wave.

References:

1) Cooker, M. J., Peregrine, D. H. "Solitary waves passing over submerged breakwaters", 3rd Int. Workshop on Waves and Floating Bodies, Woods Hole, Ma, U.S.A. April 1988.

2) Dold, J. W., Peregrine, D.H. "An efficient boundary integral method for steep unsteady water waves", in "Numerical Methods for Fluid Dynamics II" eds. K. W. Morton and M. J. Baines, Oxford U.P. 1986, pp 671-679.

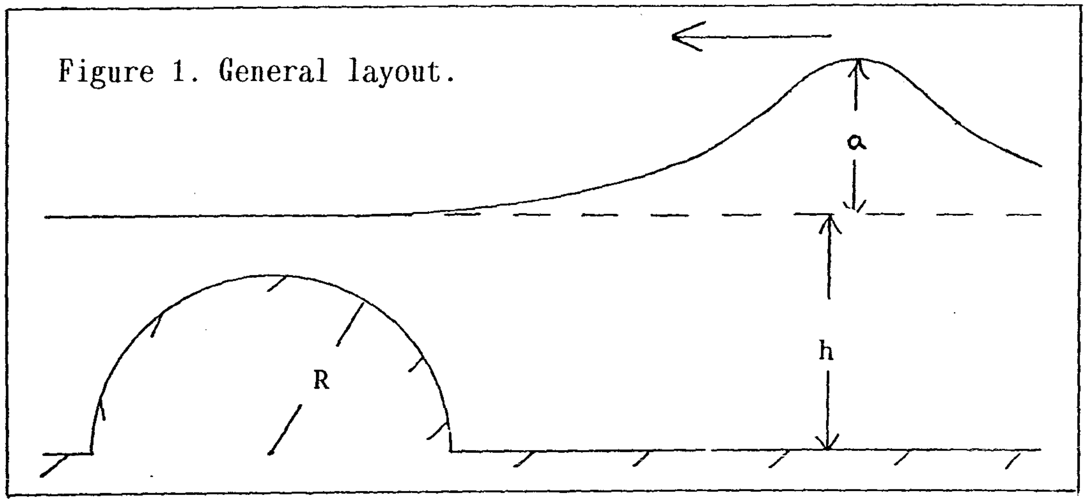


Figure 1. General layout.

Figures 2 and 3 shown on next page.

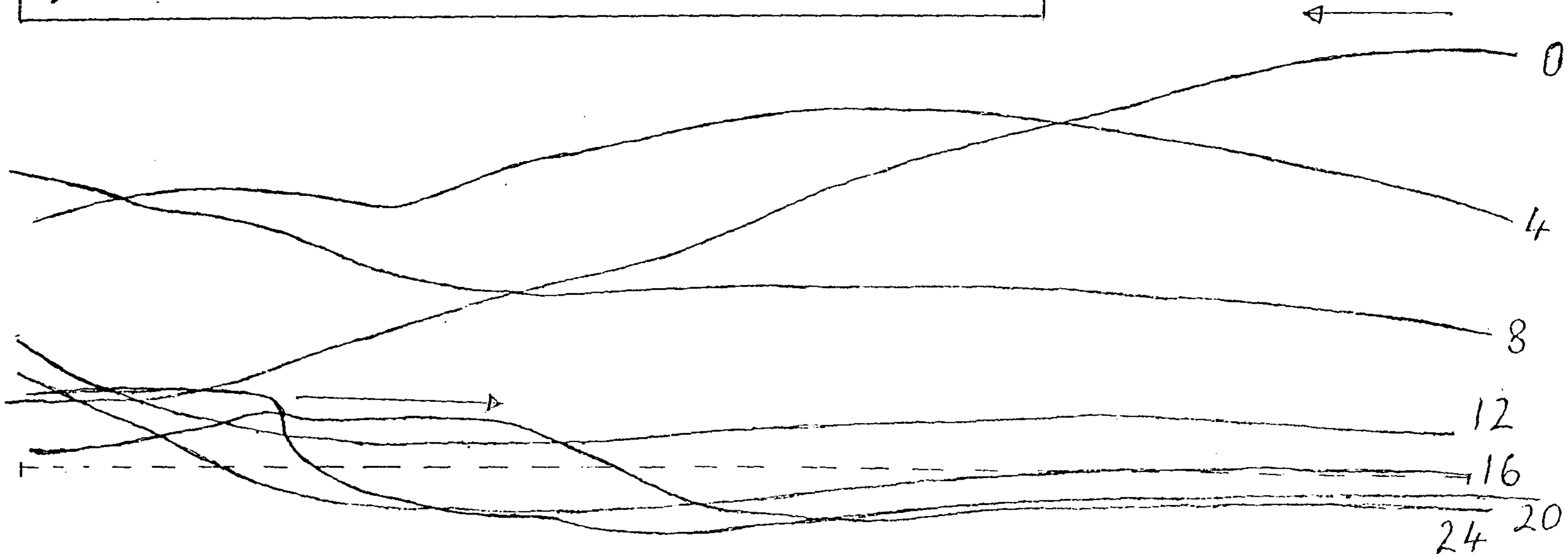


Figure 4. Video tracings of surface profiles. The frame numbers are shown.
Wave height a = 0.51, cylinder radius R = 0.7.

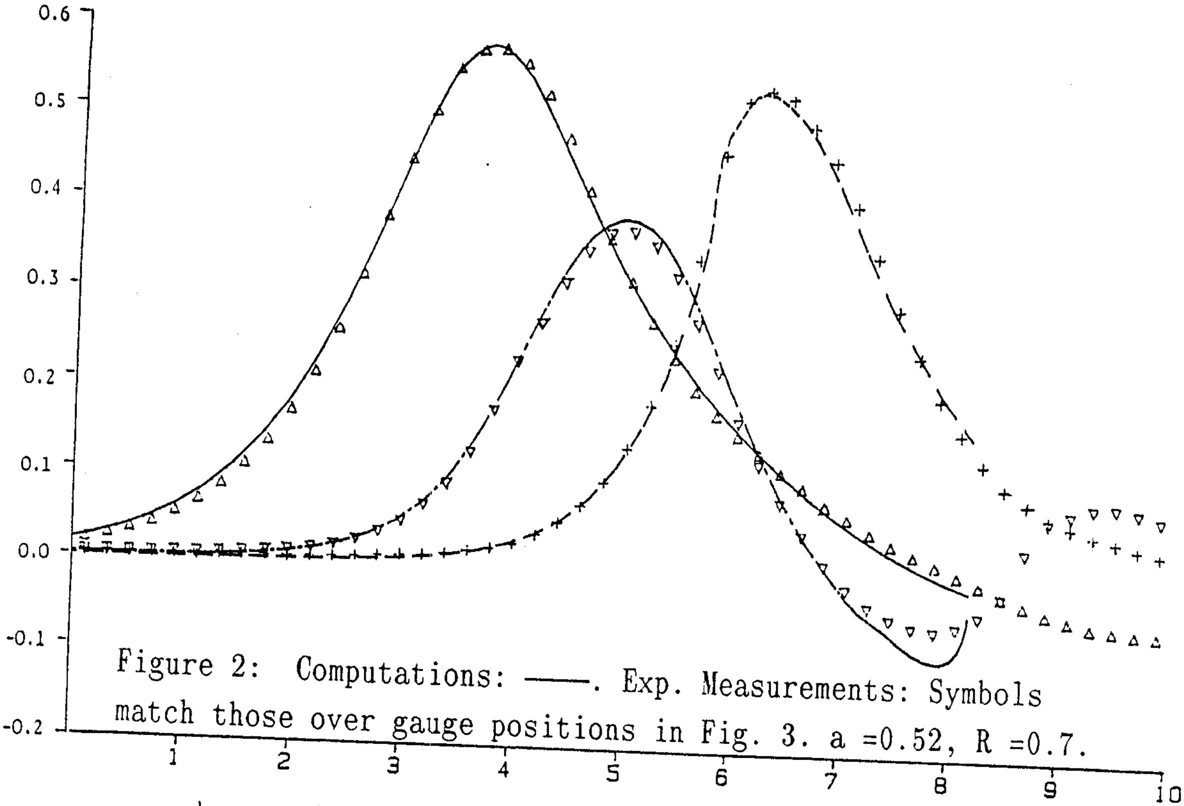


Figure 2: Computations: ——. Exp. Measurements: Symbols match those over gauge positions in Fig. 3. a =0.52, R =0.7.

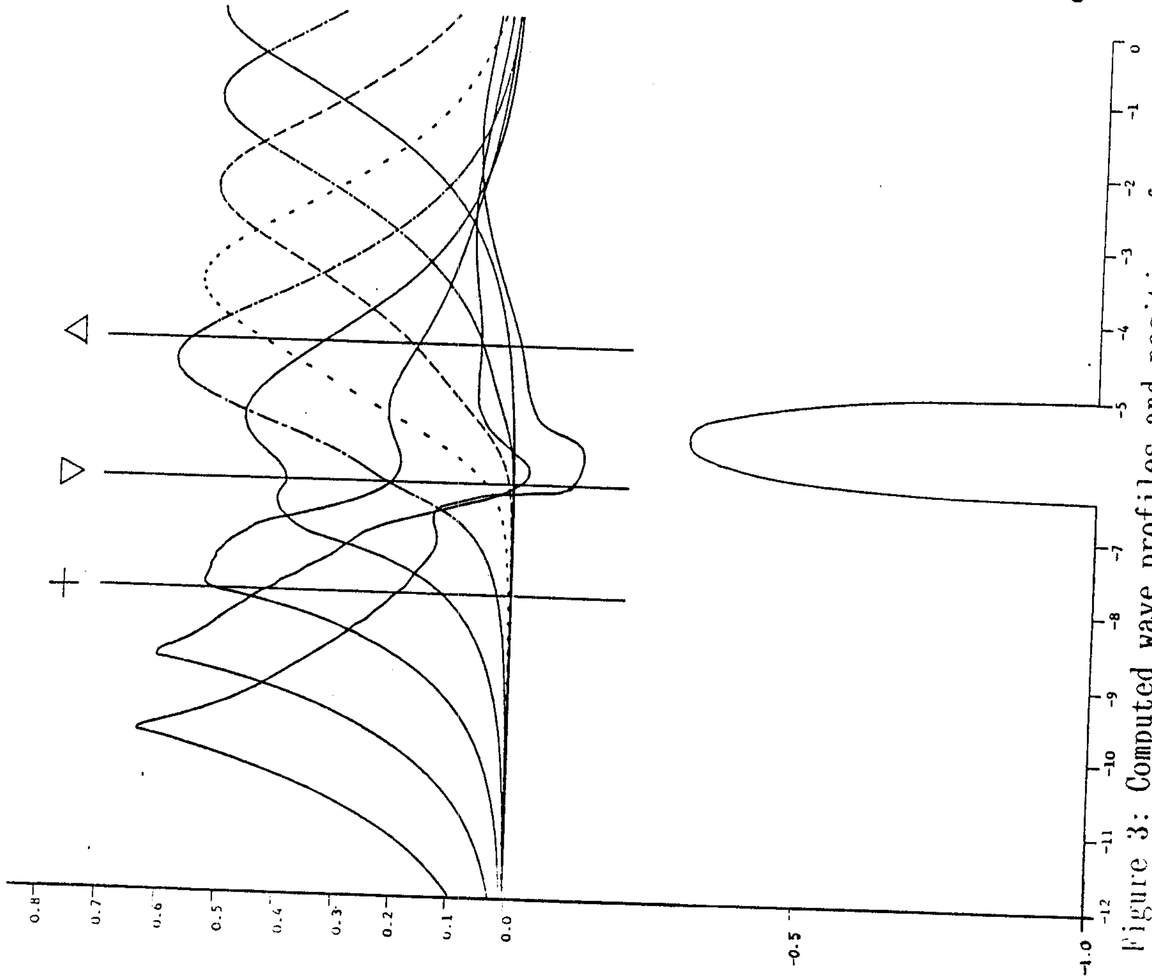


Figure 3: Computed wave profiles and position of gauges in Fig. 2. Note vertical exageration factor of 8.

## DISCUSSION

Vinje: Do you think that the backward breaking effect in this case can have anything to do with a bore-like behaviour? You used the complex velocity in your solution of the Laplace's equation. How do you step your solution forward in time then?

Cooker et al.: Our computations show that backward breaking does *not* occur in a supercritical flow. If we know initially $\phi$ on the free surface, then the integral quation gives us the derivative of $\phi$ normal to the surface $\phi_n$ .The tangential derivative can be found directly: call it $\phi_s$. Bernoulli's eq.: $D\phi/Dt = 1/n(\phi_n{}^2 + \phi_s{}^2)+gy$ gives $D\phi/Dt$. We can repeat the integral equation procedure for $\phi_t$ and so find $D^2\phi/Dt^2$, likewise the $\phi_{tt}$ problem gives $D^3\phi/Dt^3$. From these $D^n\phi/D^nt^2(\phi)$ terms we have a Taylor series for $\phi$ in time-likewise the free surface position is updated from **U**, DU/Dt etc. and we use the kinematic F.S. condition for fluid point **R** $D\mathbf{R}/Dt = \mathbf{U}$.

Dias: 1) How do you perform the marching in time (in the physical plane or in the transformed plane?)
2) In your last example, you said $U_\infty = 0.15$. Does it actually mean that the Froude number is 0.15?
3) Are you familiar with the work by Vanden-Broeck on steady solutions of ?

Cooker et al.: 1) Time-marching is only done in the physical plane.
2) Depth and gravity are scaled to 1, so $U_\infty$ is numerically the Froude no. of the flow at infinity.
3) I am unaware of Vanden-Broeck's work on the steady free-surface flow problem over a semi-circular obstacle. However, we are interested here in subcritical flows where Fr=O(0.1). [M. Cooker].

Greenhow: Is it possible that the discrepancy in measured and calculated free surface elevations is due to vortex shedding by the hump? Some flow visualizations would be nice!! [P.S. Are you sure the breaking wave is not some sort of hydraulic jump?]

Cooker et al.: I agree that flow separation from the surface of the cylinder may have occured. With hindsight we should have used a dye tracer. However, our video pictures do *not* show bubbles or cavitation at the cylinder surface. This of course does not say separation never occurred. The Froude number of the flow during backward breaking is *not* super critical, in the computations.

Moose (the huge): 1) Have you examined waves, incident on your semi-circle which are different from solitary waves?
2) In the 3D problem would you expect to find yourself wearing white shoes and white cricket trousers?

Cooker et al.: 1) Yes, I've looked at a group of sinusoidal waves, amplitude-modulated by $\exp(-x^2)$. The results are rather different with breaking occurring *at* the cylinder, in the shoaling part of the flow domain. The behaviour is very different from the solitary waves, and closer to intuition.
2) Yes!