Wave impact and aerated water

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Introduction

One of the greatest problems in scaling wave impact loads from the laboratory to prototype is the tendency for severe wave conditions at sea to be associated with much wave breaking and hence a persistent significant aeration of the sea water. Not only does aeration persist longer in sea water because of the predominance of smaller bubbles than in the fresh water usually used in laboratories, but the larger length scale of the waves leads to disproportionately longer times of residence for small bubbles. As a simple measure of the resulting compressibility of water we note that the velocity of sound can easily be reduced from 1500m s^{-1} to less than 100 m s^{-1}. This problem relates to both coastal and marine structures and to ship slamming. We note even in the laboratory that the effect of using salt water rather than fresh is significant, see Bullock et al. (2000a).

We are examining this problem for impact on breakwaters, where data is being obtained from Alderney Breakwater, and laboratory studies are being undertaken at two smaller scales, in the Breaking Waves on Coastal Structures (BWIMCOST) project. There are two major aspects to the theoretical modelling of this problem: (i) obtaining good representations of the waves at impact, and (ii) modelling the effects of the entrained air. Both offshore wave measurements and measurements on the breakwater provide input. These will be integrated with the modelling effort. At present only initial steps in the two aspects have been made, since wave data generated within the present project will only be available in the next month or two. However, data from earlier 1996 field measurements is available.

Entrained air

Figure 1 shows the record at one transducer for a single wave impact. Both pressure and air fraction are measured. As may be seen the air fraction is mostly in the range 5 to 15%, which corresponds to sound speeds in the range 45 to 80 m s^{-1}. Behaviour near the pressure peak is of greatest interest: this is shown in figure 2.

Eventually we intend to use two-dimensional modelling for the wave in its impact, with various regions given an initial air fraction β_0. However, for the present, one dimensional computations have been undertaken using the model described at the previous workshop of Porter & Peregrine (2001). The effect of the pressure recorded in figures 1 and 2 applied to the opening of a crack, 1 m long, containing aerated water has been modelled. Figure 3 shows the pressure at the end of a crack for different values of the initial air fraction β_0. Measurements of the pressure propagation into air filled cracks is also a part of the BWIMCOST project (with G. Muller, Queens University Belfast), and we therefore expect further experimental results. Further details of the computations and the differences between the dynamics of trapped air and an air-water mixture are in Porter (2003).

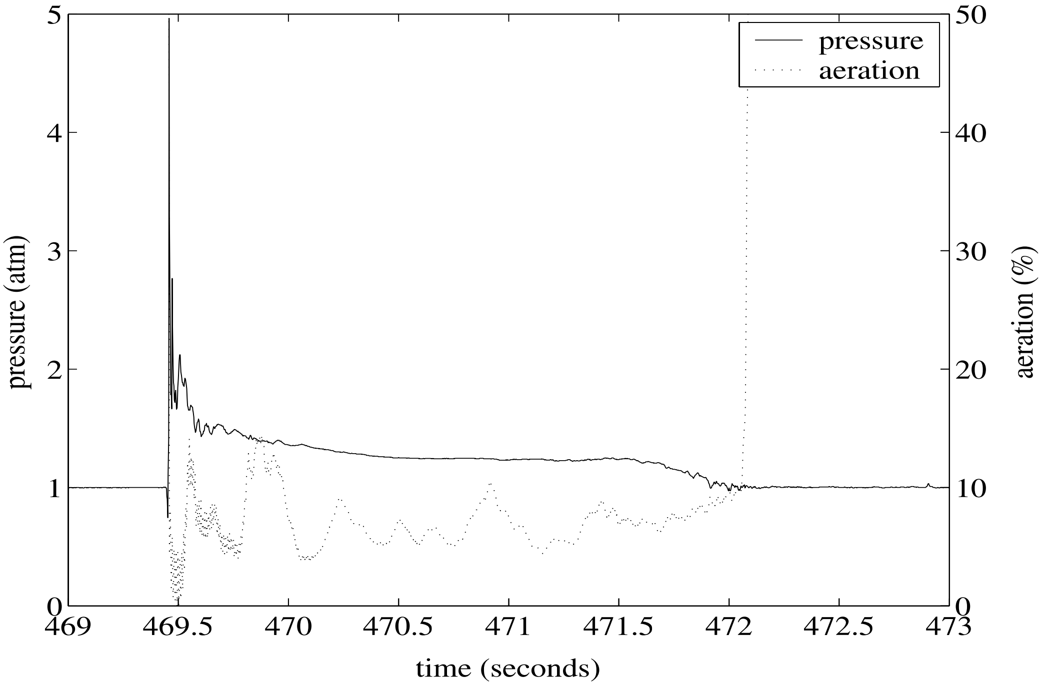

Figure 1. Pressure (solid line) and air fraction (dotted line) measurements from Alderney breakwater (see Bullock et al. 2000).

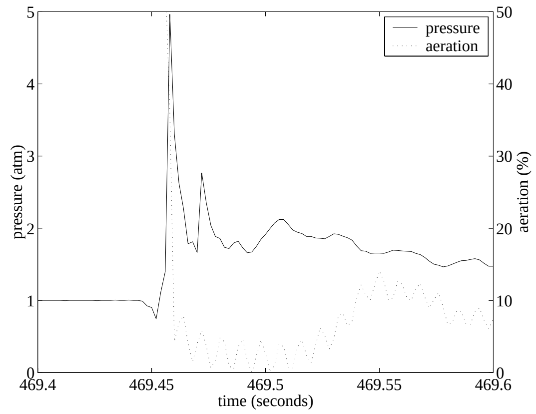

Figure 2. Pressure and air fraction in wave impact on Alderney breakwater.

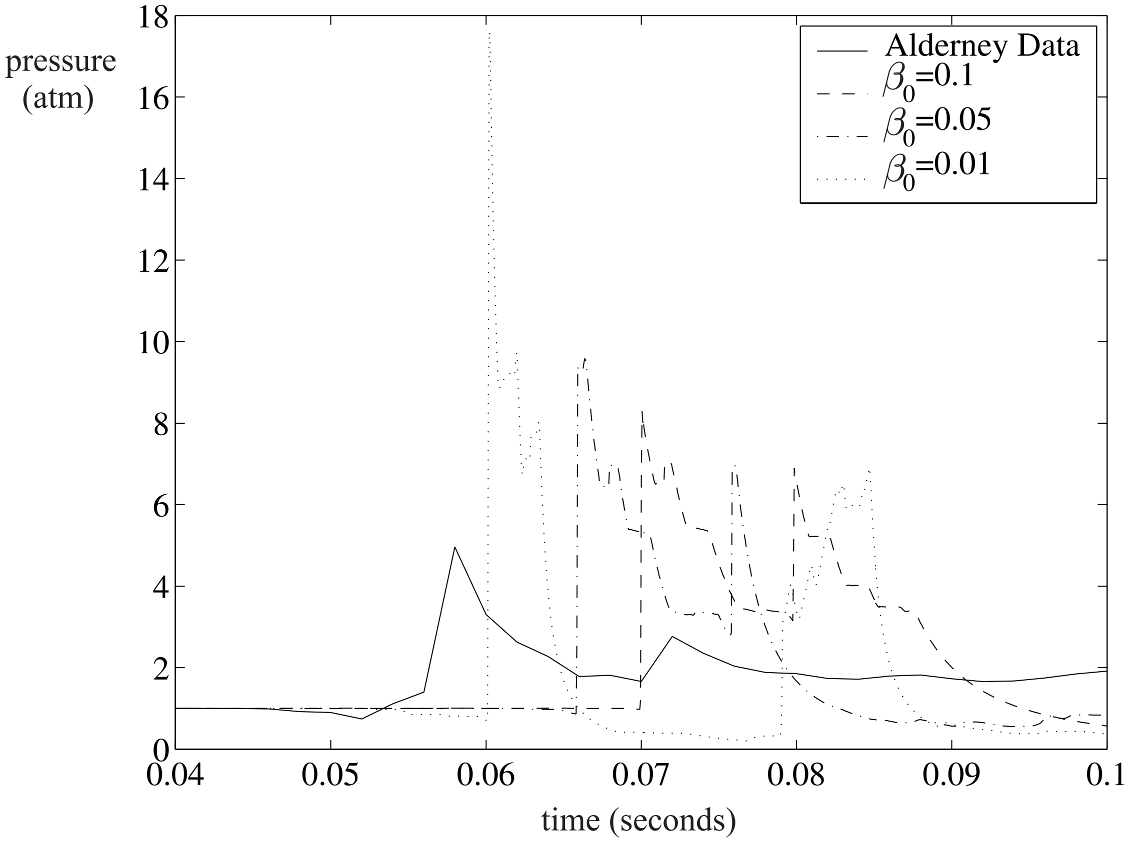

Figure 3. Pressure from wave impact applied to a crack of aerated water. The pressure at the end of the crack is displayed.

Incident waves

Measurements are often made of wave pressures on bodies, for steep and breaking waves it is often difficult to make good estimates of the waves that cause the measured loads, especially where ocean waves are involved. For the Alderney breakwater measurements there are a set of pressure recorders on the sea bed in front of the breakwater. Data from these recorders is the main source for modelling the impacting waves. Video has been tried but the rigours of field conditions, spray and lack of available light mean that such records are not practicable. Data from the 2002-03 field campaign will soon be available but, for the present, we have 1996 data which was distinguished by relatively mild sea conditions.

Preliminary results have been obtained by using a least squares solution and linear slowly varying wave theory to separate the incident and reflected waves measured from five wave recorders in a line perpendicular to the breakwater. A sixth pressure measurement off this line indicates that it is an almost two-dimensional sea. Both the incident and reflected waves are then propagated, forwards and backwards respectively, to the breakwater. The result is then compared with pressure measured at the lowest of the pressure recorders on the face of the breakwater. Figure 4 shows part of our first comparison. Very shortly we shall have corresponding records where nonlinear wave models are used to transfer the wave field from the pressure recorders on the bed to the face of the breakwater.

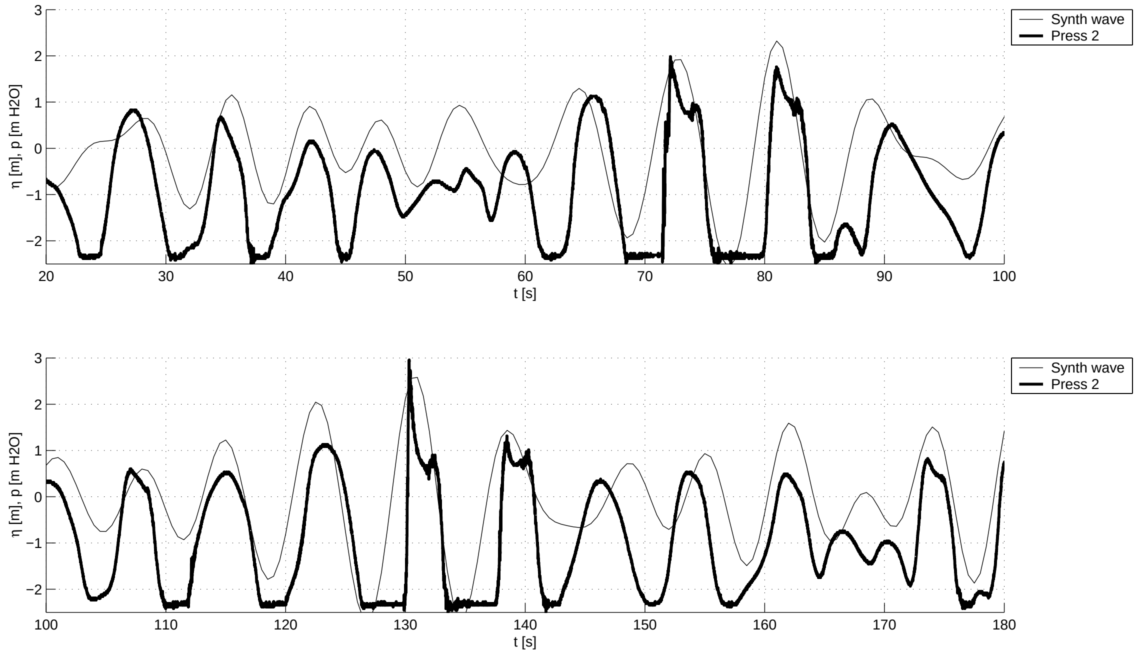

Figure 5. Pressure measurement on the face of Alderney breakwater, thick line, compared with linear prediction of waves at that point from offshore pressure measurements.

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Porter, A. and Peregrine, D.H. 2001 The effect of entrained air on pressure pulses in a thin crack, see http://www.wsatkins.co.uk/17iwwwfb/proceedings_text_graphic.htm (or, in due course, http://www.rina.org.uk/index.pl?section=IWWWFBProc&n=560).

Question by : R. Rainey
You showed a video of a series of large wave impacts in the Hannover tank and remarked that one impact was much more severe than the rest. Were the waves nominally identical (i.e. a regular wave train)?

Author's reply:
The incoming waves showed on the video are regular waves with a period of 7s. They are generated at a depth of 4.5m with a wave height of 1.3m. The water depth in front of the breakwater is 1.5m.
The large variability of the violence of impact pressures for regular waves has been described by Bagnold (1939). Witte (1988) presents statistics for a series of 200 regular waves, which also show a strong variability in the impact pressures.

References:
Bagnold, R. A. (1939) Interim report on wave pressure research. Proc. Inst. Civil. Eng. Vol 12, p 201-226.
Witte, H-H. (1988) Druckschlagbelastung durch Wellen in deterministicher und stochasticher Betrachtung. (In German, 227 pages). Mitteilungen Heft 102, Leichtweiss-Institut f\"u r Wasserbau, der Technischen Universit\"a t Braunschweig. ISSN 0 343 1223

Question by : Y.M Scolan
In time series of pressure measurements a small depression often appears before the peak occurs. The pressure gets negative just before the pressure increases rapidely as it can be seen in your figure 2. Have you tried to explain this?

Author's reply:
We have observed it too, but have not yet found an explanation. The air velocities for the escaping air are definitely large, but their unsteadiness makes a treatment using the Bernoulli equation non-trivial.
Another effect which may cause the decrease is elastic effects of the structure: The initial impact, occuring below a transducer, may accelerate the structure surface away from the surrounding air, creating a subatmospheric air pressure, until the water reaches the transducer and the pressure peak is measured.