Pressure-impulse theory for water wave impact on a structure with trapped air.

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Introduction

Research into wave impact on a vertical wall is of particular importance for the design of sea walls and breakwaters. A wave which is breaking or near breaking when it hits a structure can cause large peaks in pressure. These pressures though often of very short duration (1ms in the laboratory, 10-50ms in prototype), are sometimes substantial enough to shift or blow holes in a coastal structure. When a wave is breaking or near breaking when it hits a structure often a large amount of air becomes trapped. The amount of air which is trapped and the manner in which it is present has a significant effect on the pressures which occur. Bagnold (1939) made many observations of the impact pressures which occur when a wave hits a wall and noted the importance of any air pocket which may occur. In particular he noted that for nominally fixed wave conditions the pressures occurring vary from one wave to the next, but examination of the integral of pressure, with respect to time, over the short duration of impact (pressure-impulse) gives more stable results.

Air can be present in one of two forms: as a trapped air bubble or as dispersed air, or most likely as a combination of both. In particular Topliss (1994) looked at a theoretical model of the trapped air using an oscillating cylindrical air bubble. Peregrine (1994) gives a review of some of the methods used to model air entrainment/trapping during impact. Peregrine and Thais (1996) model scaling for entrained air in violent water wave impacts by using a 'filling flow' model (where a region is rapidly filled with liquid), following on from Peregrine and Kalliadasis (1996). This model has many similarities to the 'flip through' flow. Peregrine and Thais give an estimate of the reduction in pressure caused by the presence of the air.

In this section we consider a large air bubble trapped at the wall which produces oscillatory pressures. The impulse due to the first oscillation instead of bringing the water to rest, may bounce the water backwards. So the velocity of the part of the wave impacting may reverse in sign. Cooker and Peregrine (1990 b) looked at a pressure-impulse model for the 'flip through' conditions which corresponds to water motion normal to the wall ceasing on impact. If the compressed air causes the water to be pushed back, then the boundary conditions corresponding to a reversal of the component of velocity may be more appropriate. We call this effect 'bounce back'.

Pressure-impulse for 'bounce back'

We extend the Cooker and Peregrine (1990 a,b, 1992, 1995) model for impact of a wave on a vertical wall to allow for a trapped air bubble. We begin by assuming that the bounce back velocity is equal in magnitude, but opposite in sign to the ingoing velocity of the wave. Figure 1 shows pressure-impulse contour plots for the no 'bounce back' and 'bounce back' situations, where the bubble is supposed to be thin. The peak P is almost twice as big for the bounce back situation as for the no bounce back case. Pressure-impulse contours give a fair approximation to maximum pressure contours if a good estimate of impact duration is available. However in the case of bounce back, the time scale is dependent on the compression of the air, and hence is longer. Since bounce back gives a longer duration the estimated maximum pressures are generally smaller. If the duration is too long the pressure-impulse approximation becomes inappropriate.

Experimental comparisons

Experimental comparisons are full of complications. Firstly it is unclear over which period of time we should integrate the pressures to obtain the pressure-impulse. To begin with we have made comparisons with data from Hattori and Arami (1992 and private communication) using a very simple analysis procedure. A triangular distribution of pressure against time was chosen. Hence the pressure-impulse was calculated by multiplying the rise time (the time taken for the pressure to rise from zero to its first peak value) by the first peak in pressure. Figure 2 shows a comparison of the pressure-impulse

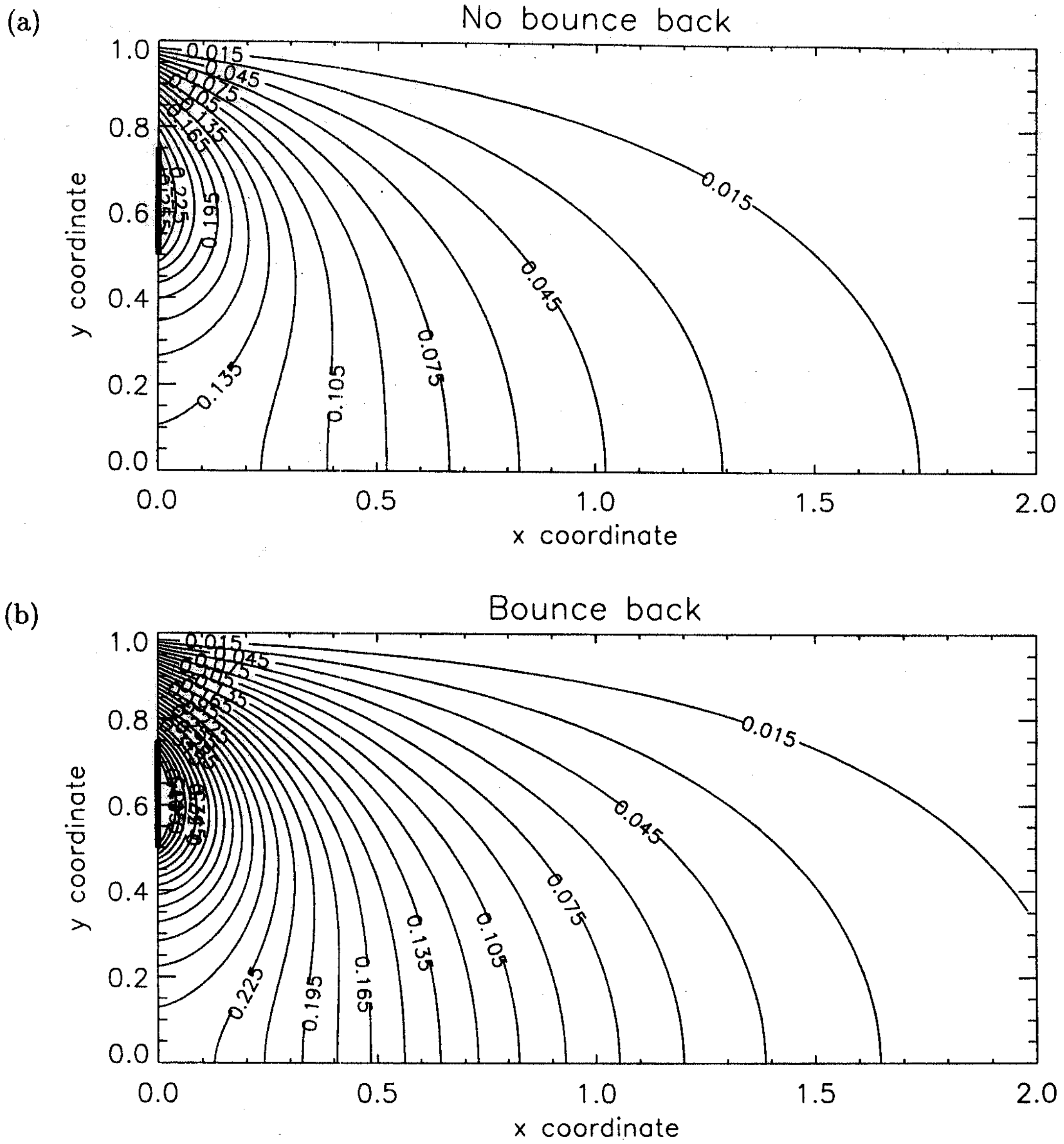

Figure 1: (a) Pressure-impulse contours for wave impact on a wall with no bounce back. (b) Pressure-impulse contours for wave impact on a wall with bounce back.

down the wall obtained in these experiments and the pressure-impulse predicted by the Cooker and Peregrine 2D wall impact model and the 'bounce back' model. The bubble position is denoted by a dark line. The 'bounce back' and 'no bounce back' are over and under predictions in comparison with some of the experimental data. The magnitude of the pressure-impulse is predicted reasonably well, but the shape of the pressure-impulse distribution is not reflected in the theoretical values. Total impulse for the 'bounce back', no bounce back and Hattori data are 1.746, 1.078 and 1.742 respectively. The value of total impulse is predicted well by using the 'bounce back' method, whereas the 'no bounce back' method under predicts.

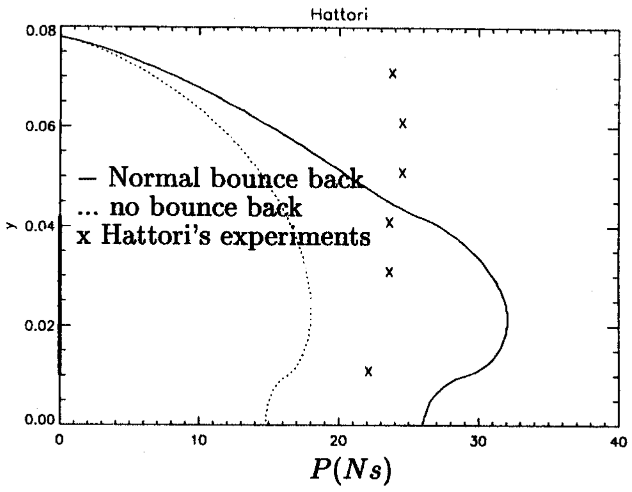

Figure 2: Pressure-impulse along the left hand wall, for 'bounce back', 'no bounce back' and Hattori's experiments (1992).

Further comparisons

A relatively new method of experimentally obtaining a velocity profile for an impact is Particle Image Velocimetry (PIV). Oumeraci, Bruce, Klammer and Easson (1995) and Oumeraci, Partenscky, Klammer and Kortenhaus (1997) describe PIV measurements made at the University of Edinburgh. We use these experiments to make further comparisons.

Two further improvements were carried out firstly in the numerical model and secondly in the analysis of the experimental data. As mentioned in the analysis of Hattori's experimental values, the 'bounce back' method produces values of pressure-impulse which are too high as we make an assumption that the bubble bounces back with the in going velocity. A more realistic approach is to consider the bubble bouncing back with a cosine velocity profile, i.e. that there is no 'bounce back' at the edges of the bubble and the maximum 'bounce back' is at the centre of the bubble. This is similar to considering the bubble as being spherical and just 'bouncing back' with a component of the velocity. This gives a slightly better prediction of the pressure-impulse.

Secondly a more complex analysis of the experimental data was used in order to separate the relatively slowly varying part of the pressure from the impulsive part. The pressure-impulse was calculated by integrating from the start in the rise in force, to the first 'flat' part of the force graph after the peak, keeping within the time limit within which pressure-impulse theory is valid. A triangular (or trapezoidal) distribution of pressure was subtracted off the pressure-impulse so as to remove the effect of a background pressure. Figure 3 shows the comparison of the Edinburgh PIV data and the 'bounce back' and no 'bounce back' prediction methods. The distribution prediction is far from perfect but adequate. The 'bounce back' model also gives good predictions along the berm in front of the wall.

Conclusion

The 'bounce back' model gives predictions of within 40% of the experimental pressure-impulse values. Currently there has been little theoretical work carried out to model this problem, so even these

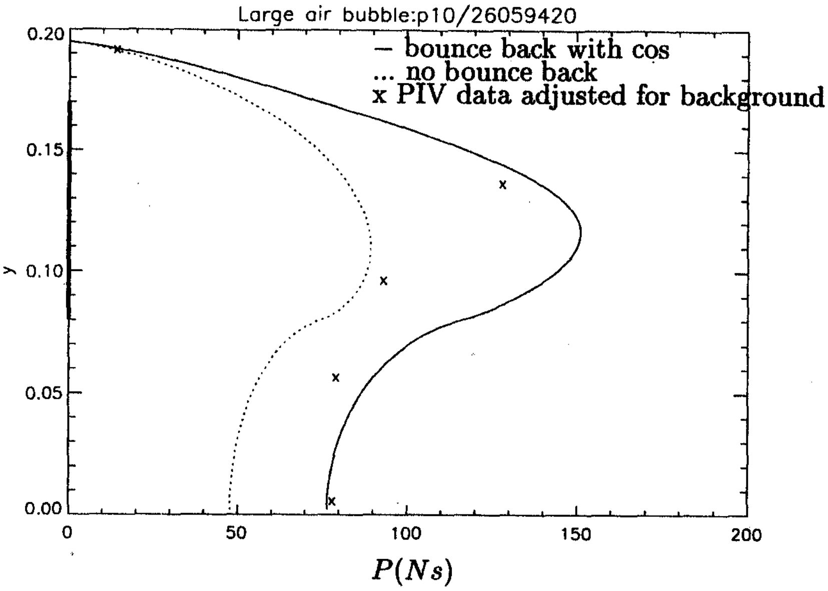

Figure 3: Pressure-impulse on the wall, for impact of a plunging breaker trapping a large air pocket

estimates are an improvement. The bounce back model also gives good predictions for pressure-impulse along a berm in front of a vertical wall. It is hoped to use new experimental data from the MAST 3 project (details below) to compare and improve the model of impact with air.

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