THE EFFECT OF ENTRAINED AIR ON PRESSURE PULSES IN A THIN CRACK

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SUMMARY

Entrained air in the form of small bubbles is thought to play a strong role in determining the pressure exerted on coastal structures in violent wave conditions. Thin cracks or fissures in sea walls or breakwaters are vulnerable to high pressures caused by wave impacts. In this work governing equations for a finite amplitude bubbly flow are presented. Numerical solutions show a strong amplification of pressure pulses in thin cracks, with possible resonant effects.

1. INTRODUCTION

When a breaking or near breaking wave hits a sea wall or breakwater, violent impacts can occur. An important design issue for breakwaters is the size and magnitude of pressures arising from such impacts. When scaling from laboratory tests to full-scale field situations, the natural choice of Froude scaling is thought to overestimate prototype impact pressures. A major difference between laboratory and field observations is the amount of entrained air in the waves. When even a small amount of air becomes entrained in the water, compressibility effects become important. The presence of air is thought to cushion the impact. With waves breaking continuously at sea, in particular during storms, entrained air is an intrinsic part of wave impact in coastal situations.

Air can be entrained in the water either in the form of small air bubbles, or an air pocket, or, more likely, as both. In this work we concentrate on the case of air entrainment in the form of small bubbles. For a 'filling flow', Peregrine & Thais (1996) were able to compare analytic solutions of the maximum pressure for a compressible bubbly flow with the incompressible results of Peregrine & Kalliadasis (1995). The presence of bubbles in the flow was shown to reduce the maximum pressures. Bullock, Crawford, Hewson, Walkden & Bird (2001) found similar pressure reductions when comparing wave impact between fresh and salt water where, due to the different properties of the bubbles in the two fluids, the aeration levels are much higher in salt water than in fresh.

We consider the particular problem of pressure pulses in a crack or fissure in a breakwater for the case where the fluid in the crack contains a mixture of air and water. Full non-linear governing equations for a bubbly flow are presented where the amount of gas in the mixture is allowed to vary. Numerical solutions for sinusoidally varying pressure pulses in a one-dimensional crack are presented and possible resonance effects noted. This is work in progress, and we expect that more results will be available for the workshop.

2. GOVERNING EQUATIONS

The bubbly flow is modelled as a two-phase air-water mixture with both phases travelling with the same velocity $\mathbf{u}$. Violent flows with large pressure-gradients are of particular interest, with the flows sufficiently violent that gravity may be neglected, but not so violent that compressibility effects in the liquid phase become apparent. The mixture is considered as a homogeneous compressible fluid with the pressure in the gas equalling that in the mixture.

Denote by β the volume fraction of air in the mixture. The density ρ of the mixture is then written as

$$\rho = \beta\rho_g + (1-\beta)\rho_l, \tag{1}$$

where ρ_g and ρ_l are the gas and liquid densities respectively. Here, both β and ρ_g are functions of space and time. Conservation of mass then gives

$$\frac{\partial \rho}{\partial t} + \nabla.(\rho\mathbf{u}) = 0. \tag{2}$$

Since the density of the gas varies with two parameters, β and ρ_g, it is convenient to have a second conservation of mass equation. Treating the two phases seperately, conservation of the liquid phase enables us to find an equation for β alone,

$$-\frac{\partial \beta}{\partial t} + \nabla.[(1-\beta)\mathbf{u}] = 0. \tag{3}$$

With the pressure p assumed to be unifrom over the two phases, conservation of momentum and energy flux gives

$$\rho\frac{\partial \mathbf{u}}{\partial t} + \rho\mathbf{u}.\nabla\mathbf{u} + \nabla p = 0, \tag{4}$$

and

$$\frac{\partial E}{\partial t} + \nabla.[(E+p)\mathbf{u}] = 0, \tag{5}$$

respectively. The total energy E is a sum of the internal energy, e, in the mixture and the kinetic energy, *i.e.*

$$E = \rho(e + \frac{u^2}{2}). \tag{6}$$

It is reasonable to assume in coastal situations that the bubbles are large enough for the gas to behave adiabatically. We use the pressure-density relation given by Peregrine & Thais (1996) as

$$\left(\frac{p}{p_0}\right) = \left(\frac{\beta_0}{\beta_0 - \delta}\right)^{\gamma} \tag{7}$$

where $\delta = 1 - \rho_0/\rho$. From standard gas dynamic reasoning, the energy pressure relation is

$$E = \frac{\beta p}{(\gamma - 1)} + \frac{\rho u^2}{2}. \tag{8}$$

A finite-difference numerical scheme is used to solve equations (2)-(5) in one-dimension. Simple analytical solutions are easily found from the shock relations and can be used to find the pressure exerted on a rigid boundary for specified one-dimensional impact velocities for varying amounts of aeration in the water. The pressure profiles for both the analytical and numerical solutions are shown in figure 1. A strong agreement here can be seen between numerical and analytical results. As expected, the air acts to cushion the impact, with the pressures dropping dramatically with only small increases of entrained air.

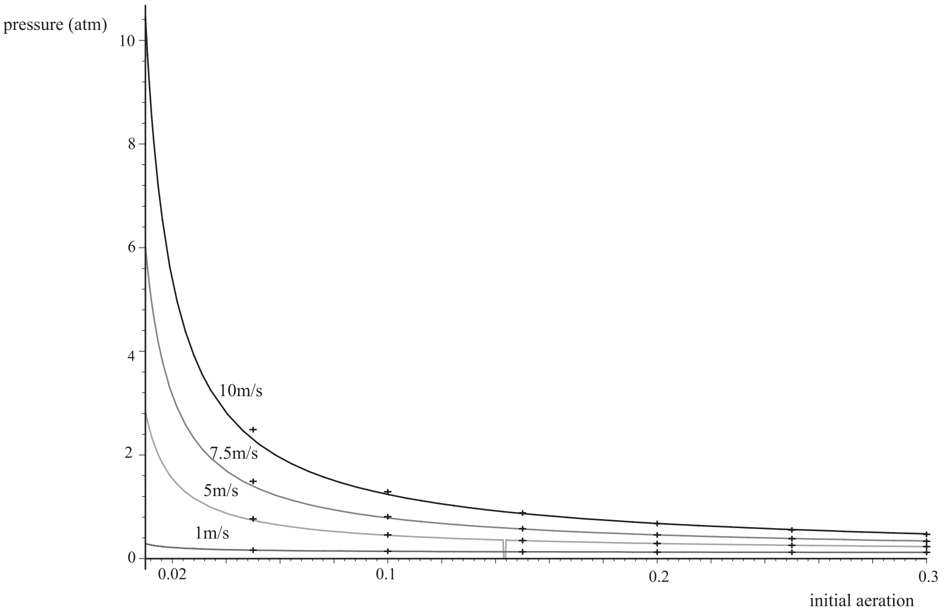

Figure 1: The pressure exerted on a wall for different one-dimensional impact velocities for water with varying amounts of entrained air: numerical (+++), analytical (—).

3. PRESSURE PULSES IN A THIN CRACK: PRELIMINARY RESULTS

In violent storms with waves crashing continually against a breakwater, thin cracks or fissures in the wall become vulnerable. Bollaert & Schleiss (2001) report on experimental measurements in simulated rock fissures subject to pressure fluctuations due to high velocity jet impacts. The situation they are investigating in particular is of high velocity plunging jets such as those that occur at the downstream end of dams, impinging onto rock beds. They seek an undestanding of the relationship between the jet characteristics in the plunge pool, and the water pressures in rock fissures. In particular they experimentally investigate the relationship between the pressure fluctuations and the air-content of the two-phase air-water mixture inside the fissure. Experimental results of the pressure measurements at the fissure entry and fissure end show a strong amplification of the pressure pulses in the aerated fluid.

Representing the pressure at the crack opening by a sinusoidally varying pressure pulse, figure 2 shows the pressure generated at the end of the crack in our numerical model. The shape and magnitude of the calulated pressure compares well with the results of Bollaert & Schleiss (2001). Note the considerable amplification of the pressure variation. The sudden increase in the magnitude of the pressure response indicates the possible effects of resonance in the crack. A preliminary plot at the first resonant frequency is shown in figure 3 showing increases in the pressure fluctuation and the development of shocks.. Work showing comparisons with the results of Chester (1964) for forced resonant oscillations in a gas is hoped to be presented at the workshop.

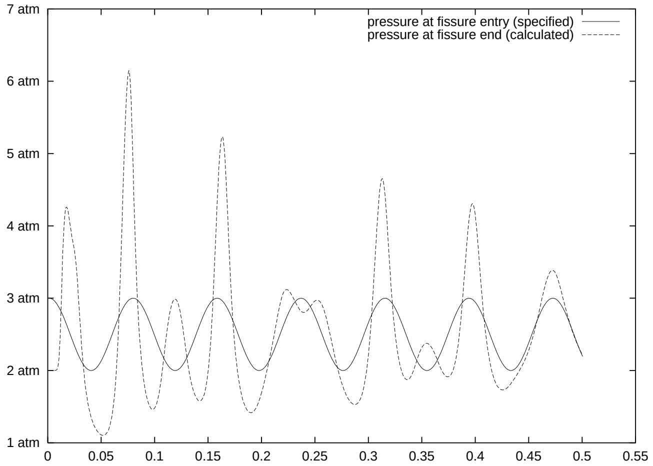

Figure 2: Pressure generated in a thin crack by a sinusoidally varying pressure pulse.

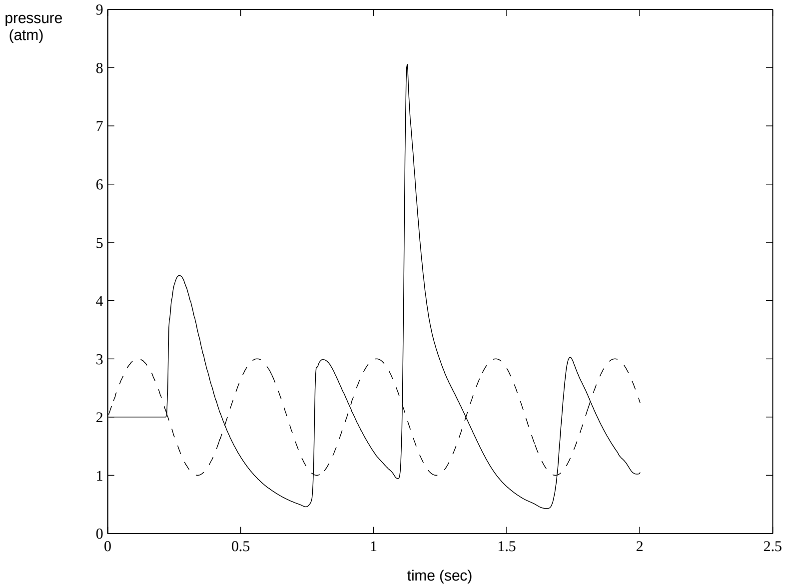

Figure 3: First Resonance; specified pressure at crack opening (- - -), calculated pressure at crack end (—).

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Discussion Sheet

Abstract Title :	The effect of entrained air on pressure pulses in a thin crack		
(Or) Proceedings Paper No. :	38	***Page :***	147
First Author :	Porter, A. and Peregrine, D.H.		
Discusser :	Rod C.T. Rainey		

Questions / Comments :

The effect you describe of a resonance in the entrained air, excited by turbulence in the water, is well-known in submarine design. A cavity open to the slipstream can have a "Helmholtz resonance", which makes a significant contribution to the acoustic signature of the submarine.

Author's Reply :
(If Available)

Author did not respond.