On the Numerical Modelling of Cavitation and Violent Wave Interactions

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ABSTRACT

The present paper focuses on a numerical approach to simulate wave propagation and phase change in compressible water. The thermal and caloric behavior of water and vapor is described by a one-fluid model on the assumption that the two-phase regime can be described locally within a finite volume cell as a homogeneous mixture that remains in thermodynamic and mechanical equilibrium. Closure of the equation set is achieved by deriving equations of state for pure fluids and the mixture that cover all possible fluid states. Following a description of the flow model and the numerical method, computations are carried out to demonstrate the potential of the method for treating wave interaction problems in water involving cavitation.

KEY WORDS: Cavitation; hydrodynamics; violent wave interactions; slamming; compressible flow.

INTRODUCTION

The numerical modelling of highly nonlinear waves and their subsequent interaction with a structure continues to receive significant attention. The prediction of greenwater overtopping, slam loadings on offshore structures, violent sloshing in LNG tanks and the survivability of moored wave energy converters are all important in engineering design. A numerical wave tank (NWT) might employ a full Navier Stokes code capable of handling overturning waves linked to a nonlinear full potential method or boundary element method to maximise computational efficiency. However, it is in the region where the wave impacts violently upon the structure that the modelling and flow physics are at their most complex and challenging. This region may require a more detailed fluid model that, in addition to solving the flow equations in both air and water regions in a fully coupled manner, also admits the additional physics of aeration, as waves break, and change of thermodynamic state, including cavitation, when the water is placed in tension. In such cases, the acoustic properties of water change substantially, as illustrated in Fig. 1, which shows that the sound speed may decrease by orders of magnitude, to a few meters per second. Thus, even in cases where the water velocity remains relatively low in absolute terms, compressibility is an important consideration including the appearance of shock waves or rarefactions during condensation and evaporation.

This paper focuses on fluid models of change of state in water without the inclusion, at this point, of the free surface, and, in particular, on cavitation, as a step in the development of a fully coupled free surface flow model of violent wave interactions with structures. The collapse of a single isolated cavitation bubble has been extensively studied experimentally and theoretically. Experimental observations demonstrate [Philipp and Lauterborn, 1988] that violent shock structures and radiated pressure waves may occur with reported shock intensities in some instances of tens of thousands of bar acting on a nearby surface due to bubble collapse. Numerical modellers have used various models to predict cavitation. These include panel methods [Dang, 2000], pressure correction techniques with phase transition modelled using calibrated rate models [Senocak and Shyy, 2002] and hybrid incompressible water–compressible gas finite volume codes [Bredmose et al., 2009]. Amongst these, two phase models are popular because it is possible to include or model much of the underlying physics of cavitating flows. These assume that each phase is governed by its own set of differential equations resulting in so-called five, six or seven-equation models [Allaire et al., 2002]. Alternatively, one-fluid models treat the cavitating flow as a mixture of two fluids but for closure they require appropriate constitutive relationships for pure fluids and the mixture that cover all possible fluid states. Models such as these include the so-called Cut-off model [Liu et al. 2004] that limits minima in the local pressure values to the saturation level, the Vacuum model [Wardlaw and Luton, 2000] and the present model. The one fluid approach we adopt for cavitating water within a Riemann-based finite volume compressible water hydrocode admits change of state thermodynamics locally and the formation and propagation of shock and rarefaction waves and associated wave dynamics.

![Acoustic properties of water: speed of sound versus water vapor fraction](image)

Fig. 1 Acoustic properties of water: speed of sound versus water vapor fraction.