The role of fluid compressibility in predicting slamming loads during water entry of flat plates

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ABSTRACT

This paper presents a numerical and experimental investigation of the water entry of a rigid flat plate. The experimental work was carried out in the Ocean Basin at Plymouth University’s COAST laboratory. An in-house CFD code AMAZON-CW, which is based on a compressible multiphase flow model, was used to simulate the slamming problem. The impact loads on the structure recorded in experiments agree well with the numerical computations. A difference from the impact of sharp, wedge-type bodies, is that the slamming loads exerted on flat plates have pulsations due to the compressibility of fluids.

KEY WORDS: hydrodynamics; multiphase flow; free surface.

INTRODUCTION

The prediction of slamming loads for hydrodynamic impact problems is an important topic in marine and aerospace engineering (Faltinsen, 1993). Under violent wave conditions, the bow of a ship can emerge from the water then re-enter water at high speed. This may cause severe local damage and high-frequency global stress (Xu and Duan, 2009). In emergencies, civil or military aircrafts need to land on the water to evacuate the crew and passengers. Hydrodynamic impulsive pressures and forces exerting on the fuselage will potentially damage the aircrafts and threaten the lives (Hughes et al., 2013).

The first theory to calculate the slamming loads on rigid structures was proposed by von Karman (1929) when he was studying the aircraft ditching problem. For a 2D flat plate, he proposed that the peak pressure \( p \) is linearly related to the water density \( \rho \), impact velocity \( v \) and speed of sound in water \( c \) as \( p = \rho vc \). This is referred to as the acoustic pressure by many scientists.

In the following several decades, different theories were proposed by other researchers. Some investigators conducted experiments to study the impact pressures on structures and they noticed that the acoustic pressure proposed by von Karman was always above their measurements. Careful inspections reveal that the underlying reason causing the discrepancy is the cushion effect of the air trapped into water by the flat plate, which was ignored by von Karman in his theory. For other blunt bodies like cylinders or hemispheres, some recent experiments also show that air was trapped into water during the slamming events (Lange and Rung, 2011; Lin and Shieh, 1997; Hicks et al., 2012).

During the water entry, blunt bodies usually trap a relatively large amount of air beneath their lower rigid or flexible surface. The air is extensively compressed and forms a very thin layer when approaching the water surface. The compressed air will deform the free surface near the edge of the structure. The slamming pressure rises sharply to its peak value then drops. After the peak, the initial compressed air layer starts to expand and the pressure drops below the atmospheric value, causing subsequent ventilation (Faltinsen, 2000). Thus air will be drawn in under the structure and the sub-atmospheric pressure will quickly recover with the ventilation and contraction of the trapped air layer which will potentially cause a second loading on the structure. The trapped air layer will then repeat expansion and contraction resulting pulsating loads on the structure. These complex but important phenomena have been observed in experiments. Although CFD methods based on the potential flow model or incompressible single-/two-phase Navier Stokes equations have been more frequently used in engineering design and analysis, the complex physics of compression, ventilation and contraction of fluid occurring in hydrodynamic impact events cannot be directly handled by the abovementioned methods. This requires a more sophisticated flow model that can deal with both the air and water phases accounting the fluid compressibility.

In this paper, a numerical and experimental study is carried out to investigate the water entry of blunt bodies. We focus on the pulsatile loadings caused by the compressibility of the trapped air layer. We apply a compressible multiphase flow model to solve slamming problems. The numerical model has the capability to properly deal with the compressibility of trapped air and air-water mixture.

The remainder of the paper is organized as follows. The experiment setup for the flat plate slamming problem is first described and the details of the numerical model presented. Then the numerical results are compared to the laboratory measurements. Finally some conclusions are drawn and future work is discussed.