Pressure measurement in 2D sloshing simulations with SPH

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Abstract

Sloshing for low filling level resonant pitch motion is studied experimentally and numerically using SPH. Special attention is paid to the pressure fields on the tanks. Comparisons are made with experimental data and with Particle Finite Element Method (PFEM) calculations.

1. Introduction

Extensive experimental programs aimed at a better comprehension of the sloshing loads have been conducted for the last 30 years (Bass, 1985, Berg, 1987). The reason for this interest lies mainly in the influence of these loads in the design and operation of LNG tankers. CFD technologies are helping in the understanding of these loads, usually tracing the free surface evolution by VOF techniques (Kleefsman, 2005), but to date, it is difficult for these techniques to model fragmentation and compressibility effects, which are crucial during the impact. Meshless methods like SPH (Monaghan, 2005) can be especially appropriate when modelling the highly non linear free surface flows with impact and fragmentation that appear in violent sloshing flows. This short paper focuses on the assessment of these local loads, following a previous one from the same group (Souto-Iglesias, 2006), in which global loads were successfully reproduced. SPH results are compared with experiments and with monophasic PFEM results (Idelsohn, 2007) for the same case.

2. Experimental results

The case studied is a 2D longitudinal section of a tank that belongs to a 138 000 m^3 LNG membrane tanker in operation, at scale 1:50. Model dimensions are 90 x 58 x 5 cm and water depth is 9.3 cm (depth ratio ≈ 0.1). The tank is excited with a sinusoidal type motion (θ_{max} = 4º) whose period matches the first sloshing period T_0 = 1.9 s.

The flow is composed by a main wave, travelling from one side of the tank to the other, forming a plunging-type breaker at half way that impacts on the structure. The dissipation due to breaking is high and the experiments demonstrate that the water motion in the tank is qualitatively periodic, including the breaking process.

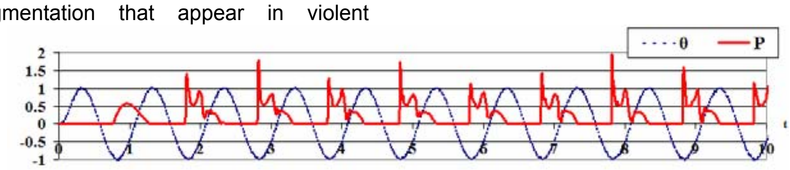

Figure 1: Experimental angle and pressure versus time (non-dimensional values)

Figure 1 shows the angle and pressure time series. In the following, the angle is made non-dimensional with θ_{max}, the time with T_0 and the pressure with the hydrostatic one. The pressure sensor is located at the unperturbed free-surface height. The pressure register is qualitatively repetitive at each cycle. However, the maximum value of the pressure is not equal in each cycle. These peaks result from the impact of the wave on the tank, presenting a random behavior. This can be explained by the very short duration of the impact and the extreme sensitivity of the impact pressure to the shape of the wave just before impact. Other physical parameters, such as the compressibility of the air and water mixture as well as the ullage pressure, have also a very important effect (Bass, 1985, Berg, 1987) and are very difficult to model

A zoom of the time series over one impact event is shown in figure 2. Frames F1 to F6 have been located on the pressure curve representing the most interesting instants regarding the pressure history. Pressure register and videos demonstrate this process to be qualitatively repetitive.

3. Simulations

A standard SPH formulation has been used for the simulation (Monaghan, 2005). Free slip boundary conditions have been imposed with boundary particles (Monaghan, 2005). In order to calculate the pressure at the sensor position, the forces exerted by all the boundary particles within a distance *h* to the center of the sensor have been averaged, *h* being the smoothing length. The standard viscosity term is used with α=0.02. Numerical integration has been performed with a leap-frog scheme.

Simulations have been performed with 5 different resolutions: 3043, 4928, 8970, 12924 and 20205 fluid particles. Figure 3 presents the pressure time series for three resolutions. The graph shows that the trends in the experimental curve are qualitatively reproduced with SPH. However, numerical instabilities appear that need further study.

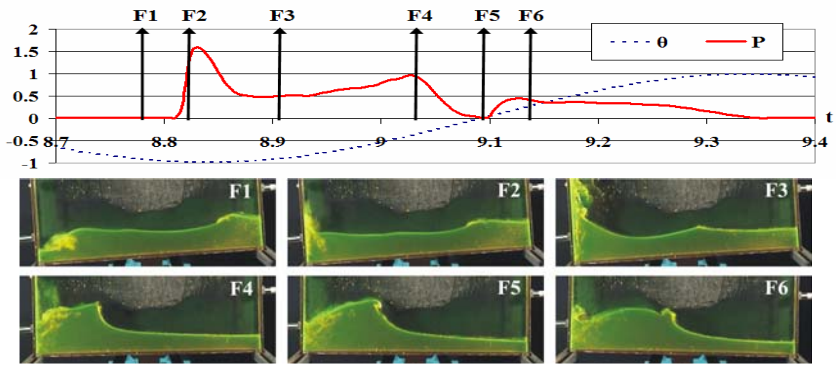

Figure 2: Experimental register above one impact event with the corresponding frames

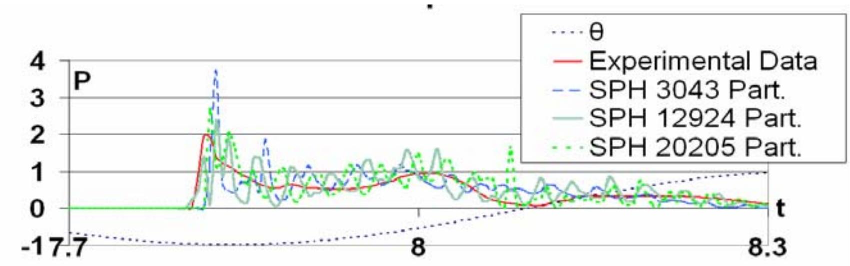

Figure 3: Non-dimensional pressure over one impact event. SPH results

PFEM results for the same case are presented in figure 4. The shape of the pressure curve is qualitatively reproduced too. PFEM results present numerical instabilities of greater amplitude and frequency. Pressure maxima at the impact are greater and this can be explained by the incompressibility of the fluid, imposed when using PFEM.

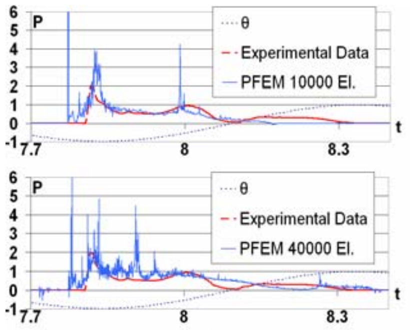

Figure 4: Non-dimensional pressure over one impact event. PFEM results

The compressibility of the fluid plays an important role in the impact phenomena (Bass, 1985). This has been investigated performing SPH simulations with different numerical sound speeds. Sound speed is typically chosen such that the Mach number is 0.01. SPH simulations have been performed using sound speeds 10, 20, 30 and 40 m/s but the variations found in the values of the pressure peaks were not significant.

It has been demonstrated (Peregrine, 2005) that the impulse given by a wave is a more useful information than the pressure in assessing its impact. The pressure impulse (integral of the pressure through the impact) can be calculated from the pressure time series and compared with the experiments (figure 6). After the third cycle, the variations of the impulse are small and it can be noticed that both SPH and PFEM overestimate the experimental value. The biphasic nature of the impact could explain the lower experimental values but further investigation has to be done.

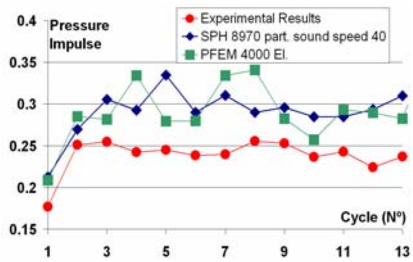

Figure 6: Pressure impulse.

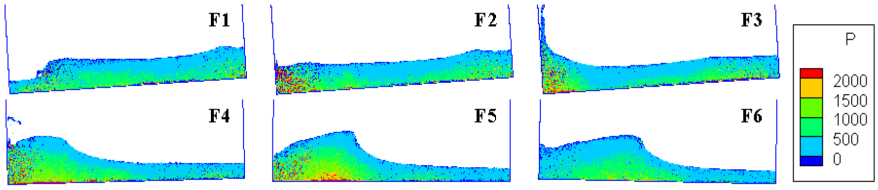

Figure 7: SPH simulation with 20205 fluid particles. F1 to F6 refer to figure 2

The global dynamics of the flow, including breaking waves, is well reproduced by both methods. Figure 7, for instance, presents the frames of figure 2 obtained with SPH, showing good agreement, even after more than eight cycles.

4. Conclusions

Numerical computations of long impact pressure sequences for a 2D low filling sloshing case have been performed both with SPH and PFEM codes. Good agreement has been found in the general dynamics but unphysical oscillations in the time series of the pressure appear for both methods. Pressure impulse has been compared and reasonable but overestimated values have been found, regardless of the resolution and of the SPH numerical sound speed. So far, the influence of the gas phase on the pressure history has not been assessed with enough quality to discriminate the origin of the numerical errors. Further work has yet to be done.

5. Acknowledgments

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