An experimental investigation on the flip-through phenomenon.

C. Lugni[*] c.lugni@insean.it
M. Brocchini[**] brocchin@diam.unige.it
A. Dolcini[*]
F. Palladino[*]
U. P. Bulgarelli[*] up.bulgarelli@insean.it
O. M. Faltinsen[***] oddfal@marin.ntnu.no

∗ INSEAN, Italian Ship Model Basin, Roma – Italy.
∗∗ DIAM, University of Genova – Italy.
∗ ∗ ∗ Centre for Ships and Ocean Structures, NTNU, Trondheim – Norway.

In the previous work of Colagrossi et al. (2004) the occurrence of slamming events and the prediction of the related loads on the sloshing phenomena have been studied, both numerically and experimentally.

Sloshing is a resonance phenomenon where the free-surface may highly deform. The liquid moves back and forth rising along the side walls, possibly impacting against the roof. Impact on a side tank wall may also occur, *e.g.* in shallow water conditions. The water wave impinging a vertical wall can experience a violent motion and, consequently, high value of local load may occur (Peregrine 2003).

As clearly illustrated in the available literature (Oumeraci et al. 1993; Hull and Müller 2002) the shape of the impacting wave largely influences the impact pressure magnitude and distribution. Here we focus our attention on a peculiar phenomenon which can characterize the water impact against the side wall of the tank: the so called flip-through. In the flip-through the wave impinges at the wall without necessarily air entrapment. The concave face of the wave approaches the wall with the crest moving forward and the trough rapidly rising at the wall (Oumeraci et al. 1993). As highlighted by Cooker and Peregrine (1992), it is the presence of the structure to avoid breaking of the wave and causes the rise of the leading wave trough. The latter focuses with the wave front originating an intense acceleration of the flow and the formation of a jet along the wall.

Peregrine and Kalliadasis (1996) proposed the *filling flow*, i.e. a flow quickly filling a limited region, as a simplified model to predict the velocity of the jet and the maximum pressure at the wall. In particular in a proper reference system the filling flow appears steady. Cooker & Peregrine related the flip-through to the filling flow due to the quasi-steady behavior of the jet like flow caused by the pressure peak moving with a nearly constant velocity along the wall. Successively, Peregrine and Thais (1996) extended the simplified model to the case of an air-water mixture. In this case indeed a consistent reduction of the peak pressure occur, due to the compressibility of the air entrained.

In this work we investigate experimentally the flip-through excited by a sloshing event inside a rigid prismatic tank. The experimental set-up is sketched in the left plot of figure 1. The tank is $L = H = 1$ m long and $b = 0.1$ m wide and is filled

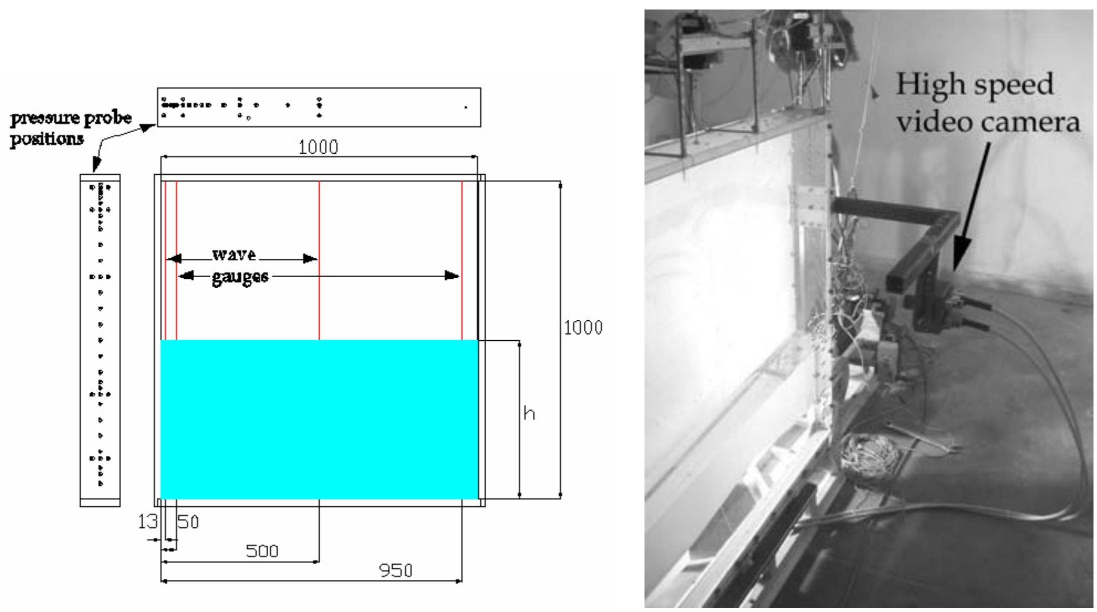

Figure 1: Left: sketch of the experimental set up. Wave gauge positions and pressure sensor locations are indicated. Dimensions are in millimeters. Right: partial side view of the experimental set-up. The high-speed video camera is shown.

with water up to a height $h = 0.125m$. The geometry of the tank ensures an almost 2D flow in the main tank plane unless flow instabilities are excited. An ad hoc mechanical system forces a pure-sway motion with a sinusoidal law, $A \sin(2\pi t/T)$. Here A is the amplitude and T is the period of the prescribed motion; in the case we studied $A = 0.03m$ and $T = 1.6s$.

Two different arrangements were used for the model tests. In the first one, the tank was equipped with four wave gauges placed along its length to measure the water height evolution during sloshing phenomena. Several pressure probes with maximum range equal to $14kPa$ were located along a vertical side wall to measure the local loads.

During the tests flow visualizations were performed through low and high speed digital video cameras with sampling frequency 23 Hz and 4000 Hz, respectively. The video cameras were placed in front of the tank, as shown in the right photo of figure 1, and focused to minimize perspective errors in the images.

In a second configuration, local flow field measurements have been carried out. Due to the extremely fast dynamics and highly nonlinear features of the flip-through, a traditional PIV technique is not reliable. The lack of repeatability of the local flow field required the use of a *Time-Resolved PIV (TR-PIV)* technique. The latter is strictly related to the availability of a high-speed camera: the capability to reduce the time interval between two successive images allows an accurate description of the flow field evolution even for a rather quick phenomenon, like the one of interest. More in detail, an infrared continuous laser source and a high-speed camera are adopted, as shown in the sketch in figure 2. The laser emitted a light from the side of the tank, and the

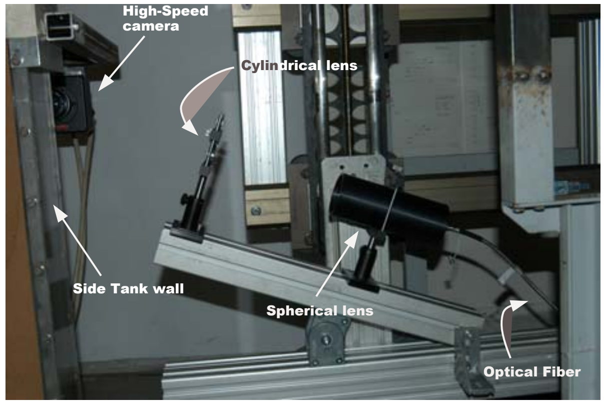

Figure 2: sketch of the Time-Resolved PIV experimental set up. After the emission from the source, the laser beam is channeled in the optical fiber.

camera in front of it recorded the images. A resolution of 1024x512 pixels for each image and a scan rate of $4000 Hz$ have been adopted. Figure 3 gives a sample sequence of images reproducing the phenomenon of flip-through. The wave front advances from right to left and a breaking of the crest appears (see frame 1). Due to the presence of the wall, the wave trough rapidly rises at the vertical wall (frame 46) until the focusing with the wave front coming from the right occurs. At this time instant (frame 91) locally the water is quickly accelerated upwards and a jet develops (frame $91 - 168$). It is in this time span that the largest values

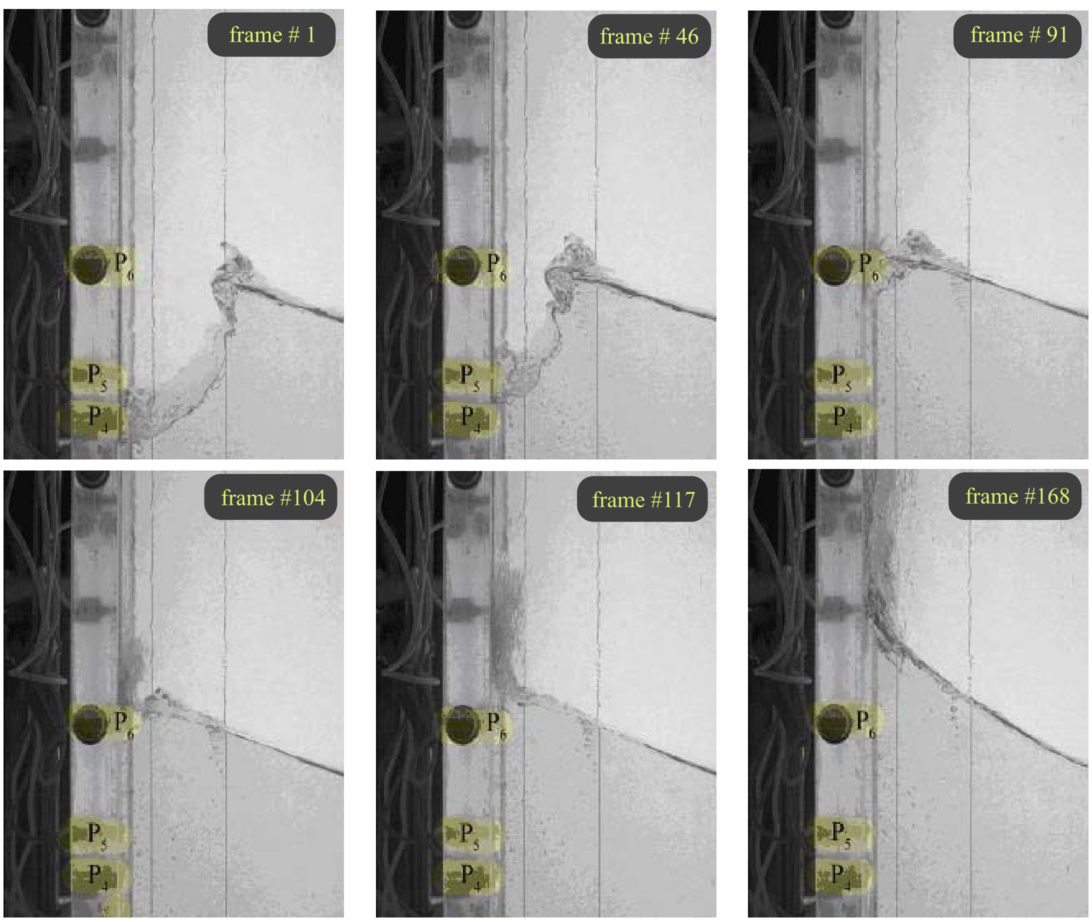

Figure 3: Sequence of images illustrating the free-surface evolution of a flip-through (Scan rate of the camera: 4000 Hz). Time increases from left to right and from top to bottom.

of local loads are induced on the wall. This is confirmed by the time history of the pressures along the wall (left plot of figure 4) showing the occurrence of a high peak of short duration (impact pressure) and a more slowly varying peak (reflective pressure) similar to those modelled in Wood et al. (2000). An enlarged view (right plot of figure 4) highlights that such peak appears at the time instant of the focusing. In particular, at the formation of the jet (frame 91), a maximum pressure peak is evident. The latter is rather localized both in time and in space. Then the jet evolves along the wall and the strong acceleration of the flow causes a local peak on the upper pressure probe P_6 (frame 117). This behavior confirms the rise of the stagnation point along the wall. In figure 5 a detailed illustration of the flow field just prior to focussing is given. We can observe the fast rising jet at

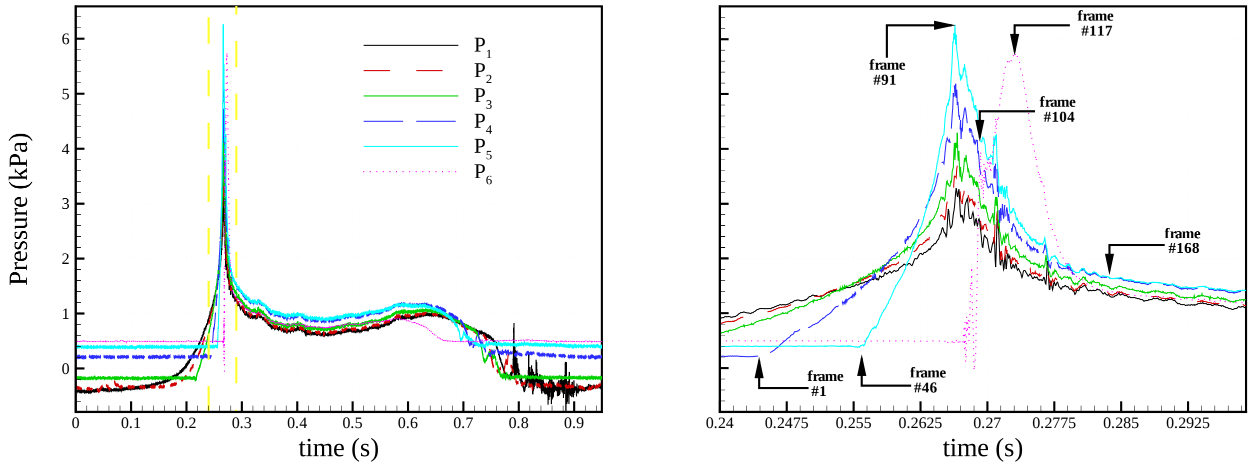

Figure 4: Time history of the pressures along the wall during the evolution of a flip-through (left). On the right an enlarged view around the time instant of the focusing is represented. The arrows indicate the related images of the figure 3.

the wall (flip-through) which develops from the upward-rising wave before the formation of a small air cavity. In this case the compressibility effects of the air entrained matter (Peregrine and Thais 1996) and the pressure peak can be strongly affected. In the present case, one of the best examples available of flip-through detection, two mechanisms concurr to the generation of the impact pressure. A first direct fluid-solid contact is followed by the generation and compression of an air pocket.

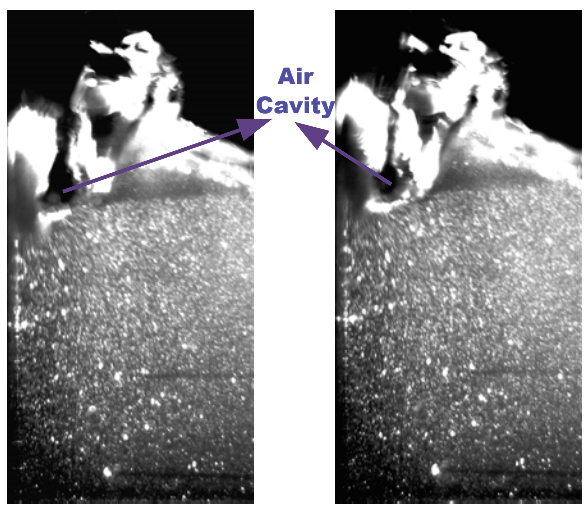

Figure 5: Free surface evolution of the flip-through at two time instants just before to the focusing. The formation of an air cavity can be observed. Left: frame at $t = T_0 + 0.003s$; right: frame at $t = T_0 + 0.0035s$, being T_0 the time instant when the jet at the wall forms.

According to our observations, the velocity of the pressure peak along the wall is almost constant and approximately equal to the wave trough speed. To this purpose figure 6 shows the experimental images in the tank reference frame. The corresponding velocity field measured by TR-PIV and the related streamlines are given instead in the reference frame moving with the wave trough. The presence of a stagnation point is confirmed by the bifurcation of the flow. A rough evaluation allows to locate the stagnation point P_m at the wall rising at points indicated by the arrows in figure 6.

The experimental data collected will be used to investigate further the flip-through phenomenon and to verify the effectiveness of the pressure-impulse approach (Cooker and Peregrine 1992) and of the filling-flow simplified model to quantitatively predict the maximum local loads and the speed of the jet along the wall. For a reliable evaluation of the influence of the air entrapment, an experimental investigation varying the pressure of the air inside the tank will be carried out. To this purpose a suitable tank has been built to work in depressurized conditions. The results will be discussed at the workshop.

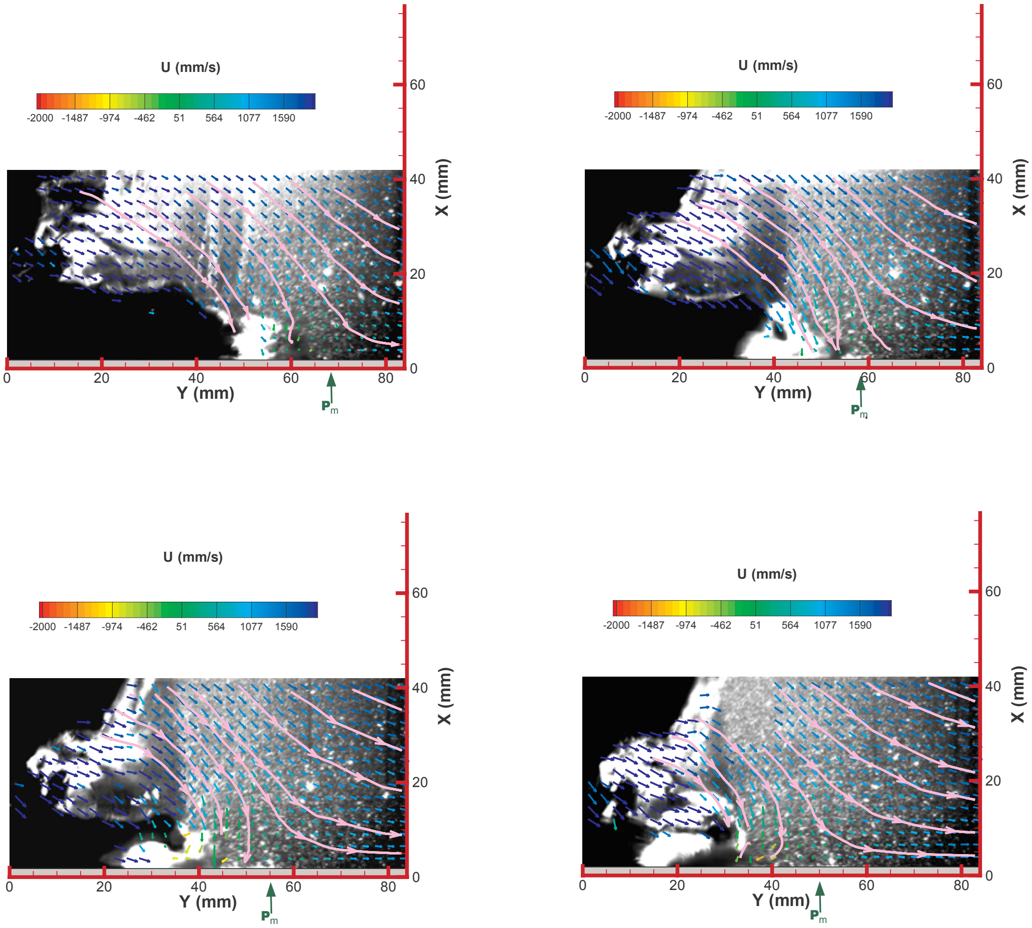

Figure 6: Velocity field measured by TR-PIV technique. The images are represented in the tank reference system, while the flow field is reproduced in the reference frame moving with the stagnation point. $X = 0$ represents the vertical wall. From left to right and from top to bottom, time instants are $T_0 - 0.001s$, $T_0 + 0.0005s$, $T_0 + 0.002s$ and $T_0 + 0.00325s$, being T_0 the time instant when the jet at the wall forms. The green arrow indicates the position of the stagnation point P_m.

The present research activity is partially supported by the Centre for Ships and Ocean Structures, NTNU, Trondheim, within the ”Sloshing Flows and Related Local and Global Loads” project, and partially done within the framework of the ”Programma di Ricerca sulla Sicurezza” funded by *Ministero Infrastrutture e Trasporti*.

References

Colagrossi A., Lugni C., Greco M., Faltinsen O.M., 2004, “Experimental and numerical investigation of 2D sloshing with slamming”, IWWWFB 04, Cortona, Italy

Cooker M.J. and Peregrine D.H., 1992, “Wave impact pressure and its effects upon bodies lying on the bed”, Coast. Engng. **18**, pp. 205-229.

Hull P. and Müller G., 2002, “An investigation of breaker heights, shapes and pressures”, Ocean Engng., **29**, pp. 59-79.

Oumeraci H., Klammer P., Partenscky H.W., 1993, “Classification of breaking wave loads on vertical structures”, J.W.P.C.O.E.-ASCE, **119**, pp. 381-397.

Peregrine D.H. and Kalliadasis S., 1996, “Filling Flows, cliff erosion and cleaning flows”, J. Fluid Mech., **310**, pp. 365-374.

Peregrine D.H. and Thais L., 1996, “The effect of entrained air in violent water wave impacts”, J. Fluid Mech., **325**, pp. 377-397.

Peregrine D.H., 2003, “Water-wave impact on walls”, Ann. Rev. Fluid Mech., 35:23–43.

Wood D.J., Peregrine D.H., Bruce T., 2000, “Wave impact on a wall using pressure-impulse theory. I: trapped air”, J.W.P.C.O.E.-ASCE, **126**, pp. 182-190.