Effects of plate stiffness on fluid-structure interaction in high-speed plate ditching

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SUMMARY
In this paper the role played by the plate deformability on the loads generated during the water impact of a plate at high horizontal speed is investigated on the basis of the experimental data of the FP7-SMAES project. Several test conditions are examined by varying the impact velocity, the pitch angle, the plate thickness and material (aluminium and CFRP panels). Comparisons established between the results obtained at the same impact conditions but for different plate stiffness reveal that, in spite of a general reduction of the pressure peaks, the total loads increas substantially, up to 40% in some cases, as a consequence of the plate deformation, independently if the deformation is of elastic or permanent origin. This result indicates that in strong fluid-structure interaction problems an accurate estimate of the loads can only be achieved if the structural deformation is properly reproduced.

1. INTRODUCTION

In this paper the experimental investigation of the water entry of plate at high speed horizontal velocity is presented. The study follows the activities presented in previous editions of the Workshop (Iafrati and Calcagni, 2013; Iafrati, et al., 2014*a*) where the basic motivations for the specific study on the plate ditching problem as well as some hydrodynamic aspects were discussed. Here the focus is mainly on the role played by the structural response and on its effects on hydrodynamics and loads.

Fluid-structure interaction phenomena and possible hydroelastic coupling taking place during the water entry have received considerable attention over the last decades, particularly in regard to the water impact of plates. In the naval context, the traditional approach to hull design consists in the use of a uniform pressure distribution over the hull panel to simulate the slamming loads, and empirical pressures are often based on classification society guidelines (Kim et al., 2008; Louarn and Manganelli, 2010; Stenius et al., 2011). However, there is evidence that when a plate impacts the free surface, the local stresses are strongly influenced by dynamic hydroelastic effects and are not much correlated to the maximum pressure. At least for these impact conditions, the design should be better based on simultaneous measurements of strains and relative velocity between the vessel and the free surface (Faltinsen et al., 1997).

Several studies have been carried with the aim of evaluating the relevance of the fluid-structure interaction taking place during the vertical water entry of wedges or plates. In Louarn and Manganelli (2010) a simplified method is adopted to investigate the role played by the panel curvature, characteristic of the bow part of racing yachts, on the shear in sandwich structures. In Stenius et al. (2011) numerical and experimental activities are carried out in order to describe and characterize the hydroelastic interaction during the water entry of wedges by varying the impact and boundary conditions. The water entry of flexible wedges is also studied in Panciroli et al. (2013) with the aim of identifying the occurrence of hydroelastic coupling as a function of the ratio between the natural frequency of the structure and the characteristic wetting time.

It is worth noticing that, although the above studies are motivated by the application to high speed planing vessels, they all refer to the pure vertical water entry only. Hence, the important role played by the high horizontal velocity component is missing, and the loading conditions are not fully representative of the problem. Those aspects are accounted for in the present test conditions.

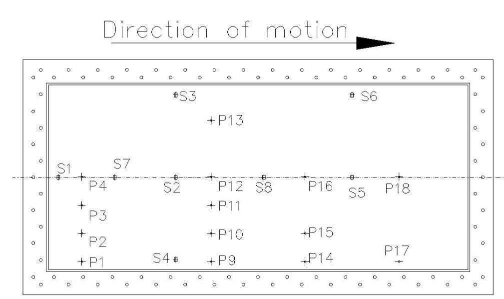

Figure 1: Position of pressure probes and strain gauges as seen from the back of the plate. The trailing edge of the plate is on the left and the plate is moving to the right. Although 14 pressure probes are used, the notation is that of the rigid plates where 18 probes were employed.

Data in terms of strains and total loads acting on the plate are here presented for different horizontal to vertical velocity ratios, pitch angle values and plate chatacteristics. For some of the test conditions, simultaneous measurements of pressure and strains are conducted and compared with rigid plates measurements.

2. EXPERIMENTAL SETUP

The experimental setup and the installed instrumentation for the thick aluminum plates are provided in Iafrati and Calcagni (2013) and in Iafrati, et al. (2014*a*) or, more recently, in Iafrati et al. (2015) where the data uncertainty is also assessed. Some information concerning the instrumentation used for the tests on the deformable plates and on the repeatability characteristics are provided in Iafrati (2015). In the following only some details on the instrumentation are illustrated, which are helpful for the discussion.

Plates are made of aluminum alloy AL2024-T3, thickness 3 mm and 0.8 mm, and Carbon Fiber Reinforced Polymer (CFRP) 1.6 mm thick. They are instrumented with a total of 8 biaxial strain gauges and, in some cases, with 14 pressure probes (Fig. 1). The plates are clamped on a thick aluminum frame by two rows of bolts, leaving an empty space of 390 mm by 890 mm (Fig. 1).

3. EXPERIMENTAL RESULTS AND DISCUSSION

Before discussing the experimental data, a comparison of the strain measured in two different repeats is provided in Fig. 2 and Fig. 3 in order to allow a qualitative estimate of the inherent uncertainty. As already shown in Iafrati (2015), even for very thin plates, which are expected to be highly sensitive to the test conditions, there is a quite high level of confidence in the data. The origin of the time axis is chosen as the time at which the strain S_{1x} takes the peak value, whereas the time interval used in the figures is much larger than the time taken by the spray root to span over the plate, which is about 0.065 s for the test conditions considered in the figures. The curves display a quite good overlapping. The differences occurring in the latest part are caused by some other phenomena taking place once the plate is fully submerged. Beside the repeatability of the data, the comparison of the strain levels measured by probes S_3 and S_4 established in the bottom of Fig. 2 denotes a quite satisfactory symmetry of the strains. Results in Fig. 3, which refer to the CFRP panels and to a probe located at the middle of the plate, are essentially in line with those found for the thin aluminum plate. The strain S_{8y} goes back to the pre-impact value at the end of the test, indicating that no permanent deformations occur in this case. In the x diretion the curves approach a finite value of the strain but, as discussed in Iafrati et al. (2014*b*), such behaviour is related to the formation of a hump which disappeared once the plates were disassembled from the frame.

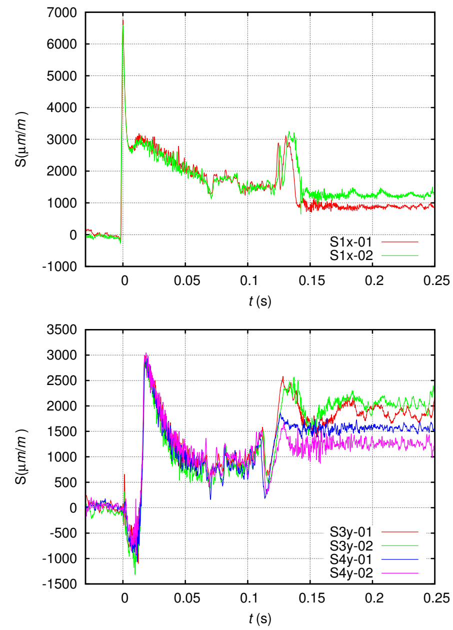

Figure 2: Test condition 3122: 0.8 mm aluminum plate, pitch angle 6 degrees, $U = 40$m/s, $V = 1.5$ m/s. Top: comparison of the strains measured at gauge S_{1x} in the two test repeats. Bottom: comparison of the strains measured at the two symmetric gauges in the two test executions.

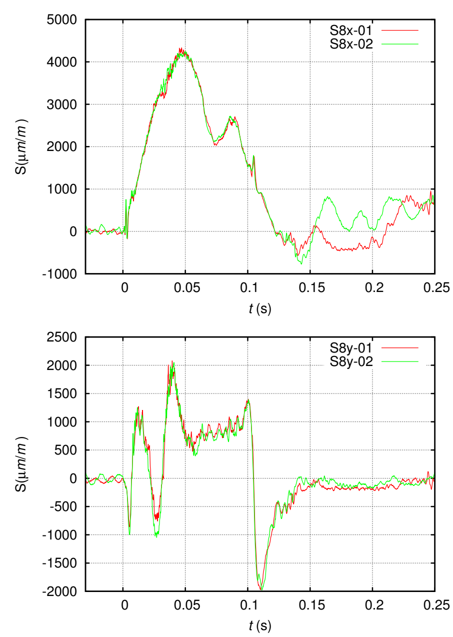

Figure 3: Test condition 5122: CFRP 1.6 mm, pitch angle 6 degrees, $U = 40$m/s, $V = 1.5$ m/s. Comparison of the strains measured in x and y directions at gauge S_8.

The important role played by the plate deformation on the total load acting normal to the plate is highlighted in Fig. 4. In the figures the data measured for different plate stiffness in three test conditions are compared. In all cases, the curves display a quite good overlapping in an early stage. In a next stage, the loads exhibit a general increase when reducing the plate stiffness.

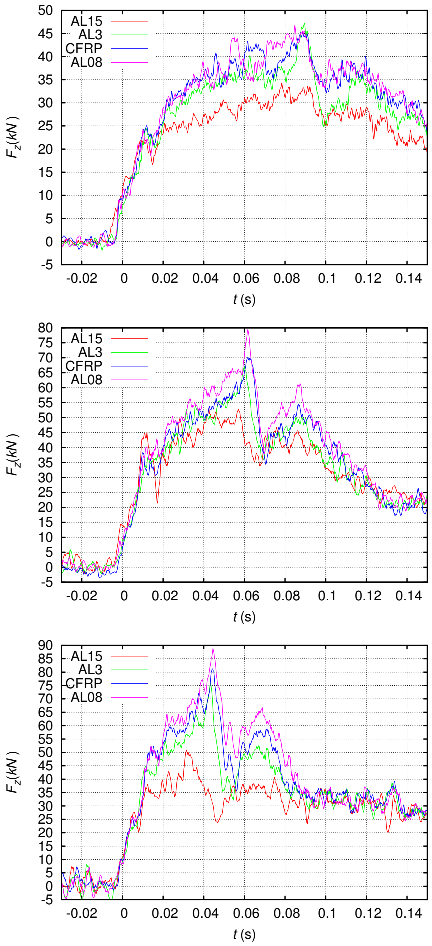

Figure 4: Time histories of the total hydrodynamic force acting normal to the plate. From top to bottom, test conditions are: $U = 30$m/s, 10 degrees pitch; $U = 40$m/s, 6 degrees pitch; $U = 45$m/s, 4 degrees pitch. In all cases $V = 1.5$ m/s.

The increase in the total loads acting on the plate wouldn't be easily explained by the pressure data. The pressure measured on the different plates by the probes located along the midline in the tests at $U = 30$ m/s, $V = 1.5$ m/s and 10 degrees pitch angle, shown in Fig. 5, indicate that the peak diminishes when reducing the stiffness and for the probes located beyond the middle of the plate the peak just disappears. However, looking at the pressure time histories, it can be seen that the area under the curves grows, and thus the reduction in the pressure peak is compensated by a widening of the pressure area, thus justifying the growth of the total load.

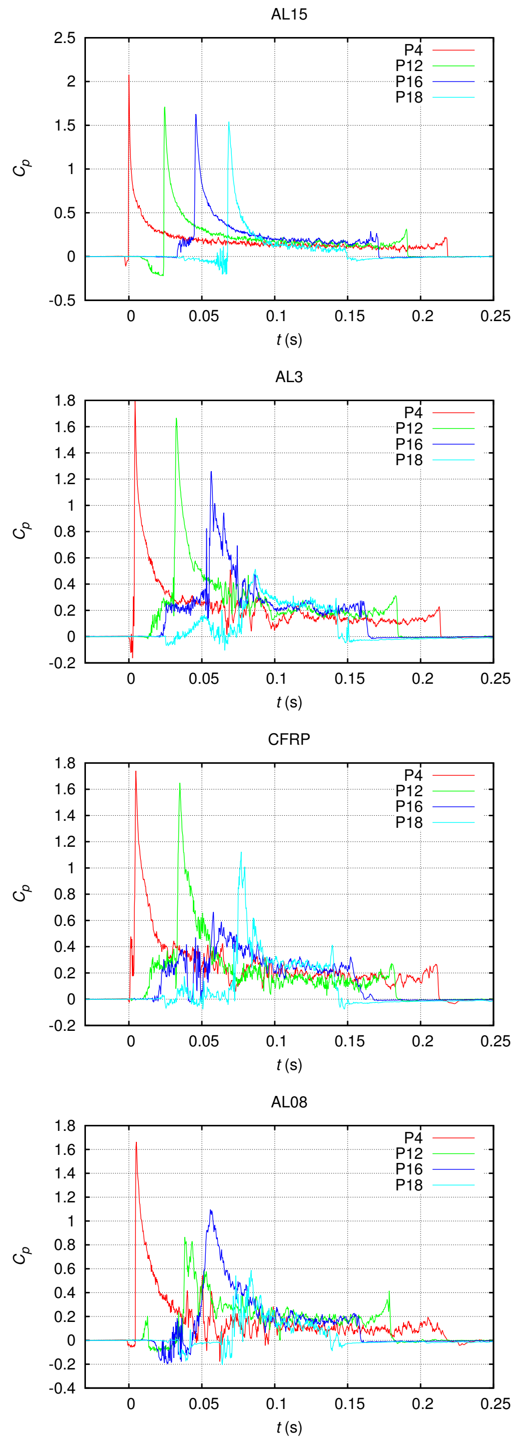

Figure 5: Time histories of the pressure measured for different plate stiffness in the test condition $U = 30$ m/s, $V = 1.5$ m/s, 10 degrees pitch.

It would be interesting to investigate the phenomenon more in depth. Unfortunately, due to the complexity of the experiments and to the time constraints of the project, it was not possible to perform additional measurements. Nevertheless, the underwater images provided in Fig. 6 clearly highligth the bending of the plate and the subsequent air entrainment. Such ventilation phenomenon is quite large considering that the images refer to the 3 mm aluminum plate for which the permenent, out-of-plane deformation was about 3 mm (Iafrati, 2014*b*).

The ventilation phenomenon explains of course the reduction in the pressure peak and the rather chaotic behaviour of the pressure measured at P16 and P18, particularly for the CFRP and AL08 cases. A deeper analysis of other pressure data will be discussed at the Workshop.

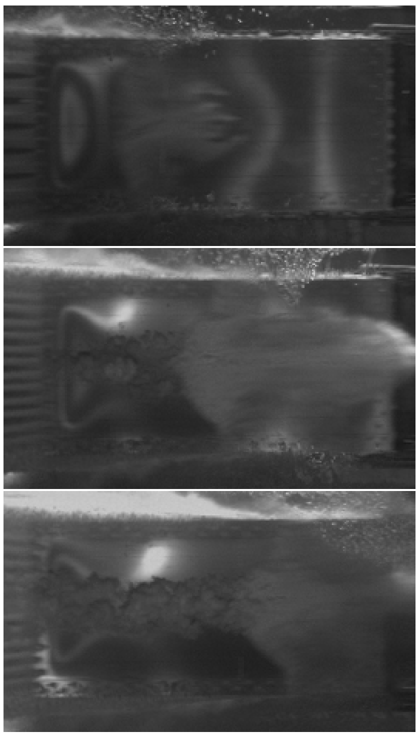

Figure 6: Underwater images in test condition 2113: 3 mm aluminum plate, $U = 45$m/s, $V = 1.5$ m/s, 4 degrees pitch. A large entrainment of air is generated as a result of the plate bending.

4. CONCLUDING REMARKS

The role played by the plate deformation and by the ventilation on the loads generated during the water impact of a plate with high horizontal velocity have been discussed on the basis of experimental data. The results indicate that the ventilation causes a reduction in the pressure peaks, at least for the probes located along the plate centerline, and a growth of the total hydrodynamic loads, which can be up to 40% in some cases. The phenomenon isn't really new being related to the air cushioning (e.g. Khabakpasheva et al., 2013), but the increased load found when reducing the plate stiffness confirms the occurrence of strong hydro-structural coupling. For the practical applications, the finding indicates, a posteriori, the need of performing tests at full scale conditions in order to avoid the scaling issues related to the ventilation and to the fluid-structure interaction phenomenon.

5. ACKNOWLEDGMENTS

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REFERENCES

Faltinsen, Kvalsvold, Aarsnes (1997) *Wave impact on a horizontal elastic plate*, J Marine Sc Tech, 2, 87-100.

Iafrati, Calcagni, (2013) *Numerical and experimental studies of plate ditching*, 28th IWWWFB, Marseille, France.

Iafrati, Siemann, Benítez Montañés (2014*a*) *Experimental study of high speed plate ditching* 29th IWWWFB, Osaka, Japan.

Iafrati, Olivieri, Santos, Grizzi, Fortunati, Ortolani, Mauro (2014*b*) *Data of the Guided ditching tests for permanent deformation SMAES deliverable D4.6*, CNR-INSEAN-Marine Technology Research Center.

Iafrati (2015) *Fluid-structure interactions during the high speed water entry of a plate*, Proc 18th Intl Conf Ships Shipping Res, Lecco, Italy

Iafrati, Grizzi, Benítez Montañés, Siemann (2015) *High-speed ditching of a flat plate: Experimental data and uncertainty assessment*, J Fluids Struct, 55, 501-525.

Khabakhpasheva, Korobkin, Malenica (2013) *Fluid impact onto a corrugated panel with trapped gas cavity*, App Ocean Res, 39, 97-112.

Kim, Novak, Weems, Chen (2008) *Slamming impact design loads on large high speed naval craft*, SuperFAST2008, ABS Technical papers 2008, 207-218.

Louarn, Manganelli (2010) *A simplified slamming analysis model for curved composite panels*, 21 Intl HISWA Symp, Yacth design and yacht construction.

Panciroli, Abrate, Minak (2013) *Dynamic response of flexible wedges entering the water*, Comp Struct, 99, 163-171.

Stenius, Rosn, Kuttenkeuler (2011) *Hydroelastic interaction in panel-water impacts of high speed craft*, Ocean Eng, 38, 371-381.