

PARAMETERS AFFECTING THE PRESSURE MEASUREMENT ON THE SURFACE OF A RIGID CYLINDRICAL BODY DURING WATER SLAMMING IMPACT

D. Van Nuffel^{1*}, K.S. Vepa¹, I. De Baere¹, J. Degrieck¹, J. Derouck², W. Van Paepegem¹

¹*Mechanics of Materials and Structures, Department of Materials Science and Engineering, Ghent University, Sint-Pietersnieuwstraat 41, Gent, Belgium*

²*Coastal Engineering, Department of Civil Engineering, Ghent University, Sint-Pietersnieuwstraat 41, Gent, Belgium*

*Diederik.VanNuffel@UGent.be (presenting author)

INTRODUCTION

Water wave slamming can be considered as one of the most critical loads that marine structures experience. To prevent naval constructions from failing due to slamming impact, slamming loads should be carefully investigated. Besides analytical and numerical calculations, experimental data is of crucial importance. Experimentally, slamming loads can be measured by performing pressure measurements on the surface of the object during impact. Previous publications showed that precise and correct measurements are very difficult to perform, especially for slamming events with small deadrise angles. Large scatter mostly characterizes these measurements.

This research focuses on improving the accuracy and reproducibility of the pressure measurements. Therefore, slamming drop tests were performed. In this paper, attention is focused on the water impact problem of a horizontal circular cylinder, since this object is characterized by a continuously changing deadrise angle along the circumference. The deadrise angle is the angle between the water surface and the tangent line drawn at the surface of the body at the point where the water surface and the impacting body are intersecting. This is clarified in Figure 1. Thus for a cylinder, the deadrise angle will increase as the penetration depth increases. At the bottom of the cylinder, the deadrise angle is 0° .

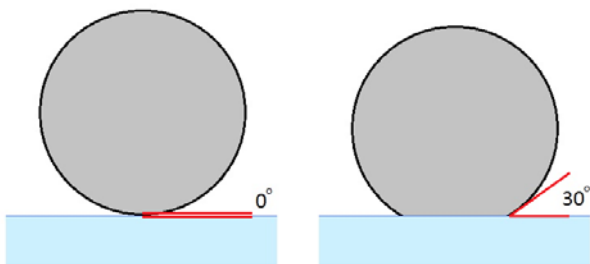


Figure 1: The concept of deadrise angle

Research on water entry of cylindrical objects has been introduced by Greenhow & Lin [1] in 1983 with a theoretical and experimental study of the fluid flow around a horizontal cylinder during water entry and exit. Lin & Shieh [2] continued this work in 1997 with experimental pressure recordings on the surface of the cylinder during water impact. Problems were encountered with the pressure recordings at the bottom

(deadrise angle of 0°) due to large scatter of the measurements. The goal of this paper is to improve these results and to check out which measures have to be taken to achieve better pressure recordings.

Later on, new research included also the water impact on vertical cylinders, since it is a well known phenomenon occurring at the piles of offshore platforms and at the piles of offshore wind turbines. Big contributions in this field were achieved by Wienke et al [3] in 2001 by theoretical developments and large scale experiments.

At this stage, also numerical modeling of the slamming phenomenon gained a lot of importance. In 2002, Battistin & Iafrati [4] performed a numerical study on the fluid flow, pressure distribution and hydrodynamic loads acting on 2-dimensional symmetric and axisymmetric bodies during water entry, including cylinders. Corte & Grilli [5] extended this research in 2006 by developing a numerical model for slamming on vertical cylindrical piles. The focus was broadened also to elastic cylindrical shells by Sun & Faltinsen [6] in 2007. The authors of this paper developed a numerical method to simulate the water flow during the water impact of a horizontal cylinder and a horizontal cylindrical shell.

EXPERIMENTAL TEST SET-UP

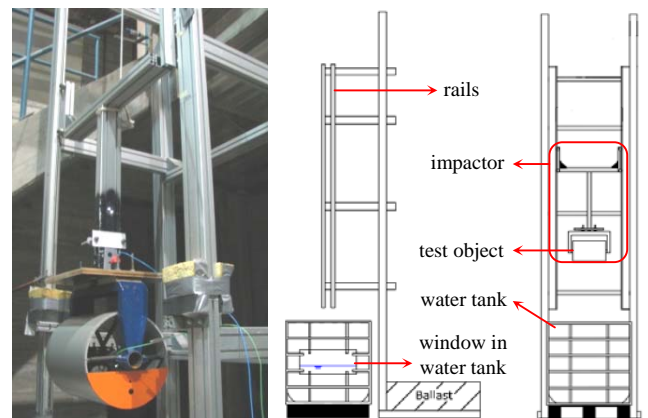


Figure 2: The experimental test set-up: (a) photograph of the real set-up; (b) schematic side view; (c) schematic front view

The experimental set-up which is used for the slamming experiments is shown in Figure 2. This is a drop set-up in which it are not the waves which slam on the structure, but the structure that is slammed on a free water surface. The set-up consists of a water reservoir which measures 1 m by 1.2 m and has a water depth of 0.60 m. The reservoir is filled with tap water. Around the water reservoir, two sliding rails are erected which are firmly fixed with a framework to the walls and floor of the testing room. Between the rails, an impactor is provided which can slide by using small wheels at the side of the impactor (2 at each side). At the bottom of the impactor, the test object is attached. Height marks are provided on the rails which make it easy for the operator to establish the desirable drop height.

EXPERIMENTAL RESULTS – IMPACT PRESSURES

In this paper, the attention was concentrated on one single test series in which the pressures were measured at 0° deadrise angle and the drop height (and thus the impact velocity) was varied between 0 m and 1.2 m. The drop height was limited to 1.2 m, since higher drop heights could introduce damage to the test set-up due to the shock that it caused through the structure during stopping the cylinder movement. For each drop height, three experiments were performed.

During the experiments performed for this paper, several factors which were affecting the pressure measurements were gradually encountered. Only when taking into account all these factors, accurate and reproducible tests can be performed. Next paragraph gives an overview of these factors.

Parameters affecting the pressure recordings

1) Sensor mounting

Adequate mounting of the sensors in the test object is an essential requirement to be capable to perform good measurements. This can be achieved by making sure that the membrane surface of the pressure sensor is as coincident as possible with the surface of the test object. In this case, the flow over de membrane of the pressure sensor will be undisturbed and pressure measurements will be accurate. This type of mounting is called flush mounting and is shown in **Error! Reference source not found.(b)**.

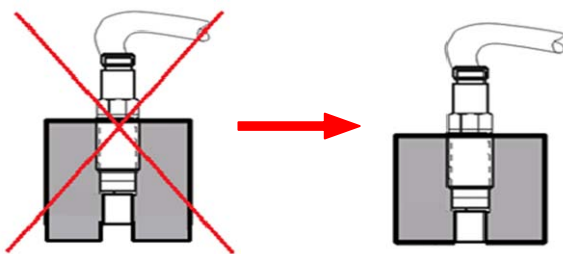


Figure 3: (a) Wrong mounting of the pressure sensor due to gap between sensor membrane and object surface; (b) Flush mounting

In the case of a gap occurring between the membrane sensor and the object surface as shown in **Error! Reference source not found.(a)**, air will be encapsulated and compressed at the moment of impact, resulting in other recorded pressures. When on the other hand the pressure sensor sticks out of the body surface, turbulence around the sensor membrane will occur, again resulting in wrong pressure measurements.

2) Data sampling rate

A parameter which is more of electronic nature, but which cannot be ignored at all is the data sampling rate of the data acquisition system for the pressure sensor signals. The data sampling rate should be chosen sufficiently high since the pressure peaks during impact only last for times in the order of milliseconds or smaller. This is especially important for measurements at small deadrise angles, since the traveling speed of the pressure peak over the object surface increases with decreasing deadrise angle. This can be seen from Figure 4(a) which shows the pressure versus time evolution during a slamming test of the rigid cylindrical object with an impact speed of 3.4 m/s (corresponding with a drop height of 0.7 m) and the pressure sensor placed at the bottom of the cylinder. In this experiment, a sampling rate of 100 MHz was used, and it is clear from Figure 4(b) that too much data points cover the top of the pressure peak to be sure of the peak value. A data sampling rate of 100 MHz is thus far too much.

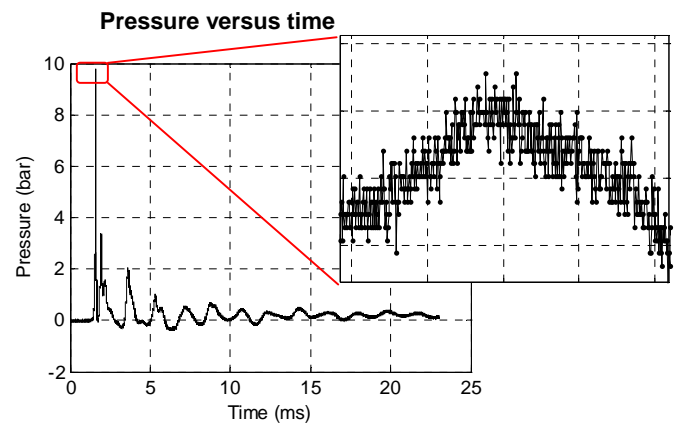


Figure 4: (a) Pressure versus time history at the point of first water contact for the rigid cylinder for an impact velocity of 3.4 m/s (drop height of 0.7 m), measured at 100 MHz sampling rate;

With decreasing sampling rate less points will cover the peak, and the measured peak value will decrease. As shown in a decrease in sampling rate from 400 kHz to 100 kHz leads to a decrease in peak value. Below a sampling rate of 200 kHz, the pressure curve loses its smoothness and the peak value of the pressure profiles deviates more than 1% from the value obtained with 100 MHz. Hence, it can be concluded that a minimum sampling rate of 200 kHz should be used. This result can explain the large scatter that was encountered during the experiments of Lin & Shieh [5] for measurements on 0° deadrise angle. In these experiments, a sampling rate of 25 kHz

was used. Resampling the data measured with 100 MHz to 25 kHz gives a peak value reduction of 24%. Consecutive experiments will lead to different reduction rates and thus scatter in the pressure peak values.

Table 1: Pressure peak values obtained with different sampling rates and deviation with respect to the peak value measured with 100 MHz

Sampling rate	100 MHz	400 kHz	300 kHz
Peak value (bar)	9,75	9,74	9,70
Deviation with respect to 100 MHz-value (%)	0	0,1	0,5

200 kHz	100 kHz	25 kHz
9,74	9,33	7,45
0,1	4,31	24

3) Temperature shock

The pressure sensors which are used in the experiments seem to be sensitive for temperature shock. It has been found out that if the temperature of the sensor differs from the temperature of the water, unexpected phenomena occur in the pressure profiles, after the first pressure peak caused by slamming has passed. These phenomena include a pressure bump after the first pressure peak in the case of the sensor being warmer than the water, or a pressure valley after the first pressure peak in the case of the sensor being cooler than the water. Both bumps and valleys last for much more time (several seconds) than the time which is characteristic for the slamming phenomenon (in the order of a millisecond).

An explanation for the unexpected phenomena can be found by considering the internal construction of the pressure sensors. The sensor consists of a piezo-electric crystal which is clamped into a steel housing. The thermal expansion coefficient of the crystal is 20 times smaller than the thermal expansion coefficient of steel ($\alpha_{\text{quartz}} = 0.59 / ^\circ\text{C}$; $\alpha_{\text{steel}} = 12 / ^\circ\text{C}$). This makes that if the sensor is subjected to a sudden cooling (e.g. by slamming in cold water), the steel housing will contract more than the quartz crystal. As a result, the quartz crystal will experience a compressive load and a positive voltage output is generated which is interpreted as a positive pressure. On the other hand, if the sensor is suddenly heated, the steel housing will expand more than the quartz crystal. Since the piezo-electric crystal is clamped in the steel housing, a tensile load will be created on the crystal and a negative voltage will be generated, resulting in a valley in the pressure recordings.

In order to avoid the pressure recordings being affected by any kind of temperature shock, the temperature of the sensors should equal the temperature of the water. This can be guaranteed by submerging the test object with the sensors

under water for a moment, just before an experiment is performed.

4) Object surface conditions

To reduce the scatter in the measurements, it is very important to perform consecutive measurements with a dry and smooth object surface. Smoothness is required since a rough surface may disturb the flow over the moving body and affect the pressure measurement. A dry surface is needed to avoid water droplets hanging on the membrane of the pressure sensors and affecting the pressure recordings. Therefore, the object surface should be dried after each consecutive test. If this was not done then water droplets would be located at different positions of the membrane of the sensors for different tests, affecting the pressure sensors in another way, and thus resulting in other pressure results for consecutive tests.

The graphs in Figure 5 compare the pressure results for 10 consecutive tests for respectively wet and dry surface conditions. It is clear that the scatter for wet conditions is much higher than in dry conditions.

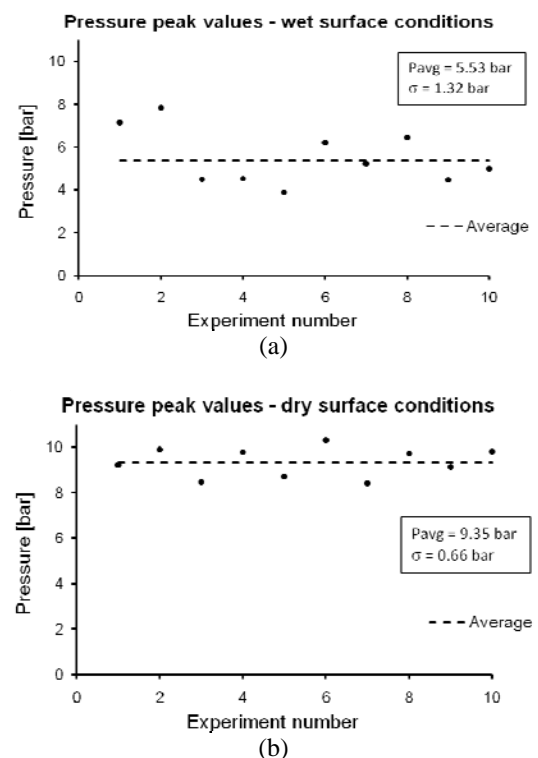


Figure 5: Pressure peak values for 10 consecutive tests in (a) wet object surface conditions and (b) dry object surface conditions

5) Water surface conditions

Before the execution of each measurement, it is very important to make sure that the water surface of the water reservoir is flat, and not disturbed by any kind of wrinkles. Wrinkles on the water surface may cause the deadrise angle at

water impact to change. This can happen when the wrinkle just reaches the point where the cylinder makes first contact with the water, at the moment of that first contact.

Pressure measurements

In the experiments performed in this paper, the parameters previously described were taken into account and recommendations were carefully followed. Figure 6 gives an overview of the pressure results as a function of impact speed.

From this graph it can be concluded that impact pressures during a water slamming event are strongly related with impact speed. As the impact increases, impact pressures will grow extremely fast.

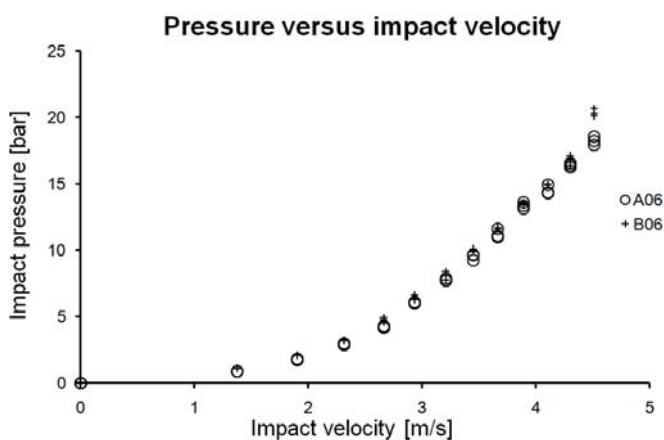


Figure 6: Impact pressures as function of impact velocities

CONCLUSIONS

In naval environments, water wave slamming is a known threat for each kind of floating or fixed offshore structure. Experimental measurements of these loads are of great value. In this paper, there has been an attempt to accurately measure body surface pressures during water impact. The attention has been focused on a horizontal cylindrical body, with pressure measurements on 0° deadrise angle.

Several parameters including physical and electronic ones seemed to influence the measurements, causing inaccurate and non-reproducible pressure results. Each of these parameters has been discussed and recommendations for good measurements are formulated. These can be summarized as:

- Place the sensors flush mounted
- Take at least 200 kHz of data sampling rate for the pressure transducers
- Let the pressure sensors exchange heat with the water to guarantee the equality of temperature
- Dry the object surface before each experiment
- Make sure the water surface is completely calm before each experiment

With these guidelines taken into account, new experiments were performed which were much more accurate and reproducible.

From the experimental results, it was found that the impact pressure is strongly related with the impact velocity of the slammed object on the water surface. The relationship indicated that if the impact velocity increases, the impact pressure will come to extremely high values, leading to enormous loads acting on naval constructions. That is why slamming loads should be important design criterions during ship construction.

ACKNOWLEDGMENTS

The authors would like gratefully acknowledge the finance through a grant of the Fund for Scientific Research – Flanders (F.W.O.).

REFERENCES

- [1] Greenhow, M. and W.-M. Lin, *Nonlinear free surface effects: experiments and theory*. Report 83-19 of Massachusetts Institute of Technology, Department of Ocean Engineering, 1983.
- [2] Lin, M.-C. and L.-D. Shieh, *Flow visualization and pressure characteristics of a cylinder for water impact*. Applied Ocean Research, 1997. **19**(2): p. 101-112.
- [3] Wienke, J., *Druckschlagbelastung auf schlanke zylindrische bauwerke durch brechende wellen*. 2001.
- [4] Battistin, D. and A. Iafrati, *Hydrodynamic loads during water entry of two-dimensional and axisymmetric bodies*. Journal of Fluids and Structures, 2003. **17**(5): p. 643-664.
- [5] Corte, C. and S.T. Grilli, *Numerical modeling of extreme wave slamming on cylindrical offshore support structures*, in *Proceedings of the Sixteenth International Offshore and Polar Engineering Conference (ISOPE 2006), MAY 28-JUN 02, 2006 San Francisco, CA*, J.S. Chung, et al., Editors. 2006. p. 394-401.
- [6] Sun, H. and O.M. Faltinsen, *Water impact of horizontal circular cylinders and cylindrical shells*. Applied Ocean Research, 2006. **28**(5): p. 299-311.