Slamming experiments on a ship model

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Introduction

Impulsive loads on ship elements may induce uncomfortable vibrations or may produce some local damages. They usually happen at the bow for severe sea conditions but moderate seas can generate slamming on flat sterns [1].

In order to investigate the effects of slamming loads on ships (vibrations, hull girder fatigue and ultimate strength), a French national research project was established with the joint support of industry and public institutions. The project involves different physical experiments and numerical simulations. This paper presents original experiments to study the sensitivity of global and local loads to kinematic parameters variation. Their results will also be confronted to data from numerical simulations developed within the project in order to validate these codes.

Wave slamming on a hull is a complex and non linear phenomenon: relative angles and relative momentum are the main parameters governing the impulsive loads characteristics (occurrence levels, localisation and duration of impacts)[2]. To investigate the effect of each kinematic parameter with predetermined water impact conditions, we decided in a first stage, to force the ship motions on calm water. This way gives the opportunity to get at the same time:

- the ship kinematics (as an imposed motion law);
- the reproducibility of the loads (localisation on the hull, duration)
- the free surface dynamics around the hull;
- the local and global loads exerted on the (model) ship.

Experimental set-up

A 6-DOF moving table (nicknamed Hexapod) is used over the free surface of the HOEG Large Wave Basin at Centrale Nantes (50m x 30m x 5m). The system is based on 6 electric and PC-controlled actuators linked to a moving platform by universal joints. Furthermore the model is attached to this platform by a custom-made 6-DOF dynamometer using four 3components piezo-electric cells. Hexapod is supported by a 3-legs framed structure (Tripod) built on the basin floor. Weight, dimensions and arrangement were designed to get a stiff structure with a first vibration mode over 6 Hz (measured frequency in water).

The reference ship in the project was chosen to present some characteristics of actual boat designs: it is a large cruise ship with a fairly thin bulb (touching the free surface) in front of wide squared stations and ended by a relatively flat stern just over the water line. The model is 3 m long for a 0.32 m moulded breadth, made of composite to reach high longitudinal and transversal strengths.

As shown on Figure 1, the hull is equipped on starboard with 19 miniature pressure cells (Druck PDCR 200, 12 at the bow, 7 at the stern). On port side and symmetrical to the pressure cells, 4 pressure panels are located at the bow and at the stern. They are built from force transducers (TME 521 TC) measuring the normal force exerted on a 50 mm diameter disk outcropped to the hull. The free surface elevation along the ship is also measured at 3 stations and three 1-D accelerometers are completing the embedded instrumentation. A b&w high speed digital camera (500 frames/s) is placed in the vicinity of the impact to help the analysis of the temporal signals.

The acquisition system consists of several computers located on a platform close to the tripod and connected to the signal conditioning systems. A trigger signal from the ship model gives a synchronisation of the data logger, the camera and the Hexapod motions measurement system. The sampling frequency is 1 kHz by channel.

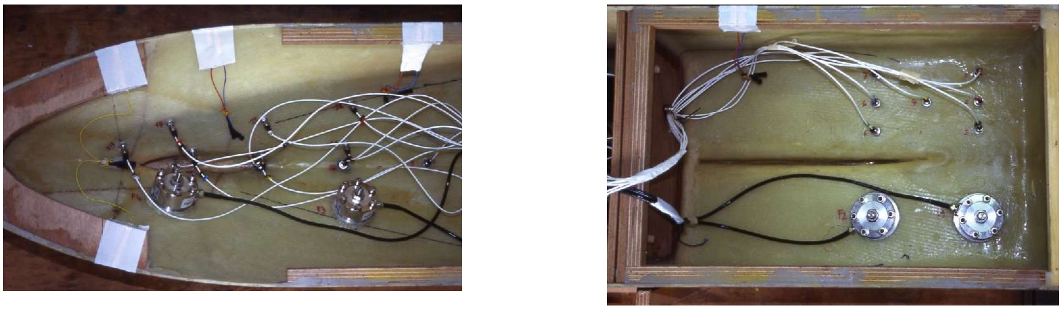

Figure 1: Pressure cells (starboard) and force transducers (port side) in the ship model.

Experiments characteristics

Three main groups of tests can be drawn according to the different motion laws applied to the model for these experimental campaign:

- vertical impact test: the model has a constant momentum downwards and hits the free surface with the entire hull;
- inclined entry test: the model has an oblique momentum and the bow hits the free surface;
- forced pitching test: the model has a dynamic pitch from an initial stable position.

For each group of tests, different velocities, several additional degrees of freedom (pitch angle, roll angle, ...) and motion laws (roll, heave, ...) are defined to get a final test matrix of 82 configurations, each of them being performed at least twice. In addition to these forced motion tests, some captive tests are carried out in regular waves. A vertical impact configuration is presented and discussed below.

Preliminary results of a vertical impact test

Figure 2 presents the chronology of pressure measurements for 3 different tests of the same vertical impact configuration: downward speed of 0.6 m/s and pitch angle of -4° (the bow is inclined downwards). This configuration leads to a violent water impact around the bulb.

Reproducibility of the experiments

The signals of 4 transducers regularly deployed in the keel are superimposed with a common time origin defined as the hull hits the water close to C18 (station 19.5). The successive peaks show the usual shape of an impulsive phase (strong increase of pressure) then a pressure decreasing to a quasi-static phase. This phase is extended by an increase of the hydrostatic pressure, the downward motion of the hull continuing. The delay between the pressure peaks is almost constant (16 ± 1 ms) leading to a propagation velocity of 8.2 ± 0.5 m/s, value close the theoretical one of 8.5 m/s.

Peak values are growing with the distance from the initial point of contact in a good agreement with the associated deadrise angle decrease. A very high pressure peak, far from an expected value, can be noticed for pressure transducer C13. An explanation could be an air bubble trapped in the vicinity of the cell membrane and exploding during the impact. The hull being actually quite thin around that point, this transducer was delicate to install and to fix at level of the keel: it would then result in a shrinkage of 1/10 of millimeters possibly entrapping some air.

However similar time lags and pressure values for the 3 tests (except C13) confirm a fairly acceptable reproducibility of the experiments. The experimental data are therefore reliable enough to be used for numerical code validations.

Local loads on the hull

A comparison between experimental data and some numerical results is carried out for a defined location on the model bow, just below the water line at Station 17.5. A pressure panel (F3) is centered on that point on port side. Two pressure cells (C11 and C12) are placed on both sides of the symmetrical F3 position (same station on starboard). In this configuration the roll angle being null, the pressure exerted simultaneously on both sides on the hull are assumed to be similar.

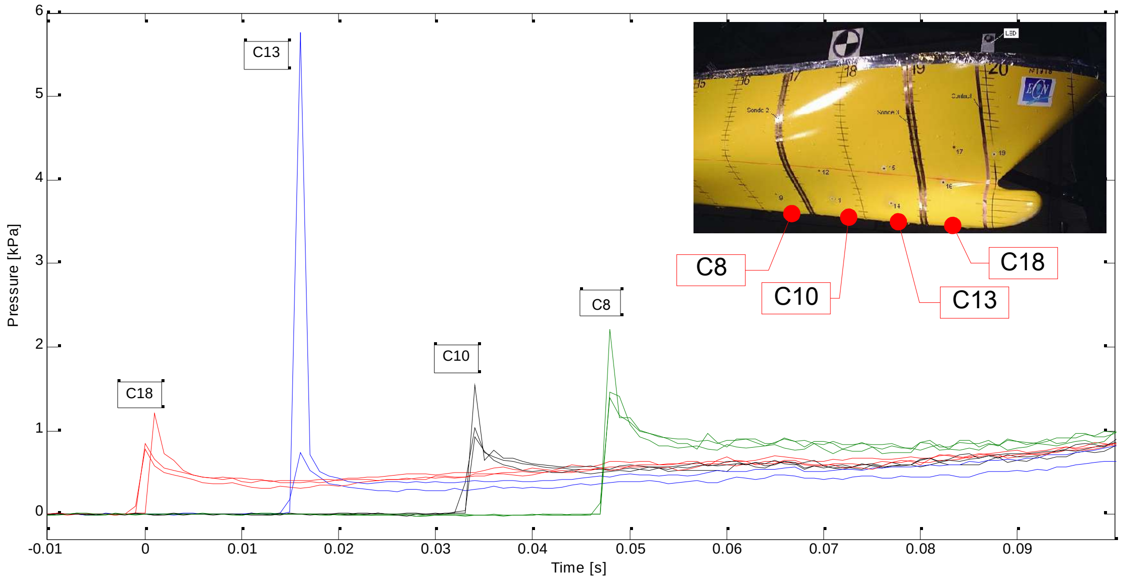

Figure 2 : Successive pressure pics for 3 vertical impact tests (V = 0.6 m/s, pitch = -4°).

The upper graph of Figure 3 shows the pressure at C11 and C12. C11 hits the water first: the impact is defined by the strong pressure gradient (t=0.07 s) followed by a hydrostatic pressure linear increase. C12 hits the water at t = 0.12 s with a pressure gradient slightly lower than C11.

The pressure oscillations before the impact may be caused by the air displacement generated by the model motion or by a water strip raising against the hull, as demonstrated by pictures from the high speed camera [3]. This strip tends to grow and to become a spray which will be detached from the model at t=0.15 s because of a hull curvature change. This loss of fluid explains the simultaneous pressure decreases on C11 and C12 from that instant.

In addition to these data, we plot an interpolated curve corresponding to the pressure at F3 position This curve is also plot on the next graph (Figure 3, below) and compared to the pressure measured by the pressure panel F3 (thick line). The impulsive phase begins around t=0.09 s and the spray effect is also present from t=0.13 s. A good agreement between these two sets of data can be noticed even if the measured pressure at F3 is slightly lower. The pressure on this panel is calculated from a force acting on a larger area (Φ=50 mm) than the area of the pressure cell membrane (Φ=3.7 mm). This area is also larger than the one on which the impact pressure works: it is then consistent to get a lower pressure by the panel method.

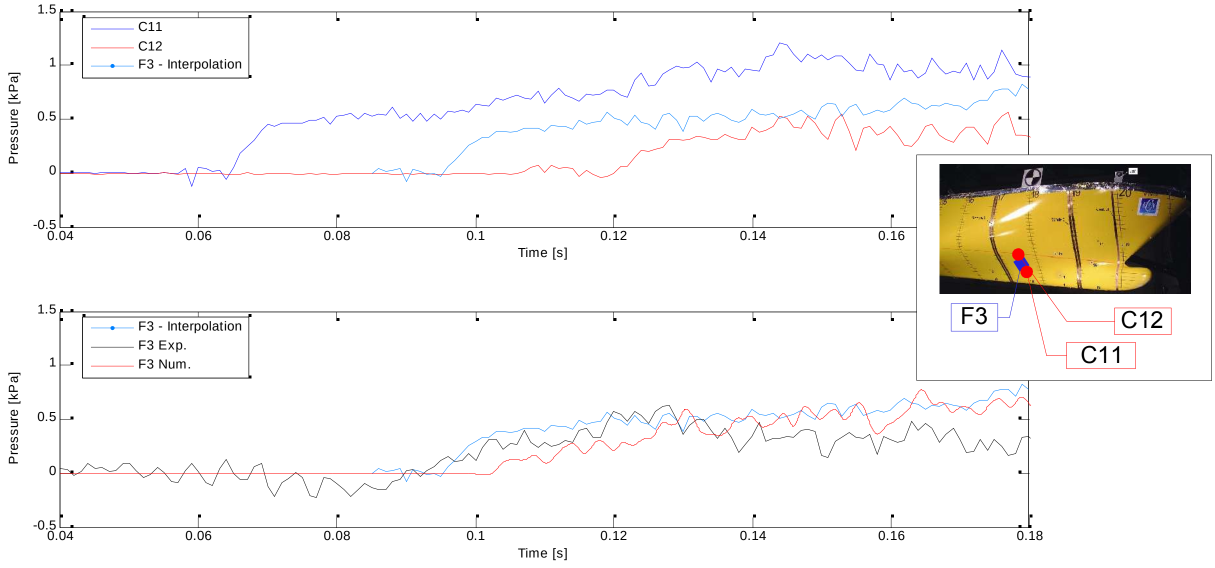

Figure 3: Comparisons between experimental data and numerical results for F3 position.

A result from a numerical simulation (FEM coupled to VOF method [4]) is plot as well on Figure 3. The experimental (pressure panel F3) and numerical pressure gradients are similar but a delay exists between the 2 impulsive phases. This drawback should be corrected by a finer mesh and a larger domain to get a spray evolving freely. It would also reproduce the pressure decrease (from t=0.13 s) which is not the case so far.

Global loads on the hull

Horizontal forces Fx and vertical forces Fz represent the global loads exerted on the complete hull (Fy is negligible in this configuration). A time domain correction is applied to the 6-DOF dynamometer measurements to remove the inertial effects. This correction is estimated from the accelerometers signals and the complete model weight (hull and embedded instrumentation).

Figure 4 presents the mean vertical force from two successive experiments and the corresponding numerical simulation. The numerical simulation predicts correctly the vertical force from the initial contact with the free surface (t=0) to t=0.16 s. The peak of Fz appearing then is caused by a unexpected flow blockage: the model is still in downward motion but its midship hits the domain rear boundary. Again a larger domain should correct that problem (at a notably high cost of CPU-time).

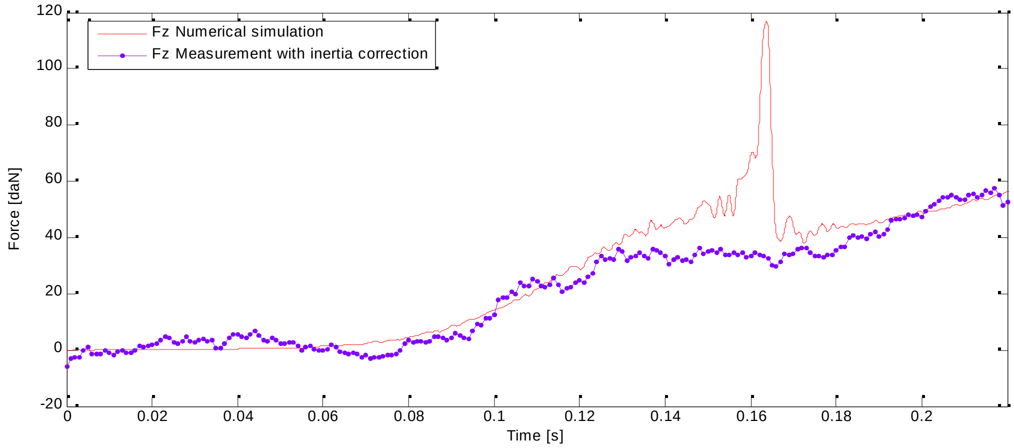

Figure 4: Comparison between measured ans calculated vertical force.

Conclusions

Physical model tests on ship slamming are described and the innovative experimental set-up is detailed. Some preliminary results are also presented. A good reproducibility of the tests is shown confirming the reliability of the data used to validate numerical simulations.

So far comparisons between experimental and numerical results lead to good agreements but this should be extended to more complex motion laws. Ongoing works are focused on that validation aspect and some efforts are also done to reduce the calculation time needed by larger domains.

References

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