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Impact of three-dimensional standing waves on a flat horizontal plate

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1. Introduction

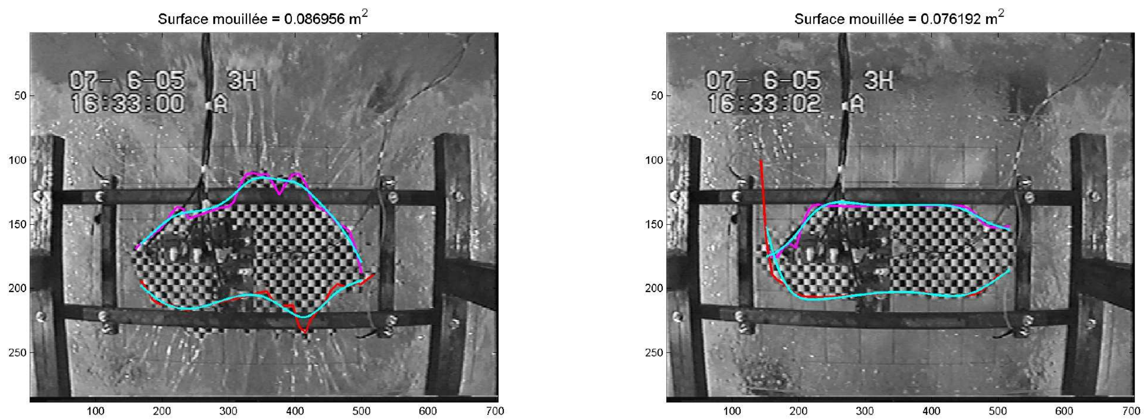
A set-up is designed in order to study the wave impact on structures. These structures can be the stern part of cruiser, a fixed structure as a pier or the roof of LNG-tank. The traveling waves impact was already studied by Smith *et al.* (1998) but it seems difficult to elaborate a model except some empirical formulæ linking the drop height, the wavelength and the wave steepness. Barrholm (2001) as well studied the travelling wave impact underneath decks of platforms. His modelling is based on a two-dimensional Wagner model where the determination of the wetted surface is not a simple task.

Here a simplified impact phenomenon is investigated since standing waves are generated. The set-up is installed in BGO-First (La Seyne-sur-Mer, France).

The picture above shows a side view of the set-up. A vertical plate is set at right angle with the direction of regular progressive waves. This plate is rigidly mounted on the flat bottom at a water depth $1m$; its length is $L = 2.4m$. Its role is to locally reflect the incident wave. As a result, depending on the wavelength of the generated wave, a three-dimensional pattern of standing wave occurs in front of this plate. The first step is to calibrate these waves. Their wavelengths λ vary in the range $[1.5m : 2.1m]$ and their steepnesses ϵ (ratio of the wave height to the wavelength) vary in the range $[3\% : 6\%]$. This calibration provides the location of the maximum of wave height, which is supposed to be fixed in time; roughly at a half wavelength of the plate. In order to perform this calibration, a computational code has been used. This code (see Jamois, 2005) models the diffraction of regular waves with a fixed structure in the frame of a Boussinesq approach.

A horizontal transparent plate (Plexiglass) is rigidly mounted on a stiff support. It is $1.5m$ long, $0.8m$ wide and $0.02m$ thick. Its center is located at the maximum of wave height. Its vertical position (h) may vary from $0.05m$ up to $0.11m$ measured from the initially still water surface.

The instrumentation consists in 6 wave gauges (Orca type) fixed on the horizontal plate through sealed holes. All sensors are located close to the maximum of wave height. The vertical force is measured by means of force sensors at the junctions between the four vertical columns and the plate. The sampling frequency is $f = 2KHz$. A video camera is located above the transparent plate so that it can record the expanding/shrinking wetted surface as the impact of wave occurs repeatedly. Its sampling frequency is $25Hz$. A large draughtboard lies on the sea bottom so that it makes it possible to measure (more or less) precisely the time varying wetted surface. This is achieved by post-processing each successive image of the video recording. An example of it is shown on the picture below.

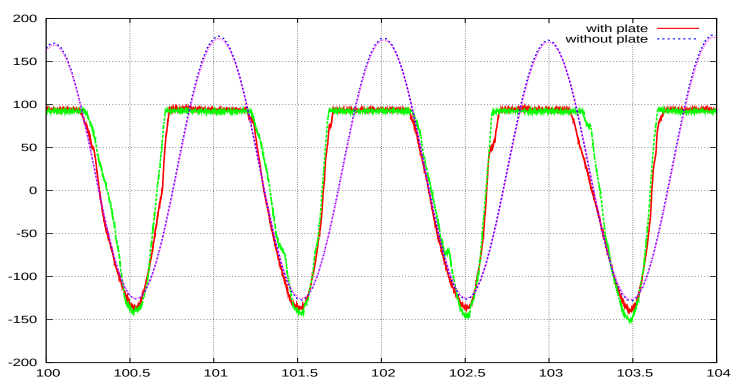


The duration of the measurements depend on the time during which the standing wave pattern is stable. As soon as the reflection on the wavemaker gets sensitive in the vicinity of the vertical reflecting plate, measurements stop.

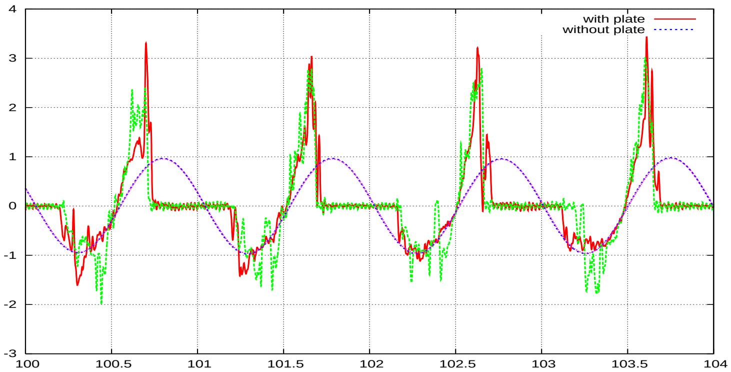
The following developments mainly describe the phenomenon through the analysis of the acquired data: free surface kinematics, wetted surface and vertical force.

2. Impact of standing waves

The presence of the horizontal plate significantly disturbs the wave kinematics locally. It is worth comparing the wave elevation with and without the obstacle. The figure below show their time variations at points close to the maximum of water oscillation.



When the flate plate is hitted, the wave gauges saturate at a threshold which corresponds to the airgap h. What is most noticeable is the larger slope of the ascending wave. This means that the local vertical velocity increases due to presence of the flat plate. This vertical velocity is calculated by a time differentiation of the wave elevation. This leads to a very irregular signal and a smoothing is necessary. The figure below shows a time sequence of the velocity variation.



The signals are shifted in time so that the minima of all time series occur at the same instant. It is clearly shown that 1) the kinematics of the descending wave is hardly modified, and 2) the kinematics of the ascending wave differ significantly with and without the plate. The vertical velocity has a factor of amplification ranged between 2 and 3 and the velocity may reach $3m/s$ just before the impact. Clearly the wave pattern obtained at the calibration stage cannot be used to characterize the impact phenomenon.

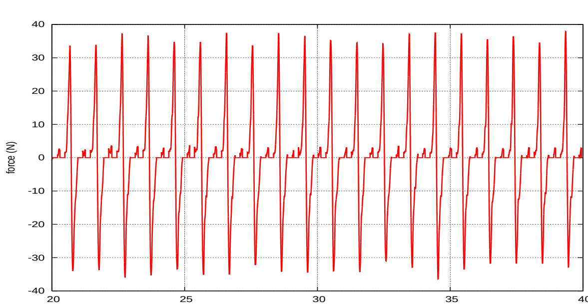
It should be noted that the set-up was originally designed to analyze the run-up along vertical wall (see Molin *et al.*, 2005), hence without the horizontal plate. It was observed that the phenomenon is transient and the free surface elevation along the vertical wall increased slowly during the whole duration of the trial, until reflected waves come back from the wavemaker. Indeed, the pre-calibration of the standing wave exhibit this transient phase not only at the vertical wall but also in its vicinity, at least at a halflength of this wall. On the other hand the presence of the horizontal plate makes that the phenomenon gets more stable in time and except at the first three impacts, no transient phase can be identified further in time. Two parameters here are implied in the phenomenon: the steepness and the airgap. Unfortunately the experimental database is not rich enough to draw clear trends.

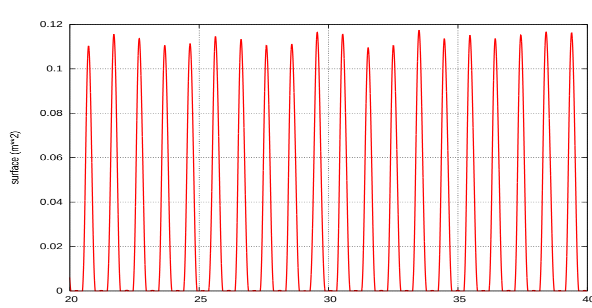
The fact that the velocity is amplified suggests that energy accumulates locally below the plate. It is not clear at present which mechanism governs this amplification.

3. Hydrodynamic force and wetted surface

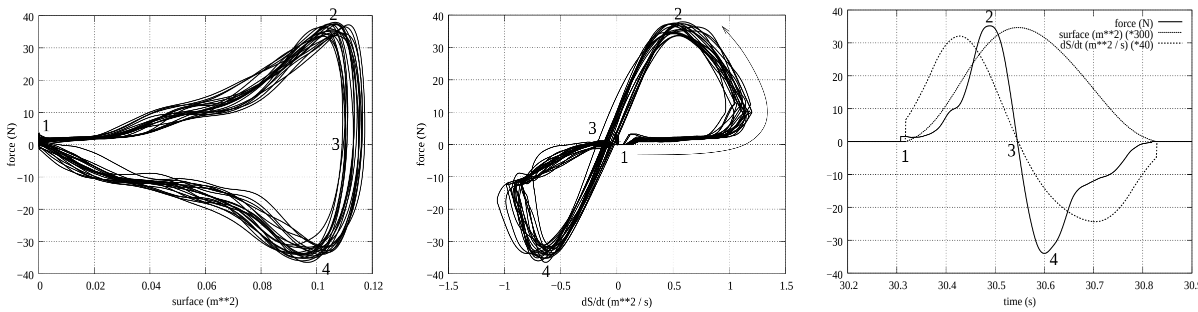
More interesting are the time variations of the force and the wetted surface. It should be noted that the measurement of this surface suffers from numerous short-comings. These short-comings follow from 1) the low sampling frequency of the video camera, 2) the way to post-process the images and 3) as a matter of fact the presence of stiffeners significantly disturbs the frame of visualization. Much improvments could be brought to the set-up regarding this key feature of the present experiments.

Two phases can be clearly identified during the fluid-structure interaction. The first one corresponds to the acsending wave during which the wetted surface expands; it will be called "impact phase". The next phase corresponds to the descending wave when the wetted surface shrinks; it will be called "exit phase". The time variations of the force and the wetted surface are plotted in the figures below.





It is worth noticing that the positive and negative maxima of the force are of the same magnitude. This was also revealed by Barrholm (2001). These plots also show that the repeatability of each impact of standing wave crest is reasonable consistently with the repeatability of the measured wave kinematics. In order to check this point, the force is plotted in term of the wetted surface (figure below, on the left).



Each step of the two phases are numbered in the figures over one cycle. The force is also plotted in term of the time derivative of wetted surface (figure in the middle). The zoom (on right side) indicates that the duration of the exit phase is slightly higher than the duration of the entry phase. This suggests that the surface roughness may play a role. This problem has not been investigated here but it can be expected that a hydrophobic surface would lead to a symmetric behavior of the force variation. Here the non hydrophobic nature of plexiglass makes that fluid ”sticks” to the plate and that could explain the difference of duration.

At that stage, in order to avoid the difficult task to elaborate a proper model, some identifications can be done. The most natural identification follows from the fact that the monotonicities of both the force and the time derivative of the wetted surface $S(t)$ are similar. Indeed these variations suggest to find the force $F(t)$ in term of $S^n(t)\dot{S}$ and then to find the exponent n which fits the curves. The first identification shows a variation of $F(t)$ with $S^4(t)\dot{S}$ and a reasonable fitting is reached at least between the two instants corresponding to the negative minimum and positive maximum velocity of surface expansion. The validity of this empirical formula is questionable since its dimensionality is not obvious. It is clear that this simplified formula has nothing in common with a Wagner model which is actually known to be valid at the very first instant of contact. More generally, the force could be decomposed in terms of $(S, \dot{S}, \ddot{S})$ then the identification is more complicated. Further work is needed to elaborate a model reproducing such a phenomenon.

6. References

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