Experimental study of the wave response of a two-dimensional rectangular barge in very shallow water.

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Introduction

Albeit the offshore oil industry is quite active in very deep water (1000-1500 m), there is a growing interest for shallow water hydrodynamics. Part of this interest comes from the expected raise in LNG consumption which will require new offloading terminals and storage structures by the coast. Many operations, such as structure assembling or on-boarding of equipment, are carried out in restricted waterdepths. This raises new hydrodynamic problems associated with station-keeping and slow-drift motion (release of infra-gravity components when wave systems propagate to the coast, derivation of the QTF's), or with the incident waves not being Stokes waves any more, or small under keel clearance.
In this study we focus on the latter two problems, through dedicated experiments and numerical analysis.

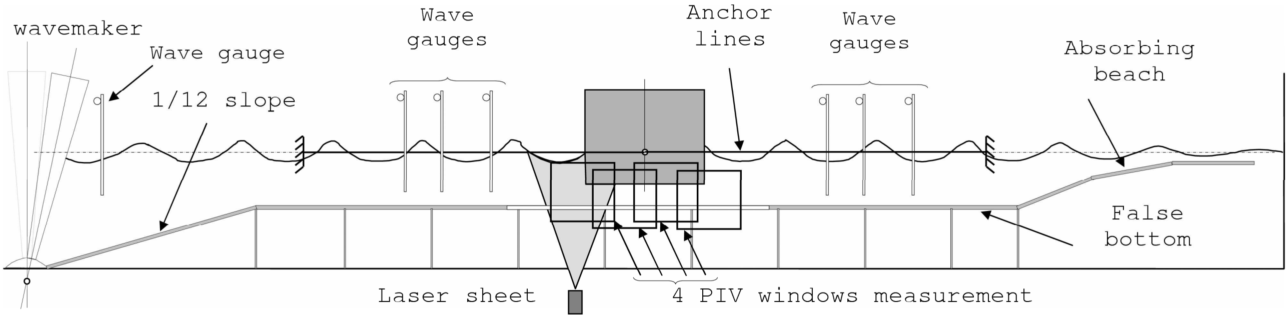

Figure 1: *experimental set-up*

Experimental set-up

The experiments were conducted in the EGIM glass-walled wave tank in Marseille. A sketch of the experimental set-up is shown in figure 1. The tank is 16.8 m long and 0.65 m wide. The wavemaker is a flap type with the axis of rotation located at 0.50 m under the tank bottom. In order to produce waves of large steepness even in very shallow water, a false bottom made of polyvinyl plastic, 0.25 m high, was installed in the tank, with a 1/12 slope over the first 3 m from the wavemaker. The rectangular wooden barge model is 0.65 m wide, 0.65 m long and has a draft of 0.15 m. It was moored by elastic ropes, attached to the glass walls, which opposed the drift without affecting the sway response. To measure wave characteristics, two sets of three wave gauges, on either side of the model, were used. To measure the motion of the barge, a pair of luminescent diodes set to the hull as shown in figure 2 are followed by a video camera.
Finally, a PIV technique was used to measure the velocity fields under the barge. To allow the laser sheet to flash through the false bottom, a windowed part was installed. The PIV measurements were performed only at the smallest waterdepth.

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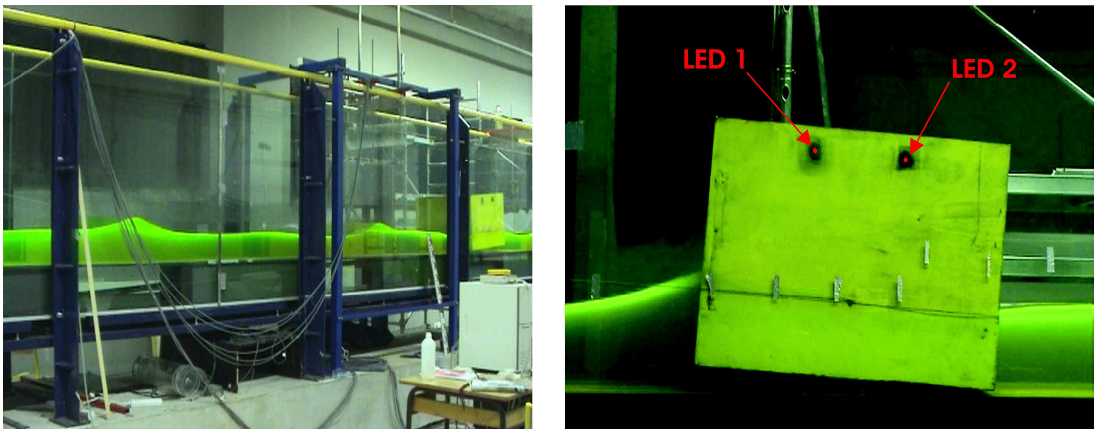

Figure 2: *photographs of the experiments*

Experimental conditions

The experimental conditions are reported below:

Period : 0.6 s to 2 s by step of 0.1 s
H/λ : 1.5 %, 2.2 % and 3 %
Waterdepth over the false bottom : 0.37 m , 0.32 m, 0.27 m and 0.217 m
$U_R = H\lambda^2/h^3$: 0.05 to 42

A previous set of experiments had been performed without the false bottom and at a depth of 0.74 m. The tested periods were the same and the steepness was equal to 3%.

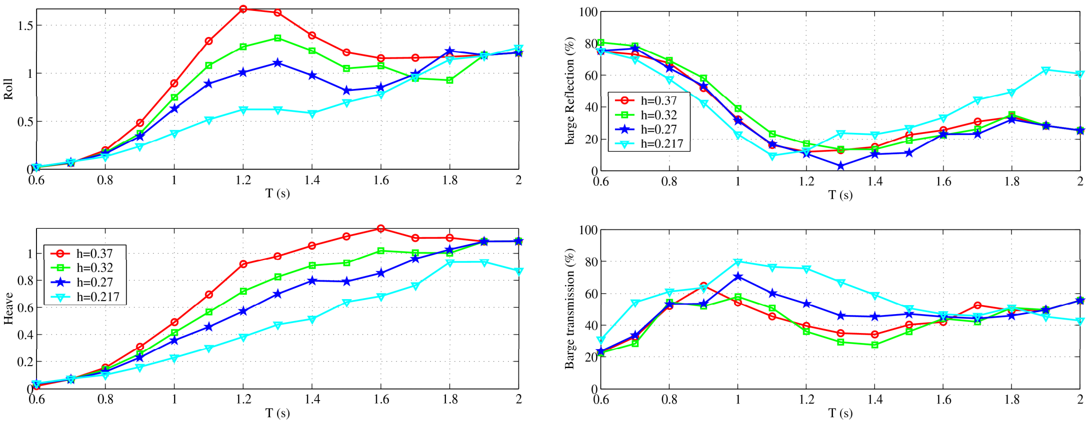

Figure 3: *(Left): evolution of the roll and heave RAO's vs. the waterdepth. (Right): evolution of the wave reflection (top) and wave transmission vs. the waterdepth*

Results

The RAO's for roll (normalized by the steepness kA) and heave motions vs. the wave period for different waterdepths and at a steepness equal to 3 % are presented in figure 3 (left). They were obtained from Fourier analysis of the records. As for the roll motion, the resonance period slowly increases as the depth decreases, except at the smallest depth, where the resonance seems to disappear. This might be associated with the hydrodynamic cushioning effect provided by the small under keel clearance (e.g. see Drobyshevski, 2004). The roll RAO's decrease with the depth, and at the smallest depth they become less than one, meaning that (the fundamental component of) the barge angular motion is less than (the fundamental component of) the wave slope. As it is shown in figure 4 (left), the behavior of the barge has become strongly nonlinear, as well as the free surface elevation, the Ursell number being larger than ten. For the heave motion the behavior is more monotonous, the amplitude decreases when the waterdepth increases.

In figure 3 (right), the reflection and transmission coefficients, as functions of the period, for the same cases as before, are presented. A minimum of reflection is reached, except for the smallest depth, for a period approximately equal to 1.3 s, slightly larger than the roll resonance period (1.2 s). For the smallest depth, the minimum is reached for a period approximately equal to 1.1 s and the reflection coefficient reaches a value of 60 % for a period of 2 s, instead of 25 % for greater depths. For the transmission coefficient, the same kind of comment can be done. It can also be observed that, around the roll natural period, $C_R^2 + C_T^2$ is much less than one (as low as 0.2-0.3), meaning that energy dissipation is strong, or that energy is being transferred to higher harmonics.

In order to evaluate the capability of a linear code to predict the barge response in such conditions, we have compared our experimental results with the numerical predictions from the linear diffraction-radiation code described in Cointe *et al.* (1991). In figure 4 (right), we present the measured and calculated roll RAO's for three different waterdepths (0.74 m, 0.32 m and 0.217 m). In each waterdepth a drag coefficient (introduced in the roll viscous damping moment) was adjusted to minimize the difference at the peak RAO value. At the larger waterdepth, as expected, the comparison is very good. But at shallow depths, discrepancies appear for increasing values of the wave period. Again they must be related to the high values of the Ursell number.

We finally report on the PIV investigation. Examples of results are given in figure 5 for the velocity and in figure 6 for the vorticity. The measurement window is located at the corner on the weather side. This corresponds to a very shallow water case. It can be observed that a very strong vortex is created and ejected from the corner. This is at variance with results from flow visualizations at larger waterdepths (Kwang *et al.*, 2005) which show vortices trapped by the corner. Presumably the vortex ejection is associated with the strong flow velocities in the small gap below the keel, which flush out the vortex. This effect should increase energy dissipation and raises the question of the appropriateness of potential flow theory in such small under keel clearance conditions.

Nonlinear numerical simulations

We are planning to perform fully nonlinear calculations with a 2D numerical wavetank (Cointe *et al.*, 1991). Hopefully results will be reported at the workshop.

References

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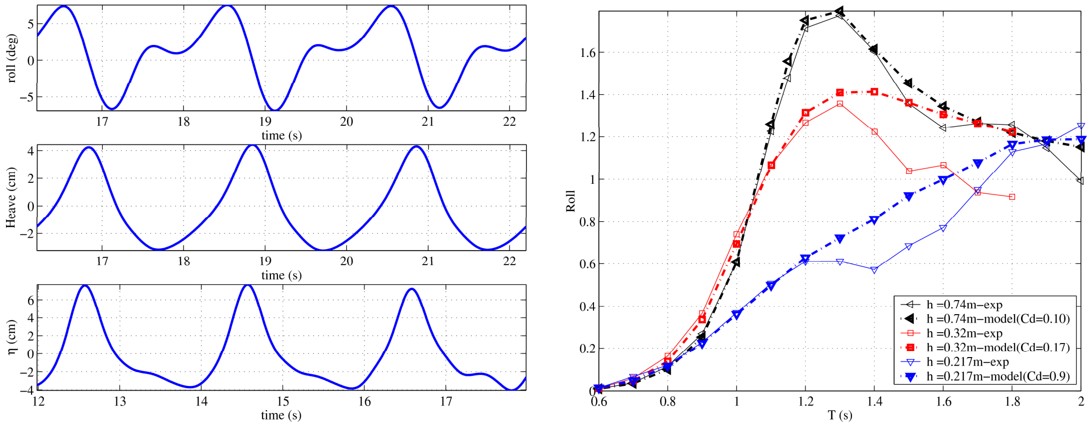

Figure 4: *(Left) time series for respectively from the top to the bottom, the roll, the heave and the surface elevation. T=2s, H/λ=2%, h=0.27m and U_R=31.5. (Right) comparison between linear calculations and experimental results*

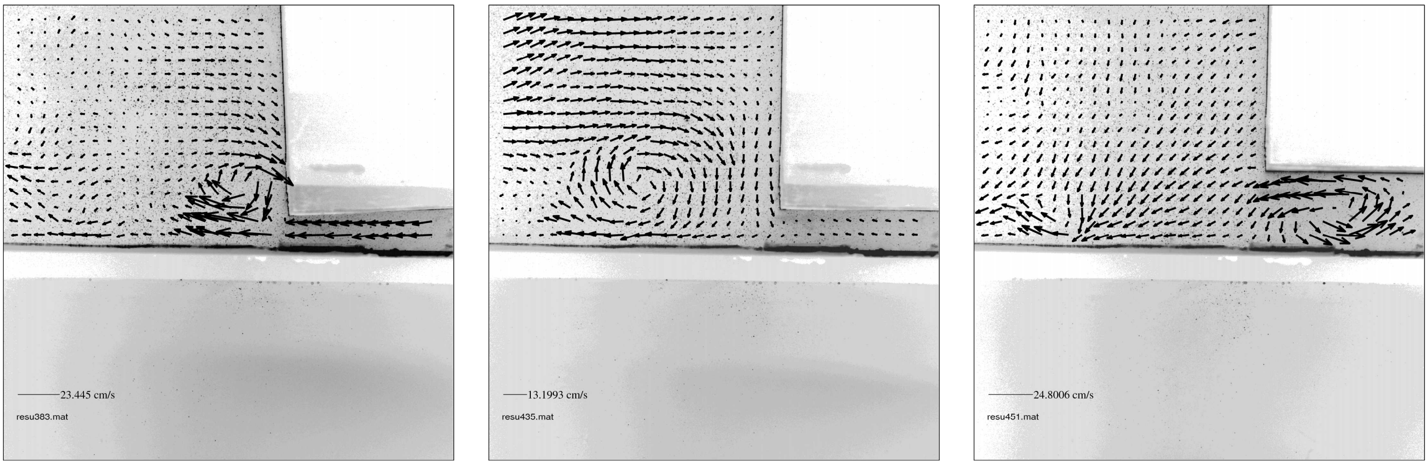

Figure 5: *examples of PIV results for depth h=0.217m, wave period T=1.9s and steepness H/λ= 2.2%*

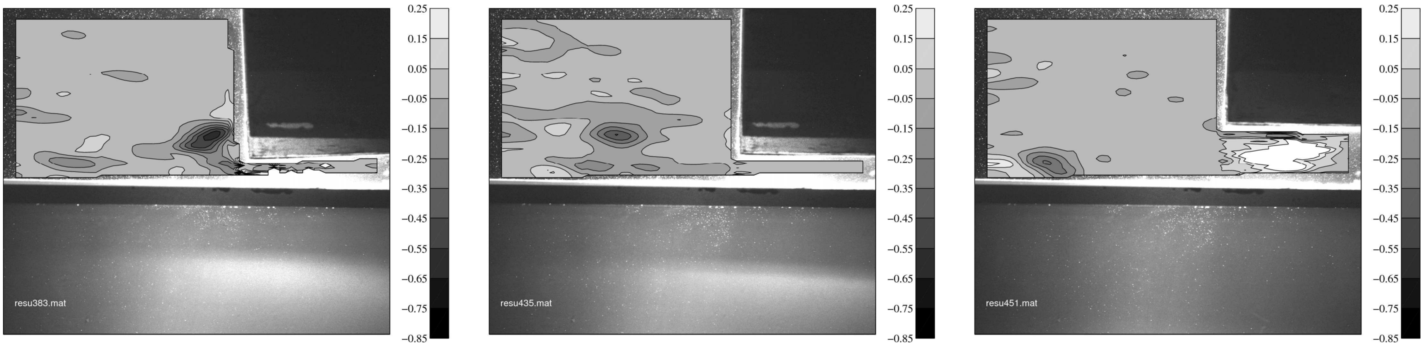

Figure 6: *examples of vorticity results for the same case as figure (5)*