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Experiments on a barge rolling next to a wall

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1 Introduction

The hydrodynamic roll response of a ship is modified when in close proximity to a second vessel or a solid terminal, exhibiting multiple, coupled resonances. Provided that the bilges are sufficiently sharp, flow separation and hence the roll damping may be attenuated or amplified depending on the fluid in the gap and the roll motion. The piston response of the fluid in the gap, though damped through viscosity and flow separation, can also induce significant pressures gradients along the surface of the hull to affect the roll motion.

Recent studies in the context of side by side offloading of floating liquid natural gas (FLNG) have provided measurements of the resonant fluid motion in the narrow gap between two rigid boxes in surface waves (e.g. Zhao et al. (2017)). These investigations have provided valuable insights into the underlying hydrodynamics associated with the flow in the gap but have not explicitly considered the relative motion of the bodies. Accurate prediction of the roll response of the LNG carrier is however critical for ensuring the safe and efficient side by side offloading of FLNG in the open sea (Zhao et al., 2018).

Motivated by this, a new series of experiments were devised to study the response of a barge next to a wall which was free to respond to beam waves in pure roll. The tests may be considered to be a simplified analogy of the side by side offloading scenario. The objective was to evaluate the barge roll response and the free surface in the gap as well as visualize of the flow around the bilge near the gap. The measurements also assist in the validation of numerical models to estimate the roll response.

2 Experimental set-up

The experiments were performed in the wavetank at Ecole Centrale Marseille. The wavetank is 16.77 m long, 0.65 m wide and the water depth was set to 0.6 m. The barge had a beam of $b = 0.6$ m, draft $d = 0.12$ m and square bilges. It spanned the width of the tank with small clearances between the side walls to allow for motion. The distance between the barge and the vertical wall was $w/b = 0.09$. To assist in isolating the effect of the wall, tests were also performed for the case without the wall with a beach present to damp reflected waves.

The motion was restricted to pure roll through a mechanical bearing that was fixed rigidly to an external support structure. The roll axis was located at the geometric centre of the barge and aligned with the mean free surface. The angular displacement of the barge was measured by tracking a diode on the barge using a high frame rate camera. The flow field around the bilge next to the wall was captured using a PIV system.

The barge response was measured in regular waves with constant steepness. Response amplitude operators (RAOs) for the barge roll and surface elevation in the gap were computed after excluding initial transients and reflected waves from the time histories.

3 Numerical model

A linearized potential flow model, based on eigen-function expansions, was used for comparison with the experimental results. This is the same model as used by Kimmoun et al. (2011). To account for viscous damping of the piston mode in the gap, a fictitious rigid lid was introduced at the free surface in-between the barge and the wall, following the technique used in the software Diodore of Principia (see Molin et al. (2009)). Quadratic damping is introduced in the roll motion of the barge and in the heave motion of the lid, based on the relative velocity of the lid with respect to the barge edge next to the wall.

For the lid the viscous damping force is written as

$$F = -\frac{1}{2}\rho C_{Dlid} w |\dot{z} + b\dot{\theta}/2|(\dot{z} + b\dot{\theta}/2) \tag{1}$$

while the viscous roll moment is written as

$$M = M_1 + M_2 \tag{2}$$

$$M_1 = -\frac{1}{4}\rho C_{Droll} b^4 |\dot{\theta}|\dot{\theta} \text{ on the outer side and} \tag{3}$$

$$M_2 = -\frac{1}{4}\rho C_{Droll} b^4 |\dot{\theta} + 2\dot{z}/b|(\dot{\theta} + 2\dot{z}/b) \text{ on the wall side,} \tag{4}$$

where $\dot{\theta}$ is the roll angular velocity and $\dot{z}$ is the velocity of the lid. The response is obtained through iterations. In the 'decoupled' case the roll moment is taken as $2M_1$.

4 Results

The barge roll response without the wall is first plotted in Figure 1. The roll RAO is defined as $|\theta|/kA$, where θ is the roll angle in radians, k is the wave number and A is the wave amplitude. The measurements were obtained for a wave steepness of $H/\lambda = 2\,\%$. The numerical estimates are also shown for comparison. In the computations the box inertia (not measured yet) and the drag coefficient C_{Droll} are adjusted in order to get the best fit possible. This yields a drag coefficient equal to 0.07 (somewhat low as compared to our experience probably due to some friction in the bearings, a matter still to be improved).

The effect of the wall is demonstrated through comparisons with the roll RAOs in Figure 2 for the gap ratio of 9 % and the same wave steepness. The introduction of the wall results in a reduction of the resonant roll amplitude and an attenuation of the response either side of the peak. The piston mode in the gap at around $T = 1$ s results in a relatively small amplification in the response. Figure 3 shows the free surface elevation in the gap and serves to further elucidate the gap resonances.

The lid and roll drag coefficients for this case have again been adjusted in order to get the best fit possible for the roll and gap elevation RAOs. The numerical curves plotted have been obtained with $C_{Droll} = 0.05$ and $C_{Dlid} = 3$. (Note that the roll inertia had to be slightly decreased, suggesting that gap viscous effects also affect added inertia). The decrease of the roll drag coefficient, due to the wall, is consistent with the findings of Milne and Graham (2018). There is a relatively small difference between the coupled and decoupled numerical results and a reasonably good fit to the experimental data is obtained.

In order to illustrate the vortex shedding dynamics near the roll resonance, measurements of the instantaneous vorticity contours at the bilge edge adjacent to the wall are shown in Figure 4. As the barge is displaced clockwise from its maximum angular displacement, a vortex which has a size comparable to gap width is formed at the bilge. This vortex is subsequently shed and is convected around the edge, forming a pair with a newly formed vortex of opposite sign as is typical for oscillatory viscous flow around a sharp edge (Graham, 1980). The displacements of the vortices are however highly constrained by the geometry of the gap. The significant background flow serves to first convect the vortices upwards towards the free surface before subsequently ejecting the vortices from the gap during the reversal of the flow.

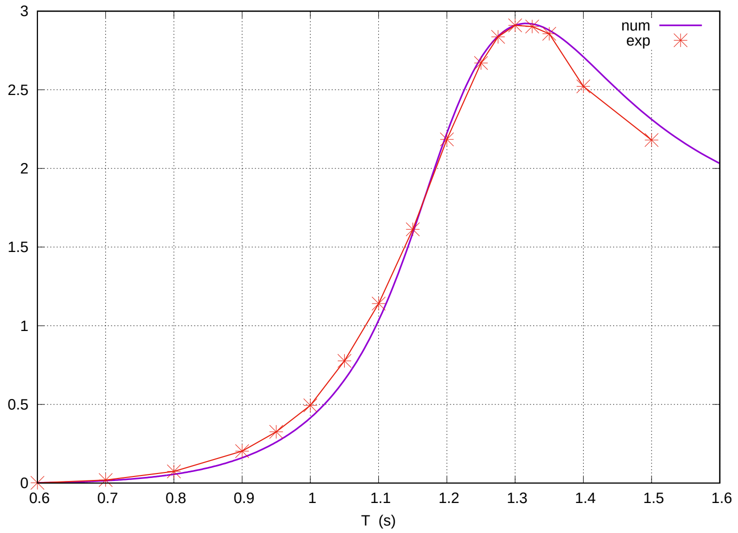

Figure 1: Barge roll RAO without the wall, $H/\lambda = 2\,\%$.

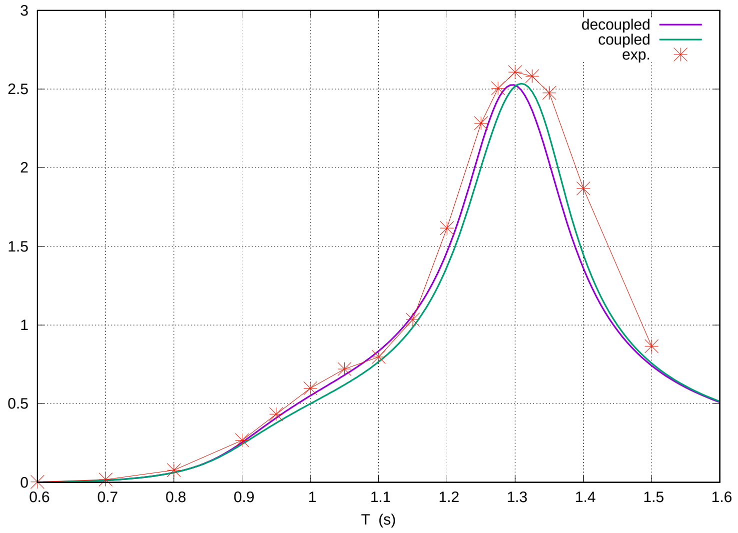

Figure 2: Roll RAO for the barge next to a wall, $w/b = 9\,\%$, $H/\lambda = 2\,\%$.

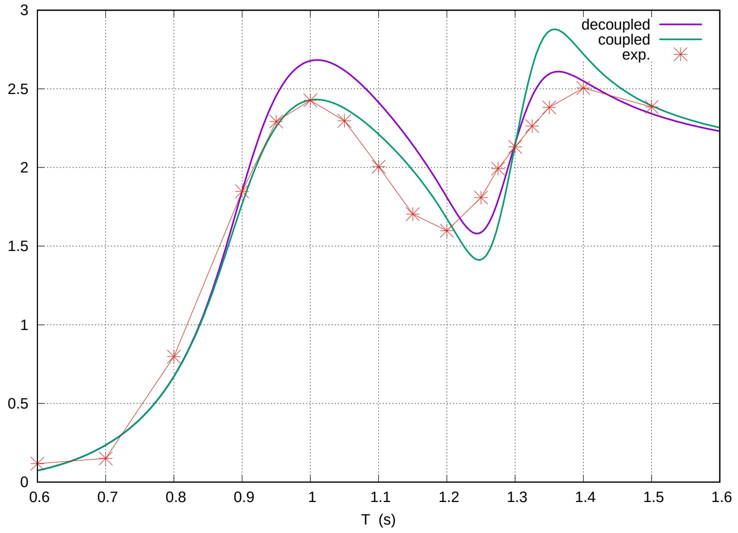

Figure 3: Free surface in the gap for the barge next to a wall, $w/b = 9\,\%$, $H/\lambda = 2\,\%$.

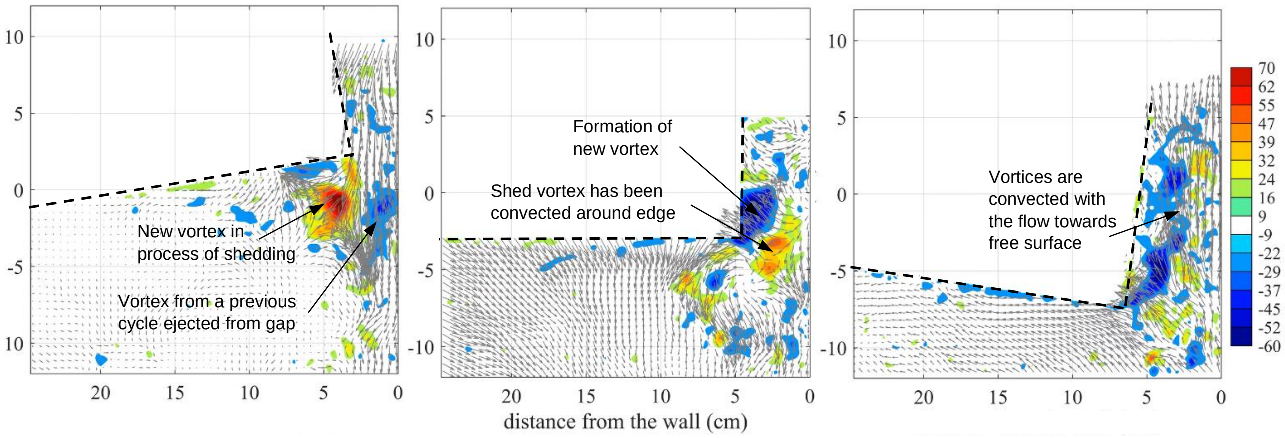

Figure 4: Vorticity measurements (sequentially, left to right) for the barge rolling next to a wall, $w/b = 9\,\%$, $T = 1.275\,\mathrm{s}$, $H/\lambda = 2\,\%$.

Acknowledgment

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