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Experimental measurements of perfect absorption on surface water waves

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***Abstract* – We present experimental measurements of perfect wave absorption on surface gravity-capillary waves. The equilibrium between friction losses and coupled resonance yields a zero reflection coefficient. As a simple resonator, among other possibilities, the trapped modes produced by a non-symmetrical cylinder are used to generate absorption.**

I. INTRODUCTION

The absorption of water waves is a problem that catches the interest of scientists and engineers due to the direct applications. Theoretical studies, as well as experimental investigations, have been performed in useful and promising problems like power generation or coastal protection. Regarding the vast theory developed in the last decades, one can mention [2], which gives a theory for predicting the wave absorption by oscillating damped floating bodies. Later works [3–5] present new devices, as the oscillating water column, that improves the energy absorption.

Now, we turn our attention to a simpler problem. The absorption of water waves by means of friction losses, which in this case plays the role of the mechanical absorber. In this case, when the friction losses are equal to the radiation of the coupled resonator the reflection coefficient is zero. This type of perfect absorption has been proposed recently in acoustics by [6].

II. EXPERIMENTAL SET-UP

Experiments were carried out in a narrow channel designed to measure the wave deformation by means of Fourier Transform Profilometry (FTP) [1], as described in figure 1. The water depth was fixed at 50 mm, which permits us to generate easily linear waves in intermediate depth conditions by a flap-type wavemaker.

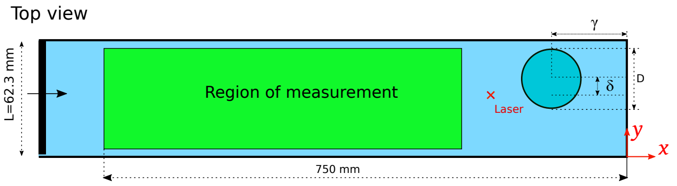

Fig. 1: Experimental set-up

The position of the cylinder is defined by the parameters δ and γ corresponding to the distance from the longitudinal axis and to the end wall respectively.

III. OBTAINING THE REFLECTION COEFFICIENT

Considering a linear regime, with negligible contribution of higher harmonics, we average the FTP data in time by means of a Fourier Transform at the forcing frequency ω. Thus, the fundamental mode $\eta_1(x,y)$ is obtained as:

$$\eta_1(x,y) = \frac{2}{T}\int_0^T \eta(x,y,t)\cdot e^{i\omega t}dt \tag{1}$$

where T represents an integer number of wave periods.

Once we have the complex field of the fundamental mode, we average in the transverse direction y, considering plane waves. Thus, we have a one-dimensional wave, which can be approximated by the addition of two linear waves in opposite directions:

$$\bar{\eta}_1(x) = a\left(e^{ikx} + Re^{-ikx}\right) \tag{2}$$

where a is the amplitude of the incident wave, R represents the reflection coefficient and k the wavenumber.

IV. VARIATION OF RESONATOR PARAMETERS

The influence of the cylinder position has been inspected by varying the parameters δ and γ indicated in figure 1. The variation of these parameters influences the absorption due to the amplification of the resonance.

A. *Variation of δ*

The first analysis consists of varying the transverse asymmetry of the cylinder located near the end-wall. As indicated in figure 1, the parameter $\delta = 0$ corresponds to the cylinder located at the center line of the channel. The increase of δ produces excitation of non-symmetrical trapped modes resonance, and consequently a growth in the absorption. In figure 2 we compare four different values of δ with the reflection measured without cylinder (called *wall* in the figure). The absorption increase almost twice when δ changes from 2 mm to 5 mm. That is an experimental confirmation of the larger contribution of trapped modes to the resonance. In the vertical line k_cL represents the resonant frequency of trapped modes [1].

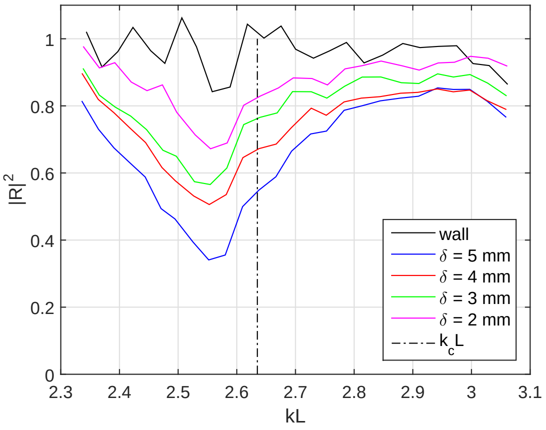

Fig. 2: Reflection coefficient measured at the wall position. The distance to the end $\gamma = 55$ mm or $\gamma/L = 0.88$. The size of the cylinder is $D/L = 0.8$.

B. *Variation of δ for a larger γ and smaller cylinder*

In order to allow more freedom of movement to the cylinder, we use in this case a smaller cylinder, with a diameter $D/L = 0.64$. Likewise, we consider that the best absorption in the γ varying experiment was obtained at $\gamma/L = 1.45$, which we fix as well in this experiment. The reduction of the cylinder size gives us, as expected, an improvement in the absorption with values of $|R|^2 < 0.05$, as shown in figure 3. This improvement can be explained by the greater asymmetry given by the smaller cylinder that amplifies the trapped modes.

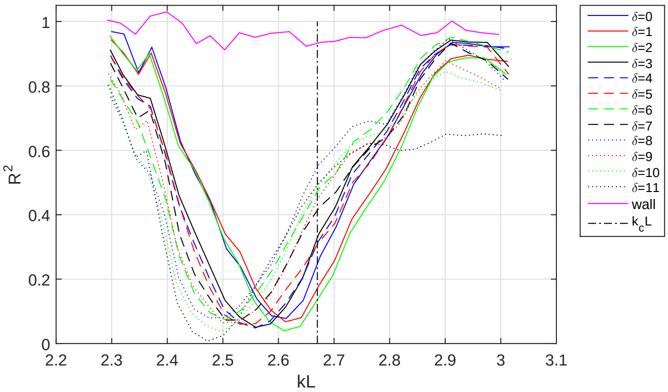

Fig. 3: Reflection coefficient measured at the wall position with $D/L = 0.64$; γ/L=1.45; $\delta_{max} = 11$ mm.

V. Conclusion

We have presented an ongoing work that has given so far promising results, showing experimental evidence of the perfect absorption with a simple resonator.

We have verified that the excitation of non-symmetrical trapped modes grows with the asymmetry of the cylinder. When the cylinder is located sufficiently close to the end-wall, the asymmetry is the main parameter that controls the absorption. The maximum absorption was found for the maximum transverse eccentricity.

When we vary the distance between the cylinder and the end-wall, the absorption grows significantly. We observed that when the cylinder is sufficiently distant from the end-wall, the transverse position of the cylinder does not affect the absorption. Therefore, we consider in this case the existence of other resonances that are excited at the same frequency, for instance, a harbor-type resonance can be generated in the partially-closed region behind the cylinder.

This project will be continued with the trial of other types of resonators, with the objective of finding the best configuration that produces perfect absorption. One possibility is a rectangular Helmholtz-type resonator, which permits us to better control the resonance in terms of the quality factor.

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