# Experimental Study of Non-Linear Effects in a Model Oscillating Water Column Wave Energy Converter

Danica Tothova, Swinburne University of Technology

Supervisors: R. Manasseh (Uni. Swinburne), S. A. Sannasiraj (IITM), A. Toffoli (Uni. Melbourne), I. Penesis (Uni. Tasmania)

**Oscillating water columns (OWCs) are a class of Wave Energy Convertors (WECs), which may reduce the energy of the waves at lower long-term cost and with lower environmental impact than the conventional alternatives of coastal protection. There are many scientific models for prediction of the performance of OWCs, most of which are based on linear theory, assuming small wave amplitudes. However, OWCs are designed to work at resonance with the incoming waves to achieve a large amplification of the wave height and therefore, large power output. This implies non-linear behaviour along with a possibility of large energy removal from destructive waves. Experiments in wave flumes allow us to study the non-linear effects of OWCs and thus understand better how their energy generation performance and coastal protection performance changes with their geometry and with ocean conditions. Our experiments show a significant dependence of the amplification at resonance on the incoming wave height and frequency as well as on the length and diameter of the column, which is inconsistent with the linear theory.**

## Objectives of Integration of Wave Energy Conversion and Coastal Protection

1. Conversion of energy from the incoming waves into a useful form (optimum is achieved at resonance and with minimum losses of energy)

2. Reduction of energy of destructive waves (optimum is achieved at resonance, and with maximum losses of energy)

## Operating Break-Water Power Plants

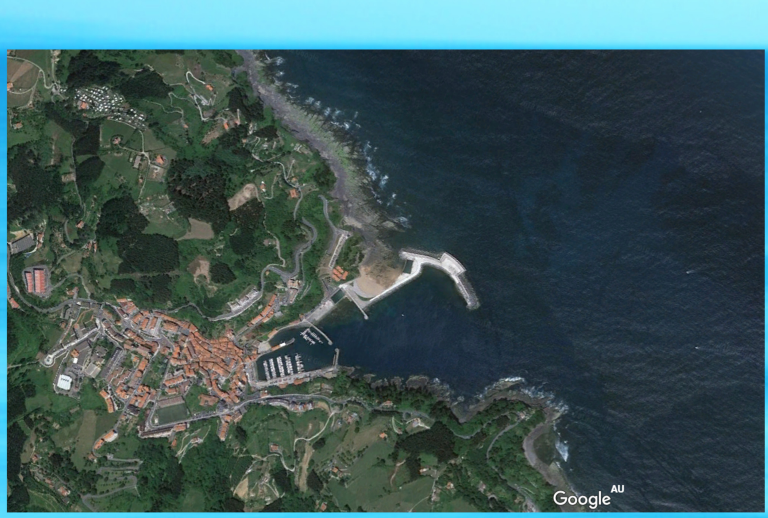

Figure 1. Mutriku, Pays Basque – first commercial , commissioned in 2011. Photo from Google Earth.

*Figure 2.* REWEC3 - Resonant Wave Energy Convertor, commissioned in 2012 in Civitavecchia, Italy. *Photo by www.Duomi.it.*

## Possible Sources of Non-Linearities

1. Mass of the liquid pendulum is time-dependant, as it increases with the free-surface elevation inside the OWC

2. The incoming waves are linear as in the presented experiments, but the amplified waves in the column are not (non-linear losses due to vortex shedding (Fig. 4), turbulence, and boundary layer friction at the mouth of the OWC).

3. The incoming ocean waves are non-linear – they are steeper than sinusoidal waves (wind waves, surges (Fig. 3), shallow water waves, ka >1)

*Figure 3. A surge wave breaks over Mornington Pier during wild weather across Melbourne and Victoria on June 24 2014. Mornington Peninsula News: Cameron McCullough.*

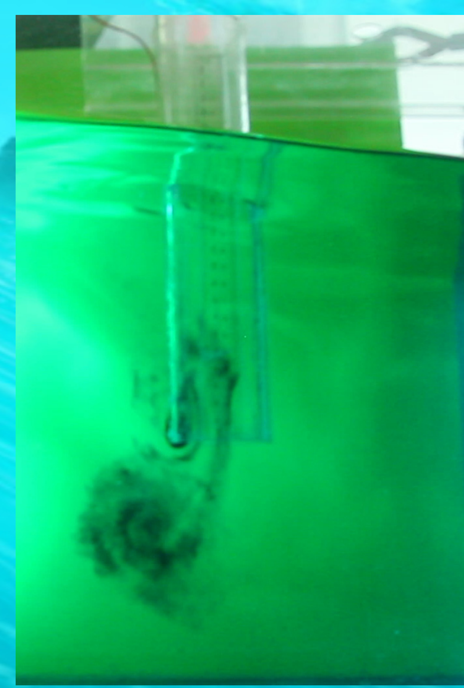

*Figure 4. Vortex formation at the mouth of our model OWC. Vortices and turbulence represent irreversible non-linear losses of energy.*

## Preliminary Results and Outlook

❶ The measured resonant frequency (Fig. 5b) is lower than the theoretical one (Fig. 5a), suggesting there is a mass of water underneath the column oscillating coherently with it. This added length depends on the forcing amplitude, as well as on diameter and length of the column. The maximum added length (about 22 %) was found for the shortest column. It has to be added to the equation of motion as added mass.

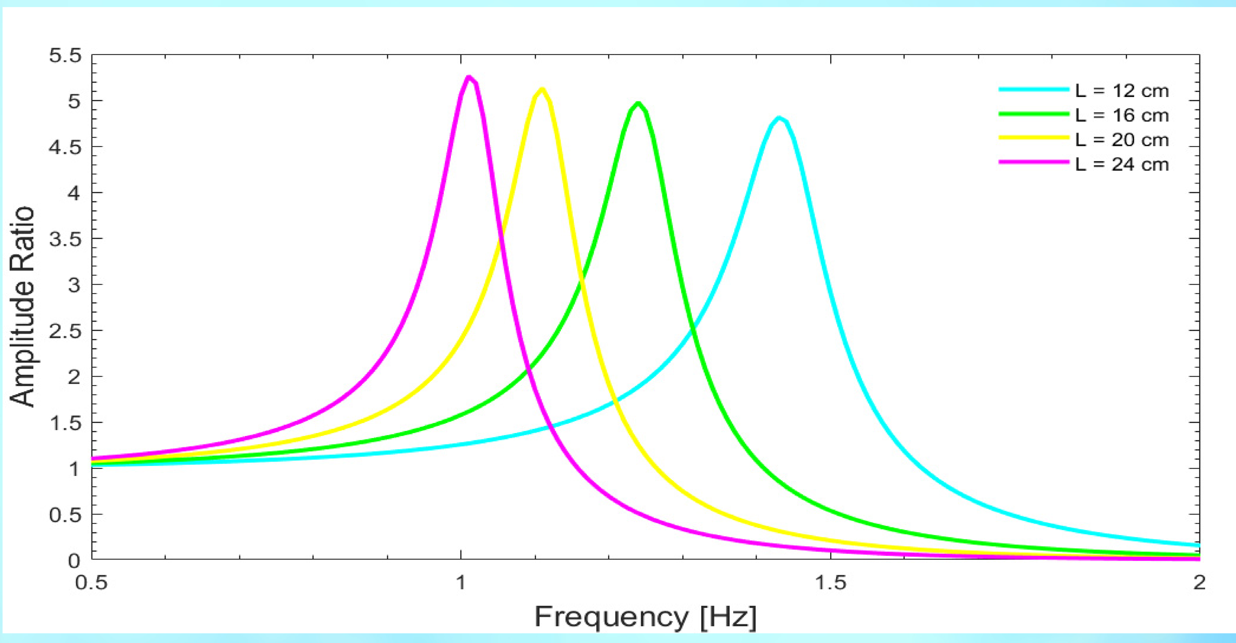


*Figure 5a. Theoretical resonance curves assuming linear theory.*

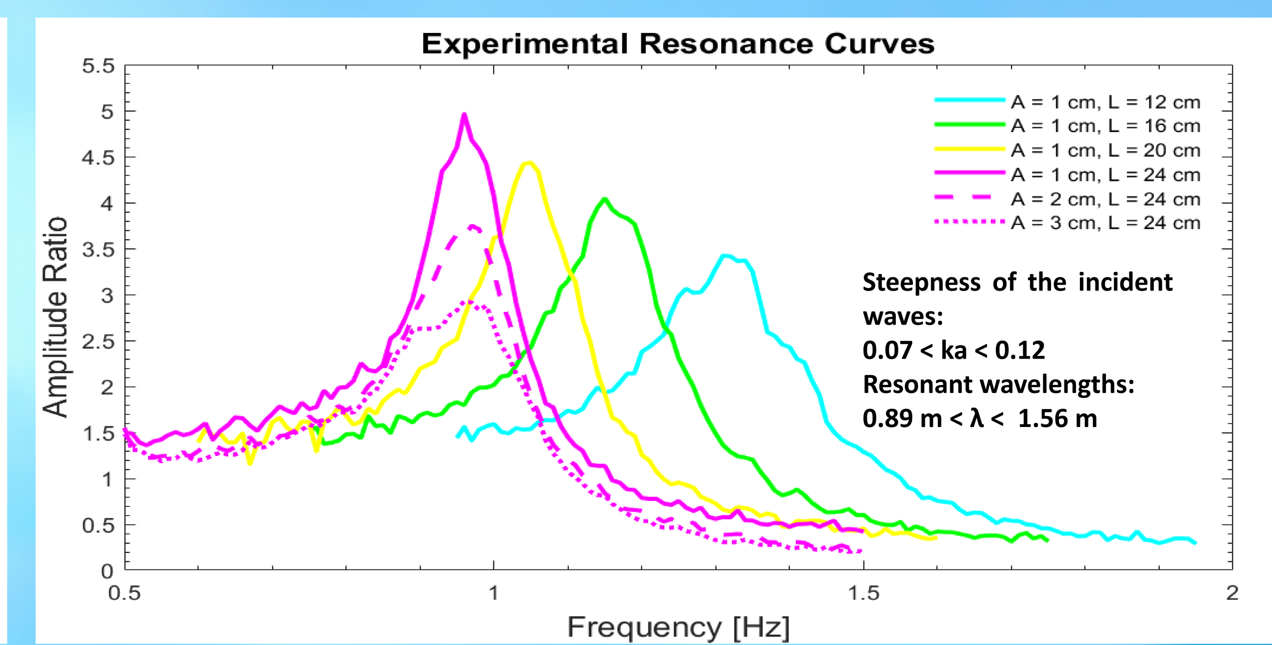


*Figure 5b. Experimental resonance curves.*

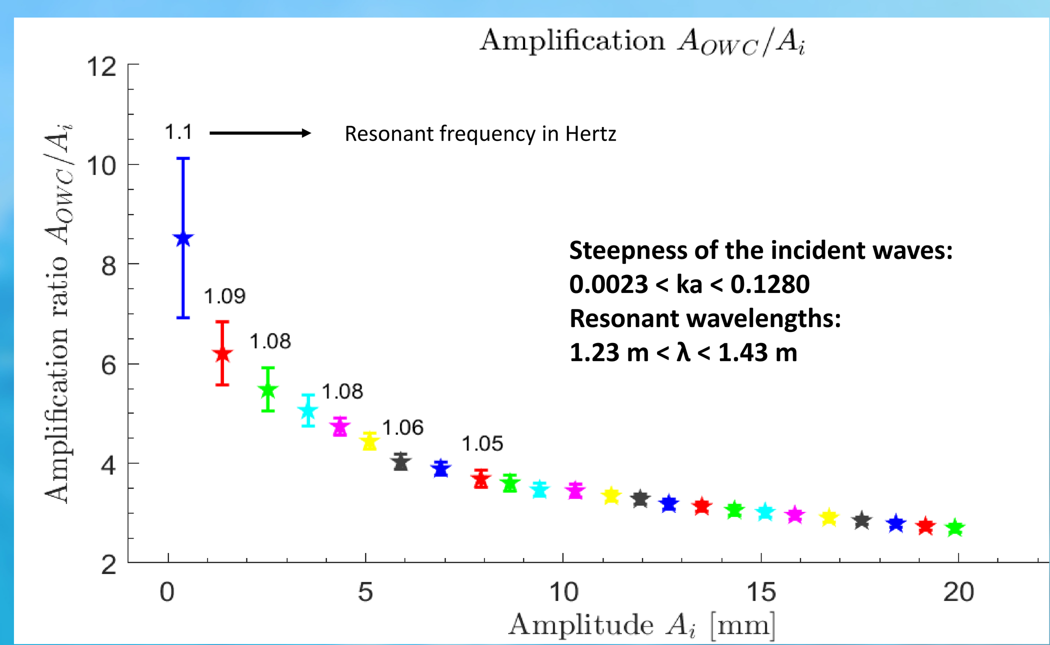


*Figure 6. Amplification as a function of the incident amplitude.*

❷ The measured resonant frequency decreases with the amplitude of the incident waves (Fig. 6) due to the increase in non-linear loss of energy.

❸ Deeper columns exhibit higher and narrower peaks (Fig. 5b) owing to the dependence of damping on frequency. This is partially due to the inverse relationship between the exciting force and the frequency, but this trend is much stronger than that predicted by linear theory (Fig. 5a). Hence, we suggest it is due to non-linear losses at the mouth of the OWC.

❹ The resonance peak of the column with diameter D = 5.5 cm, was higher and narrower than that of the columns with diameters 3 and 9 cm, suggesting a possible optimum width of OWCs in given conditions, which can not be explained in terms of linear theory.

❺ Splitting of resonance peak (red curve in Fig. 7) is observed for incident amplitudes above 4 mm. This may be due to the maximum non-linear damping at resonance, but further research is needed to fully understand this effect.

❻ Decrease in incident amplitude at resonance (blue curve in Fig. 7) for all incident amplitudes may be due to maximum extraction and dissipation of energy from waves at resonance, which is the goal of coastal protection. Further studies are needed in order to estimate the amount of energy lost from the incoming waves.

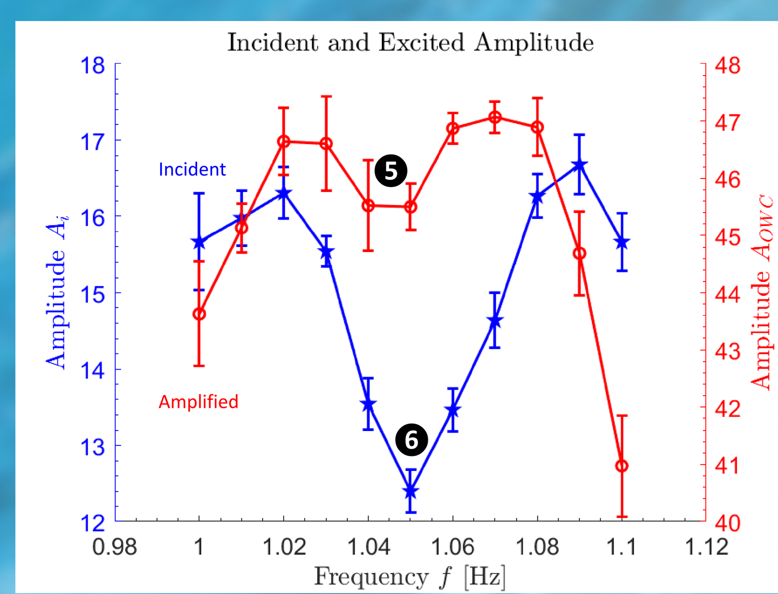


*Figure 7. Incident and amplified amplitude as a function of frequency.*

❼ The most interesting and important finding is another non-linear effect: the amplification peak is smaller and wider for larger amplitudes of the incoming waves (Fig. 5b and 6), suggesting that damping increases with forcing amplitude. This can be observed for the smallest measurable incident waves generated by our wavemaker supplied by HR Wallingford. To the best of our knowledge, such behaviour of OWCs has not been reported in previous studies. This may imply that in storm waves, OWCs could dissipate proportionally more energy than in regular waves, which may be beneficial in coastal protection. More research is needed in order to understand how much energy is dissipated and how much can be converted into a useful form.

Acknowledgement: Support from the Australian Renewable Energy Agency under grant ERP A00575 and from Swinburne University's Faculty of Science, Engineering & Technology is gratefully acknowledged. We thank HR Wallingford for supplying the wavemaker used in experiments.