Analytical and experimental modelling of a floating/submerged elastic disk

Dr Siming Zheng, Dr Simone Michele

School of Engineering, Computing and Mathematics, University of Plymouth

Ocean waves are huge untapped renewable energy resources. A large number of wave energy conversion concepts have been proposed since the 1790s. In recent decades, due to the energy crisis and climate change, wave power has received more attention and has been developed faster than before. In spite of this, the levelised cost of energy (LCOE) of wave energy converters (WECs) is still high, and wave energy has struggled to have the same success as other renewable energies, such as solar and wind power.

One of the effective ways to increase the LCOE of WECs is to enhance their wave power absorption efficiency. It has long been known that there is a theoretical limit for wave power absorption by axisymmetric WECs operating in rigid-body motion. What is worse, the complexity of many rigid body-made WECs proposed and tested during the past couple of decades has so far hindered their scalability and commercialisation.

In the recent decade, there has been a growing trend towards flexible-body-based WECs, e.g., elastic plate WECs, SQ devices, and bulge wave devices. The flexible WECs are believed to offer improved reliability/survivability and reduced cost superior to steel/concrete alternatives. Moreover, they are advantageous for the larger potential of wave power absorption. Among the different kinds of flexible body WECs, the flexible plate WEC could be one of the simplest and is expected to have a range of potential applications. This research project aims to study the wave interaction with a floating/submerged elastic disk by using both theoretical simulation and physical tests.

Two analytical models were developed to evaluate the hydrodynamics and wave power absorption of a floating flexible circular wave energy converters. These two analytical models related work has been published in two journal papers (Michele et al., 2022; Zheng et al., 2022).

In Michele et al., (2022), *we present a theoretical model to investigate the hydrodynamics of a floating flexible circular wave energy converter (WEC). Decomposition in rigid and bending elastic modes of the plate allows us to investigate power extraction efficiency in monochromatic incident waves. We show that plate elasticity increases the number of eigenfrequencies, which has a positive beneficial effect on power output. We also show how plate radius and power take-off (PTO) distribution affect the response of the system and the consequent absorbed energy. This work highlights the need to extend theoretical studies and experimental investigations on flexible devices, currently seen as the future of WEC technology.*

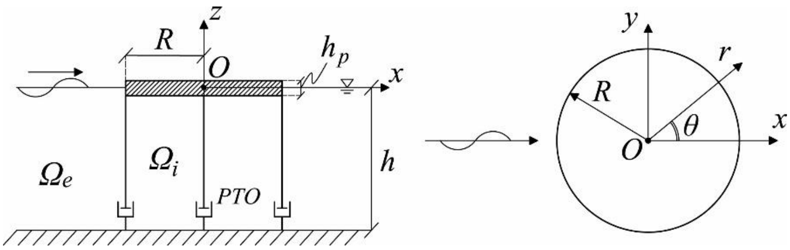

Fig. 1. View from above and horizontal cross-section of the flexible circular WEC (Michele et al., 2022).

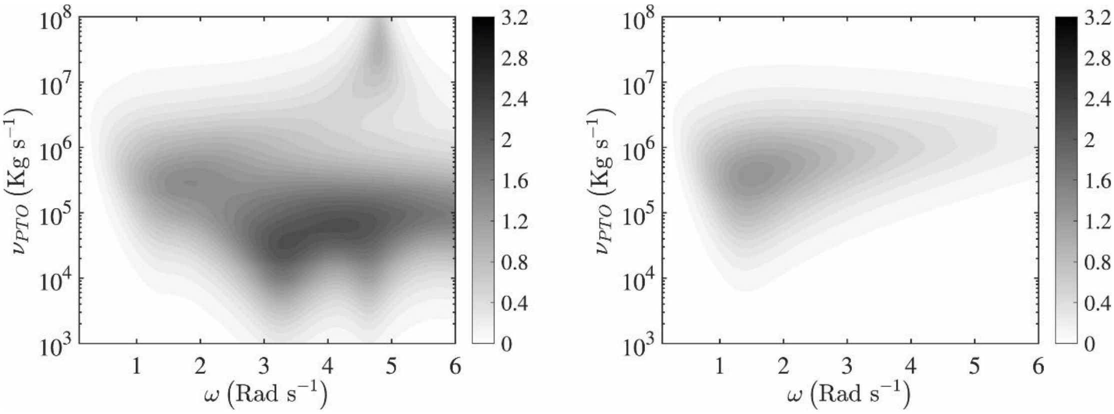

Fig. 2. Behaviour of wave power capture width versus frequency of the incident waves and PTO-Coefficient. (a) Flexible plate with Young's modulus E = 0.05 GPa; (b) The case of a rigid plate. The 5 PTO devices are located in r=0 and r_i=R, θ_i=0, π/2, π, 3π/2 rad (Michele et al., 2022).

In Zheng et al., (2022), *a concept of a floating elastic wave energy converter consisting of a disk-shaped elastic plate is proposed. The floating plate is moored to the seabed through a series of power take-off (PTO) units. A theoretical model based on the linear potential flow theory and eigenfunction matching method is developed to study the hydroelastic characteristics and evaluate wave power absorption of the device. The PTO system is simulated as a discrete PTO, and moreover, it is also modelled as a continuum PTO to represent the case when the PTO system is composed of a large number of PTO units. The continuum PTO approximation is tested against the discrete PTO simulation for accuracy. Two methods are proposed to predict the wave power absorption of the device. After running convergence analysis and model validation, the present model is employed to do a multiparameter impact analysis. The device adopting a continuum PTO system is found to capture wave power efficiently in an extensive range of wave frequencies. For the continuum PTO system, it is theoretically possible to adopt optimised PTO damper and stiffness/mass to guarantee the absorption of 100% of the energy flux available in one circular component of the plane incident wave.*

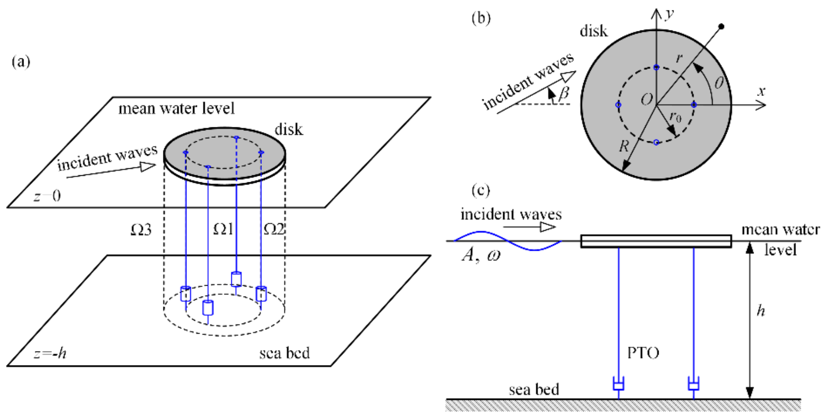

Fig. 3. Sketch of a floating elastic disk-shaped WEC with a discrete PTO system (N = 4): (a) bird's-eye view; (b) top view; (c) side view (Zheng et al., 2022).

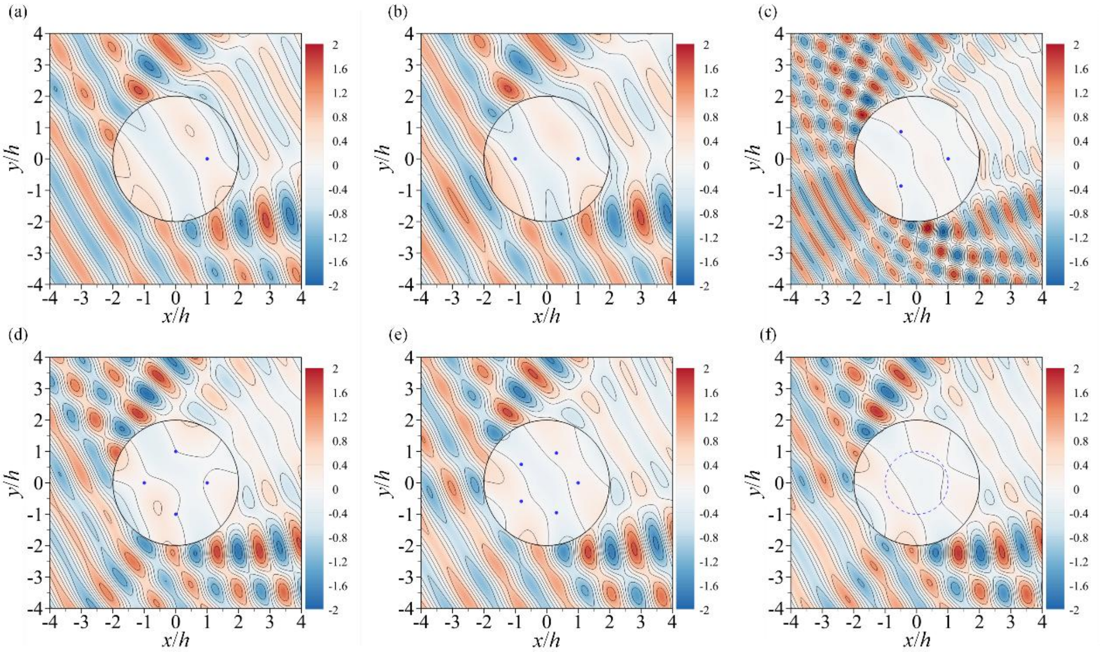

Fig. 4. Deflection of the floating elastic disk and the near-field wave motion for R/h = 2.0, r_0/R = 0.5, and $\beta = \pi/6$: (a) N = 1; (b) N = 2; (c) N = 3; (d) N = 4; (e) N = 5; (f) $N = \infty$ (Zheng et al., 2022).

We have also carried out a series of physical tests of a floating elastic disk in the Ocean Basin, COAST Laboratory at the University of Plymouth. Deflection of the floating elastic disk was observed. We are still working on the analysis of the physical data, and planning to evaluate the nonlinear dynamics of the device and attain a detailed physical insight of flexible WEC dynamics.

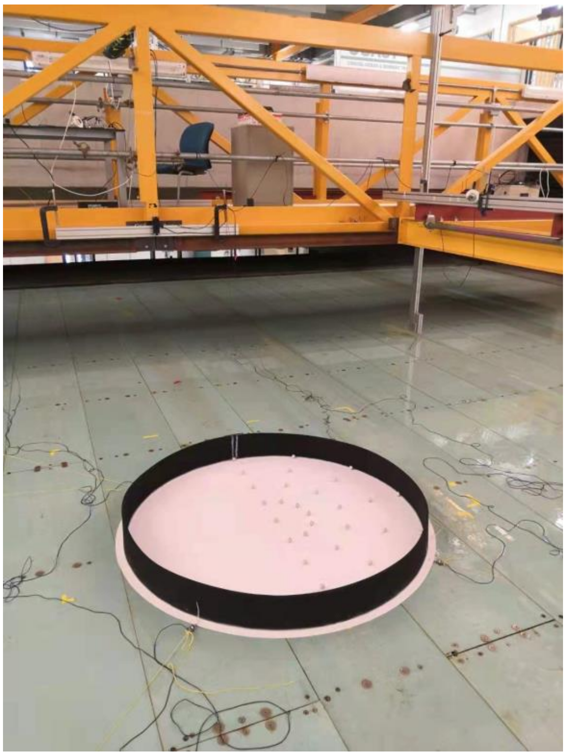

Fig. 5. The elastic disk to be tested placed on the floor of the Ocean Basin. 29 markers are deployed on half of the disk, and their motion can be captured by 6 high-speed cameras (Qualisys System) to monitor the deflection of the disk. The strip in black is to avoid overtopping.

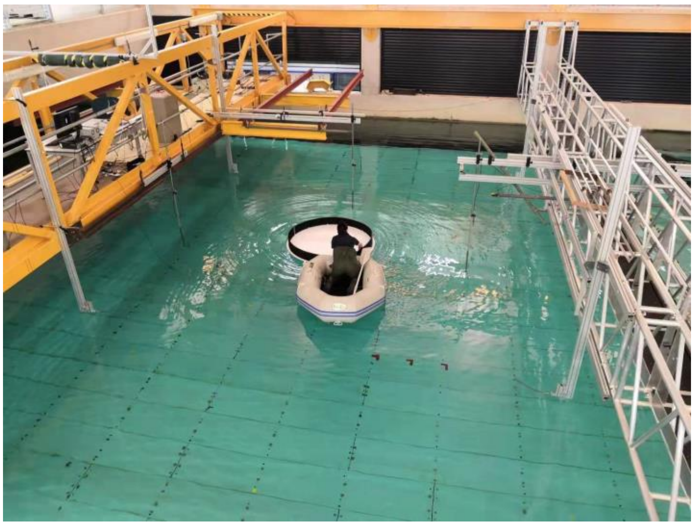

Fig. 6. Installation of the device in the Ocean Basin.

Fig. 7. Regular waves interaction with the floating elastic disk in the Ocean Basin. Obvious wave scattering is observed.

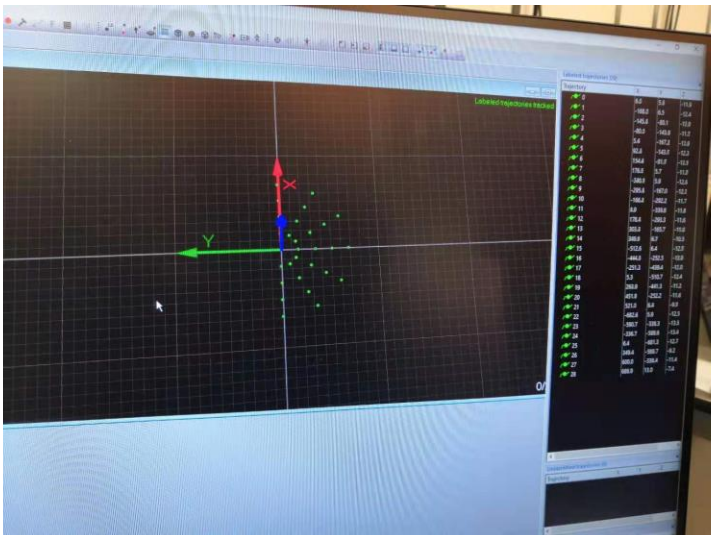

Fig. 8. Indicator of the Qualisys System, where the instantaneous motion of the 29 markers is displayed.

Fig. 9. Videos of the device motion from different views.

References

[1] **Michele, S., Zheng, S.**, Greaves, D., 2022. Wave energy extraction from a floating flexible circular plate. ***Ocean Engineering***, 245, 110275. [open access] https://doi.org/10.1016/j.oceaneng.2021.110275

[2] **Zheng, S., Michele, S.**, Liang, H., Meylan, M.H., Greaves, D., 2022. Wave power extraction from a floating elastic disk-shaped wave energy converter. ***Journal of Fluid Mechanics***. doi: 10.1017/jfm.2022.701 [accepted for publication]