# METAREEF, a sustainable submerged floating metamaterial structure to attenuate surface gravity waves

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## 1 INTRODUCTION

Tethered floating breakwaters, built as a regular lattice of reversed pendula [1] provide an attractive option for beach management. With respect to rubble mound breakwaters, this type of structures has small impact on water circulation. Without localized refraction/diffraction effects, the formation of tombolos and stagnating pools between them is prevented. Moreover, if the floaters are kept below the water surface, their visual impact from the shore is negligible, similar to artificial reefs. On the other hand, in the presence of rising sea levels, tethered floats are much more adaptable than artificial reefs. The environmental impact of point-wise hinged floaters is very small throughout the entire the operating life of the structure, from deployment to decommissioning. Depending on their efficiency, the cost-effectiveness of beach protection using tethered floats is favourable compared to the current hard-engineering strategies. Tethered floating breakwaters have been studied since the late 70s with extensive laboratory and field tests, exploring different configurations for the anchoring and submergence of the floats [2, 3, 4].

The models proposed for the efficiency of these devices are based on experimental results obtained with waves impacting on a single float (single row of floats) [2, 4]. The underlying hypothesis is that subsequent floats behave with the same efficiency. This means that the only wave attenuation mechanism that has been considered so far is fluid drag dissipation, while wave scattering has been considered negligible [4]. Of course, wave reflection from a single float (or row) might be small, but, in principle, in regular structures, we must consider possible wave scattering that may emerge from a collective behaviour.

This phenomenon is typical of metamaterials that are engineered structures designed to interact with waves and manipulate their propagation properties, such as phase and group velocity, or to produce effects such as negative refraction, cloaking, superlensing and absorption. In terms of wave attenuation, the key concept is that metamaterial dispersion relation may be non-monotonic or even involve *bandgaps*, *i.e.* ranges of frequencies for which wave propagation is inhibited [5].

## 2 METAREEF

The purpose of METAREEF is to investigate to which extent the concept of metamaterial wave control can be applied to an efficient attenuation system for surface gravity waves. The periodic structure of METAREEF is designed as a lattice of submerged inverted pendula, in which each pendulum is anchored to the seabed (fig.1a).

Using direct numerical simulations of the Navier-Stokes equation in its two-dimensional form with periodic boundary conditions, free boundary and moving bodies, De Vita et al. [6, 7]

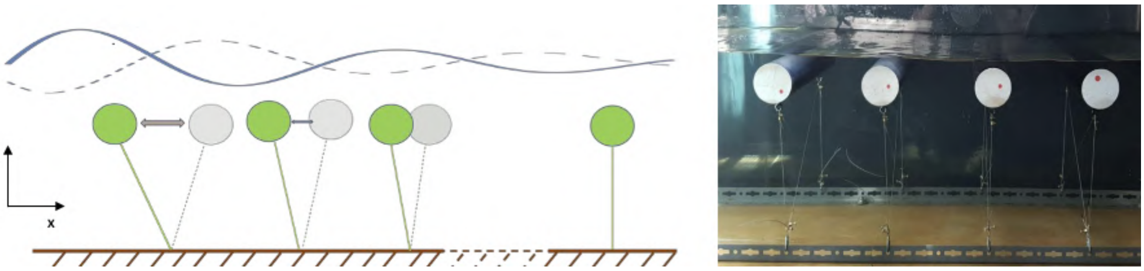

Figure 1: METAREEF device. a) Basic design concept with energy attenuation of the incident wave along $x$ direction. b) Experimental configuration with 4 pendula.

showed that large energy attenuation is possible if the wave and the pendula resonances are characterized by similar frequencies. As the number of resonators is increased, the range of attenuated frequencies also grows. The periodic configuration considered in [7] is going to be updated in the form of a numerical flume. This will help in understanding the fluid dynamics around the pendula to better understand the dissipation processes.

Here, we consider physical experiments with the purpose of characterizing the dissipation and reflection processes, while looking for possible collective behaviours. While the structure to be considered should be a lattice of spherical floats, the preliminary tests are performed in a 2DV configuration, using a line of cylindrical pendula (fig.1b).

## 3 EXPERIMENTAL SET-UP

Experiments are performed at the "G. Bidone" Hydraulics and Fluid Dynamics laboratory of the Politecnico di Torino, in a 55 m long channel, 0.6 m wide and 1 m deep, equipped with a piston-type wavemaker. Resistance wave gauges are placed before and after the device to measure the surface elevation. Incident and reflected wave fields are separated with a windowed least squares scheme [8]. In order to minimize the uncertainty for the incident and reflected fields, six gauges are placed on the ocean side of the device, while transmitted waves are measured with only one gauge. The duration of the timeseries is limited accordingly, removing any effect of the reflection from the channel end and the wavemaker.

The metamaterial is made up of an array of submerged cylinders anchored to the bottom, with their axes parallel to the wave crests (fig.1b). Cylinders are made with commercial pvc pipes (diameter is 82 mm with wall thickness of 3 mm), filled with air so as to be much less dense than water and waterproofed with polyurethane foam. The length of the pendulum is fixed, with a distance between the bottom of the flume and the top of the cylinder equal to 43 cm. Cylinders are braced with two additional cables in order to constrain the motion in the plane as far as possible. The resonant frequency of the pendulum is estimated empirically to be approximately equal to 0.6 Hz.

As a first validation, we maintained the system as linear as possible, by keeping the amplitude of waves equal to 1 cm for the range of tested frequencies (0.4 to 1.4 Hz). Tests were carried out by varying the mutual distance (L), the number of oscillators and the water height (h), keeping the periodic configuration.

Reflection and transmission coefficients ($C_R$ and $C_T$) are computed as ratios between energies (spectral zero-th moments) and dissipation coefficients are consequently calculated as $C_D = 1 - C_R - C_T$.

## 4 RESULTS AND DISCUSSION

In Figure 2 the dissipation coefficients are plotted against the frequency of the incident waves.

In the left plot (fig.2a), each curve represents a configuration with a different number of pendula with the same mutual distance between the pendula (equal to 24 cm) and the same water height. Increasing the number of pendula (up to 11), the dissipation around the resonant frequency (0.6Hz) increases, as predicted numerically [7].

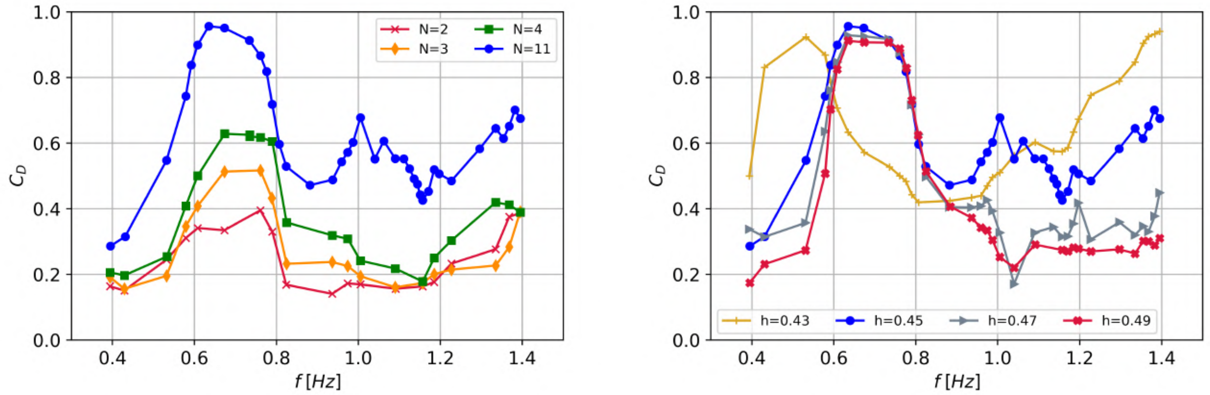

Figure 2: Dissipated energy as function of the generated waves' frequency. a) L = 0.24m, a = 0.01m, h = 0.45m. Each series represents a configuration with a different number of resonators. b) L = 0.24m, a = 0.01m, 11 cylinders. Each series represent a different water level. Blue-dotted line represents the same configuration.

The right panel (fig.2b) shows results for the 11 cylinders configuration; here each curve represent a different water level. The behavior changes drastically as the water height decreases to 43 cm, corresponding to the cylinder location at the still water level, with dissipation increasing below the modal frequency. This appears consistent with previous studies ([9]), which concluded that, for long waves, an emerging device is more effective. Short waves lose significant energy only if the wave amplitude is comparable with the gap between the mean water level and the top of the cylinders.

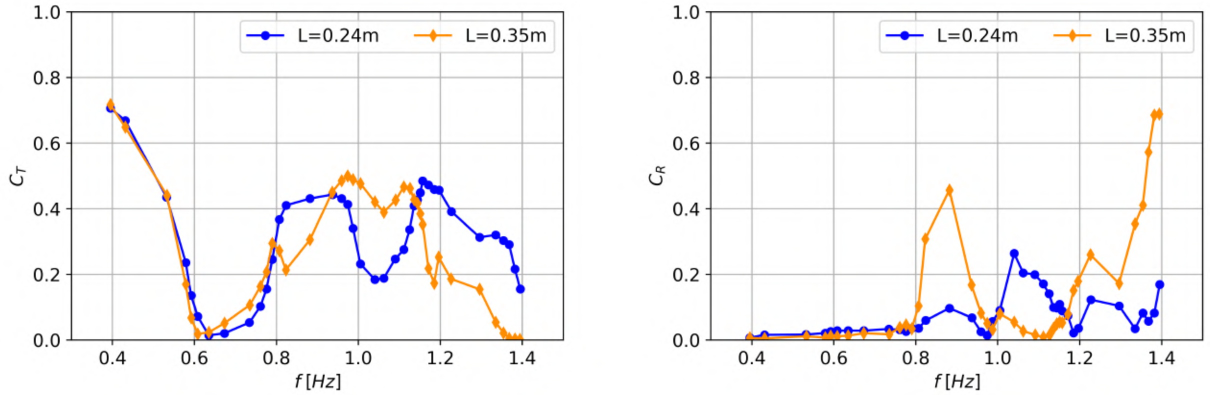

Figure 3: 11 cylinders configuration with a = 0.01m, h = 0.45m. On the left Transmitted energy (a) and on the right Reflected energy (b) as function of the generated waves' frequency for different mutual distances.

In fig.3 we compare transmission (3a) and reflection coefficients (3b) for two different mutual distances (L). It is interesting to see that the reflection, although almost negligible for the whole range (3b), is characterized by sharp peaks, and that the position of the peaks changes with L.

Further analysis is required to understand the origin of the peaks, but it appears certain that the wave reflection depends on the geometry of the metamaterial.

Comparing fig.3a (L=0.24m) with the corresponding dissipation (fig.2) and reflection (fig.3b), we see that the efficiency of the system mainly depends on dissipation, especially in the low frequency range around the modal resonance. Moreover, in this range, the metamaterial geometry seems to be unimportant. For shorter waves, the contribution of the reflection is not negligible (see *e.g.* the through in fig. 3a around $1.05 Hz$ and the corresponding peak in fig. 3b).

## ACKNOWLEDGMENTS

All authors have been funded by Compagnia di San Paolo Progetto d'Ateneo/Fondazione San Paolo "Metapp", n. CSTO160004. and Proof of concept "Metareef" grant. Furthermore, M. Onorato, F. Bosia, F. De Lillo and M. Lorenzo acknowledge the EU, H2020 FET Open "Bio-Inspired Hierarchical MetaMaterials" grant No. 863179.

## REFERENCES

[1] Dai, J., Wang, C. M., Utsunomiya, T., and Duan, W. 2018. *Review of recent research and developments on floating breakwaters.* Ocean Engineering 158( March), 132–151.

[2] Agerton, D. J., Savage, G. H., and Stotz, K. C. 1977. *Design, analysis and field test of a dynamic floating breakwater. Coastal Engineering 1976 3*, 2792–2809.

[3] Jones, D. B. 1978. An Assessment of transportable breakwaters with reference to the container off-loading and transfer system (COTS). Tech. rep., Civil Engineering Laboratory, Port Hueneme, California.

[4] Seymour, R. J., and Hanes, D. M. aug 1979. *Performance Analysis of Tethered Float Breakwater.* Journal of the Waterway, Port, Coastal and Ocean Division 105( 3), 265–280.

[5] Hussein, M. I., Leamy, M. J., and Ruzzene, M. 2014. *Dynamics of phononic materials and structures: Historical origins, recent progress, and future outlook.* Applied Mechanics Reviews 66( 4).

[6] De Vita, F., De Lillo, F., Verzicco, R., and Onorato, M. 2021. *A fully Eulerian solver for the simulation of multiphase flows with solid bodies: Application to surface gravity waves. Journal of Computational Physics 438*.

[7] De Vita, F., De Lillo, F., Bosia, F., and Onorato, M. 2021. *Attenuating surface gravity waves with mechanical metamaterials.* Physics of Fluids 33( 4).

[8] Zelt, J. A., Skjelbreia, J. E., and Wave Technologies. 1993. *Estimating incident and reflected wave fields using an arbitrary number of wave gages. Proceedings of the Coastal Engineering Conference 1*, 777–788.

[9] Sergiienko, N. Y., Cazzolato, B. S., Ding, B., Hardy, P., and Arjomandi, M. 2017. *Performance comparison of the floating and fully submerged quasi-point absorber wave energy converters. Renewable Energy 108*, 425–437.