# A new type of wave tank: prototype and assessment

Joannès Berque, Iñigo Zarate, Jesus Mª Blanco, Iñigo Bidaguren, Imanol Touzon, Luisa Fernandez

***Abstract*—The prototype and progress in assessing of a new type of wave tank are described. If successful, this innovation would enable many wave tank experiments for only a few percent of current costs. Tank testing remains indispensable for new designs, and its high cost is a significant inhibitor of offshore innovation. To date, all wave tanks generate and propagate scaled but real water waves towards a physical model. This new type of tank instead reproduces the velocity field that such waves would have, but only near the model. In practice, this can be approximately achieved only for cases where the marine structure is much shorter than the wavelength, and its draft shallow compared to the wavelength and depth. In such cases the wavefield is time-varying but approximately spatially uniform near the structure. Therefore, it can be reproduced by moving a container of water like wave orbitals; and ensuring slosh modes are minimised. A prototype was built, and after initial challenges in controlling slosh excitation, a proof of concept was successfully achieved: a cylinder was excited by surge oscillations and its response appears consistent with rough calculations. However, detailed implementation is uncovering issues yet to be resolved such as small-scale water motion and assessing the role of mooring forces. Range of potential applications of the new type of wave tank, lessons learnt by prototyping, and next developments are discussed.***

*Keywords*—**physical modelling, prototype, wave tank.**

## I. INTRODUCTION

DESPITE rapid advances in the accuracy of numerical modelling, physical modelling in wave tanks remains as important as ever for advanced design of offshore structures. This is particularly true for innovative designs, where experience has shown that tank testing uncovered theretofore unknown phenomena, such as the springing excitation of tension leg platforms in short seas; or has shown over-design due to conservative representation of physics that are hard to model numerically, such as the effect of non-linearities, turbulence or wave breaking [1].

Rapid cost reduction in computing power, and progress in computational methods, open the prospect that tank testing costs may be reduced for new technical developments. Computational Fluid Dynamics (CFD) is finding new applications every year [2]. An active area of research is the application of machine learning to improve the trade-off between CFD cost and accuracy [3]. Nearly two orders of magnitude reduction in cost without loss of accuracy is reported in modelling 2D turbulence [4]. Nonetheless, the advanced design of marine renewable energy structures is likely to require physical modelling for some time.

In the case of wave energy converters (WECs), the physics of wave-structure interaction is inherently difficult to model based on previous experience, as unlike other structures, it seeks to maximise extraction of energy from the wavefield. CFD methods must still validate their representation of this interaction with physical modelling [5]. Further, in addition to computational cost, setup time also is significant [6]. For the time being, physical tank testing is required to validate concepts and justify further investment, for example to reduce uncertainty in the predictions of a WEC's cost of energy once the technology matures [7].

Besides cost, physical tank testing of WECs presents new technical challenges [8], such as modelling the power take-off at reduced scale [9], or correctly scaling new physical phenomena, such as the interplay of a marine structure with several fluids in oscillating water columns [10]. The development of guidelines for tank testing of WECs is thus an important area of R&D [11], [12]. Up-to-date best practices and challenges in this field can be found in [13].

The physical modelling of tidal turbines may be said to be generally less demanding than for WECs [8]. Current



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best practices can be found in [14].

Floating offshore wind design will continue to require tank testing for some time [15], [16]. While numerical methods are rapidly advancing, there are discrepancies between them that need to be assessed with physical modelling [17]. Offshore wind turbine models must represent phenomena such as the interaction of aerodynamic loads, power extraction therefrom, control strategies, the structure's elasticity and hydrodynamics. The physical modelling of such phenomena also requires assessing new sources of uncertainties [18]. Up-to-date best practices may be found in [19].

## II. Tank testing cost, significance and drivers

A tank testing campaign typically will cost over one hundred thousand euros, and many developers of novel concepts in offshore renewables struggle to validate their ideas for lack of such funds. Tank tests are also out-of-reach for many academic investigations of new designs or new physics of fluid-structure interaction. There is no doubt that the possibility for much cheaper tank testing, even for a subset of marine structure types and applications, would unlock a great innovation potential that would accelerate progress in the offshore industry.

The main cost-driver for wave tanks is their size, and resulting facilities, staffing, and energy needs. And this size is imposed by the wavelength that real water waves have in a basin. Smaller tanks may be used for specific applications, but for advanced design, large facilities are required. The typical configuration is a one-meter or so physical model, floating in a water basin the size of a large swimming pool.

Wave tanks operate by generating and propagating scaled but real water waves, which must satisfy a dispersion relation, that associates wavelength to wave period. As a result, water waves of interest to offshore design usually include wavelengths longer than 10-20 meters (when scaled for the model). Water basins must have correspondingly large dimensions: to avoid severe distortion the tank must be large enough to contain at least one wavelength. Further, in practice, due to evanescent modes from the wavemaker, reflection and dissipation requirements, the necessary dimensions are significantly larger than the wavelengths of interest. Finally, a typical testing campaign will often require the entire facility for several weeks.

Considering these dimensions, it may in fact appear rather challenging for vendors to compete at market rates for tank testing services. Put another way, there is little prospect for significant cost reduction with current wave tank technology.

## III. Principle of operation of the new wave tank

The physical basis of the new wave tank is that for a structure's response to wave forces, only the wavefield near the structure matters. If this near-wavefield is correctly reproduced, and gravity, inertia and mooring forces are properly represented, the problem and its solutions are not affected by the wavefield further away. And as far as the structure response is concerned, it doesn't matter if this near-wavefield is achieved through a propagating wave or by other means.

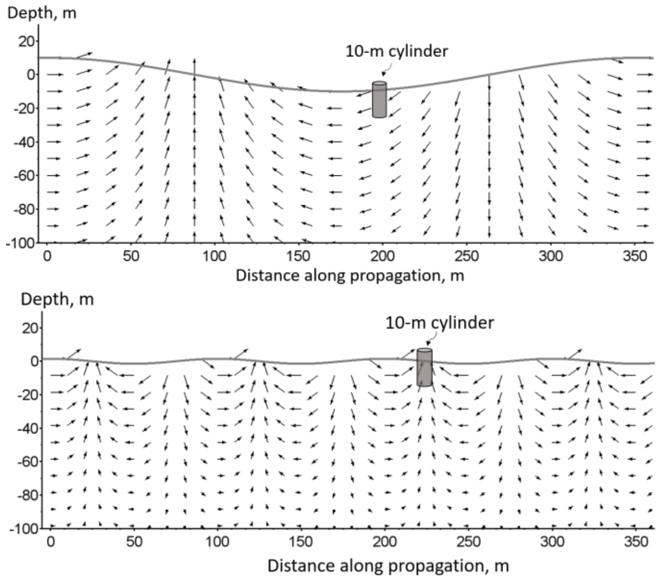


Fig. 1. Velocity fields of deep-water Airy waves of height 20 m, period 15 s, wavelength 351 m (upper plot); and of height 3 m, period 8 s, wavelength 100 m (lower plot). A 10-m wide, 20-m high cylinder is shown for scale. The approximation of spatially uniformity of the wave velocity field near the cylinder is less valid for an 8-second wave than for a 15-second wave.

In the particular case of a structure that is much smaller than the wavelength, with a draft much smaller than the depth, this wavefield is time-varying but approximately spatially uniform. An example is shown in Fig. 1 (upper plot), as the velocity field of a deep-water linear Airy wave of 15-second period. The corresponding wavelength is 351 m. A 10-m wide, 10-m high cylinder is shown for scale. Clearly, in this case, the cylinder "sees" an approximately spatially uniform wavefield. In contrast, in the lower plot of Fig. 1, the structure's dimensions are about 10% of the wavelength, and some non-uniformity of the wavefield between the up-wave and down-wave sides of the cylinder are apparent. Real waves behave differently, but the Airy wave often gives a useful approximation.

The water's motion in an Airy wave is illustrated in Fig. 2. This orbital is circular and closed for a linear wave in deep water. The orbital's diameter is the wave height. An important aspect here for the sizing of the new wave tank, is that the amplitude of water motion is only a few percent of the wavelength for many applications.

If we consider a volume of small dimensions relative to the spatial scale of variation of the fluid motion, for example, the volume of water surrounding the cylinder in the upper plot of Fig. 1, then the water parcels within that volume move approximately uniformly (i.e., nearly in-phase in the case of wave motion). This is illustrated in

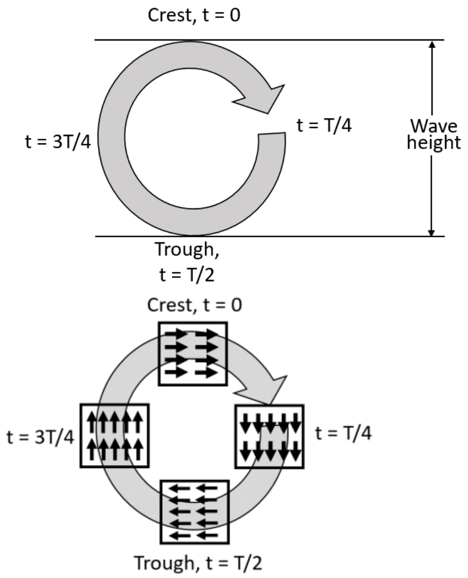


Fig. 2. Schematic of water motion in linear surface gravity waves, showing the orbital diameter equal to the wave height (upper drawing), and the motion through a wave period of a volume of small dimensions relative to the wavelength and depth (lower drawing). In such a volume, water "particles" are moving in phase, in approximately uniform motion at each phase of the wave period, horizontally and down-wave in the crest, up-wave in the trough half a period later. Water particles move in trajectories of spatial dimensions of only a few percent of the wavelength. This is the physical basis for the large reduction in necessary tank size that is aimed at with this method.

Fig. 2, where said volume has been delimited graphically by a box.

It is clear that there is nothing special about the volume boundaries depicted in Fig. 2, apart from the requirement that dimensions be small relative to the wavelength. Further, if the fluid motion is irrotational, thus unmixing, it does not make a difference for the fluid motion inside the box whether these boundaries are made of other water molecules, or made of air for the upper boundary, or of glass for the other boundaries. It should be noted here that this is adding a further simplification to that of an approximately spatially uniform wavefield, namely of small surface tension effects, viscosity or mixing processes. However, neglecting the latter three is part of the standard set of assumptions used in much of the hydrodynamics of relevance to offshore energy.

Finally, Fig. 3 depicts a floating object within the volume shown in Fig. 2. As far as wave forces are concerned, the object only "sees" the immediate nearfield of the wavefield. Therefore, so long as the motion of orbitals in the vicinity of the object are correctly reproduced, it "sees" the exact same wavefield as if the wavefield were reproduced over 10 wavelengths than if it is reproduced over 1/20$^{th}$ of a wavelength, in its immediate vicinity. Further, the hydrostatic pressure field on the object is completely determined by the distance from the surface, from the waterline to the draft, and this will be correctly reproduced so long as the object's heave is correctly reproduced (and, again, the assumption of small dimensions relative to wavelength, i.e., of negligible

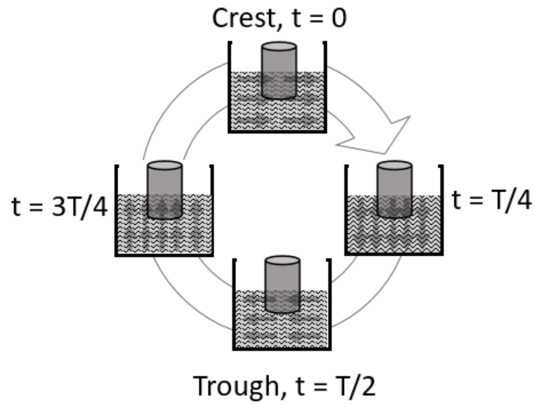


Fig. 3. Schematic of a floating object in the volume depicted in Fig. 2. The object "sees" the same wave velocity field, pressure field, and inertial and gravity force that it would if the volume of water was extended to many wavelengths – as long as the orbital motion of water near the object is correctly reproduced (note: the amplitude of the orbital relative to the tank size is greatly exaggerated for visualisation).

inclination and curvature of the surface elevation over the nearfield).

Hence, if inertial forces and gravity are properly scaled, e.g., as per Froude scaling, all the forces of relevance to the floater's motion are the same as if many wavelengths were reproduced. In principle, then, if initial conditions are the same, and all the forces are the same initially (inclusive of those depending on floater's motion relative to the water), the evolution of the system being completely determined by these forces, then the floater must, according to classical mechanics, have the same trajectory in phase space as the one it would have if it were floating in a propagating wave of same orbital motions near the floater.

A caveat of yet unknown impact is that the lack of such classical determinism in real applications is precisely what gives the value of tank testing, relative to theoretical and numerical models. The motion of a floater in real waves is an inherently chaotic problem, where after a few wave cycles, turbulence and non-linear effects quickly lead to significant error growth in numerical models relative to physical models, no matter how precisely set the initial conditions. It could well be that small differences in the velocity field, surface slope, or other effect that appear negligible over one wave cycle, could lead to statistically significant differences between the motion of a floater in the new wave tank and that in a large wave-propagating tank. This, along with other potential challenges, is discussed in Section V.

A clarification is perhaps useful here on what makes this novel relative to existing experiments since some confusion has been expressed in earlier discussions of this concept. Slosh tanks, while sharing much of the hardware with this concept, do precisely the contrary to what is aimed at in this new wave tank: they excite motions of the water relative to its container. There are no slosh tank applications, to the best of our knowledge, that look at mimicking the motion of water waves without propagating an actual water wave.

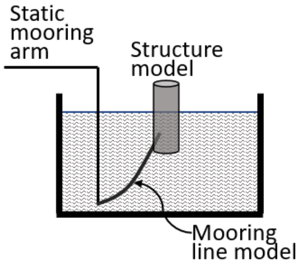


Fig. 4. Schematic of mooring or fixed bottom modelling with this method. Drag from the static arms are easily minimised. The ease of experimental setup in a meter-scale basin, with anchor points adjustable by hand, is expected to be major benefit of this method.

There are also some experiments where a physical model of e.g., a vertical cylinder, is made to oscillate by an articulated arm within water, with the goal of obtaining information on drag coefficients or other hydrodynamic property. These experiments, unlike the new wave tank, do not represent inertial forces, and much less their interplay with hydrodynamic forces and gravity, or the response of an object in six degrees of freedom.

Summarising this section, the principle of operation and key assumptions of the new wave tank are as follows:

1) Within a volume of dimensions much smaller than the wavelength and depth, the motion of water due to a wave is approximately spatially uniform
2) A container can be moved in the same way as the water particles in this volume
3) The water in this container will then move like the water moves with the wave, as long as the motion of the water relative to the container is kept negligible
4) If a physical model of a marine structure is also in this container, water exerts the same forces on it as would water in the real wave

## IV. Domain of validity and potential applications

A pre-requisite for this method to work is that the structure's dimensions must be small relative to the spatial scale of variation of the fluid flow. There is no clear criterion and ultimately only comparison with other tank testing results will give an idea of how small the structure must be relative to this spatial scale. In the case of ocean waves, a structure with horizontal dimensions at some 5% of the wavelength is exposed to a very nearly spatially uniform wavefield, as illustrated in the upper plot of Fig. 1. As can be seen in the lower plot of Fig. 1's, starting at some 10% of the wavelength, the structure's response may be impacted by non-spatially uniform flow. For steep waves, the finite slope over the structure's horizontal extent will also impact response. (It is possible that with some extensions such as flexible walls of adequate stiffness, the tank reproduces wave slopes realistically, since the container boundaries will then move more like adjacent water particles do in real waves).

In addition to these expected limits, the application of the method may be limited by hardware and practical issues. This could include the ability to avoid slosh excitation or ensure fast damping of the water's motion relative to the container. Other unforeseen issues may well appear as the tank is built and operated. Early results on these aspects are discussed in Section VI.

From the requirement of near-spatial uniformity of the flow, when applied to wave energy converters, this method can be expected to be potentially useful for point absorbers, and less so for devices of significant down-wave extent. The method should also be useful to explore the wave response of many floating tidal turbines. Reproducing currents within the box will require some additional contraptions, but these may be expected to be far less expensive than in large basins, since there may be three orders of magnitude less water to move with this method.

For floating wind, spar-type platforms are a prime application. The method cannot reproduce the vertical attenuation of wave motion with depth, but this should be seen in the context that this is challenging to reproduce realistically for existing wave tanks as well. In fact, the depth-truncation of physical modelling for deep water applications has not prevented wave tank experiments to be extremely valuable for ultra-deep oil and gas platform design [1].

For large semi-submersible platforms, one possibility would be to use a different container for each leg, to reflect the different wave phases over the extent of the platform. Barge type floaters and long vessels are probably more difficult to model with this method.

At any rate, it should be noted that for many marine structures, sizing is governed by ultimate loads resulting from extreme waves, which have long periods and long wavelengths. The method may thus be valuable in designing larger structures even if their response to shorter waves cannot be realistically modelled.

The addition of mooring forces would simply require a static arm and anchor point. Drag loads from the arm would be easily minimised to a negligible impact on the water motion. Because with this method, a meter-wide basin can easily model large waves at 1/25$^{th}$ or 1/10$^{th}$ scale factor, the ease of experimental setup and any adjustment to the mooring and anchor model should be apparent, when compared to installing anchors and lines in large basins.

Bottom-fixed structures may be usefully modelled by providing a static point and possibly part of a static false-bottom above the container's lower face. This may be useful to model certain aspects of wave-induced scour physics.

## V. Potential advantages and novel experiments

The main advantage of modelling wave motion without the need to propagate a real wave is the dramatic reduction in required basin size, and thus, costs. The dispersion relation of real wave imposes basin sizes in the several tens of meters in two dimensions (for multidirectional waves). By contrast, if this method were to be successful, the required basin size is only imposed by the need to accommodate the structure model's motion, perhaps a few times the model's dimension in oscillatory flow. For example, modelling a 10-m cylinder would require a basin some 30 cm across at 1/100th scale factor, some 50 cm at 1/64th modelling, some 85 cm at 1/36th, and 1.2 m at 1/25th. The basin area is thus reduced two orders of magnitudes for many applications. It could be installed and operated on the corner of a lab's table.

The basin volume is similarly reduced two or three orders of magnitude, with corresponding savings in energy, hardware, and water requirements. The cost reduction for applications where the method can be proven to be valid would be of the same order.

In addition, the experimental setup would be greatly sped-up. Any modification to instrumentation onboard the model, mooring and anchors, or ballast distribution, is easily achieved from the lab bench. This is to be compared with the requirement for a small boat and even divers in many wave-propagating basins. Such flexibility would no doubt allow much tinkering and exploration of the design space that is currently out of reach.

In other ways, the method, if successful, would also allow the exploration of many wave sizes and types, or other oscillatory flows, that are for the moment not achievable with real water waves in tanks. While for the moment they are little more than wishful speculations, it is worth briefly mentioning some of such possibilities here. The largest wave sizes currently achievable in wave tanks are around 1.5 m in height. It is not difficult to imagine that a meter-size container can be moved in much larger orbitals with motor requirements only a fraction of those of current wave tanks. As well, being free of the need to satisfy the dispersion relationship may permit the exploration of low-frequency oscillatory phenomena, of period of 100 seconds or more, such as infra-gravity waves, excitation at typical catenary mooring natural frequencies, or at spar eigenmodes. Seiche, harbour modes and tsunami are other low frequency phenomena of interest that cannot be modelled with wave-propagating tanks.

Another novelty would be the ability to control wave orbital shape arbitrarily, such as for example highly eccentric ellipses in very shallow water. In fact, our first prototype is working in pure surge, a type of oscillatory motion that could not heretofore be applied to free-floating objects, to the best of our knowledge. Depending on hardware performance, certain non-linear orbitals, such as the Stokes wave, may also be within reach.

Finally, the ability to excite a floating structure in pure-surge, pure-heave, or pure-sway oscillatory flow may also open interesting new possibilities. For example, the response amplitude operator may be populated column by column, or the coupling of pitch and surge may be assessed experimentally (our first successful runs exhibited such a coupling, as discussed in Section VI).

In summary, aside from the main objective of reducing costs of certain tank testing applications; or offer cheap and flexible test runs prior to testing in large basins; much exciting speculation may be roused in the curious mind about the new applications and research that may be enabled, should this method prove successful.

## VI. Expected uncertainties and challenges

The main uncertainties considered thus far with this new method are the impact of non-zero spatial variation of the wavefield, avoiding contamination by slosh, and managing diffraction. These are discussed in turn in this section.

The central approximation in this approach to the physical modelling of wave-structure interaction is that when the structure is much smaller than the wavelength and depth, the wavefield of relevance to wave-structure interaction (the nearfield) is approximately uniform.

As mentioned earlier, the effect of non-zero slope and generally finite scale of spatial variability can be expected to be small over one wave cycle, at least as could be guessed from expanding the terms in most mathematical representations of this problem. However, this may not be the case over many wave cycles. Since the value of tank testing is in large part to uncover physics that are not represented, or poorly represented, in mathematical models, and that these terms are typically non-linear and prone to give rise to chaotic behaviour and rapidly diverging error-growths, there could be such divergence between wave-propagating physical modelling and the approach discussed herein. It is difficult to assess the importance of these effects from a theoretical point of view alone. Prototyping and comparing results with wave-propagating tanks would ultimately be the only reliable assessment.

It is worth noting here that no two runs are expected to be the same in standard wave tanks either. The *statistics* of structure response is what can be (approximately) reliably reproduced, rather than the exact trajectory of a particular realisation. This is in fact also the case with numerical models, and design codes typically require at least six different realisations for each individual load case of ultimate limit state, each with different seeds for random waves and turbulence.

For the method discussed herein to produce significantly different statistics of structure response, differences with wave-propagating tanks would have to correlate over many wave-cycles, and over several realisations. Though a disappointment for the prospect of delivering cheaper physical modelling methods for offshore renewables, this would be an interesting finding *per se*. If, for example, the nearfield is well reproduced, but the structure response differs significantly from that to a real wave, it would be interesting to identify what part of the nearfield, or other mechanism, has to be reproduced through a real propagating wave in order to obtain the same response.

The main concern regarding this method was with regards to the capacity to avoid exciting slosh modes. After all, the hardware is quite similar to that of slosh tanks. At the prototype design stage, various strategies were considered, such as a box shape avoiding in-phase reflection (no flat walls), or irregularities to ensure incoherent scattering. However, implementation showed that none of these were relevant to managing the slosh problem, which indeed was a problem (see next section).

Another expected source of relative motion between the container and the water are diffraction and absorption/emission of waves by the model itself. These phenomena should be similar in magnitude to those in standard wave tanks, but since this wave tank may contain three orders of magnitude less water, and similarly less total energy in the wavefield, they could result in far more significant changes to the water motion impacting the structure.

At time of writing this problem has not been assessed. What can be said however, is that in general the method proposed herein is only applicable to structures at least ten times smaller than the wavelength, a range within which diffraction phenomena are expected to be small. However, they may prove to require dedicated hardware for absorption and scattering on the walls. Incidentally, the easiest shape to build the container is circular, with the structure's model floating in the middle – precisely the shape where diffracted waves reflected off the walls would have the worst effect near the structure. So, diffraction may prove to be a problem even if in our first prototype tests its effect seems negligible.

These are the main potential caveats that we can predict at the moment. There may be others, the reader's suggestions in this respect would be gratefully appreciated.

## VII. Prototype building and first results

A first prototype, the Wavebox, was designed with the objective of allowing motion of the container in two degrees of freedom: surge and heave. In theory this would allow the modelling of orbitals of any unidirectional random sea, of any spectrum, within operational limits set by the motors and slosh.

However, the precise control of the electric motors unveiled some unforeseen difficulties. Their nominal power and torque, as per product specs, were comfortably larger than those required to move and accelerate the water-filled container. However, sine-wave like reciprocal motion proved in fact to be challenging to reproduce. In large part this was due to the peak in inertial loads coinciding (phase-wise) with the end points where the motors also have to reverse direction. In addition, friction in the system was significantly more than could be expected from components specifications. It was thus decided to focus initially on a surge-only system, since the surge are less than 10% of loads in heave, even for extreme waves. Container motion then was reasonably well controlled over a useful range of wave height and period.

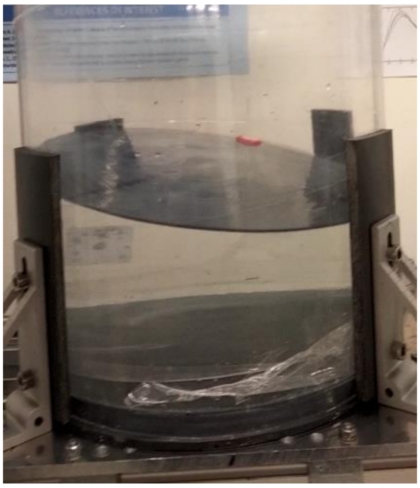

Fig. 5. Slosh excitation in the initial realisation of the Wavebox control. Surge-only excitation at 2.5 seconds, end-to-end amplitude (corresponding to wave height) of 5 cm. The main mode excited was at a quarter-period instead of a half-period as expected.

The first runs, however, exhibited very large slosh excitation. This is shown in Fig. 5, for the case of an excitation at 2.5 seconds with a surge amplitude (corresponding to orbital diameter, i.e., wave height) of 5 cm. This scales to a design situation of a 12.5-second, 1.3-m wave for a scale factor of 25, or 20-second, 3.2-m for a scale factor of 64, as per Froude or other similarity conserving the ratio of inertial to gravity and inertial to drag forces.

While we expected slosh energy to accumulate at a half-period mode, it instead was dominated by a quarter-period oscillation. This hinted at a problem with higher harmonics in the container motion. Thus, the control was changed to include micro-stepping of the motor and focus on better reproducing smooth, more sine-like motion and direction change at the end points. The resulting reduction in slosh excitation was spectacular. In fact, for the case of a 2.5-second, 5-cm surge excitation, sloshing all but disappeared with the new control.

Next, a cylinder of diameter 3 cm and height 6.5 cm was ballasted for stability, and to obtain a draft of 5 cm at rest. This corresponds to an 80-cm wide, 1.6-m high cylinder with a draft of 1.25 m at scale factor 25. These dimensions were small enough to move freely in the Wavebox, but large enough for inertial forces to approach the magnitude of drag forces, when subjected to the oscillatory flow in surge with a period of 2.5 seconds. As hoped, the cylinder exhibited a clearly observable velocity relative to the water and container, and generally a phase lag with the oscillatory flow. A small response in pitch was also observed.

This was the first successful run for the Wavebox, demonstrating that (1) oscillatory flow could be achieved with no significant slosh, in a range of amplitude and period of relevance to the physical modelling of certain marine structures, (2) diffraction and its reflection towards the structure, for these dimensions, was minimal and doesn't appear to affect structure response, and, most

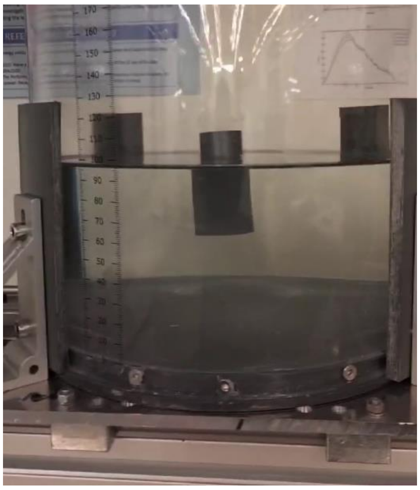

Fig. 6. First successful run of the Wavebox. A 3-cm wide cylinder is excited by the same surge-only excitation as in Fig. 5. After motor control adjustments, slosh excitation is minimal, and the cylinder has sufficient inertia that it exhibits an obvious phase difference with the water motion. The pure-surge excitation also led to a small pitch response, potentially providing a potentially interesting way to analyse coupling of surge and pitch for various shapes.

crucially (3) the setup is appropriate to physically model the phenomena of interest to the response of marine structures to surface waves, namely the interplay of drag, inertia, buoyancy, gravity, and the coupling of the motion in different degrees of freedom of a free-floating body in a wavefield. In this sense, this was a successful proof of concept for this new type of wave tank.

However, the reproducibility of experiments for a fully free-floating body proved elusive: in many cases the cylinder would drift towards a wall over a few cycles. This appears related to tiny disturbances in initial conditions, such as non-zero yaw rotation velocity, or to small currents inside the cylinder. Rather than trying to resolve these, it was thus decided to move on to moored experiments, since most applications of this tank would be in moored systems anyways.

For simplicity of setup and easier comparison with published results, the mooring system was designed to exert negligible force on the floater while it is away from the walls, and rapidly increase in stiffness when the floater approaches the wall. Simple tethers of light strings of adequate length were used (Fig. 7).

A basic monitoring system was setup based on the Tracker application developed by Open Source Physics [20]. The floater motion was tracked with a bright sticker and that of the container with a bright screw.

Finally, to avoid the complication of yaw and pitch motion with a vertically elongated cylinder, a floater with high hydrostatic rigidity in all motions except surge 3-D printed and used in subsequent experiments. The general configuration may be seen in Fig. 7.

Fig. 8 shows time series of surge obtained with this setup for two different excitation frequencies and amplitude. The 2-seconds period excitation resulted in purely “cohesive” motion of the floater with the water and container, suggesting a dominance of drag forces, whereas

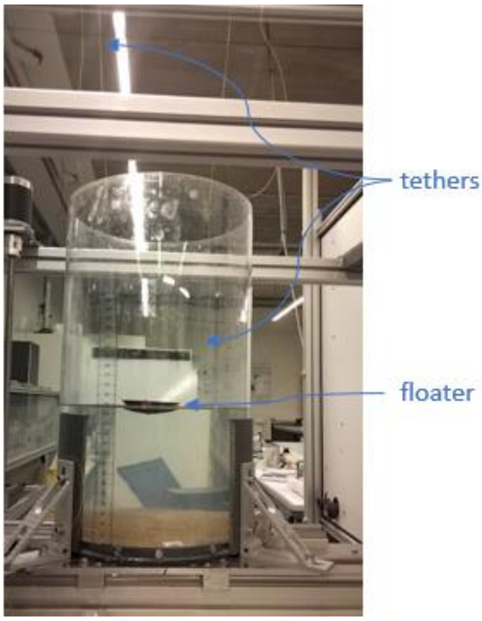


Fig. 7. Wavebox with tethers designed to avoid collision with the walls and otherwise exert negligible force. The floater shown ensured yaw or pitch response were minimal and the analysis could focus on nearly pure surge response to pure surge excitation.

a phase lag and 50% reduction in amplitude was observed with the slightly longer, larger amplitude excitation. The phase lag for longer period was contrary to expectations and may result from larger forces from the tether occurring further from the walls than expected. At time of writing no simple coherent interpretation of these and other results has been proposed, and the focus is on refining the experimental setup and obtained larger datasets.

## VIII. CONCLUSION AND NEXT STEPS

Progress in assessing a new type of wave tank is reported. This innovation has the potential to greatly accelerate progress in offshore renewables by delivering a new tool for the physical modelling of wave-structure interaction, and potentially reduce the costs of certain such studies by two orders of magnitude. Should we be successful in this endeavour, one can hope that this would unleash a great many innovations that were heretofore fenced off from the group of validated concepts by the high cost of tank testing. As well, by opening completely new spaces to the physical modelling of oscillatory flow, the system could be a highly valuable tool for fundamental academic research.

There is however a long way from this prototype to these goals, with many known challenges and perhaps many more unknown, and, as always, no clear prospect for the necessary resources. For the moment, the focus is three-fold: (1) using the working prototype to obtain more precise results that can be compared to theory or existing experimental results, (2) install and operate standard wave tank instrumentation, and (3) extend the working prototype from only-surge to also include heave, and thereby enable modelling of unidirectional random seas. Regarding (1), the first focus is to explore excitation of the

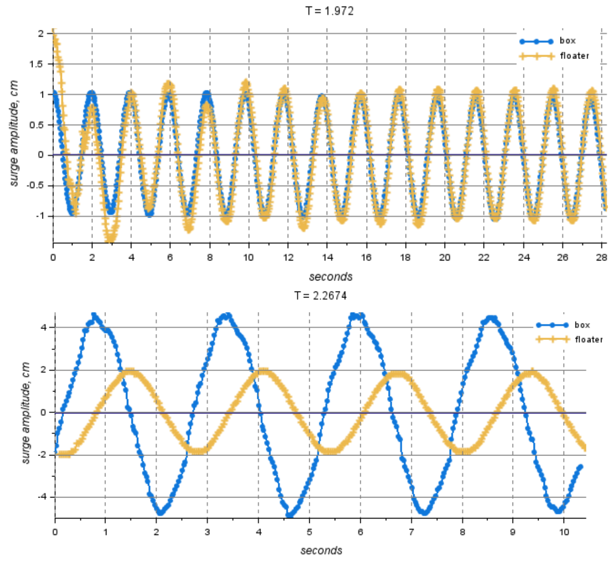


Fig. 8. Surge response of the floater shown in Fig. 7 to a surge excitation of 2 seconds period, amplitude of 2 cm from the wavebox (upper panel), and to a 2.3 s, 8 cm excitation (lower panel).

floater in a range of frequencies and check if resonance occurs at the mode expected from calculations. The result should be interesting either way.

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