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The application of Froude scaling to model tests of Oscillating Wave Surge Converters

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ABSTRACT

Experimental tank testing of scale models is a standard tool in marine engineering. The underlying problem is well understood and refinements to standard applications, like resistance testing of typical ship hulls, have led to widely accepted methodologies. Similarly Reynolds-averaged Navier-Stokes computational fluid dynamics solvers have been used to assess the effect of scaling from model to full scale for ships successfully. Problems still arise when new structures, with very different shapes or modes of motion, are tested. The OWSC is such a new structure, and this paper investigates whether Froude scaling is adequate to extrapolate model scale tank testing to full scale devices. Since only limited full scale data is yet available, the investigation is mainly based on numerical simulations. It is shown that for current designs Froude scaling of typical tank scales is probably appropriate. The application of Reynolds-averaged Navier-Stokes computational fluid dynamics methods to scaling issues in the wave energy industry is demonstrated and some challenges, mainly the demands of industry standard wall functions on appropriate mesh resolution highlighted. Although the observed changes in flow patterns seem reasonable and can be explained by changes in viscosity, some uncertainty remains on the influence of mesh resolution.

1. Introduction

The Oscillating Wave Surge Converter (OWSC) consists of a buoyant, bottom hinged flap. It penetrates the water column completely and rotates back and forth around the hinge when acted upon by waves. This motion is used to drive a power take off system and generate electricity (Whittaker et al., 2007). The second prototype, build by the company Aquamarine Power Ltd. was tested at the European Marine Energy Center. It is 26 m wide and about 15 m high.

Most tank testing in the area of marine engineering, and thus most numerical and experimental methods, are developed for propulsion, resistance or manoeuvring of ships. The objective of ship or propeller design is to find an optimal shape with little resistance. Almost all shapes encountered in technical fluid dynamics, from wings, fans, propellers, turbines, ducts, cars, ships or submarines are streamlined.

While heaving buoys might be fairly similar to ships, an oscillating bottom hinged flap in a free surface flow is different from any other known technical off-shore structure. Firstly, the dominant fluid motion in the boundary layer is perpendicular to the flap's face and direction of motion. Secondly, the flap is an extremely blunt body and large areas of flow separation can be observed in the tank. These separation areas are not simply moved away by the waves, as they might be in typical hull resistance testing, but are constantly moved back and forth around the flap.

Depending on wave and flap characteristics the model or full scale flap might operate anywhere in a fully turbulent or even creeping flow. Changes can even be expected over the height of the flap. Short or small amplitude waves will not induce velocities close to the bottom, while in extreme waves, at very large rotation angles and high flow velocities, the flap seems similar to a flat plate and will experience significant viscous force components (Henry et al., 2014). The shape of OWSCs might vary considerably as shown in the study by Schmitt et al. (2013), further complicating general conclusions.

The boundary layer development is expected to affect the separation at the sides and maybe the flow close to the bottom. The influence of the bottom boundary layer is limited to the area close to the bottom and close to the hinge. Scaling errors in the velocities of the incoming flow field around the hinge will contribute little to the pitching moment. For sediment transport this might be of concern but for power output estimations they seem of little importance. Depending on the shape of the side effector, the location of the separation point is expected to vary for different scales. A sharp edge will force separation at small and large velocities alike. Rounded shapes will behave similar to the sphere in Prandtl's famous experiment (Prandtl, 1965) and are

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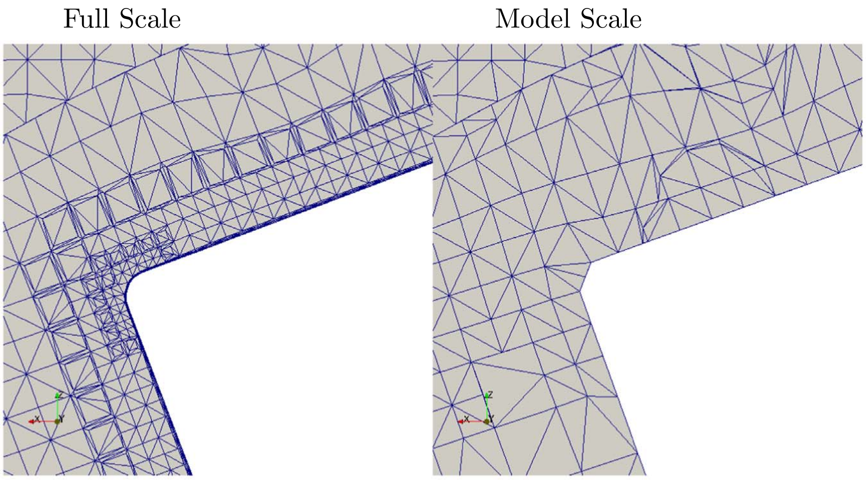

Fig. 1. Mesh refinement around flap. Boundary layer refinement for low viscosity (left) and standard case (right).

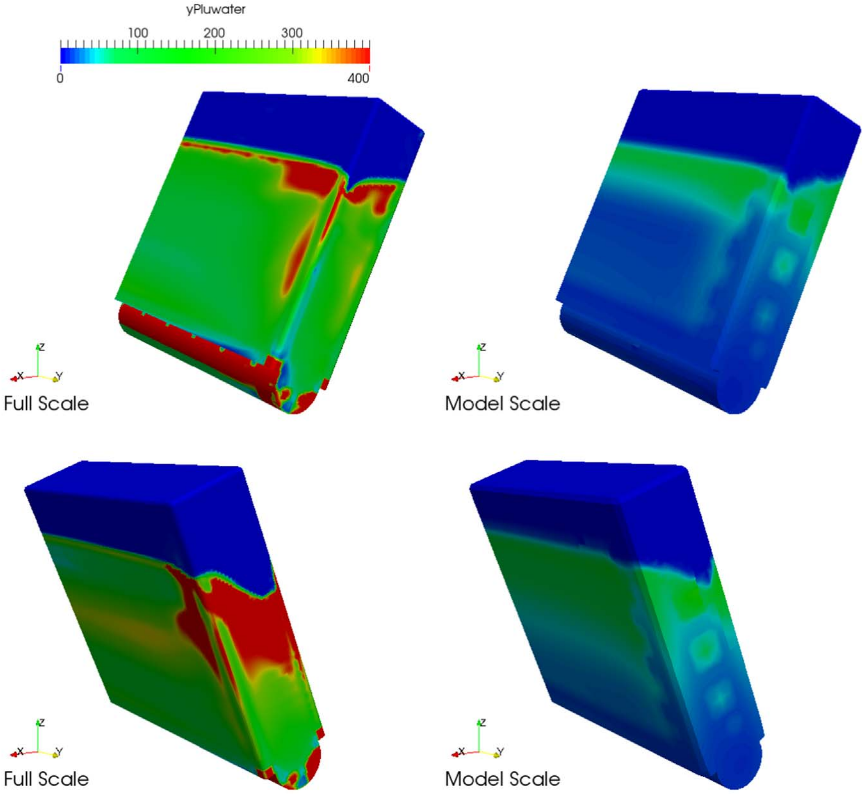

Fig. 2. Wall distance Y^+ for model scale and equivalent full-scale simulation for different time steps in a wave cycle. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

thus difficult to predict and more likely to be wrongly simulated in the tank. At the same time, the effect of the form of the side on performance is not well understood.

Since the mode of operation of WECs varies considerably across the industry, and because of the issues discussed above, it is not possible to define a suitable Reynolds number for reliable tests. Recommended scales are 1:40 or above, although for floating, ship-like structures, scales of 1:100 might still be suitable (Holmes and Nielsen, 2010).

The physical background of scaling issues, that is the deviation in Reynolds number when the Froude number is conserved and vice versa, has been discussed in great detail for the case of wave power converters in general (Sheng et al., 2014) and are also commonly referred to in industry guidelines (Holmes and Nielsen, 2010). In general, Froude scaling is the only possible option when testing prototypes of wave energy converters, since water is the only medium available in test tanks. Researchers agree that above a certain Reynolds number, the flow regime is fully turbulent and coefficients of drag tend to become almost constant for a high Reynolds number range.

In many technical applications like pipes or propellers the choice of characteristic length and velocity has been standardised and thus Reynolds number dependent force coefficients are readily available. In other cases, for example WECs, defining a suitable Reynolds number is not trivial. The characteristic length scale of a device might not be readily defined or even vary depending on the aim of the investigation. For OWSCs the width of the flap could be used, based on the assumption that the most similar case is a thin plate perpendicular to the flow direction. If the flow between the bottom of the flap and the sea floor was of interest, it would of course be better to obtain similar