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The effect of inlet design on the flow within a combined waves and current flumes, test tank and basins

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ABSTRACT

The motion of the sea, through waves and currents, represents a large source of clean and safe energy. However, any structure built to operate in the sea will experience large varying forces and a difficult environment. It is therefore crucial to develop realistic and repeatable sea-like conditions in a laboratory in order to lower the cost and risk of developing off-shore structures. Building on previous efforts, an experimentally validated numerical model is used to predict the current-only flow in flumes capable of combining waves and current. This model is then used to simulate the flows within common flume configurations and within a new concept known as the "isolating inlet flume". The results of these simulations are then analysed to assess the performance of each flume type and to understand the fluid dynamics that govern each type. Flume performance is found to be largely determined by the creation and dissipation of shear layers. The tests proved that a flume using the isolating inlet requires significantly less downstream length to achieve a developed flow and acceptable turbulence levels than the previous flume configurations. The isolating inlet has the additional benefit of creating a still zone where a conventional wave-maker might be used. Further simulations are used to investigate the design of the isolating inlet flume and demonstrate how it works. This paper should be of use to scientists and engineers seeking to design flumes, test tanks and basins that create sea-like test conditions, thus improving the scope and range of laboratory testing.

1. Introduction

Flumes and test tanks that combine waves and currents to produce realistic two and three-dimensional seas provide an opportunity to test scaled off-shore devices and structures, reducing the cost and risk of development. To provide this testing capability several configurations of Combined Wave and Current (CWC) test tanks and flumes have been developed. The current is usually driven either by a pump or by an impeller and then guided into the test tank. The waves are made using an oscillating paddle or piston. The wave-making paddles also have the task of reabsorbing the waves to remove unwanted reflections from the tank (Salter, 1981). To date the production of the current compromises the wave-field and vice versa once a certain flow speed is reached. This means that it has not been possible to create sea-like test conditions representative of important potential tidal power generation sites like the Pentland Firth in terms of wave-field, current speed and turbulence level.

Here a numerical model based on the Reynolds Averaged Navier–Stokes (RANS) equations is developed to aid flume design and assess current-only performance of CWC flumes, tanks and basins. The method is then used to investigate the flow within various configurations of flume that have been designed to include wave-making and current creation simultaneously. Here the current is assessed in isolation of the waves with the effect of waves on performance not assessed.

All of the flume designs tested are based around a re-circulation principle where flow moves across the test section before it is drawn below a floor, then accelerated with an impeller or pump to be re-injected at the start of the test section (Fig. 5). Test tanks exist where current is provided by either jets supported on frames or by arrays of propellers in the test areas of the flume or tank. These configurations are useful in some cases but cannot achieve test conditions as sea-representative as a recirculating tank.

Here four configurations of re-circulating CWC flume are tested at the same scale and operating velocity to allow comparison. The first is up-welling paired with a conventional flap wave-maker where the current enters the tank vertically directly in front of the wave-maker (Fig. 1).

The second method of combining currents and waves could be described as undershot where the current is inlet horizontally below the wave-maker (Fig. 2).

The third method of combining currents and waves works by using a shaped current guiding wave-maker to produce a racetrack-shaped flume (Fig. 3).

The final method tested is the 'isolating inlet flume'. This new inlet design introduces current into the tank in a way that creates a turbulent

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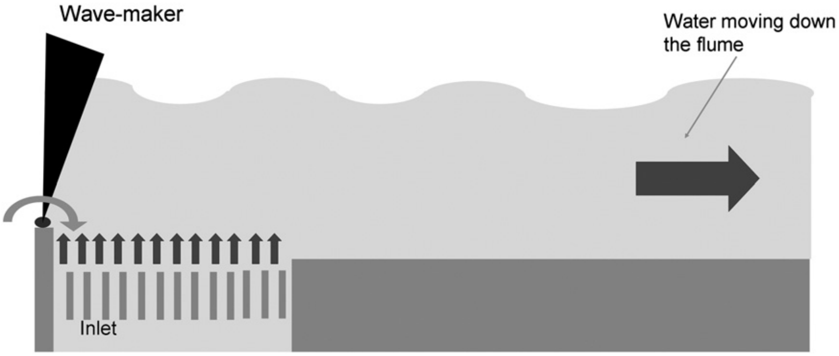

Fig. 1. Up-well type flume sliced along the centre line.

mixing layer which divides the area in front of the wave-maker and the fast moving flow entering the flume, minimising energy transfer, as shown in Fig. 4.

Once the waves reach the dividing shear layer they pass through this boundary and are imposed on the current stream. The wavelength should then elongate in a consistent way dependent on the current velocity and direction.

Fig. 5 is a diagram showing this inlet system implemented on a 3D CWC test tank.

In the test region of a 3D tank (Fig. 5) where arrays of devices may be tested it is critical that the flow has developed a consistent velocity profile. Only changes in the velocity profile due to the upstream device, not flow development, should be experienced by a downstream device. This also determines how much of a 3D tank can be used for array testing and how large the tank needs to be to provide a given test area. The distance the flow takes to develop for a given flume configuration is a critical performance criterion and will be assessed here using a validated numerical model.

The geometry of the isolating inlet is critical to its performance, in particular the inlet angle, the effect of which will be investigated here through simulations.

This investigation aims to improve the physical understanding of what determines flume, tank and basin performance. The numerical model and functional explanations will provide a means of creating a test tank where more realistic representations of the tidal channels in terms of current speed and wave-field can be produced. Thus lowering the cost and risk of developing off-shore devices and structures.

This paper will begin with a review of existing CWC tanks and flumes (Section 2). Following this will be a description of a numerical model based on the RANS method useful for flume design (Section 3.1). A description of the experiment used to validate the experiment is available in Section 3.2. In Section 4.1 these experimental results will then be used to validate this method. The numerical model is used to assess the performance of different common flume configurations in Section 4.2. Section 5 will summarise the findings of this paper.

2. Background

2.1. Wave/current interaction in nature

In nature waves and currents combine in areas of the sea such as tidal channels and costal zones as the tides come in and out. To an engineer the combination of waves and current is of interest because it leads to increased stresses and wear on off-shore structures (Salter, 2003; Wolf and Prandle, 1999). Current affects waves in the following ways:

- Wavelength increases when the current and waves are in the same direction and decreases when they move in opposing directions. (Jonsson, 1990; Wolf and Prandle, 1999).
- Currents reduce or increase wind shear on the surface affecting wave shape (Wolf and Prandle, 1999).
- Waves turn to the current direction over time (Wolf and Prandle, 1999).

Waves affect currents in the following ways:

- The presence of waves can increase turbulent intensity of the bulk flow (Kemp and Simons, 1982).
- Increase wind drag on surface due to waves alters the velocity profile (Janssen, 1989).
- Waves increase friction on the sea bottom (Wolf and Prandle, 1999).

Most of the effects described above do not influence the behaviour in a combined wave and current test tank. If the waves and currents combine in a similar way in a flume as they do in a tidal channel the wavelength should elongate and contract in a predictable way.

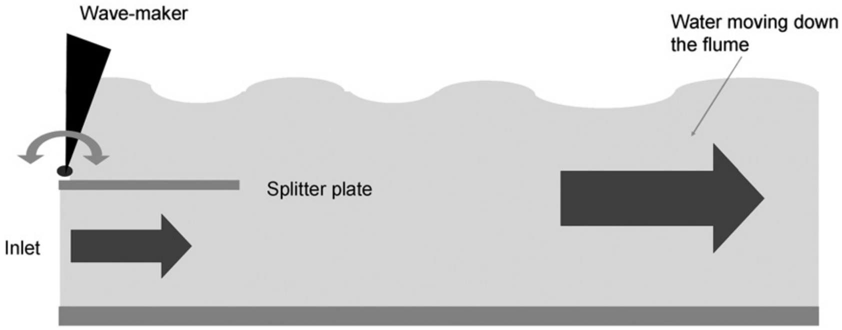

Fig. 2. Undershot type flume sliced along the centre line.