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Damping of unwanted turbulence in wave–current experiments

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ABSTRACT

Laboratory testing of structures placed in combined wave–current flows is a valuable source of information for the fulfillment of offshore engineering related tasks and the development of ocean energy devices. In recirculating wave–current flumes, one of the problems encountered during such experimental studies is the occurrence of undesirable current induced velocity fluctuations. These fluctuations often result in significant disturbances of the generated wave profiles. In this paper, a physical flow filter is introduced that significantly reduces fluctuations in the current profile while permitting wave passage. This is achieved by passing the wave–current flow through a setup of perforated net tubes that allows for both horizontal and vertical flow motions. An in depth investigation of the properties of different filter configurations is presented, focusing on the reduction of turbulence intensities in the flow field as well as the influence of the setup on waves. The filter characteristics are quantified in terms of its deflection, absorption, and transmission properties. It is shown that the overall setup effectively reduces velocity fluctuations, resulting in stable wave–current conditions and allowing for high quality laboratory testing.

1. Introduction

Ocean environments relevant to offshore engineering applications are often encountered as a combination of waves with an underlying current. Such combined conditions are of high interest in various fields: They play a vital role in the development of ocean energy devices, such as tidal turbines or wave energy converters, or in fundamental studies of sediment transport and scouring, to name a few. As part of such studies, it is often desirable to carry out laboratory testing. However, an efficient and accurate generation of wave–current conditions remains to be a challenging task.

A number of experimental setups have been designed in order to model waves in combination with a current. In the design of a structure or device subjected to wave–current conditions, one approach is to utilize a wave towing tank. Previous experimental studies following this concept have for example been carried out by Barltrop et al. (2007), Galloway et al. (2010) as well as Faudot and Dahlhaug (2012). These experiments aimed at modeling tidal turbine behavior in wave–current conditions. Towing tank experiments do not require the generation of a current as part of the experimental setup. However, as discussed by Myers and Galloway (2011), the free stream turbulence levels from the current are zero when carrying out a towing tank experiment, because the water in the free stream is only subjected to the wave motion. Furthermore, the boundary layer of the current is not represented in this approach, which is particularly problematic in the case of bottom mounted structures. Therefore, the physical characteristics of the flow are only partially considered in towing tank experiments.

The alternative is to utilize a recirculating water channel in combination with a wave maker. This approach was followed by de Jesus Henriques et al. (2013). In the suggested setup, the water is directed through a flow straightener at the inlet of the channel. Prior to entering the working section, the water flow passes under a hinged wave paddle located on the water surface. Using an electrical motor, the paddle generates waves by oscillating vertically. The resulting wave–current field generated with this setup agrees well with theoretical reference solutions and studies of tidal turbines were carried out on its basis. A trade-off with this type of wave–current flume is the inherent limitation in the wave height to water depth ratio.

This is likely part of the reason why a majority of flumes consist of a vertical wave paddle with the current typically entering the channel in front of the paddle, or below the paddle. Under such conditions, the current will have a strong circulatory motion in the inlet region, particularly when the inlet pipe is oriented vertically. As assessed by Nowell and Jumars (1987), these circulations propagate through the flume for about 20 times the inlet diameter. This distance is usually beyond the test section and thus the flow field will not consist of a simple boundary layer in the vicinity of testing.

Several approaches have been developed to unify and straighten flows in pure current flumes. At present, this is usually achieved by passing the flow through a wire mesh screen and a honeycomb

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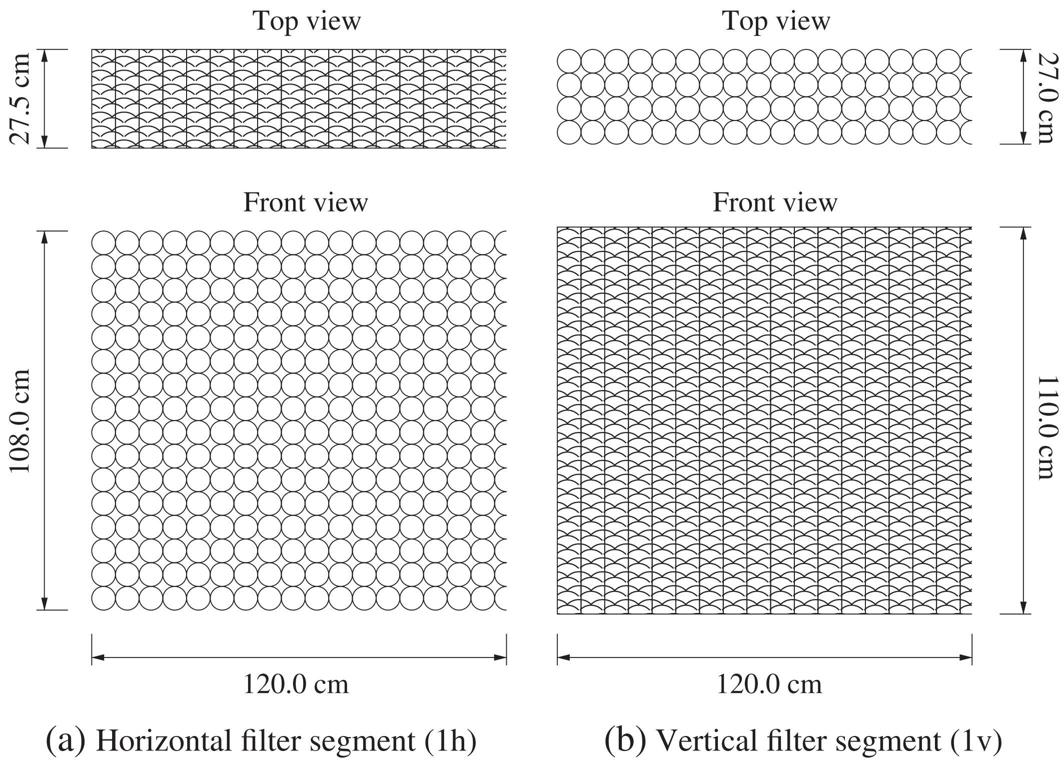


Fig. 1. Dimensions of the individual horizontal and vertical filter segments.

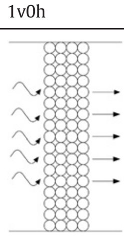
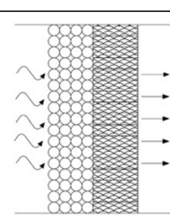
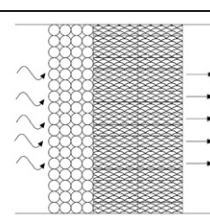
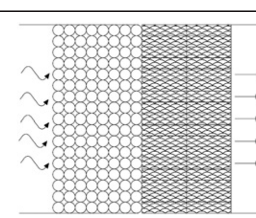
(Kulkarni et al., 2011). Flow distribution control using screens is well established and was analyzed in detail by Laws and Livesey (1978), including calculations that can be used to predict the effects of the screen on the flow field. Although screens can be used effectively to either suppress or generate turbulence in the flow, their functionality in essence is limited to flows that are already well developed, as pointed out by Nowell and Jumars (1987). The dissipation of large-scale motion in a flume is achieved more effectively using honeycombs. Here, the flow is passed through an assembly of horizontal ducts in order to break down large-scale motion. The characteristics of honeycombs and the optimal geometric dimensions to reduce turbulence in a flow were analyzed and documented by Mikhailova et al. (1994). Scheiman and Brooks (1981) analyzed both screens and honeycombs and concluded that a combination of the two setups is the most effective approach to reduce turbulence in a flow. This setup is specifically designed and optimized for pure current scenarios, while it is not intended to function in combination with waves. The closed chamber walls of a honeycomb serve to break down the vertical motion, which would also affect wave induced vertical velocities. This motivates the introduction of alternative experimental methods that are specifically geared towards wave–current scenarios.

In this paper, a physical flow filter is introduced that serves the purpose of diffusing undesirable velocity fluctuations in the current flow, while simultaneously allowing for the passage of waves. The filter consists of net tubes that permit fluid motion in both horizontal and vertical directions. The setup consists of vertically placed tubes to diffuse turbulence from the current, as well as horizontally oriented sections that act as a flow straightener. A detailed description of the filter layout and experimental setup used to test the filter is given in the succeeding sections. Following, the results of an elaborate test series are documented, which describe the characteristics of different filter configurations in waves and currents. It is shown, that the setup allows for the generation of stable and well formed wave–current conditions. The filtering technique is a low cost approach to enhancing recirculating wave–current flumes consisting of vertical wave paddles, allowing for laboratory testing of devices and sea floor conditions in wave–current environments.

2. Filter description

The basic concept of the filter setup is to diffuse turbulence in the flow field, while permitting a vertical flow through the setup. This is

Table 1
Tested filter arrangements and corresponding total filter widths.

	1v0h	1v1h	1v2h	2v2h
Setup				
Width	27.5 cm	54.5 cm	81.5 cm	109.0 cm