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Measurements of overtopping flow time series on the Wave Dragon, wave energy converter

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ABSTRACT

A study of overtopping flow series on the Wave Dragon prototype, a low crested device designed to maximise flow, in a real sea, is presented. This study aims to fill the gap in the literature on time series of flow overtopping low crested structures. By comparing to a simulated flow the characteristics of the overtopping flow are discussed and the simulation algorithm is tested. Measured data is shown from a storm build up in October 2006, from the Wave Dragon prototype situated in an inland sea in Northern Denmark. This wave energy converter extracts energy from the waves, by funnelling them to run-up a ramp and overtop into a reservoir. This water is stored at a higher level than the average sea surface, before being discharged through hydro turbines. The waves, device sea handling and overtopping flow are measured by pressure transducers ahead of, beneath and in the device. Comparisons of the distribution and correlation show that the measurements support the use of the algorithm for generating a simulated flow.

1. Introduction

Much of the existing literature on overtopping flow (e.g. Van de Meer and Jansen [1] and Franco et al. [2]) has investigated flow over breakwaters and dams. These have developed and tested models for both the time average rate of discharge and the distribution of these flows. As the interest has been in coastal defence structures these have always high crest freeboards and therefore low flow rates. For wave energy utilisation where maximum flow rates are desired low crested structures (where the crest level is comparable to or lower than the significant wave height) are optimum. In this case detailed work has only studied the average rate of overtopping, as in Kofoed [3]. This paper aims to fill this gap in the literature by considering the distribution of overtopping flow on a low crested structure.

An advancing branch of wave energy is that of the overtopping type device, gathering the energy by waves overtopping into a raised reservoir, and extracting this by draining the water through low head turbines. This principle is shown in Fig. 1. When modelling the power capture of such devices a set of equations is used to generate a time series of the flow into the reservoir. This allows design of the geometry of the reservoir, and the turbines to be used, and the optimal control strategy to use on these. It is therefore crucial that this simulated flow into the reservoir is accurate. Such simulations have been based on theory developed and tested for overtopping on higher relative crest freeboard structures.

The Wave Dragon device is by far the most developed of the overtopping type of devices. The layout of the device is shown in Fig. 2. The device consists of three main components.

- Two wave reflectors. Attached to the central platform these act to focus the incoming waves. Laboratory tests have verified numerical simulations showing their effect of increasing the wave height. Kramer and Frigaard [4] show these to improve the energy captured by approximately 100% in wave conditions typical of the Danish North Sea, Bølgekraftudvalgets Sekretariat [5].
- The main platform. This is a floating reservoir with a double curved ramp facing the incoming waves. The waves overtop the ramp which has a variable crest freeboard 1–4 m. Underneath the platform open chambers operate as an air cushion maintaining the level of the reservoir. Venting air into and out of these chambers allows both the level of the reservoir to be optimised as well as the pitch and roll of the platform to be minimised. This control is fully discussed by Kofoed et al. [6].
- Hydro turbines. A set of low head Kaplan turbines converts the hydraulic head in the reservoir. These turbines are attached to PMG allowing variable speed operation. The produced electricity is converted using AC/DC/AC power electronic converters to the grid frequency.

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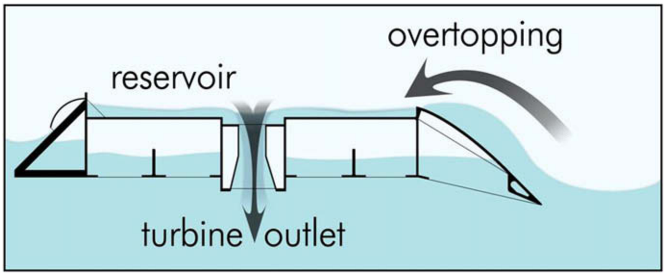

Fig. 1. Overtopping principle.

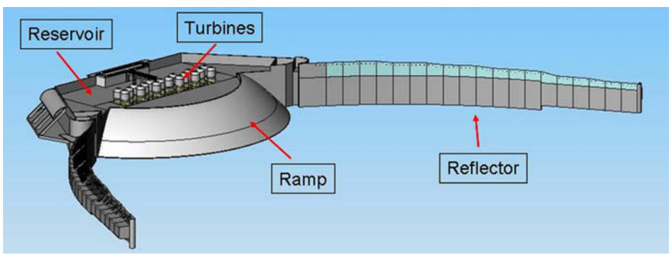

Fig. 2. Layout of the Wave Dragon device.

Since April 2003, a 1:4.5 scale device has operated in an inland sea in Northern Denmark. The project and results are described fully by Kofoed et al. [7] and Tedd et al. [8]. During a storm on October 26, 2006 the prototype was used solely for purposes of measuring overtopping flow distribution. These results are presented. This is a test at almost full scale, in that the scale effects (due to surface tension) seen in the laboratory setting will be insignificant.

2. Instrumentation

The measurements for this study have all been taken on the Wave Dragon prototype device, shown in Fig. 3, at location in Northern Denmark. The wave climate at the fairly sheltered site allows for an approximate scale 1:4.5 to the North Sea. The water depth at the site is around 6 m.

In order to measure the flows over the ramp of the device and compare to the model the following measurements have been made.

Table 1
Filter settings for pressure transducers

	Transducers in reservoir	Transducers beneath device
Low pass cut-off frequency [Hz]	0.4	0.15
Filter length [–]	1024	1024
Sample frequency [Hz]	10	10

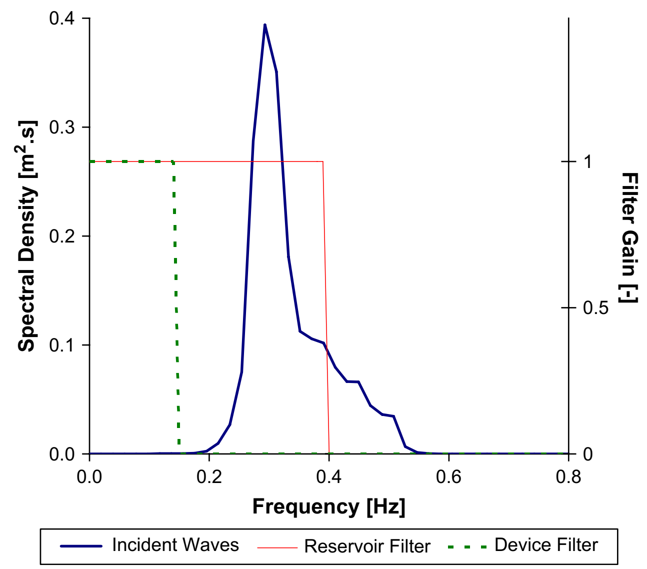

Fig. 4. Frequency spectrum of incident waves for Record 3, and transducer low pass filter gains.

- Incoming wave climate – measured at the mooring point, around 60 m ahead of the device, by a pressure transducer approximately 1.5 m below the water surface.
- Water level in the reservoir – three pressure transducers mounted to the floor of the reservoir, measure the water in the reservoir.
- Crest freeboard – three pressure transducers mounted below the reservoir measure its floating height.
- Turbine outflow – measurements of the rotational speed and the head across a turbine allow calculation of the flow according to the turbine characteristic.

Fig. 3. Wave Dragon prototype operating in Nissum Broads.