Optimal pattern of interacting wave power devices

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Abstract **The contribution of Wave Energy Converters (WECs) to the renewable energy supply is continuously rising. To produce a considerable amount of electricity, wave power devices or WECs need to be placed in a farm.**

In a farm WECs interact and the amount of produced electricity is affected to a certain extent, depending on the lay-out of the farm. In order to find the optimal lay-out WECs are studied in a numerical mild-slope type model, generally used for wave propagation in coastal applications. The existing model is adapted by simulating the energy extraction of a WEC through sponge layers.

The adjusted model can be used to study the optimal lay-out and electricity production of a farm.

Keywords **mild-slope model, farm, wave energy converters**

I. Introduction

The need for renewable energy is rising at light-speed. The increasing energy demand, the greenhouse effect and the approaching exhaustion of conventional energy resources, forces humanity to develop alternative energy supplies, a.o. wave energy.

A Wave Energy Converter (WEC) converts the kinetic and potential energy in ocean waves into electricity. A single WEC, with a capacity comparable to a classic power plant (e.g. 400 MW), is technologically impossible. Therefore arrays of WECs, placed in a geometric configuration or 'farm', are needed.

WECs in a farm interact and the overall power absorption is affected. An optimal pattern of WECs in order to maximise the power absorption is of major importance in the design of a wave farm. An existing mild-slope wave propagation model MildWAVE [1], developed at the Department of Civil Engineering, Ghent University, is adapted to investigate the interaction between WECs.

In this paper the simulation of a farm in a mild-slope, phase-resolving wave propagation model is presented.

II. Numerical model

A. *MildWAVE*

At Ghent University MildWAVE has been used, e.g. to study diffraction patterns in a harbour [2]. MildWAVE uses the mild-slope equations of Radder and Dingemans [3] in a numerical finite difference scheme. The phase-resolving model is able to generate linear water waves over a mildly varying bathymetry and to calculate instantaneous surface elevations (and velocity potential) throughout the domain. Wave transformation processes such as refraction, shoaling, reflection, transmission and diffraction are simulated intrinsically. Moreover wave energy is dissipated, similar to a wave power device, by implementing sponge layers.

B. *Set-up*

A numerical wave basin (1000 m x 2000 m) is designed to study interacting wave power devices (Figure 1). In the basin waves are generated on the wave generation line. A sea state (significant wave height H_s = 1 m and peak period T_p = 5.2 s) with a high occurrence frequency in the North Sea is selected as an input for the wave generation ([4] – Wave Buoys Auk and K13). A uniform water depth of 30 m is applied, in order to avoid wave breaking. At both ends of the wave basin sponge layers are placed to absorb the generated and scattered waves. Several groups of 7 Wave Gauges (WG) are placed in the basin (Figure 2) to measure the incident, reflected and transmitted wave height and wave energy [5]. The signals of the wave gauges are processed with the 3D wave analysis software package WaveLab [6].

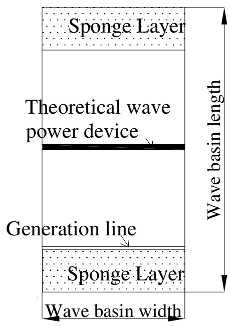

Figure 1 Numerical test basin with sponge layers – plan view

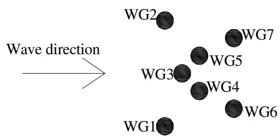

Figure 2 Wave Gauge (WG) pattern to measure the incident, reflected and transmitted wave

C. *Simulation of a wave power device*

A wave power device is modelled by sponge layers with a specific sponge layer coefficient. By adapting the sponge layer coefficients the reflected, respectively transmitted wave, H_r and H_t (and the amount of *absorbed energy*) can be changed. For each combination of sponge layer coefficients H_r, H_t and H_i are measured by groups of 7 wave gauges. Based on those measurements the *absorbed energy* is calculated by using equation (1).

$$1 = \frac{H_r^2}{H_i^2} + \frac{H_t^2}{H_i^2} + \frac{absorbed\ energy}{available\ energy} \tag{1}$$

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In (1) the *available energy* can be expressed as a function of the incident wave H_i. Equation (1) allows to model different amounts of *absorbed energy*.

In order to simulate a wave power device with a fixed amount of *absorbed energy*, the effect of different sponge layer coefficients on the transmitted and reflected wave is investigated. For this purpose one theoretical wave power device, with a width equal to the wave basin width, is tested in the test wave basin (Figure 1).

III. RESULTS

A. A fixed amount of absorbed energy

First all cells of the WEC are assigned the same sponge layer coefficient α. The measured incident wave height H_i, reflected wave height H_r and transmitted wave height H_t are shown in Figure 3 for different values of α. When the sponge layer coefficient α is 0.0, respectively 1.0, all energy is reflected, respectively transmitted. When the sponge layer coefficient is varying between 0.8 and 1.0, the incident wave is partly reflected, absorbed and transmitted (Figure 4). Further by combining different sponge layer coefficients, a fixed amount of *absorbed energy* can be simulated.

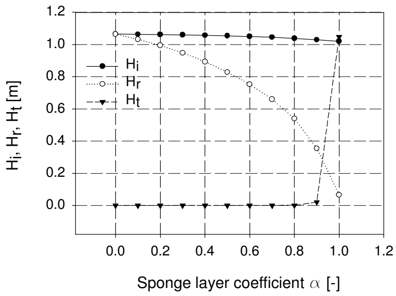

Figure 3 H_r, H_t and H_i for a WEC with a constant sponge layer coefficient for all cells of the WEC between 0.0 and 1.0

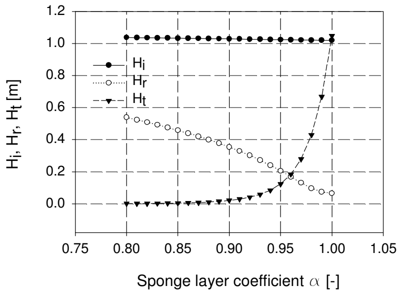

Figure 4 H_r, H_t and H_i for a WEC with a constant sponge layer coefficient for all cells of the WEC between 0.8 and 1.0

B. A farm of interacting wave power devices

As an example a pattern of two arrays of WECs with 25% absorption (= capture ratio = ratio between the absorbed power and the wave power incident on a wave-front width equal to the width of the wave power device) are modelled.

Irregular long-crested waves are generated in the test wave basin. The interacting wave power devices and the resulting calculated wave heights are shown in plan view on Figure 5. The individual shadow zones of the different WECs are very expansive and their interaction is affected by the distance between the WECs. As a result the available wave energy behind an array is reduced, furthermore the potential energy absorption of the next array is decreased. The distance between the WECs and the successive arrays affect the decrease of the available energy and the overall energy absorption. Figure 5 illustrates the possibility to model a larger wave farm and to study different patterns of interacting wave power devices in order to maximize the energy absorption in MildWAVE.

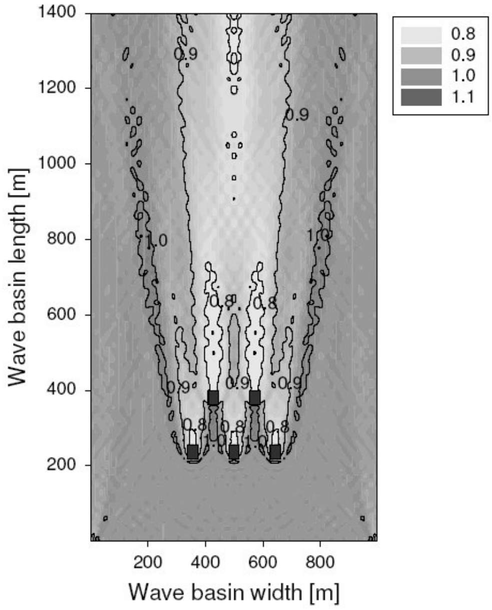

Figure 5 Calculated wave heights in a wave basin with two arrays of wave power devices (25 % absorption) for irregular long-crested waves (head on)

IV. CONCLUSIONS

The modelling of a wave farm in an adapted mild-slope wave propagation model MildWAVE is presented. A WEC is simulated through sponge layers with different sponge layer coefficients. With the adapted model, optimal power absorption by a farm of WECs can be studied.

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