A FREQUENCY DEPENDANT METHOD FOR THE SIMULATION OF DISTURBANCES AROUND A SMALL SCALE WARE FARM USING A BOUSSINESQ SIMULATION

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ABSTRACT

A Boussinesq model has been created to simulate the presence of an array of shallow water wave surge oscillator devices using DHI's MIKE21 Boussinesq wave (BW) model suite. The simulation uses a regular grid domain with a constant depth of 10m and a grid spacing of 2m in the x and y dimension.

This new method provides a crucial enhancement of including a frequency dependant absorption, where the devices reflected, absorbed and transmitted characteristics are shown using a realistic power transfer function. The frequency spectrum as a set of *n* monochromatic waves at frequency intervals with a proportional energy scaled wave height. A simulation is then run for each frequency where the porosity value is dependent on the WEC's absorption spectrum. The results of each simulation are then summed to form overall wave energy.

The results demonstrate the application of this new method and provide a detailed map of the spatial change in wave energy around devices, highlighting the regions of importance.

INTRODUCTION

Recent interest from industry and academia has led to the development of several wave models. A review paper introducing the main methods of simulating wave energy converters (WECs) discusses the advantages and disadvantages of several wave models [1]. This outlined that when looking at environmental and more specifically wave climate alterations there are four general categories; potential flow, Boussinesq/MILD slope, spectral wave, and computational fluid dynamics (CFD) models. As this study assess the regional wave disturbance of an array of nearshore oscillating wave surge converters a Boussinesq wave model has been applied. The Boussinesq model applies phase-resolving characteristics that provide an accurate simulation of the nearshore/shallow water hydrodynamics environment where diffraction is accurately portrayed.

Numerical modelling of WEC arrays using Boussinesq and MILD slope models have previously been used to assess the potential impacts on the surrounding wave climate. An extensive overview of the simulation of single and multiple Wave Dragon devices using a MILD slope model to determine

wave array disturbances [2]. The absorbed and transmitted wave properties were applied using an incident wave parameter dependant sponge value based on mathematical assumptions. This method provides a representation of the disturbance behind an array of Wave dragon devices in different sea state but remains to apply a frequency independent absorption and transmission. The simulation of a small array of WEC's in a shallow water nearshore environment using combined physical and numerical models provides a calibrated numerical model [3, 4]. These studies use DHI's Mike21 Boussinesq model to simulate DEXA WECs composing of a simple mono-hinged wave attenuator. This study provides simulated and measured reflection and transmission coefficients along with the spatial disturbance. The devices were simulated using a porosity layer, where a constant porosity value of 0.9 was selected. The simulated data provides a reasonable agreement between the numerical and physical model for reflected and transmitted waves. However there seems to be a larger variation in the numerical model data through the different sea states tests. This provides a good assessment for an initial study regarding general nearshore WEC arrays and the approximate reflection and transmission coefficients.

The report looks at the simulation of nearshore shallow water oscillating wave surge converters using a frequency dependant WEC absorption.

METHODOLOGY

The device simulation was conducted in DHI's Mike21 Boussinesq wave (BW) model. As stated in [1] this wave model allows the effective phase resolving simulation of nearshore shallow water environments. The model applies a time domain calculation in order to find the solution for surface elevation using flux densities. Further information on the BW model is available at [5]. This report uses the 2DH simulation which provides two dimensional space coverage.

I. General Model Setup

As the focus of this report is to asses a new method of simulating devices within the BW model a simplified test bathymetry with a constant depth of 10m was used. This model uses regular grid mesh with a 2m resolution. This allows the deep water terms to be excluded as all waves are considered to be in shallow/intermediate water depth. The numerical parameters apply a central differencing

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with side-feeding space discretisation, a time discretisation factor of 0.8 and exclude depth dependant time extrapolation. The simulation is run for 12000 time steps with a time step interval of 0.15 seconds. This provides a maximum courant number of 0.74 which is well below the suggested maximum value of 1 which increases the model stability. A 50 cell sponge layer was applied to either end of the model domain to absorb all propagating waves.

II.   Simulation of WECs

The implementation of WECs within the BW model is achieved by the application of porosity layers. While the use of a porosity layer within the BW model provide no frequency dependant absorption, the summation of multiple simulations with a varying porosity values provides a linear frequency dependant absorption. This method provides a flexible way of applying any wave device characteristics based on reflective and power transfer function (PTF) information. In order to calculate the wave disturbance for a given frequency spectrum the spectrum is separated into a number of bins. An energy equivalent monochromatic wave ($\widehat{H_{m0}}$) is created within the Random Wave Generation toolbox in Mike 21 for each frequency bin. This is shown in Figure 1 where the input wave frequency spectrum is split into 10 bins and 10 equivalent monochromatic waves are created. This is done by calculating $m_0(f_n)$ where f_n denotes the power spectral density within the respective frequency bin using the trapezoidal integration of the input S(f). $\widehat{H_{m0}}$ is calculated by

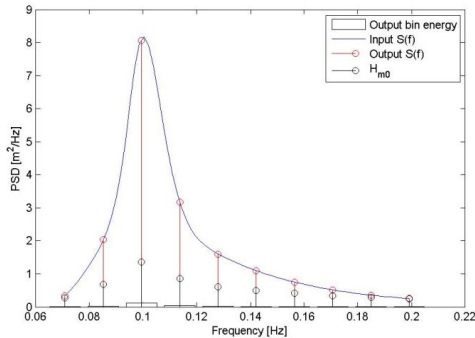$$\widehat{H_{m0}} = 4\sqrt{m_0(f_n)}.$$

Figure 1. Example of the deconstruction of an example frequency spectrum resulting in 10 energy equivalent monochromatic waves.

A PTF obtained from a previous study was used to simulate the absorption from the WEC's [6]. This study used a physical scaled tank model to provide a normalised frequency dependant power capture for an oscillating wave surge converter. This result was smoothed and a peak absorption coefficient of 0.2 was applied. This provided the frequency dependant power capture for each frequency interval (see Figure 2). Note: the frequency bins were increased to 15 for this simulation.
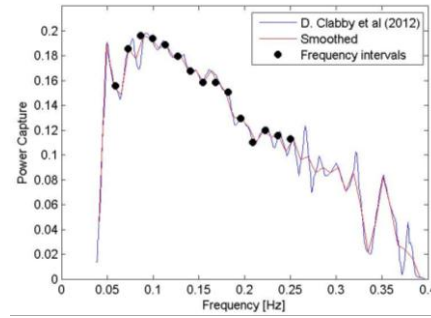

Figure 2. Frequency dependant power capture.

The frequency dependant power capture is then converted to a representative porosity value based on the results of previous work. This gives a separate porosity value for each frequency interval dependant on the physical absorption characteristics. The model is then run in parallel with a base model that uses an identical model comprising of the same wave conditions without the presence of the hypothetical WECs.

Results/Discussion

The model output for each frequency interval are provided in the term $\widehat{H_{m0}}$. The desired output is in the form of energy and percentage change in energy. To maximise the efficiency of the combined simulations an intelligent post processing script was applied. This script calculated depth dependant wave speed and provided the number of time steps before tank side wall reflections could interfere with the area of interest.

The results for a single device can be seen in Figure 3. A box is shown inside the domain that illustrates the extent of the "useful" domain. The device reflection and transmission coefficients were calculated directly in front and behind of 0.9 and -0.58 respectively. This is equivalent to an increase of 90% in front and a reduction of 58% behind the device. The up-wave results show that a large reflective modulation is observed in front of the device that decays with distance. The down-wave results show the wake of the device causing a large reduction in energy that increases with distance behind the device.

Following the simulation of a single device the effects of multiple devices were simulated. Three devices were used with a separation of 100m. **Error! Reference source not found.** shows the disturbance around 3 devices with the area of interest shown within the black box. The individual device reflection and transmission coefficients for all devices are similar to the single device test. The reflected change in energy shows a 2 dimensional variation that shows a general reduction as the distance in front of the device
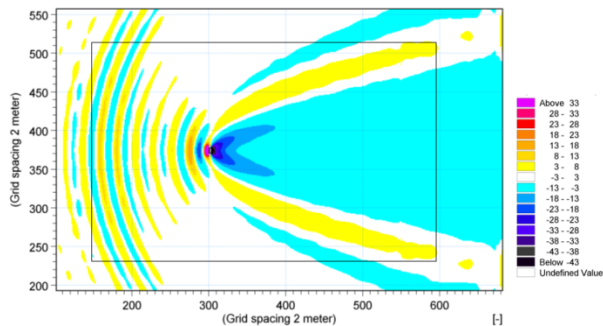
Figure 3. Percentage change in wave energy around a single oscillating wave surge converter.

increases. However at approximately 220m in front of the central device a secondary increase in energy is observed. The down-wave device disturbance also shows a 2 dimensional variation in wave disturbance. The combined effects from several devices provide regions of increased negative wave energy disturbance. The down-wave external increase in wave energy shows a larger increase in wave disturbance for the array test case.
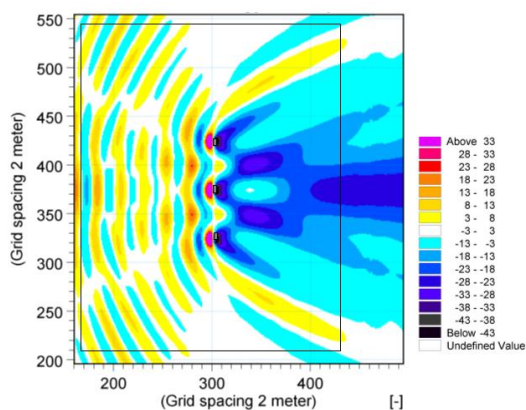

Figure 4. Percentage change in wave energy around multiple oscillating wave surge converters.

As the single device and multiple device models used the same domain, the area unaffected by the side wall reflections was considerably smaller for the array simulation. When the results are compared the wave device interactions observed in the array test show a much more complex spatial variability. The combined effects of the multiple devices cause a larger magnitude in the mid-field maxima and minima. This results in the potential increase in wave energy of 24% in front of the device or a reduction of 30% behind the devices. These statistics neglect the large interference caused locally to the simulated devices.

CONCLUSIONS

This report has demonstrated a new method of simulating WEC-wave disturbances within the BW model. The application of a PTF though frequency

dependant porosity values provides reasonable results. While this report shows an example of the application of this technique by increasing the number of frequency intervals the level of detail should be increased. The PTF values used within this study provide a reflective/transmission coefficient of 90% and 58% respectively. This result is deemed to be the worst case realistic scenario and can be adjusted through the peak absorption coefficient or the PTF porosity relationship.

The application of the model shown within this report attempts to optimise the large computational demands in time and data storage through data post processing. The smallest usable domain should also be applied in combination with the wave speed dependant on post processing for a faster simulation completion. The application of such a post processing and simulation control script requires a considerable commitment.

As the current progress shows a good application for the simulation of WECs this will topic remain under development. Future work will focus on the nearshore aspects of the device and effects of a sloping bathymetry on the WEC-wave disturbance.

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