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Methods to enhance the performance of a 3D coastal wave basin

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ABSTRACT

Following completion of a new 18 m by 16 m 3D coastal wave basin facility by Queen's University Belfast in 2010, efforts to assess and enhance the performance were undertaken. A combined physical and numerical modelling methodology was employed. Key findings are presented which should benefit others using or developing such facilities. Physical mapping was carried out using a specially developed polychromatic wave packet allowing accurate and efficient mapping of multiple frequencies simultaneously. Numerical modelling was undertaken using a phase resolving coastal wave propagation model to determine causes of observed non-homogeneity in the wave basin and efficiently determine an optimum wave basin design. Lateral absorption implemented along the side walls of the basin as a result of this work has significantly improved the homogeneity of the wave climate with little reduction to the total energy in the main working area. The shape of transition panels provided between the wave paddles and side beaches have been optimised using the wave propagation model. These developments have resulted in a wave basin which is significantly improved in terms of wave climate variability and energy absorption.

1. Introduction

Laboratory wave generation and wave basin experimentation are invaluable within the fields of coastal engineering and naval architecture. Even taking into consideration the recent progress in computing and numerical modelling capabilities, physical modelling remains a critical step for numerical modelling validation. However, no wave basin is perfect. Variations in the wave climate within a basin are to be expected due to interactions with the wave-maker and beaches. On the other hand there is an increase in the levels of precision required from physical testing in wave basins. Traditionally the use of wave basins for modelling harbours, ports breakwaters, offshore structures and early stage marine renewable device development has primarily focused on matching statistical properties such as significant wave height and mean wave period at a single point in the basin, i.e. the model location. Where the area of interest covers a number of points within the basin (e.g. WEC array studies) a different approach is required. In this case the variation in amplitude of each frequency component within the entire area of interest should be quantified and understood. Therefore it is desirable to minimise variations in wave climate as much as practically possible.

Reflection of wave energy from wave tank boundaries and model structures, which are re-reflected from tank boundaries, is one of the most common effects influencing the accuracy of laboratory experiments. Unless these reflections are accounted for in the experimental analysis, they are undesirable and can mask real effects, contaminating experimental results. To ensure high quality experimental results, particularly where physical measurements are required for validation of numerical models, wave energy absorption is one of the most important parameters to control in the tank.

Two dimensional wave tanks (or wave flumes) commonly consist of a straight channel with a wave-maker at one end and an absorbing beach at the other. A review of developments in wave-maker theory is given by Dean and Dalrymple (1991) and Hughes (1993). In a good quality facility there should be minimal spatial variability in the wave field, aside from evanescent waves which occur due to the mechanical wave generation in addition to the propagating wave and exist very close to the wave-maker (Dean and Dalrymple, 1991). Therefore the wave field can be characterised using reflection analysis (e.g. Mansard and Funke, 1980). This allows separation of the incident and reflected wave spectra assuming the surface elevation measured at a particular point is the summation of these two components travelling in opposite directions to each other.

Three dimensional wave generation is more complex. This requires the use of multi-unit, directional wave-makers which move in a snake like action to generate long crested waves at oblique angles to the wave-maker and multidirectional short crested seas. Directional wave-makers are also usually installed along one side of the basin only,

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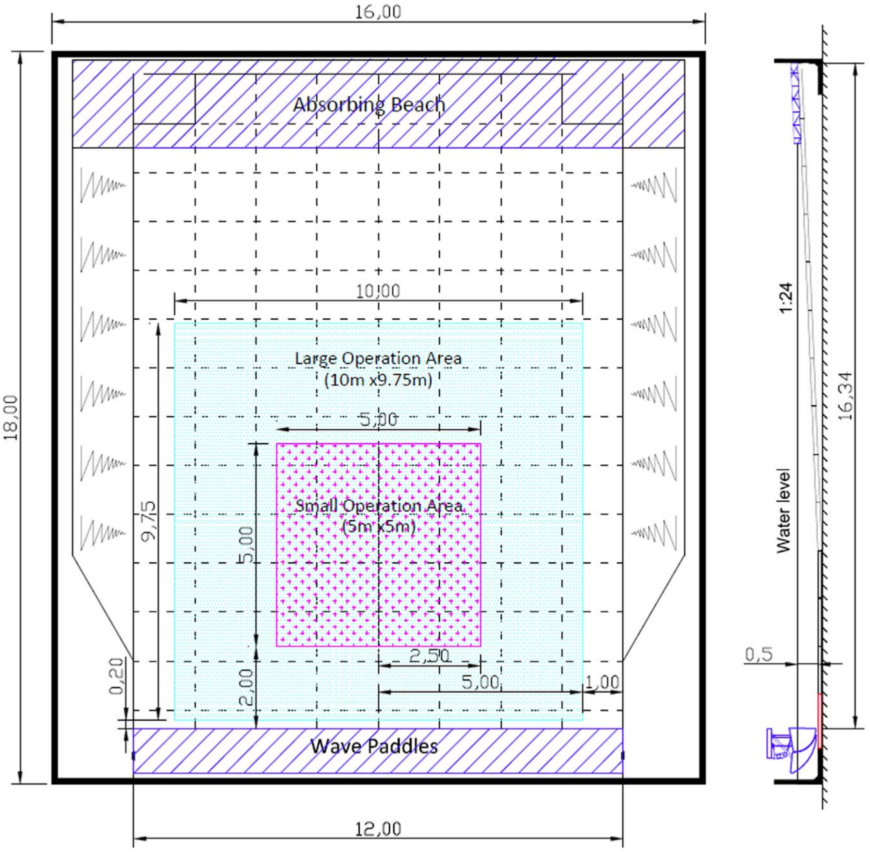

Fig. 1.1. : Layout and bathymetric profile of the original wave basin (2010) including the position of the large and small operation areas used for assessment of performance.

meaning that oblique waves will at some point approach the side walls of the basin. This can be dealt with in a number of ways for example by providing passive absorption on the side walls to minimise reflections into the main test area. Alternatively active absorption, in the form of additional mechanical wave-makers, may also be provided e.g. the FloWave circular wave basin (FlowWave, 2016) however this is an expensive solution. Another approach is to utilise intentional reflections from the side walls into the main test area, e.g. Dalrymple (1989), Gilbert and Huntington (1991) and Molin (1991) which increase the area in a tank which exhibits a homogeneous wave field. These methods have been validated experimentally by Mansard and Miles (1994) and Roux de Reilhac et al. (2008).

While these methods may be successful at generating a relatively homogeneous wave climate in an 'empty' wave basin (i.e. no test model installed) only passive or active absorption on all sides of the wave basin can deal with waves reflected and radiated from the model. The challenge is to achieve a balance between lateral absorption of wave energy and minimised diffraction due to the finite length of the wave-maker. If the wave paddles extend to the full width of the wave basin (e.g. wave paddle width=16 m for the basin shown in Fig. 1.1) there is no available ‘width’ for inclusion of absorption. On the other-hand, if the paddles do not extend for the full width of the basin, a transition panel (or wave guide) is required to prevent water sloshing around the sides of the wave paddles and affecting operation. The transition panels must eventually diverge to provide the full width of the wave basin and introduce absorption on the sides. As the transition panels diverge, waves diffract into the undisturbed area of the basin, spreading energy along the wave front. This may be accounted for by adjusting the wave amplitude generated at the wave-maker to allow for wave energy spread. In addition, where the wavelength is less than the total width of the wave-maker a more detrimental diffraction phenomenon may occur within the length of the basin known as the Fresnel interference regime (O’Boyle, 2013). This results in regions of constructive and destructive interference across the entire wave front, creating a non-homogeneous wave field throughout the basin.

This paper describes the development, testing and modelling of a new coastal wave basin built and originally commissioned at Queen's University Belfast in 2010. Following a fire in the building the facility was rebuilt in 2011. During the design, construction, refurbishment and final commissioning a range of important conclusions were reached which should be of benefit to anyone contemplating building or refining such a facility.

1.1. Original wave basin set-up

The wave basin is 18 m long and 16 m wide with an operating water depth of up to 0.65 m. An adjustable floor facilitates testing at various depths and a range of bed profiles. The original setup of the tank geometry and bathymetry is shown in Fig. 1.1. Wave generation is provided by 24 no. 500 mm wide piston type, sector carrier wave paddles supplied by Edinburgh Designs Ltd which have active absorption via a force feedback mechanism. Each element of the wave generator is independently driven and controlled enabling full three dimensional sea generation. From the outset the facility was equipped with absorbing beaches on three sides to minimise unwanted reflections particularly in the transverse direction. This was achieved by limiting the wave generator to a total width of 12 m thus leaving 2 m on both sides for the longitudinal beaches. When first commissioned in 2010 the back beaches consisted of folded geotextile material (see Fig. 2.4 A). The side beaches comprised concrete slabs which formed a steep impervious slope of 1:2 at its steepest point with its top edge at mean water level and shoaling further back in the tank (see Fig. 2.4B). Straight panels provided the transition from the outer edge of the wave generator to the side beaches. Design guidance was taken from previous experience with a 4.5 m wide tank, knowledge and expertise provided by Edinburgh Design Ltd. (the wave-maker manufacturer) (E