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Validation of a hydrodynamic model for a curved, multi-paddle wave tank

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ABSTRACT

Obtaining a hydrodynamic model for a wave tank has many benefits, from allowing the useable test zone to be identified, to helping with the tuning of the wavemaker controllers. This paper explores a first-order, boundary element method (BEM) that has been previously proposed for modelling wave tanks, applying the method to a tank with a unique, curved geometry. In a series of experiments, the model is shown to provide a good representation of the wave profile across the tank. Inherent limitations in the method are also identified: in the case when only a single paddle is moved, significant, un-modelled second-order spurious waves are found to emerge. Moreover, the representation of the wave absorbers by a simple, partially reflecting surface does not adequately reproduce the measured spatial variation in the reflection coefficient.

1. Introduction

1.1. The Edinburgh curved tank

The Edinburgh curved wave tank [1], which is shown in Fig. 1, was commissioned in 2003 to allow the physical simulation of multi-directional random wave conditions. It utilises an array of force-feedback wave boards (see, for example, Spinneken et al. [2]) to generate waves in a frequency range of 0.5Hz to 1.6Hz and with a directional spread of approximately 60°.

Fig. 2 shows a plan view of the tank. There are a total of 48 wave-making paddles arranged along an arc of radius 9 m that subtends an angle of 96°, with a work platform above the paddles. The paddles are dry back and have a rolling gusset seal. Facing the wavemaker is a bank of wedge-shaped passive absorbers ("beaches"). A wide and deep glass viewing panel, at 90° to the absorber array, completes the tank. The water depth is 1.2 m, and the hinge depth of the paddles is 0.5 m.

Whilst the curved tank is to date unique in featuring a (near) quarter-circular arc of wavemaker segments, there are fully circular wave tanks in existence, namely the Deep Sea Basin at the National Maritime Research Institute in Tokyo [3], the AMOEBA tank in Osaka [4], and FloWave TT [5], a combined current and wave test basin currently under construction at Edinburgh. Table 1 contrasts the main features of these tanks.

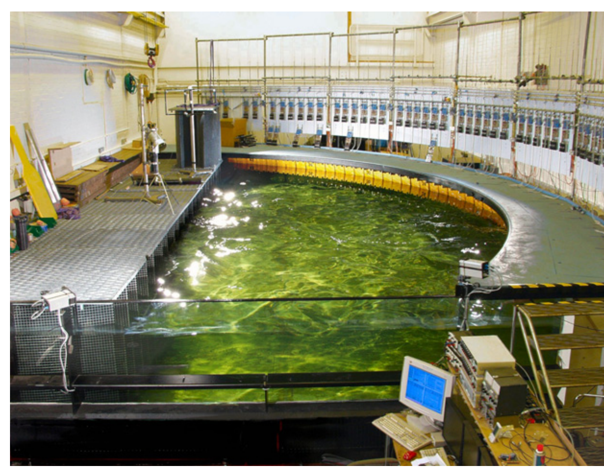

Fig. 1. The Edinburgh curved tank.

Indeed, Naito [6], following a comprehensive review of wave generation and absorption theory, suggests a circular (or elliptical) array of absorbing wave boards as an ideal configuration for a wave tank. The statement is backed up by experimental measurements in the compact AMOEBA tank indicating very similar wave excitation forces to those obtained in much larger wave tanks.

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Table 1
Characteristics of the curved tank and circular tanks.

Tank	Curved tank	FloWave TT	NMRI	AMOEBA
Geometry	Curved	Circular	Circular	Circular
Radius	9 m	12.5 m	7 m	0.8 m
Actuator	48 force-feedback, dry back paddles	168 force-feedback, dry back paddles	128 position-feedback, wet back paddles	50 force-feedback plungers
Depth	1.2 m	2 m	5 m	0.25 m
Maximum wave height	0.12 m	0.7 m (planned)	0.5 m	0.02 m
Frequency range	0.5–1.6 Hz	0.3–1 Hz (planned)	0.25–2 Hz	1.6–3 Hz

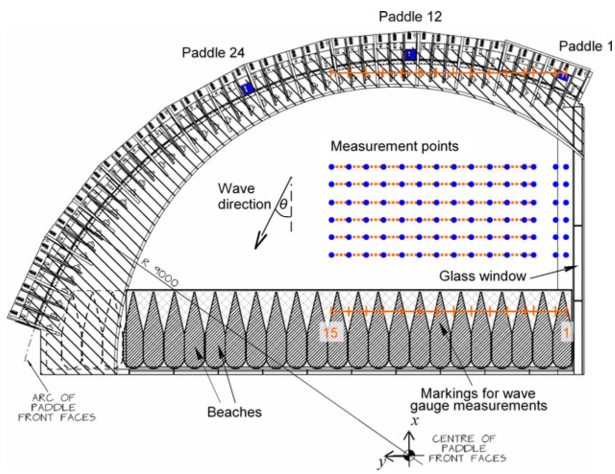

Fig. 2. Plan view of the curved tank.

1.2. *The operation of the tank*

At the simplest level, the generation of waves in the curved tank can be considered as a generalisation of the "snake" approach which has been used in multidirectional waves for decades and is widely discussed in the literature (for example, Jeffrey et al. [7] and Linfoot et al. [8]). In principle, the wavemaker can be considered as an arc of finite-width sources. Sinusoidal signals are sent to the individual wavemaker segments, through an appropriate control system, with phase and amplitudes adjusted to generate unidirectional waves with preset periods, directions and amplitudes.

An important distinction between using force control rather than position control of the wavemaker, as emphasised by Spinneken et al. [2], is that in force control the generated wave field directly feeds back into the wave generation process. One of the consequences is that the wavemaker "senses" and tends to compensate for some of the spurious free waves at harmonics of the desired wave frequency. Furthermore, by incorporating the wave board velocity into the force feedback loop, effective wave absorption can be obtained, without requiring wave gauges in front of the paddle to measure the incident waves [9].

Once it is assumed that control algorithms are available to generate travelling waves with defined heights, periods and directions, then, in principle, it is possible to combine signals to the wavemaker linearly to create physical simulations of random seas, the frequency and directional statistics of which can be defined according to any available parametric spectra (see, for example, Ochi [10]), such as the Pierson-Moskowitz, JoNSWAP, ITTC or ISSC.

In the curved tank, the required wavemaker demand signals are computed by taking the inverse discrete Fourier Transform of the desired spectrum, and applying a pseudo-random generator to imitate the stochastic nature of the sea [11]. The resulting physically simulated random sea states in the curved tank are repeating complex-periodic processes, which do not require window functions to be applied in the analysis of recorded wave elevations. This has a significant advantage when it comes to measuring wave spectra for validation purposes, as it allows for more accurate spectral estimates [12].

1.3. *Modelling 3D wave tanks*

Whilst snake theory gives a useful approximation of the wave field generated by a segmented wavemaker, it does not account for the geometry of the tank or the exact characteristics of the wavemaker segments. To obtain accurate predictions of the wave field corresponding to a given wavemaker motion, enabling different tank layouts or wavemaker designs (and control schemes) to be assessed, one has to consider more sophisticated models.

One of the first studies looking at the limitations of snake theory was Sand [13], which investigated the spurious waves that can arise due to the finite width of wave board segments. This was followed by further advances in modelling directional waves in a rectangular tank. Takayama [14] considers each wavemaking segment as a "finite-width" (piston or flap-type) source in an infinitely long wall. The first-order wave field from each wave board (given in closed-form) is then superimposed to obtain the overall wave field, which is found to be in reasonably good agreement with experimental results.

Dalrymple et al. [15] give the first-order solution for finite length and infinitely long wavemakers (both comprised of infinitely narrow segments), as well as point wavemakers. Two scenarios are considered: the wavemaker is either placed in a wall or free standing in the tank. Dalrymple [16] analyses the more practical situation of a closed rectangular tank, with a sloping bottom. A directional wave generation procedure is presented that exploits sidewall reflections to produce uniform planar waves at specified locations within the tank.

An alternative, numerical model is detailed in Isaacson et al. [17] for the wave field in a closed tank with a segmented wavemaker. The method uses linear diffraction theory and a point source representation of the wavemaker and the tank walls, and is experimentally validated in the case of a rectangular tank in Hiraishi et al. [18]. An extension of the technique for partially reflecting boundaries is given in Isaacson [19].

There has also been significant interest in extending wave generation models to second (and higher) order, with a view to derive wavemaker control signals that better reproduce the second-order effects in naturally occurring wave fields, and in particular suppress the generation of second-order spurious waves [20]. Li et al. [21] derive the second-order solution for regular waves generated by a wavemaker at one end of a semi-infinite rectangular basin with reflecting side-walls. A complete second-order wavemaker theory for multidirectional waves (including the second-order control signal) is presented in Schaffer et al. [22], assuming an infinitely long wavemaker. Ducrozet et al. [23] discuss the development and validation of a rectangular, numerical wave tank based on a higher-order spectral method. The numerical tank is seen to provide an accurate prediction