Proceedings of the 6th International Conference on the Application of Physical Modelling in Coastal and Port Engineering and Science (Coastlab16)

Ottawa, Canada, May 10-13, 2016

PHYSICAL MODELLING AND NON-HYDROSTATIC NUMERICAL MODELLING OF WAVE PROPAGATION IN A WAVE BASIN

R.Y. MARMOUSH[1], R.P. MULLIGAN[2]

1 Department of Civil Engineering, Queen's University, Canada, 13rym@queensu.ca

2 Department of Civil Engineering, Queen's University, Canada, mulligar@queensu.ca

ABSTRACT

Surface wave propagation in a large wave basin is simulated using a physical model and a numerical model. In the physical experiments unidirectional irregular waves are generated by a wave paddle, and wave properties are observed using a Nortek Aquadopp HR profiler at several stations. The SWASH model, a non-hydrostatic wave-flow numerical model, is used to simulate the waves. The model is validated by comparing the results of water surface elevation spectra with experimental measurements, indicating acceptable prediction of wave propagation in the wave basin. The aim of the study is to implement a physical model with modifications to the wave paddle such that is produces a more natural wave field with directional spreading. The numerical model is applied to investigate this by implementing directionally spread wave boundary conditions to guide planning of future experiments. The model results indicate a reduction of wave height due to energy spreading and wave reflection from the basin boundaries that need to be dissipated.

KEWORDS: wave basin, SWASH, wave pressure, surface spectra, directional spreading.

1 INTRODUCTION

Numerical and physical models are both useful tools for simulating surface waves and helping to understand wave propagation and transformation processes. The SWASH model (Zijlema et al., 2011) is a non-hydrostatic phase-resolving model. This relatively new type of wave model has already shown good capability in resolving wave transformations under certain conditions. Zijlema et al. (2011) validated the model with experimental measurements by Haller et al. (2002), where the measurements were collected in a multi-directional wave basin and regular waves over a submerged bar. Smit et al. (2013) validated the model with laboratory observations in a two dimensional wave basin by Dingemans et al. (1986), with a submerged breakwater extending across half the basin and directional irregular waves. In the present study, results from the SWASH model are compared with measurements from laboratory experiments in a wave basin with unidirectional irregular waves and constant water depth.

2 PHYSICAL MODEL

2.1 Wave basin

The laboratory experiments are conducted in the wave basin at Queen's University Coastal Engineering Research Laboratory. The basin is 26.0 m long and 20.5 m wide (Figure 1) with a smooth flat concrete bottom. It is presently surrounded with 0.80 m vertical walls and this height limits experimental conditions to approximately 0.60 m water depth and 0.15 m wave height. The basin is presently configured with vertical walls, however sand bags and a sand slope are located in a region opposite to the wave paddle and concrete blocks are stacked along the side wall adjacent to the paddle. These materials will be used in future experiments to dissipate wave energy and attenuate reflection from the boundaries.

The basin is equipped with a 10.5 m long, piston-type unidirectional wave generator with a 0.70 m high paddle located 4.0 m from the wall. The wave paddle is controlled by a computer station located on an elevated concrete platform in the corner. The Generalized Experiment Control and Data Acquisition Package (GEDAP) software is used to control the paddle and generate a random wave signal with a specified spectrum (Funke and Mansard, 1984). In the present study, the experiments have a water depth of 0.61 m and waves have a Jonswap spectral shape with a significant wave height (H_s) of

0.09 m and a peak wave period (T_p) of 1.68 s.

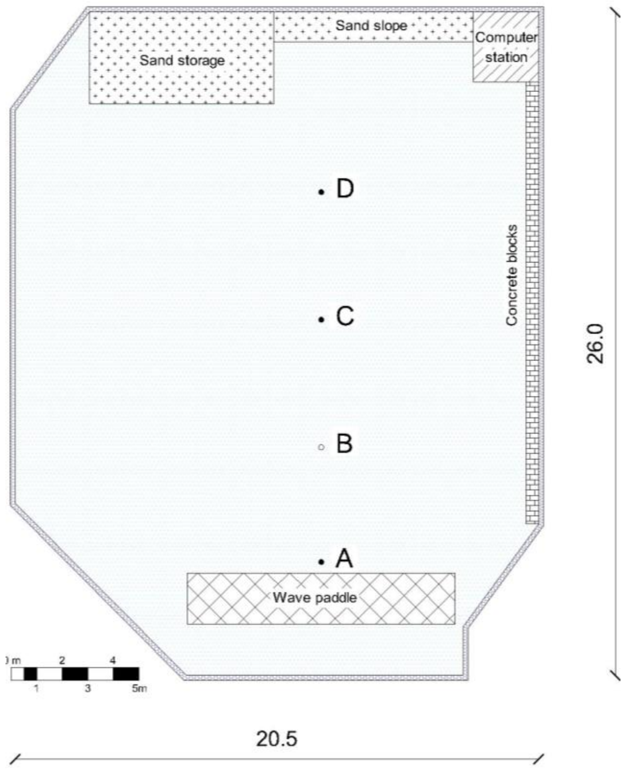

Figure 1. Configuration of the wave basin with locations of the wave paddle and measurement sites A-D.

2.2 Wave observations

The experimental measurements are collected using a Nortek Aquadopp HR profiler. This is a pulse coherent sensor where acoustic pulses are transmitted and the phase difference (Doppler shift) is used to estimate the current velocity. The Aquadopp HR profiler is equipped with a pressure sensor to measure the pressure fluctuations induced by wave orbital motion at the instrument elevation. In this paper we focus on the wave-induced pressure measurements that were collected at sites A, B, C and D where A is immediately in front of the paddle and the other locations are spaced 5.0 m apart (Figure 1). The pressure measurements were collected at sampling rate of 8 Hz for a duration of 240 s, and an example time-series of these data are shown in Figure 2a at site C near to the wave basin centre.

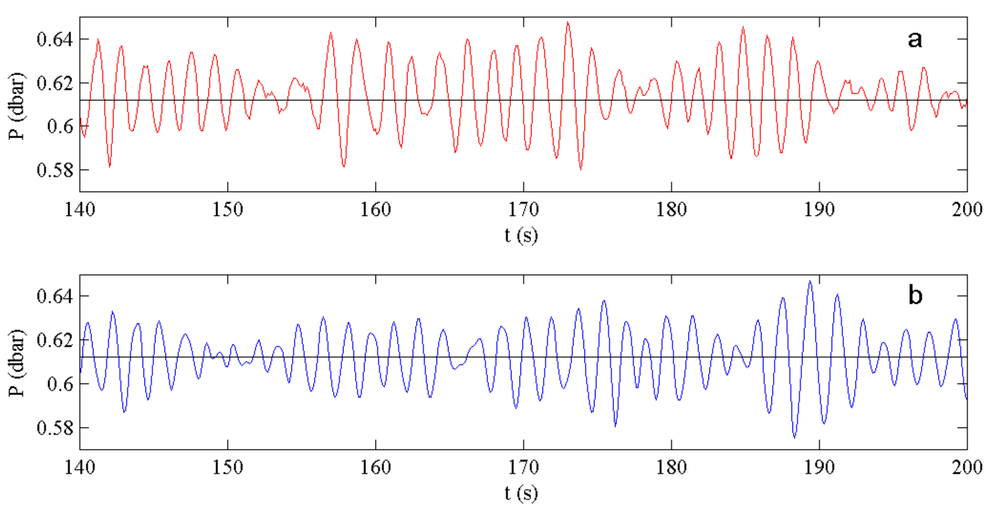

Figure 2. Selected time series of near-bottom pressure from: a) laboratory observations; and b) model results at site C.

3 NUMERICAL MODEL

The SWASH (Simulating WAves till SHore) numerical model (Zijlema et al, 2011) is used to predict transformation of surface waves and rapidly varied shallow water flows in coastal waters. The model solves the shallow water horizontal momentum equations including non-hydrostatic pressure, and the vertical momentum equation. The benefit of a non-hydrostatic model is to reduce the vertical grid resolution required to resolve wave breaking by solving the hydrostatic pressure distribution at wave front (Smit et al, 2013). To numerically simulate the experimental domain, the wave basin geometry is implemented in the SWASH model with high spatial resolution. A computational grid with a horizontal resolution of 0.10 m by 0.05 m in x- and y-directions respectively is used to ensure a sufficient number of grid points per wave length and one vertical layer is used in the present simulations. A wave generating boundary condition is defined at the wave paddle as a weakly reflective boundary with a constant Jonswap wave spectrum with the same bulk wave properties (H_s and T_p) as in the physical experiments. To provide dissipative boundaries, the side walls that have a sand slope and concrete blocks in the physical model are represented by absorbing sponge layers in the numerical model. A time step of 0.01 s is used to ensure the Courant number is within recommended range, and the model is run for a duration of 330 s to account for both the model spin-up time (100 s) and one cycle of the wave paddle time-series (230 s). Time-dependent model results for water surface elevations at the basin and near-bed pressure are output at sites B, C, and D, and time-averaged results for wave statistics are output at the end of the simulation. An example of the near-bottom pressure prediction time series is shown in Figure 2b.

4 MODEL VALIDATION

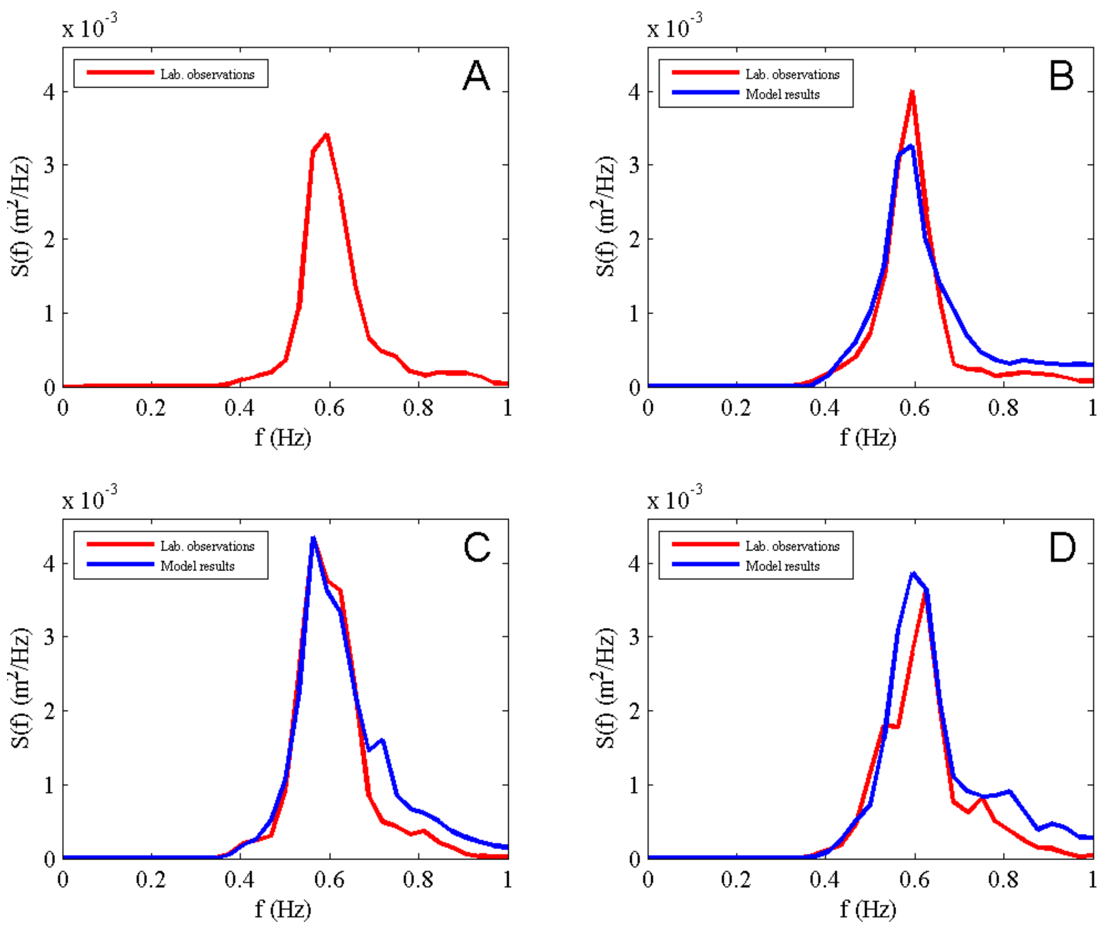

Figure 3. Water surface elevation spectra for laboratory observations (red) and model results (blue) at sites A, B, C and D, with observed and predicted H_s of: 0.09 m and 0.1 m (at B); 0.10 m and 0.11 m (at C); and 0.09 m and 0.11 m (at D).

Pressure spectra are calculated from time series of pressure measurements by applying a Fast Fourier Transform (FFT) at sites A-D. Using the dispersion relation from linear wave theory, pressure spectra are transferred to water surface elevation spectra as a function of frequency. The FFT was applied directly to model results of water surface elevation time series to calculate surface wave spectra. Measured and predicted wave spectra are shown in Figure 3 and in general the spectra indicate a small increase of wave energy and thus wave height from A to C due to boundary reflections while a slight decrease from C to D, in result of less reflection by the absorbing side walls. The model peak frequency and spectral distribution of wave energy are well estimated at sites B, C and D compared to measurements and the model prediction of spectral density is slightly less than observed at site B, the same as observed at site C and slightly higher at site D with small differences in the significant wave height (H_s). Overall, the SWASH model shows good agreement with observations in simulating wave propagation in the wave basin.

5 EFFECT OF WAVE DIRECTIONAL SPREADING

Surface waves in nature typically have an energy density spectrum with some degree of directional spreading (Long, 1996) and the present study aims to implement a physical model in the wave basin to simulate a natural wave field. This requires that the wave paddle be modified to produce a directionally spread wave field. Prior to implementation in the physical model, we apply the SWASH model to numerically examine the influence of changes to the wave generating boundary conditions.

The model results for instantaneous water surface elevations (η) and the significant wave height (H_s) are shown in Figure 4 for the base case corresponding to the present configuration and unidirectional wave boundary condition in the wave basin. The results indicate concentrated energy in the region irradiated by the wave paddle along the length of the basin. The results also indicate wave reflection from the side boundary where waves enter this region due to diffraction particularly adjacent to the paddle. The sand storage region causes reflecting waves into the basin that increase the energy in this area.

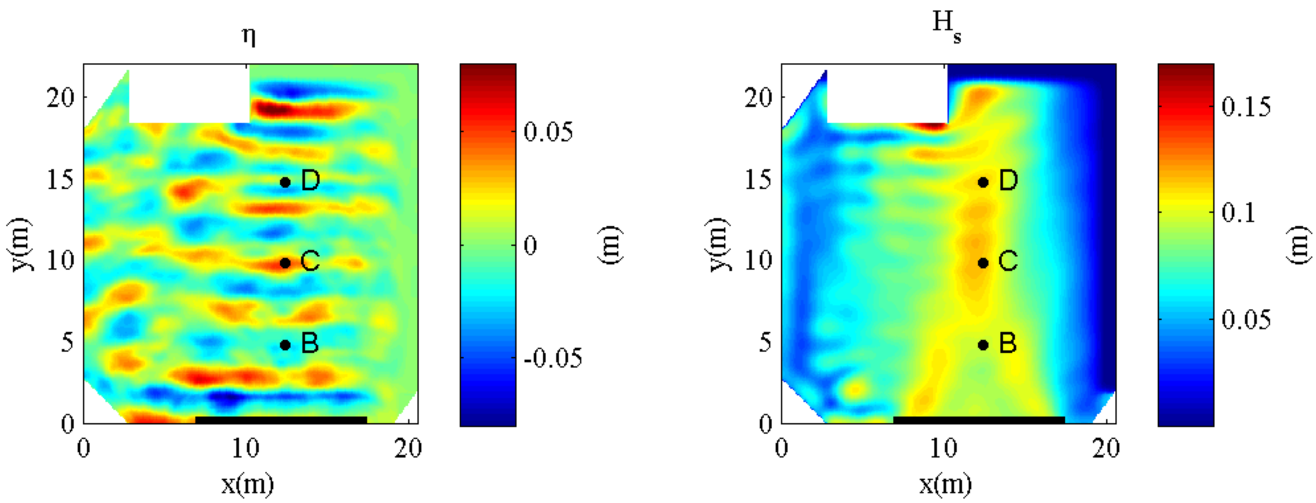

Figure 4. Model results for the base case with unidirectional waves and sand storage at y = 18-22 m: instantaneous water surface elevation η at time t = 330 s (left); and significant wave height H_s over the duration of the model run (right) where the bold line indicates paddle location at y = 0.0 m and B, C and D denote the observation sites.

Figure 5 shows the model results corresponding to changing the wave-generating boundary condition by increasing the directional spreading from 0^o to 20°. In comparison with the results of the base case, the results show reduction in wave energy along the wave paddle direction as waves are more widely distributed in the basin domain by spreading. Also, wave reflection from the side boundary still occurs as in the base case due to both spreading and diffraction. Wave reflection from and diffraction around the sand storage area are weaker compared with base case because of lower incident wave energy. When wave spreading angle is increased to 40° as shown in Figure 6, wave energy is even more distributed within the basin. The water surface elevation spectra for the simulations with different directional spreading are shown in Figure 7 at site C. As the directional spreading at the paddle increases, the spectral density and therefor significant wave height decrease.

The long-term goal of this research is to develop a set of experiments with wave breaking over a sloping sandy beach that generate an alongshore current with natural conditions that includes directional spreading of the wave field. The wave paddle will be modified to include directional spreading, and undesired reflections from the boundaries will be absorbed using a sloped sandy beach at the shoreline boundary and sloping gravel piles to reduce wave reflection at the sides. The numerical model results to date are therefore very useful in guiding the planning of upcoming physical model experiments.

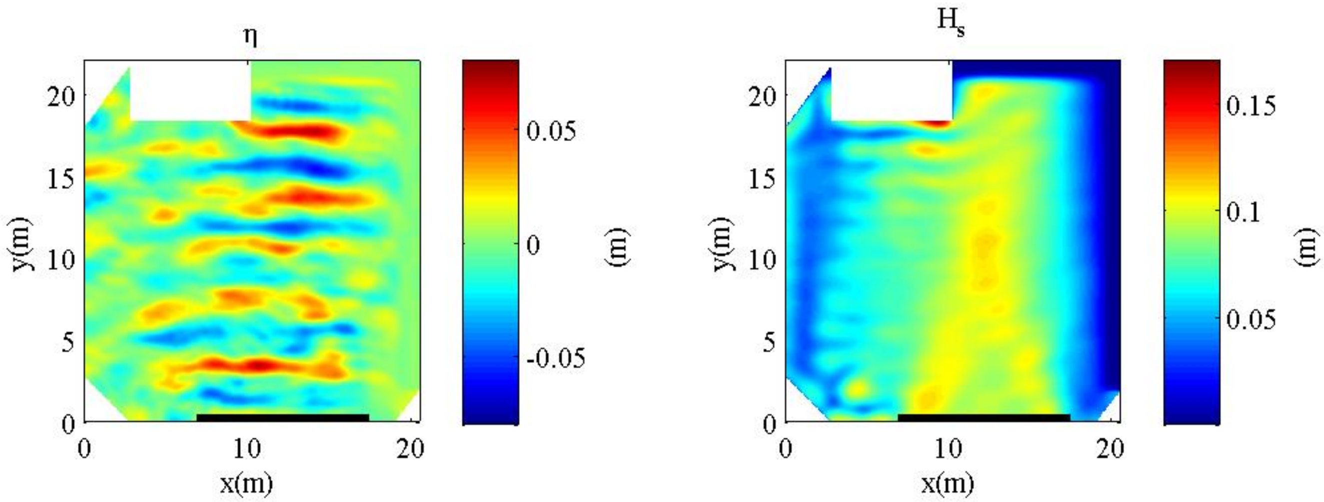

Figure 5. Model results for the case with directional wave spreading of 20^o and the wave paddle at y = 0.0 m: η at time t = 330s (left); and H_s over the duration of the model run (right).

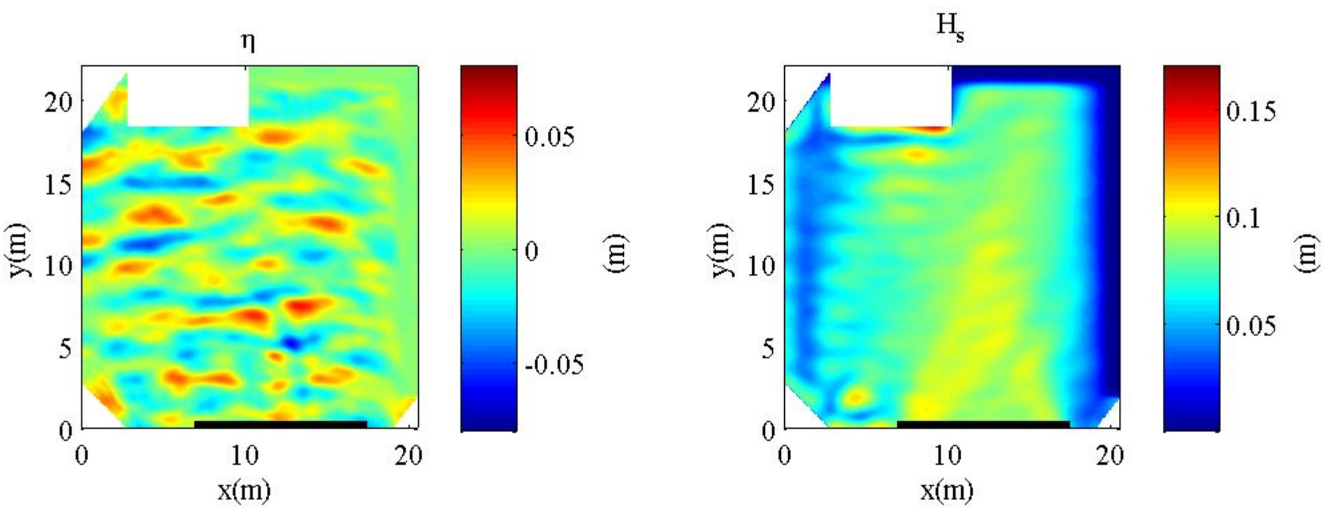

Figure 6. Model results for the case with directional wave spreading of 40^o and the wave paddle at y = 0.0 m: η at time t = 330s (left); and H_s over the duration of the model run (right).

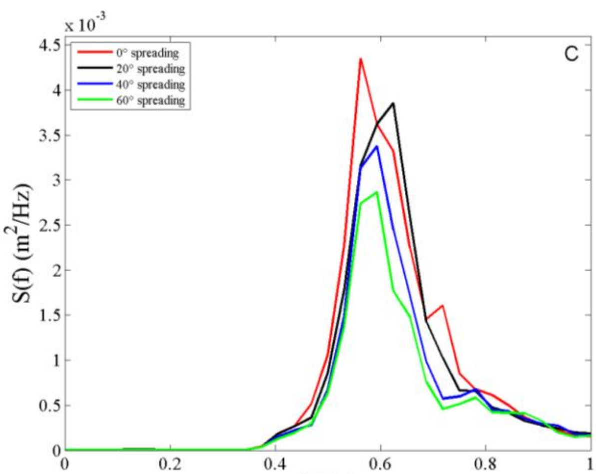

Figure 7. Simulated water surface elevation spectra at site C for different directional spreading, resulting in H_s of: 0.11 (0^o spreading), 0.11 (20^o spreading), 0.10 (40^o spreading) and 0.09 (60^o spreading).

6 CONCLUSIONS

Observations in a wave basin and numerical simulations with the SWASH non-hydrostatic model are used to investigate propagation and reflection of surface gravity waves. Comparison of water surface elevation spectra based on near-bed wave pressure shows reasonable agreement between measurements and model results, indicating that the numerical model is capable of predicting surface wave propagation and transformation in the wave basin. The model is further applied to investigate changes to the wave generating conditions by adding directional spreading to guide planning for future experiments. The directionally spread wave field indicates the need to attenuate wave reflection to achieve a natural wave energy distribution.

ACKNOWLEDGEMENT

This research is funded by a Natural Sciences and Engineering Research Council of Canada Discovery Grant and a Canada Foundation for Innovation Leaders Opportunity Fund award to the second author.

REFERENCES

Dingemans M.W., M.J.F. Stive, J. Bosma, H.J. Vriend-de and J.A. Vogel, 1986. Directional nearshore wave propagation and induced currents. *Proc. 20th Int. Conf. Coastal Eng. ASCE*, Taipei, Taiwan, 1092–1106.

Funke E.R. and E.P.D. Mansard, 1984. Random Wave Generation Package. *Tech. Rep., NRCC* 23571, 78 pp.

Haller, M.C., Dalrymple, R.A., Svendsen, I.A., 2002. Experimental study of nearshore dynamics on a barred beach with rip channels. *J. Geophys. Res.*, 107 (C6).

Long C.E., 1996. Index and bulk parameters for frequency-direction spectra measured at CERC Field Research Facility, June 1994 to August 1995. Misc. Pap. CERC-96-6, U.S. Army Eng. Waterways. Exp. Stn., Vicksburg, MS.

Smit P., M. Zijlema and G. Stelling, 2013. Depth-induced wave breaking in a non-hydrostatic, near-shore wave model. *Coastal Engineering*, 76, 1–16.

Zijlema M., G. Stelling and P. Smit, 2011. SWASH: An operational public domain code for simulating wave fields and rapidly varied flows in coastal waters, *Coastal Engineering*, 58, 992–1012.