EFFICIENTLY FORECASTING 2-DIMENSIONAL SPECTRA INSIDE SHELTERED PORTS USING SPECTRAL AND PHASE-RESOLVING WAVE MODELS

Jacob Suhr, SeaportOPX, jsuh@dhigroup.com
Prema Shree Bhautoo, SeaportOPX, prb@dhigroup.com
Jarrod Harkin, SeaportOPX, jhar@dhigroup.com
Timothy James Womersley, SeaportOPX, tjw@dhigroup.com

SWELL WAVES IN SHELTERED PORTS

Ports today are grappling with the impacts of increasing ship sizes and increasingly frequent and more extreme weather events. Under these conditions, being able to predict navigation, handling, and mooring risks accurately, is becoming more crucial to safe and efficient port operations. This is especially important in ports subject to complex wave transformations.

Traditionally, in order to capture the various wave transformation processes accurately from offshore to nearshore areas, the coupling of a Spectral wave (SW) and Boussinesq wave (BW) model has been required. Unfortunately, the very high computational costs of BW modelling have inhibited running such models in forecast mode.

In response to this highly technical challenge, DHI have developed a transformative method for concatenating outputs from SW and BW models, enabling modelers to forecast 2D Spectra accurately, both inside and outside a sheltered port basin in a computationally efficient manner. The methodology utilises the SW results outside the port where these are still accurate, and switches to BW results in the entrance channel and inside the port where diffraction and reflections are of paramount importance. The output for our use is a continuous line of 2D Spectra along the entire vessel track, starting offshore, all the way to the berth pocket. The track may also include other points of interest. This concatenated set of 2D Spectra can then be used by NCOS Online Safe Transit to predict vessel motions, Under-Keel Clearance and ship handling performance for any ship calling the port with a much higher accuracy, *Harkin (2018), Kazerooni (2022).*

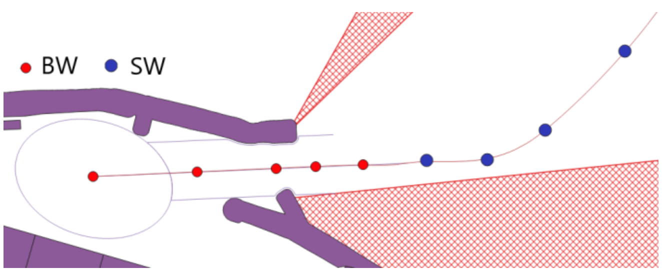

Figure 1 – Example of combination along entrance channel of BW and SW 2D Spectra for a deep water port, where SW is used offshore in deep water and BW is used inside the port. The red hatched area shows the port's no-go zones, and the line represents the track used by vessels during transits.

METHODOLOGY

The method consists of three steps. The first step is to set up and calibrate a SW and BW model of the port.

The Spectral Wave model should cover all areas of wave generation that could have effect at the port, as even smaller wave components generated far away can be included in the model. Three SW models were used for this purpose; a global model giving wave generation across the entire globe; a regional model with a much finer resolution covering the regional wave generation and transformation; and finally, a local model covering the nearshore area of the port, which is used to model the transformation of the waves much more accurately in the nearshore area. For each finer model, the boundaries are forced using the larger, coarser model.

These SW models are run in forecast mode with a forecast period of up to 7 days ahead of time, depending on the wind fields used to force the models.

The BW model or another phase resolving wave model is set up covering the nearshore area and the port area. This models the transformation, diffraction, and refraction of the waves as they move from the offshore area into the nearshore area and into the port. The model also includes reflections off port structures, etc.

The phase-resolving model is run for a large matrix of offshore wave conditions from the SW model's results. Along the entrance channel and at any points of interest inside the port, the 2D wave spectra from both the SW and BW models are saved.

DECOMPOSING OFFSHORE SPECTRA

Step 2 takes a representative point on the boundary of the BW model. Here, the 2D Spectrum from the forecast SW model is extracted and the spectrum at this point is decomposed using a 'watershedding' algorithm, *Couprie (2005)*.

This algorithm identifies each individual wave component, both in terms of offshore wave direction and period, which makes up the complete spectra. This step identifies any bimodal or multimodal sea states so that these can accurately be accounted for in the concatenated spectra.

For each of the identified components/peaks in the offshore 2D spectra, the spectral parameters of the wave component are calculated. These include Significant Wave height, Hs. Peak wave period, Tp. Mean Wave Direction, MWD, and Directional Standard Deviation, DSD.

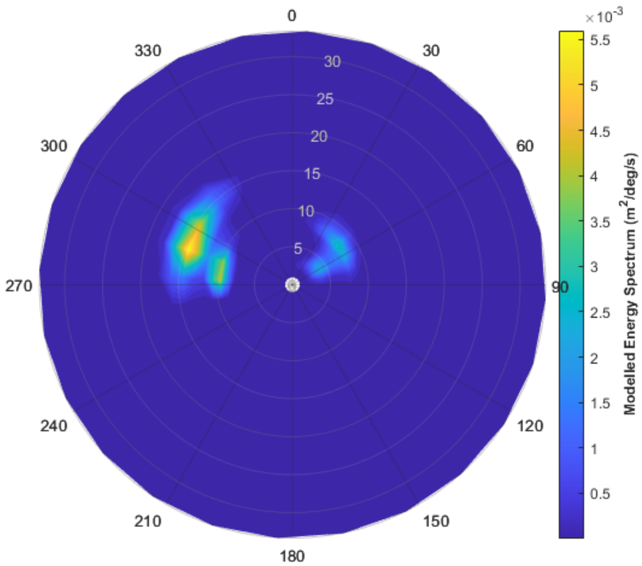

Figure 2 - Offshore 2D SW Spectrum showing a complex sea state with four (4) distinct peaks. The method concatenates SW & BW results for each individual peak. The radial axis shows the wave period. Note that the frequency axis is logarithmic, so lower periods have a much finer discretisation.

Table 1 shows the major spectral wave parameters for the four wave components identified by the watershedding algorithm for the SW modelled 2D Spectra shown in Figure 2. The spectral parameters for the entire 2D Spectra are also shown.

Table 1 - Calculated spectral parameters for the entire 2D Spectra example shown in Figure 2, and each of the four wave components identified by the watershedding algorithm.

Wave Component	Hs [m]	Tp [sec]	MWD [deg]	DSD [deg]
Entire Spectra	0.70	14.46	40	23.8
Component 1	0.51	4.13	50	14.7
Component 2	0.30	7.73	49	12.9
Component 3	0.24	14.46	291	12.4
Component 4	0.22	9.52	291	9.1

The results in Table 1 for each of the four wave components compared to the spectral parameters for the entire spectra clearly shows why it could be important to split the wave into different components. If only using the spectral parameters for the entire wave spectra, this would be assumed to be a wave with a significant wave height of 0.7m, with a peak period of 14.5sec, coming from a mean wave direction of 40degrees. Re-generating a 2D Spectra from these values would be significantly different than the actual spectra and would not accurately capture any energy at 290degrees, as well as having too much energy at higher periods, as this is the frequency band with the highest peak of energy. But most of the wave energy is sitting at lower wave periods/higher frequencies in the spectra. Using only a single wave component would in many cases be okay, but in some locations, and even only during some periods of the year, the assumption of a single modal sea state can lead to large inaccuracies if used for engineering analyses. It can be both extremely conservative or non-conservative, depending on the exact sea state and usage case.

CONCATENATION METHOD

For each wave component/peak in the offshore spectra, the equivalent BW model is found in the run matrix, and the 2D Spectra from all the found BW models are scaled and combined into one 2D Spectra at each point of interest. This assumes linear superposition between the different wave components during the combination Therefore, nonlinear interaction between the different swell components is not included in this concatenation methodology. This could have a large effect for higher period wave components, especially long period waves, so this methodology would have to be further validated and extended to handle these transformations.

A combination of 2D Spectra have now been found at various locations along the channel. Offshore, the SW results are used, and inshore and inside the port, the combined BW 2D Spectra are used. This methodology accurately includes effects from diffraction, refraction, and reflections inside the sheltered port basin in a computationally efficient way for forecasting purposes.
The above methodology has been operationalised and the above concatenations and calculations are done every half an hour during the 7-day forecast to create a temporal variation in the wave conditions over the next 7 days on top of the spatial variation.

RESULTS

Figure 3 shows the results in a single timestep along a vessel track from outside the breakwater and offshore, all the way to the most western part of the port, when using the BW concatenation method compared to the results from using only an SW model for the timestep of the Offshore 2D Spectra shown on *Figure 2*.

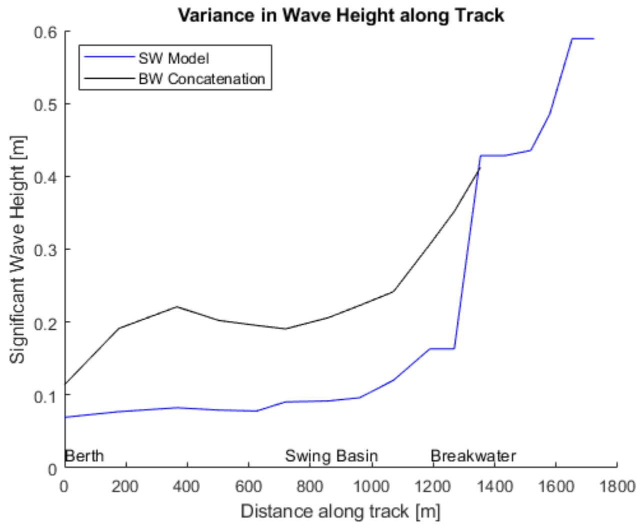

Figure 3 – Variance in the significant wave height along the entrance channel of the port. Showing significant wave height from the SW model and from the BW concatenation method. Results are for the offshore spectra shown in *Figure 1*.

Because of the reduced diffraction and reflections in the SW model, there is very little energy in the port once you are past the breakwater. This can be seen as a steep drop off in the significant wave heights in the SW model results. The BW concatenation method captures the diffraction and reflection of the waves inside the port entrance and basin, all the way to the berth. The BW concatenation has up to a factor of three times as high significant wave heights in this single timestep. This amplification can be even larger in even more sheltered areas such as behind the eastern breakwater seen on *Figure 1*.

It can also be larger for other combinations of wave components and wave directions.

CONCLUSION

A new method for combining the speed of Spectral Wave modelling with the accuracy of Bousinessq wave modelling has been developed specifically for ports. The method also includes the effect of multimodal sea states, which is shown to be quite important when these sea states occur.

This transformative method now makes it realistic to create highly accurate, 7-day dynamic forecasts of waves in ports subject to highly complex wave transformations. The implications for better risk management and consequently safer and more efficient operations are significant.

The method is used operationally together with SeaportOPX's safe transit system NCOS Online to screen for Under-Keel Clearance and manoeuvring issues in ports up to 7 days ahead.

REFERENCES

heltered

Michel Couprie, Laurent Najman, Gilles Bertrand (2005), Quasi-linear algorithms for the topological watershed, Journal of Mathematical Imaging and Vision, Springer, 22 (2-3), pp. 231-249.

Alex Harkin, Jacob Suhr, Marcus Tree, William Hibberd, Simon Mortensen (2018). Validation of a 3D Underkeel clearance model with full scale measurements. PIANC World Congress. Panama City.

Reza Fathi Kazerooni, Alex Harkin, Tim Womersley, Bugge Jesen (2022). Dynamic Assessment of safety in manouvering through constricted navigational channels using an online operational system. Australasian Coasts & Ports 2021 Conference, Christchurch.