NUMERICAL MODELLING OF WAVE DISTURBANCE IN A HARBOUR IN THE PRESENCE OF A FLOATING BREAKWATER

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Floating Breakwaters (FB or Floating Wave Attenuator) find application in coastal areas characterized by limited wave height and short period, such as lakes, sheltered bays, or within ports. Nowadays, it is possible to construct precast reinforced concrete structures of significant size and displacement, which, when connected in series and/or in parallel, form a robust, and durable floating barrier. These structures generally have high costs, and their use should therefore be carefully evaluated in relation to their benefits (mainly environmental).

Figure 1. Example of a large floating breakwater unit installed at Port of La Spezia (photo courtesy of INGEMAR).

FB are typically tested in wave flumes or basins in hydraulic laboratories. The purpose of these tests is to assess wave transmission and reflection, and to provide an indication of the loads transferred by the FB to the anchoring system. Test results are usually presented by the manufacturer as tables or graphs.

Assessing wave disturbance inside a port or marina is one of the fundamental steps that designers undertake when defining the port layout. For this purpose, commercial numerical models are generally applied; physical model tests in 3D basins are rare, as they usually require time and costs that are not compatible with design activities.

Is it then possible to effectively incorporate the performance of an FB in a numerical model?

The mathematical modelling of an FB is highly complex. Its attenuation capabilities depend not only on the characteristics of the waves (wave height, period) and on geometry (water depth, FB width and draft), but also on the dynamics of the floating body and on the constraints (chains, piles) which restrain its movements.

Although not many, a few currently available calculation tools allow including the presence of an FB. Among these, the finite element model CGWAVE (Panchang and Xu, 1995), based on the elliptic mild-slope wave equation, implements the simulation of an FB via a simplified approach (based on the work of Tsay and Liu, 1983).

On the other hand, the computational power of a current generation PC allows faster testing over extensive computational domains, even in the presence of very short waves (with periods of 2-3 s). All this considered, the use of such computational tool is advantageous even if based on a simplified approach.

The simplified approach by Tsay and Liu (TL approach) is known as the "rigid lid" approximation. The energy transport under the FB is a function of local depth (h), wave number ($k = 2\pi/L$), characteristic width ($2a = W$), and draft (d) of the FB; and of the clearance under the structure d_1 (under-keel depth), see scheme of Figure 2.

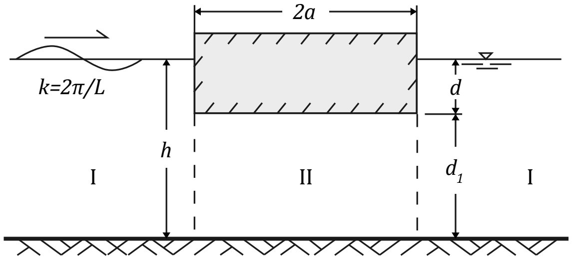

Figure 2. Scheme of a rectangular floating breakwater.

Li et al. (2005) developed a modified approach, TL$_{mod}$, (implemented within the CGWAVE model) which considers an adjusted under-keel depth $d_1' = \alpha d_1$ where $\alpha = A \ln(ka) + B$, is the corrective factor, and A and B are coefficients provided for different values of the relative draft (d/h) as a function of kh.

This study presents the results of the application of the CGWAVE model to assess the performances of a high-displacement FB in the context of the ongoing design activities for the expansion of a yacht harbour in Italy. An FB ($2a = 8\,m, d = 1.7\,m, d/h = 0.21$) is envisaged to protect the marina from locally generated seas over a fetch of approx. 5-6 km (period $T = 2 - 4\,s$) that can directly penetrate into the outer harbour basin.

The preliminary tests conducted with CGWAVE, using the TL$_{mod}$ approach implemented in the model, showed an overestimated attenuation by the FB, with values of the transmission coefficient Kt much lower than those provided by the manufacturer after laboratory tests. It was observed that for short waves $T \to 0$ (compared to the water depth and the dimensions of the FB), the TL$_{mod}$ approach imposes a high attenuation of the wave ($\alpha \to 0$).

In the initial phase of the study, numerical simulations were therefore conducted with the CGWAVE model to reproduce the hydraulic model tests carried out in the Maritime Laboratory of the University of Padua on the FB with a width of $2a = 8.0\,m$ and a draft of $d = 1.7\,m$ in depths of 10 m (Figure 3).

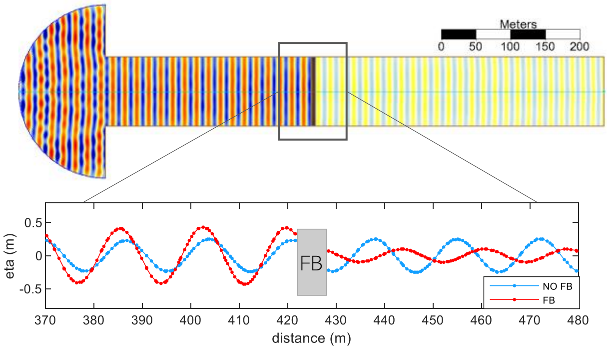

Figure 3. CGWAVE calibration run ($H = 0.5\ m, T = 3.0\ s$). Red line shows the sea surface elevation obtained with an FB ($2a = 8.0\ m, d = 1.7\ m$). Blue line without the FB.

Following a "trial & error" procedure, numerous simulations were conducted by manually varying the factor α until the same values of the transmission coefficient Kt measured in the laboratory were obtained (Figure 4).

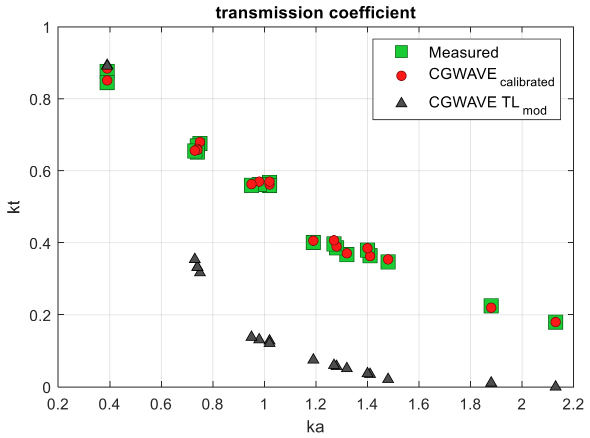

Figure 4. Measured transmission coefficient Kt for the design FB ($2a = 8.0\ m, d = 1.7\ m$) versus calculated Kt from CGWAVE simulations (black triangles: default α from TL$_{mod}$ approach, red circles: calibrated α factor).

The values of the correction factor α obtained after calibration are shown in Figure 5. It is observed that for ka greater than 0.5, the value obtained for the corrective factor α is significantly higher than that provided by the TL$_{mod}$ approach and it follows an almost exponential trend as ka $(= W\pi/L)$ changes.

For waves with longer period ($T > 7.0\ s, ka < 0.5, kh < 1$), the wave transmission underneath the FB becomes predominant, with experimental Kt values ranging from 0.8 to 0.9. In these conditions, a value of about 0.55 is obtained for the corrective factor α, in line with that provided by the uncalibrated TL$_{mod}$ approach. Also, the reflection performances of numerical and physical models have been investigated.

Using the results of this calibration, a numerical model was setup in CGWAVE to evaluate the wave disturbance within the marina in the presence of the FB (see example test in Figure 6). To allow the correct reproduction of very short waves, the computational domain was divided into triangular elements with sides of 2 m.

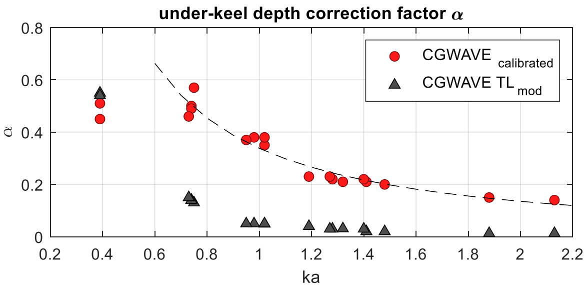

Figure 5. Calibrated under-keel depth correction factor α values versus default values from TL$_{mod}$ approach.

To fully evaluate the wave agitation in the harbour, various scenarios will be considered, differing in geometric characteristics and FB position.

Both short-period sea states (2-3 s), locally generated, and long-period sea states (8-9 s), coming from the prevailing wave sector, will be examined. The linearity of the model will allow for the consideration of the frequency and direction distribution of wave energy by operating through the superposition of multiple monochromatic components. The results in terms of performance of the various FB configurations will guide towards the final choice for the port layout.

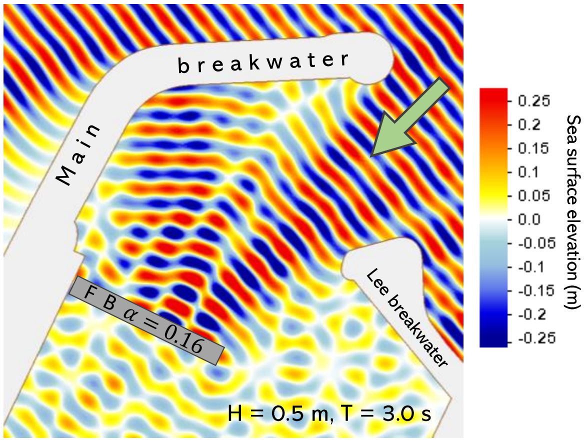

Figure 6. Sea surface elevation obtained with a CGWAVE simulation for a short sea state ($H = 0.5\ m, T = 3.0\ s$) with an FB 80 m long ($2a = 8.0\ m,\ d = 1.7\ m,\ \alpha = 0.11$).

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