PHYSICAL MODELLING FOR THE PRINCESS ELISABETH ISLAND, OVERTOPPING DESIGN FOR A CAISSON WITH A DOUBLE WAVE WALL GEOMETRY

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ABSTRACT

For the design of the world's first offshore energy island, consisting of vertical caisson breakwaters with a double row of wave walls to prevent the land area from severe wave overtopping, intense physical modelling has been carried out in 2D wave flumes and a large 3D wave basin. Some lessons learned throughout the detailed design will be presented, with a focus on wave overtopping. Rockwork stability and wave impact forces also have been measured but are not the focus of this abstract.

INTRODUCTION

About 40 km offshore of Ostend, the Belgian part of the North Sea will become home to the world's first offshore energy island: the Princess Elisabeth Island. The island, 520 m long and 230 m wide, is an energy hub where array cables from Belgium's 2nd offshore wind zone and future interconnectors with neighboring countries such as the United Kingdom and Denmark will arrive. Up to 3.5 gigawatt (GW) of wind energy will be connected on the island.

The island consists of 23 caissons, each 58 m long and 28 m wide and 25 m high. The detailed design is carried in 2023. The caissons will then be built onshore, after which they are towed out and installed in two summer seasons, 2024 and 2025. The island will be reclaimed, and its top surface will be finished in 2026. Offshore cables will be connected to the island in the years after. More info can be found in Van Doorslaer et al. (2024).

BOUNDARY CONDITIONS

There is a strong tidal current along the Belgian part of the North Sea directed from SW to NE (flood) and vice versa (ebb) with highest depth averaged yearly velocity of about 1.4 m/s. The island is aligned with the dominant current direction, to minimize the morphological influence on the seabed. Nevertheless, scour holes at the corners will develop, and are taken into account in the rock works design.

The dominant wind and wave directions, with design waves up to 8 m significant wave height, are N and WSW. The eastside of the island is more sheltered, offering a quay wall and small harbour for Crew Transfer Vessels (CTV).

The wave spectrum is a JONSWAP spectrum with peak enhancement factor 1.3, and Sea Level Rise (SLR) is taken into account for an island lifetime of 100 years.

The island must be designed for storms up to 10,000 year return period (joint probability) for structural design and rock stability, and 1,000 year return period for overtopping. The limiting criteria are average overtopping discharge $q < 1$ l/m/s and individual overtopping volume $V_{max} < 1$ m³/m (mean value of 10 repetitions).

2D TEST CAMPAIGNS

Two different test campaigns have been carried out in the 2D wave flume of Ghent University (30m x 1m x 1.20m), one in the tender phase with a flat bathymetry and one during the detailed design phase with a scour hole in front of the caissons. The Froude scale was 1:48. The first study aimed at designing the optimal wave wall configuration for each island side: height, interdistance, bullnose. Only average overtopping discharges have been measured, assuming a logic relation between q and Vmax. The main lesson learned from this campaign was that a concept with even wave walls (Figure 1) works better than a high primary wave wall and a low secondary wave wall, which is beneficial for the floating stability of the caissons too. Bullnoses work well, but only to a certain wave height beyond which they are flooded and don't contribute anymore.

The second campaign included a scour hole in front of the structure. The depth and geometry of the scour hole in reality evolve over time. Different geometries of the scour hole and their impact on the wave conditions at the toe of the structure have thereby been studied in SWASH after which a representative scour hole was built in the wave flume. Test conditions in detailed design had slightly changed, however it was mainly the fact that Vmax was now measured too that led to some changes in wave wall geometry. Individual overtopping volumes are very stochastic, and for a geometry with a double wall and bullnoses even more. Results weren't even always logical, showing the complexity of designing for a Vmax criterion. Most island sides now have a compliant design for 2D wave overtopping, for some a reduction for oblique waves is required to avoid overly increase wave wall heights. It is noted that the highest waves from the relevant directions have been tested fully perpendicular and no reduction for obliqueness was taken into account in 2D. It is assumed that the results are thereby conservative.

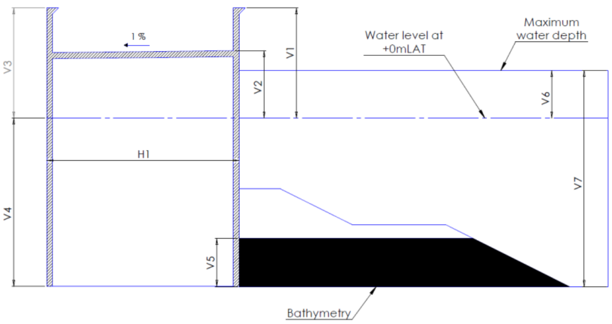

Figure 1. Double wave wall geometry in 2D tests (UGent)

3D TEST CAMPAIGN
In 3D, a 1.5km by 2.5km representative North Sea bathymetry was built in DHI's shallow water basin at scale 1:60, including sand dunes and the representative scour holes derived from the numerical morphological model. Those scour holes have been simplified to a fully symmetrical shape for being able to rotate the model since the wave makers are located at two sides of the wave basin and it was required to verify design for all four island sides.
The (very large) model has dimensions 8.6m by 3.8m (Figure 2), one of the biggest models ever built at DHI for measuring simultaneously overtopping, rock stability and forces under the combination of extreme waves and currents.


Figure 2 – Model and bathymetry constructed in 3D (DHI)

The campaign was split in two large parts: the NW section and after rotation of the island the SE section. Wave conditions from the relevant sectors have been considered, and the maximum values have been tested however this time from their dominant direction which is oblique to the island.
On the NW section, also a sensitivity campaign was carried out to investigate the differences between perpendicular waves, oblique waves, long-crested waves and short-crested waves (all combinations tested) with and without currents.
Results are being processed at the moment and will be presented at the ICCE 2024 conference in Rome. The first findings are already given below.

- the reduction on q and Vmax due to obliqueness was confirmed.
- Short-crested 3D waves result in clearly less wave focusing compared to long-crested 2D waves, consequently giving lower overtopping, forces and rock movement.
- For some sectors, current has a stronger influence on the wave overtopping than expected.
- Stem waves occurred when testing oblique long-crested 2D waves, which were propagating along the vertical caissons. A standing wave formed that could run over the primary wave wall. The concept of equal wave wall heights proved effective, as most of this overtopped water over the first wall was blocked by the secondary wave wall.

More elaborate results and a comparison to EurOtop (2018) will be given on ICCE 2024.

REFERENCES
EurOtop, (2018): Manual on wave overtopping of sea defences and related structures. An overtopping manual largely based on European research, but for worldwide application.
Van Doorslaer et al. (2024). Princess elisabeth island, the world's first offshore energy island. Accepted abstract for PIANC World Conference, Cape Town, 2024.