Flow in and on the Zeebrugge Breakwater

a comparison of prototype measurement, physical model tests and numerical computations

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- a comparison of prototype measurements, physical model tests, and numerical computations.

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1 Introduction

As part of the Mast programme (MAS02-CT92-0023) the outer breakwater in Zeebrugge, Belgium has been subjected to extensive investigations. Along with prototype measurements, large-scale model tests (1:20) have been carried out at Flanders Hydraulics, Borgerhout covering a wide range of wave conditions and corresponding tests in scale (1:30) and (1:65) have been conducted at the University College Cork and Aalborg University, respectively. Furthermore, as part of the MAST programme a numerical model has been developed at Aalborg University capable of computing the flow in front of, on and inside a breakwater structure.

The Zeebrugge breakwater and the monitoring system enables prototype measurements consisting of wave recordings and pore pressures inside the breakwater, etc. The main objective is to render a comparison of results obtained by model tests, numerical modelling and prototype measurements, respectively.

Aiming at a more thorough description of the flow on and inside breakwater structures is well-founded as it leads to possible determination of responses such as forces on and stability of the structural elements of the breakwater, run-up, and overtopping.

Prototype measurements, physical model tests, and numerical modelling have associated limitations due to the complex physics involved. An inter-comparison of results is therefore deemed to give an impression of their reliability, as well as founding a basis for evaluating scale effects and determining how to approach the scaling of the materials used in the models.

The different approaches for determining the hydraulic response of the Zeebrugge breakwater enables comparison of several entities. Wave transformation, run-up and run-down levels and up-rush and down-rush velocities are compared in relation to the flow in front of and on the breakwater. Inside the structure excess pore pressures, intrinsic surface elevations, damping and transmission are dealt with.

2 Physical lay-out

The Zeebrugge breakwater constitutes a conventional rubble-mound breakwater with a low superstructure and an armour layer consisting of Antifer Cubes. The breakwater is backfilled with seasand. Figure 1 shows the cross-section of the breakwater as well as the location of 12 pressure sensors. Besides pressures, incoming waves and run-up are measured.

Scaling of the model is mainly done according to Froude scaling laws. In order to model the hydraulics inside the core of the breakwater more accurately the scaling of the material used in the core is distorted using the method of Le Mehauté [1] for the model tests at (1:30) scale. Model tests at (1:65) scale are carried out for three different scalings of the core material including simple Froude scaling.

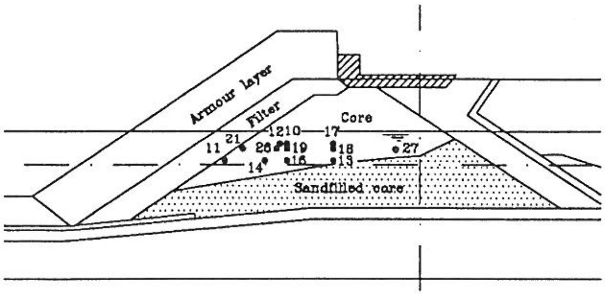

Figure 1 Cross-section of the Zeebrugge breakwater.

3 Pore pressure attenuation

Analysis of the attenuation of the pressure waves travelling through the rubble-mound has been carried out in different model scales and numerical calculations. Pressure gauges number 21, 26, 19, 18, and 27 were used for the analysis. It has been proposed that the pressure oscillations decrease exponentially according to [2]

$$p(x) = p(0)\ \exp(-\beta\ \frac{2\pi}{L'}\ x)$$

where

p(x) : pore pressure at x.
p(0) : pore pressure at $x = 0$,
i.e. at pressure sensor 21.
L' : wave length within the breakwater.
β : damping factor.

Figure 2 shows the outcome of analysing the results from prototype, model tests (1:20), (1:30), (1:65), and numerical computations.

As seen from the analysis the prototype entails the least damping of the pressure waves except for the model with distorted scaling of the core material (1:65).

The attenuation for physical models with adjusted scaling of the core material do not correspond to that of the prototype, which suggests that the methods used for calculation of the altered scales for the core material do not apply for a complex setup such as the Zeebrugge breakwater. Damping is most distinct in the

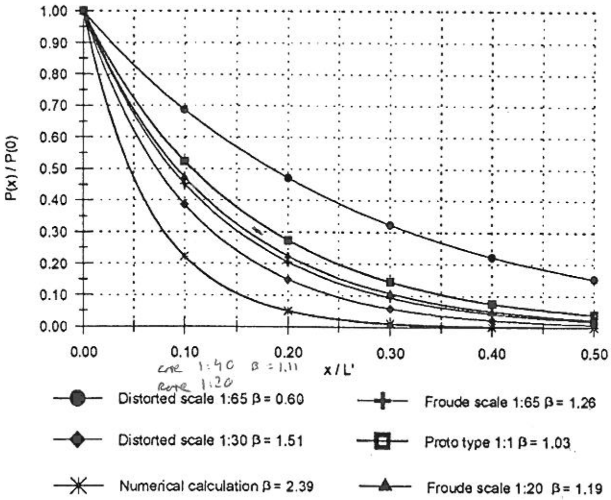

Figure 2 Pore pressure attenuation in the breakwater.

numerical model, where the hydraulic friction is based on the Forchheimer equation. The difference may be explained by lack of adequate knowledge about the hydraulic properties and porosities of the materials used in the breakwater.

4 Conclusion

In conclusion, it is found that physical phenomena in front of and on the breakwater shows exceedingly good agreement between prototype, physical model tests, and numerical modelling. Whilst agreement is still good for the determination of hydraulic responses within the breakwater, it is influenced by the complex physics involved and less reliable measuring techniques. On-going research and analysis of results from the models hopes to improve the understanding and quantification of the hydraulic processes inside porous breakwaters.

References

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