HYDRAULIC PERFORMANCE AND STABILITY OF COMBINED RECURVED WALLS

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MOTIVATION

Helgoland is a German offshore island in the North Sea with about 50 km distance to the coast. The main island is protected by dikes and revetments. Due to climate change-induced sea level rise and anticipated increasing wave loads, the existing coastal protection needs to be revised and adapted in the northeastern part of the island (Figure 1).

Figure 1 - Investigated northeastern dike section on the German island Helgoland (view looking east).

Many requirements besides the hydraulic performance and stability of the coastal protection system needed to be considered: nature conservation, land use, contaminated sites, tourism, visual landscape and existing buildings or infrastructure. The preliminary design of the cross-sectional layout included several elements: roughness elements (baffles), stepped revetments, recurved walls in two or three rows and a promenade as stilling wave basin (SWB) for drainage with a shore-based seawall. To date, the overall performance of complex coastal protection settings remain difficult to predict, given to the multitude of processes, and the two-phase flow of air-water mixture.

Due to the number and complexity of the individual elements, there is no existing data- or process-based design approach, which considers the effects of the combined elements on the wave overtopping rate and wave forces on the seawall. The obvious lack of knowledge is hence addressed in this work, using a combined experimental approach, using medium-scale 2D and 3D experimental tests.

Three main research questions had been co-designed with responsible stakeholders and taken into consideration: i) how can the existing dike be adapted without heightening of the dike >2 m above the actual crest height; ii) how can the wave impact on the vertical wall be reduced by practical means and iii) how can the wave overtopping volume be efficiently drained during the draw-down phase of the wave-structure-interaction?

METHOD - EXPERIMENTAL INVESTIGATIONS

The research questions were mainly addressed by means of hydraulic model tests. The experimental investigations were divided into three phases: I. 2D small scale experiments (1:70); II. 3D medium scale experiments (1:40) and IIIa. 2D large scale experiments (1:15) with IIIb. 3D basin experiments (1:13). Phase I aims at the selection of preferential designs of the stepped revetment, roughness elements and crown elements by qualitative findings. In phase II the eastern and northern part of the island's dike section were modeled in a 3D wave basin. The tests focused on wave refraction, shoaling, and breaking including 3D interactions with the coastal protection elements. Investigations in phase III were divided into a) 3D wave basin experiments of the eastern part and b) 2D wave flume experiments of the northern part as shown in Figure 2 with the experimental setup and instrumentation.

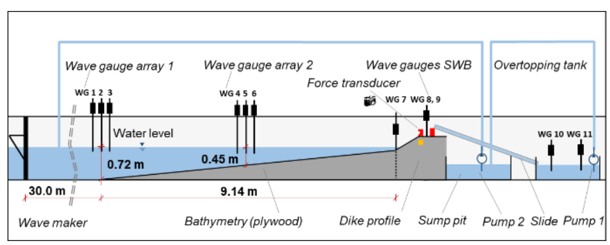

Figure 2 - Sketch of the model setup with instrumentation of the wave flume experiments of phase IIIb.

In a 90 m long and 1 m wide wave flume two wave gauges arrays with three gauges each were used in front of the dike and one single wave gauge at the dike toe. In addition, two gauges were installed in the SWB in order to measure the water level and another two gauges in the overtopping tank to determine the wave overtopping rate. In addition, the experiments were observed by video camera with a front and top view of the dike.

Focus of the large-scale tests was set on verification of the mean overtopping discharges obtained in phase II and a quantification of wave loads on individual structure elements. Besides the mean wave overtopping discharge, forces and moments on the baffle and crown walls and flow velocities over the revetment were analyzed.

Local narrowing of the SWB width and drive-through openings in the crown walls were also investigated, and measures to achieve overtopping rates were developed.

RESULTS

The optimization of the structure's cross-section based on the wave overtopping reduction resulted in a design consisting of the following components: baffle wall rows on the dike slope, a curved crown wall and a subsequent SWB, given in Figure 3.

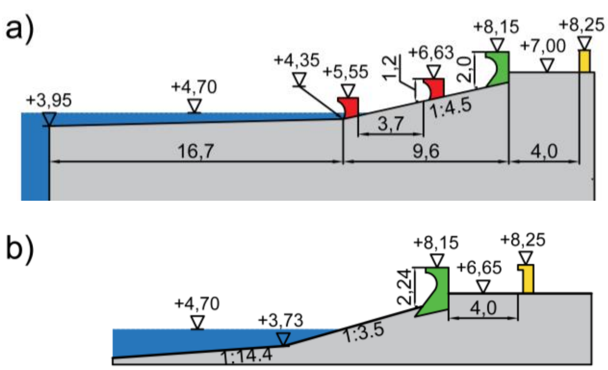

Figure 3 – Final design of a) phase IIIa for the eastern part and b) phase IIIb for the northern part (prototype scale).

The hydraulic function of the SWB between a first recurved and a second crown wall was tested in phase IIIb with three different setups for the northern dike section.

Figure 4 shows the setup A with a crown height of 7.60 m, boardwalk at 6.00 m and a SWB width of 3.00 m, setup B with a crown height of 8.25 m, boardwalk at 6.65 m and a SWB width of 3.00 m, and setup C with a crown height of 8.25 m, boardwalk at 6.65 m and a SWB width of 4.00 m. The height of the recurved wave return wall was in all cases 0.10 m below the height of the second crown wall.

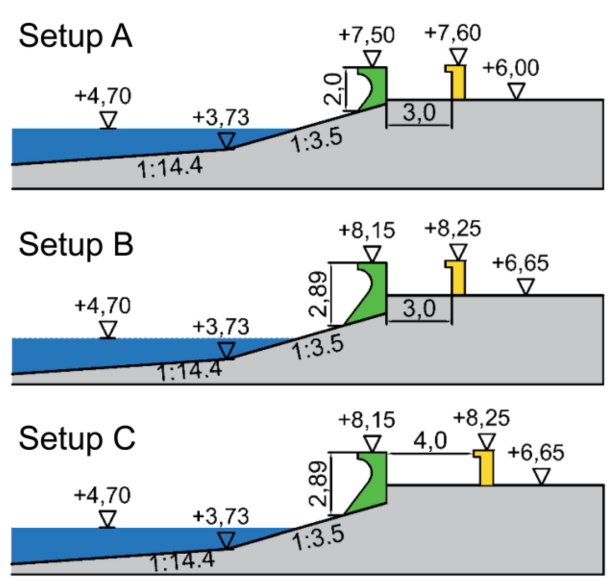

Figure 4 - Three different setups of the crown height and SWB width for the northern dike section of phase IIIb.

Figure 5 shows the wave overtopping rates for three different setups of the northern dike section. The mean wave overtopping rate could be reduced to 53.9 % in case of setup B compared to the setup A (100 %). The wider SWB of 4.0 m of setup C could reduce the mean wave overtopping rate to 29.8 % of setup A.

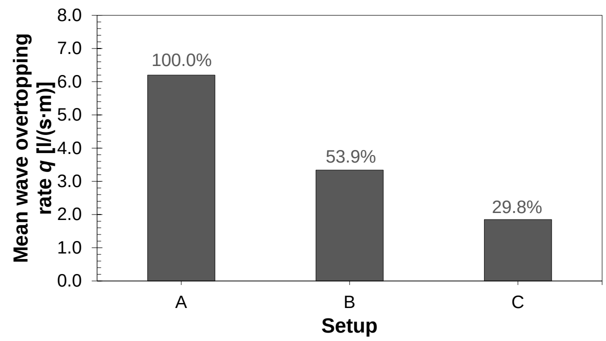

Figure 5 - Mean wave overtopping rates for setup A: crown height 7.60 m, SWB width 3.0 m; B: crown height 7.60 m, SWB width 3.0 m; C: crown height 8.25 m, SWB width 4.0 m

A selection of further findings from the study can be summarized as follows:

A seaward rounding of baffle and crest walls always led to a reduction of mean wave overtopping quantities.

The effectiveness increased the more pronounced the rounding was. As the clear distance between the baffles increases, the wave overtopping increases. A dimension of 2/3 of the baffle wall width was determined as an economic opening width.

A double-row baffle arrangement can approximately limit the mean wave overtopping and loads by 50% compared to a single-row arrangement. A SWB on the crown of the structure that can be used as a boardwalk is an effective way to further reduce mean wave overtopping rates. A higher crown height and a wider SWB reduces the wave overtopping rate. In any case, drainage of the SWB is important for the effectiveness of the wave overtopping reduction.

CONCLUSION

By means of experimental parameter studies of four different models, it was possible to develop a structure design that can turn future sea states while requiring a crown elevation of only 1.75 m. The wave overtopping rate could be significantly reduced due to the optimization of the design and the requirements of the admissible wave overtopping rate could be fulfilled due to the combination of baffle walls, crown walls and the drainage system of the promenade in the function of a stilling wave basin.

REFERENCES

Due to space limitations, references were not provided.