Wave Load and Wave Propagation over Forelands

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Abstract

Forelands are an important part of the coastal protection system at the German coast because they significantly reduce the wave load on the dike, i.e. on the main protection element. The effectiveness of forelands in wave damping was analysed using transmission coefficient for a site at the coast of Schleswick-Holstein, Germany, on the basis of field measurements, numerical modelling with SWAN and additional physical model tests in the large wave flume GWK of the University of Hannover, Germany. Besides of the influence the ratio of water depth and wave height the transmission coefficients strongly depend on the width of the foreland. With a width of more than 325 m the foreland provides maximum damping of the incoming wave field.

1 Introduction

The German coastal system comprises a series of protection elements, like tidal flats, forelands, summer dikes, polders and dikes. Besides the major defence element, i.e. the dike, forelands are more and more regarded to be a valuable defence element. This can be attributed to the fact that due to the shallow water conditions over forelands wave breaking increases within a wide area in front of the dike and therefore the energy of waves breaking directly at the dike is significantly reduced. Figure 1 gives an example of a wave field propagating towards a dike with respectively without a foreland and reveals clearly the differences in wave energy and wave load at the dike [1]. The reduction of wave load at the dike, i.e. run-up, wave overtopping and pressure peaks, reduces the expenditure for construction and maintenance because massive revetments at the toe of the dike are not necessary. This has the positive side effect that the grass covered dike is ecologically favourable [2].

Figure 1: Wave field in front of a dike with (left) and without (right) a foreland.

The reduction of wave height over forelands has so far been analysed by direct field measurements and by physical [3] and numerical modelling [4]. Besides that indirect techniques like measurements of the debris line are used to study the effect of forelands on wave height and wave run-up [5]. Beside the reduction of wave heights over foreland also reduced wave periods can be found. For this reason the wave load on the dike, especially the run-up, is also significantly reduced.

In the following a quantitative description of the wave parameters over forelands is worked out on the basis of model test in the wave tank GWK of the University of Hannover, Germany, and numerical simulations with the model Shallow Waves Nearshore (SWAN) [6].

2 Results of physical and numerical model tests

The investigations within the GWK were carried out using a prototype scaled sandy foreland. The height of the foreland was 1.40 m above the tidal flat and the foreland was non-sloped. The model tests were carried out for water levels between 3.00 m and 4.50 m above the bottom of the wave tank, for significant wave heights between 0.60 m and 1.20 m and peak periods between 3.5 s and 8 s for the incoming wave field. The variation of waves along the foreland was measured with 26 wave gauges [7].

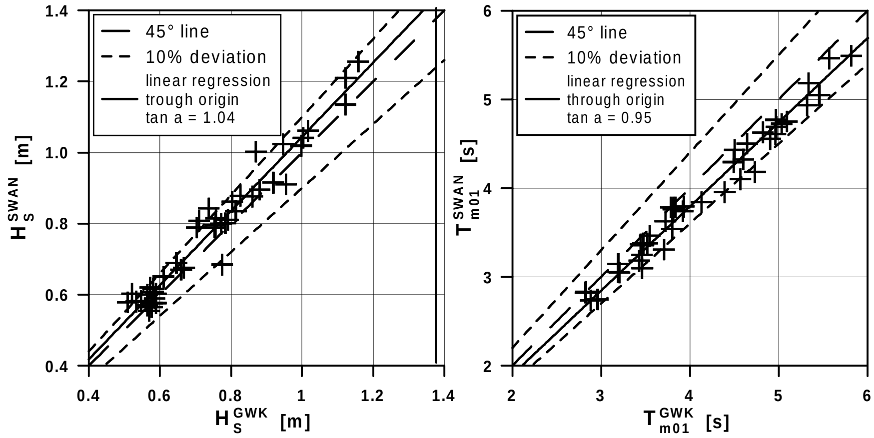

Figure 2: Comparison of physical and numerical modelling of wave propagation along a 125 m wide foreland – significant wave height (left) and mean wave period (right)

The physical models tests were complemented with numerical simulations in order to analyse the influence of different foreland geometries, like sloped forelands of different heights of waves of more than 1.20 m height. For the simulations a calibration of the numerical model was necessary. The most important processes to be calibrated are wave breaking, non-linear wave interaction (triad interaction) and bottom friction [1].

Figure 2 shows the comparison of the significant wave heights obtained by the physical resp. numerical model for waves along a 125m long foreland. The results represent waves for water levels of 2.50 to 3.00 m above the foreland and incoming waves with significant wave heights between 0.60 m and 1.20 m as well as peak periods between 3.5 s and 8 s. As shown in figure 2 good agreement between the physical and the numerical model was achieved for the wave heights as well as for the wave periods [7].

As described by Mai et al. [8], the effectiveness of forelands as coastal protection element can be determined introducing the transmission coefficients c_T and r_T. The transmission coefficient $c_T = H_{s,\ foreland} / H_{s,\ in}$ describes the relation between wave height above the foreland H_s, foreland and the incoming wave height $H_{s,\ in}$ at the seaward drop, while $r_T = T_{m,\ foreland} / T_{m,\ in}$ shows the relation of mean wave periods [4]. Figure 3 gives an example for the relation between the transmission coefficient c_T and the dimensionless parameter d/H_s, where d describes the water depth above the foreland.

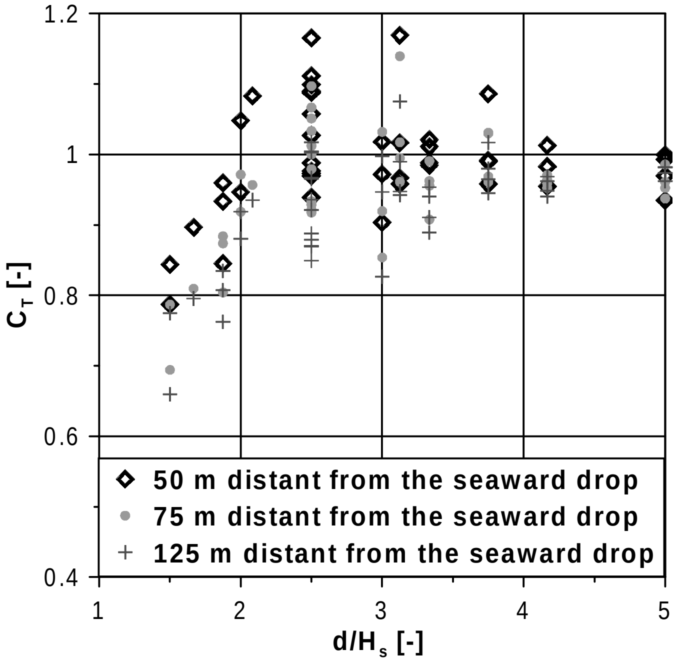

Figure 3: Transmission coefficient c_T as a function of relative water depth over the foreland at different distances from the seaward drop (derived from experiments in a wave tank)

3 Forelands as Elements for coastal protection

On the basis of the physical model tests and the numerical simulations with the model SWAN the effectiveness of real forelands can be tested and the foreland geometry can be improved with respect to an optimised allocation of investments.

In the following an example of investigation on the effectiveness of the foreland “Heringsand” at the coast of Dithmarschen in Schleswick-Holstein, Northern Germany, is shown. The wave field at the seaward drop of the foreland was obtained from a large wave model, whose results are implemented in the wave atlas of the Franzius-Institut for Hydraulic, Waterways and Coastal Engineering of the University of Hannover [9]. The model was calibrated with buoy measurements of waves in the Weser Estuary near the City of Bremerhaven [4] and in the “Hever” [7].

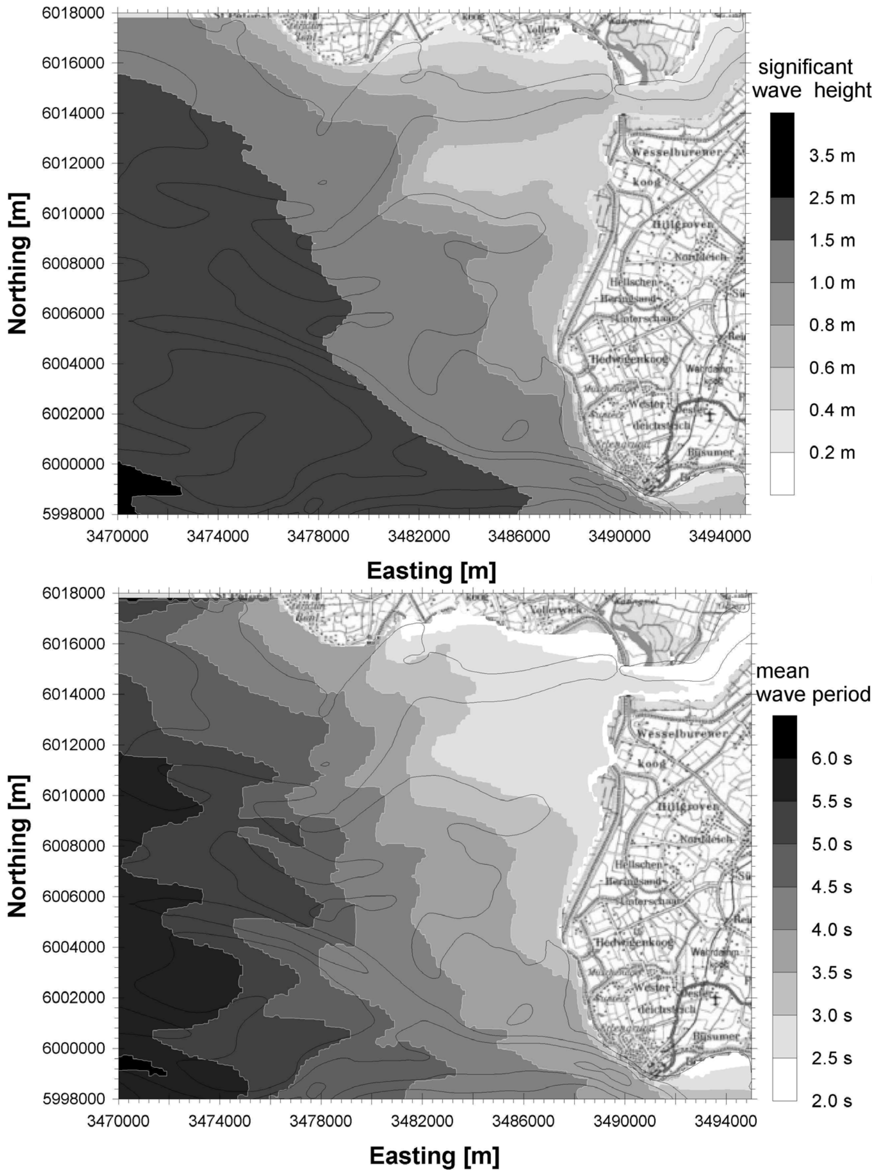

Figure 4: Wave parameter at the coast of Dithmarschen (Bight of Helgoland) – significant wave height (top) and mean wave period (bottom) (water level: 3.8 m a. MSL, wind: 20 m/s, 300°)

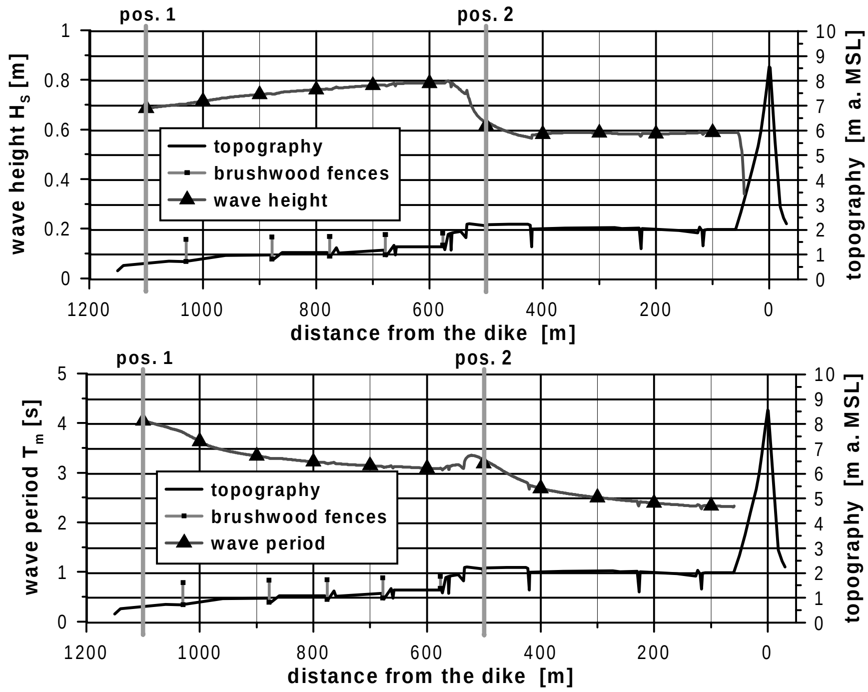

Figure 5: Wave parameter over a foreland at the coast of Dithmarschen – significant wave height (top) and mean wave period (bottom) (water level: 3.8 m a. MSL, wind: 20 m/s, 300°)

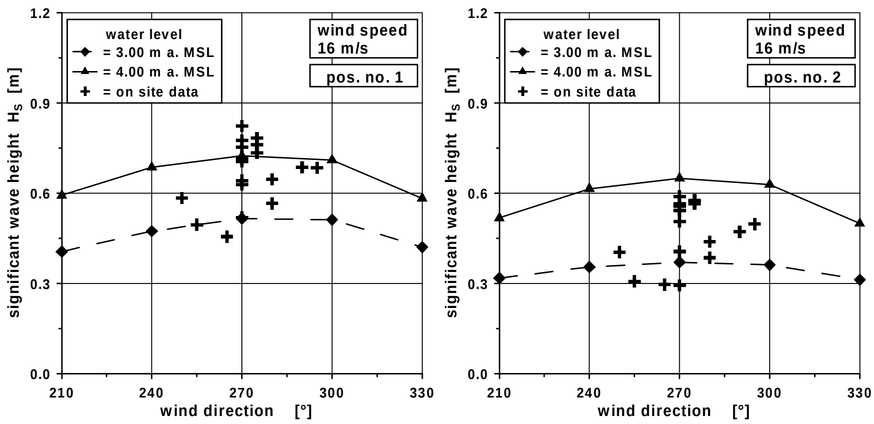

Figure 6: Significant wave height from measurements and SWAN-simulations at pos. no. 1 (left) and pos. no. 2 (right) (water level: 3 to 4 m a. MSL, wind: 16 m/s, 210° to 330°)

Figure 4 gives an example of the wave field close to the coast of Dithmarschen for a water level of 4 m above German datum, a wind direction of 240° and wind velocity of 20 m/s. At the seaward drop of "Heringsand" the significant wave height is approximately 0.70 m and the mean wave period is approximately 4 s. Using these wave data the wave characteristics along the foreland of Heringsand were calculated with a one-dimensional SWAN model. Figure 5 shows the wave propagation along the foreland. It can be seen that the significant wave height decreases and it is approximately 0.50 m at the toe of the dike, while the mean wave period decreases from 3.4 s at the seaward drop to is approximately 3.4 s at the toe of the dike. Using a formula for wave run-up at the main dike, as described by Murphy and Schüttrumpf [10], and neglecting the influence of bottom friction and wave angle (γ = 1) the wave run-up for the 1:7-sloped foreland can be calculated to 0.80 m. In comparison, the wave run-up would be 1.10 m for a dike without foreland.

$$R_{98\%} = 0.638 \cdot \gamma \cdot \frac{1}{n_D} \sqrt{g \cdot H_s} \cdot T_p \qquad (1)$$

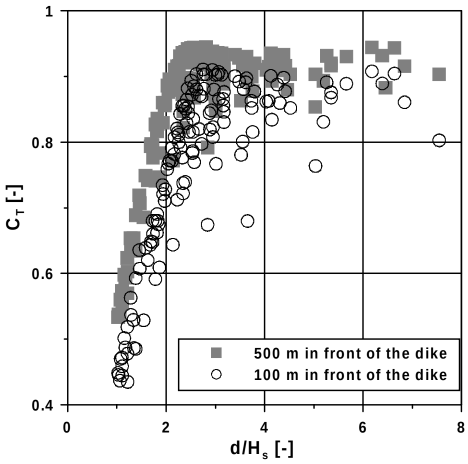

Figure 7: Transmission coefficient as a function of relative water depth at different locations in front of the dike (derived with SWAN)

Figure 6 gives an example of the relation between the waves along the foreland and the water level and the wind direction for two different positions indicated in figure 5 and a wind speed of 16 m/s. The results of the numerical simulations were related to field measurements of 1991 [11]. It is obvious, that the simulations are in good agreement with the results of the field measurements. Maximum wave heights occur for western wind directions (270°). The assessment of the foreland of Heringsand was carried out calculating the transmission coefficient c_T as for the physical model tests shown in figure 3.

According to figure 7 forelands reduce the significant wave height up to a relation of $d/H_s < 2,5$ as the numerical simulations as well as the physical model tests revealed.

For a relation of $d/H_s = 1$ the transmission coefficient is 0.45 to 0.50 depending on the distance from the seaward drop. But for distances larger than 325 m no further reduction of the transmission coefficient can be achieved [7].

4 Conclusion

Both physical and numerical modelling reveals the importance of forelands in coastal protection. This can be attributed to the increase in wave breaking in shallow waters. The efficiency quantified by transmission coefficients of wave height and wave period. The transmission coefficients decrease with an increase in the width of foreland. The optimal width is 325 m, wider forelands do not reduce wave load any further. The efficiency of forelands is restricted to a ratio of water depth and significant wave height of less than 2.5. Therefore they do not effect wave parameters at the time of maximum storm surge water levels. However the wave load on the dike time-integrated over the whole storm-surge period is significantly reduced.

References

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