

## **SENSITIVITY OF DUNE EROSION PREDICTION DURING EXTREME CONDITIONS**

DEN HEIJER C (Kees)<sup>1) 2)</sup>

1) Section of Hydraulic Engineering, Delft University of Technology  
P.O. Box 5048, 2600 GA, Delft, The Netherlands  
e-mail: C.denHeijer@TUDelft.nl

2) Deltares  
P.O. Box 177, 2600 MH, Delft, The Netherlands  
e-mail: Kees.denHeijer@Deltares.nl

### **Abstract**

Coastal dunes play an important role in protecting low-lying hinterland from flooding. In The Netherlands, dunes form the major part of the primary sea defence, that protects half of the population and over two-third of the economy from the sea. To design and maintain coastal dunes that properly protect the hinterland, a regular safety evaluation is performed every six years and measures are taken if the prescribed safety standard is not met. The empirical dune erosion model DUROS+ (Vellinga, 1986; van Gent et al., 2008) is the core of the currently used safety evaluation method for dunes. This model does only take the nearshore bathymetry explicitly into account. It is not clear beforehand whether the offshore bathymetry has a significant influence on the dune erosion rate under extreme storm conditions.

This paper aims at investigating the sensitivity of the dune erosion rate for different parts of the cross-shore profile. Three clearly distinct cross-shore profiles along the Dutch coast are used to estimate the erosion under extreme storm conditions, using XBEACH (Roelvink et al., 2009), and distinguish between the sensitivity to the lower (seaward) part and the upper (landward) part of the profile. The division between the two profile parts has been made at the MSL-4 m contour. The profiles used for this investigation are considered to cover the range of different profiles as present along the Dutch coast.

It can be concluded that the landward profile part is of main importance for an accurate dune erosion estimation. A different seaward profile part can influence the erosion, under extreme storm conditions, by about 10 %. On the other hand, a different landward profile part can lead to a few hundred percent difference in erosion.

Keywords: Dune erosion, XBEACH, bathymetry, sensitivity.

### **1. INTRODUCTION**

Coastal areas have always been attractive for people to live, because of the soil fertility and the easy accessibility of the ocean. In The Netherlands, half of the population and over two-third of the economy is in coastal areas below mean sea level. Along a large part of the Dutch coast, dunes act as a primary defence against flooding of the hinterland. To ensure the protection of the hinterland, one of the world's smallest failure probabilities ( $O(1e-5)$ ) are prescribed by law. These small probabilities correspond to extreme events which are not observed in history. Therefore, maintenance and design of

dunes that can withstand these extreme conditions should rely on dune erosion models, probabilistic methods and extrapolations.

To constrain the uncertainty of the probabilistic predictions, only the major governing variables for the dune erosion process should be part of the model while other minor variables that provide mainly noise should be left out. The selection of these major governing variables is highly dependent on the area of concern and on the used model. For a more or less uniform coast, where a relatively simple 1D approach is acceptable, a limited number of variables can be sufficient (e.g. pre-storm profile, surge level, wave height, wave period and grain size). In a more complex case, such as a strongly curved coastline, other variables can be of importance. The selection of the major governing variables should be based on the sensitivity, the non-linearity and the contribution to the uncertainty.

The safety assessment method for dunes in The Netherlands (ENW, 2007) includes an empirical dune erosion model DUROS+ (Vellinga, 1986; van Gent et al., 2008). This model estimates the shape of the post-storm cross-shore profile based on the significant wave height, the peak wave period and the fall velocity of the sediment in water. It relates the vertical position of the post-storm profile to the maximum storm surge level; the horizontal position is found by assuming cross-shore sediment conservation. This implies that the sediment volume that is eroded from the dune, is assumed to settle on the beach and foreshore (Figure 1). The model is based on several series of laboratory experiments at different scales, up to depth scale  $n_d=5$ . As a consequence, the model can only be validated for the cross-shore profiles as applied in the experiments. The model takes the bathymetry within the cross-shore region of bottom change explicitly into account by the sediment conservation assumption. Application along the Dutch coast leads in general to predicted bed changes no further than about the MSL-4 m contour, under extreme storm conditions. The influence of the remaining offshore part of the bathymetry, however, is implicitly based on the experiment series bathymetries. As a result, areas with an offshore bathymetry that significantly differs from those of the laboratory experiments cannot be modelled adequately.

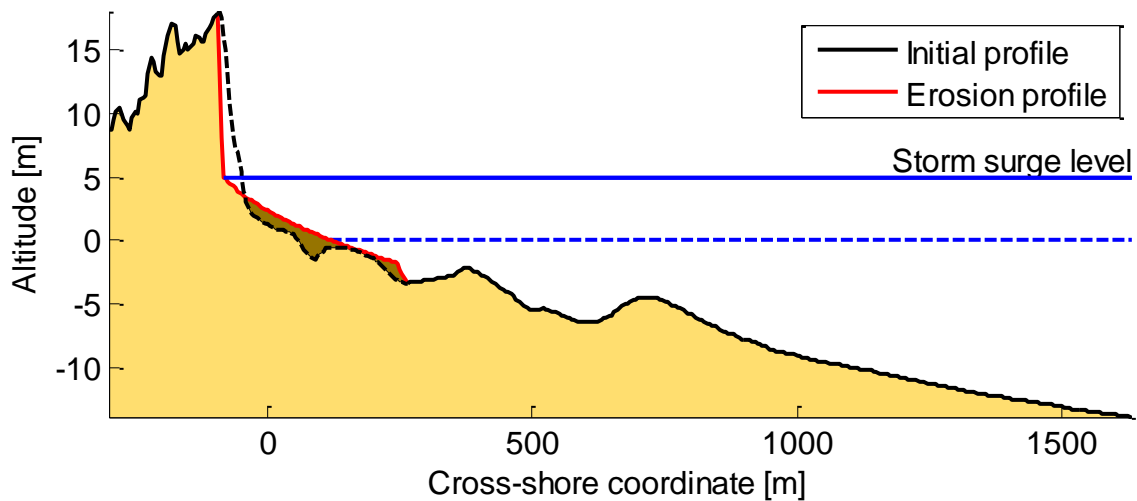


Figure 1: Illustration of erosion profile as estimated by DUROS+.

This paper aims at investigating the sensitivity of the dune erosion rate to the shape of different parts of the cross-shore profile. The XBEACH (Roelvink et al., 2009) is used to estimate the influence of the bathymetry on the dune erosion rate. Three cross-shore profiles selected along the Dutch coast, that are considered to cover the relevant range of bathymetries, serve as input data for this investigation.

## 2. METHODS

In this paper three cross-shore profiles (Figure 2) out of the yearly Dutch coastal bathymetry survey are used as basis to investigate the influence of the upper and lower profiles parts on dune erosion. The profiles are selected based on their foreshore slope; steep sloped (7003775), mild sloped

(4001740) and in between (7001503). The locations of the profiles are indicated on the map in Figure 3. The numbers are unique identifiers of the cross-shore profile locations, where the millions refer to the coastal area and remaining part of the number indicates the alongshore location within the particular area. A division has been made at the MSL-4 m contour between the upper (landward) part and the lower (seaward) part. This division is related to the maximum seaward extent of the erosion profile according to the DUROS+. The three divided profiles lead to a matrix of nine unique combinations of upper and lower parts of profiles, of which three are the original profiles and the remaining six are artificially combined.

For each of the nine profiles, the erosion rate has been estimated by XBEACH. The hydraulic boundary conditions as well as the grain size are kept equal for all simulations, in order to get a fair comparison. The simulations are performed with stationary extreme storm surge conditions with a duration of 5 hours. Experiments showed that that the dune response after 5 hours of stationary maximum storm surge conditions is approximately the same as an actual time series of varying conditions (Vellinga, 1986). The conditions as applied in the simulations are summarized in Table 1.

Table 1: *Representative storm surge conditions.*

variable	symbol	value	unit
water level	$WL$	MSL + 5	m
significant wave height	$H_s$	9	m
peak wave period	$T_p$	12	s
grain size	$D_{50}$	225	$\mu\text{m}$

The nine simulations with bathymetries based on combinations of upper and lower profile parts allow for clear distinction between the influence of both cross-shore zones. The influence of the upper profile part can be isolated based on three distinct lower profile parts. And the other way around, the influence of the lower profile part can be isolated for three distinct upper profile parts.

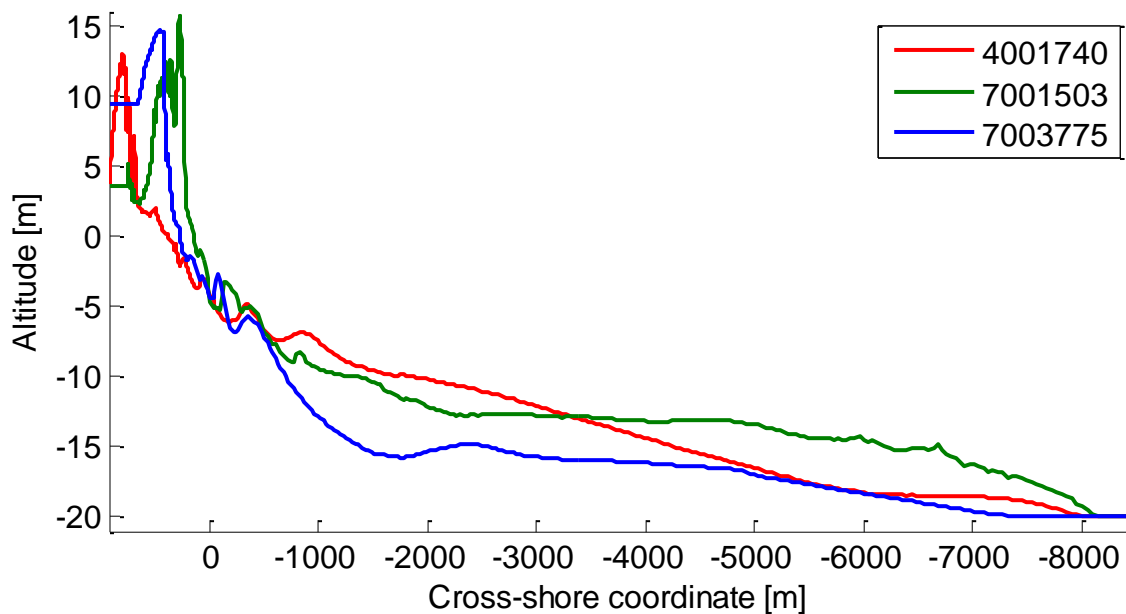


Figure 2: Three cross-shore profiles used as basis for the profile influence investigation.

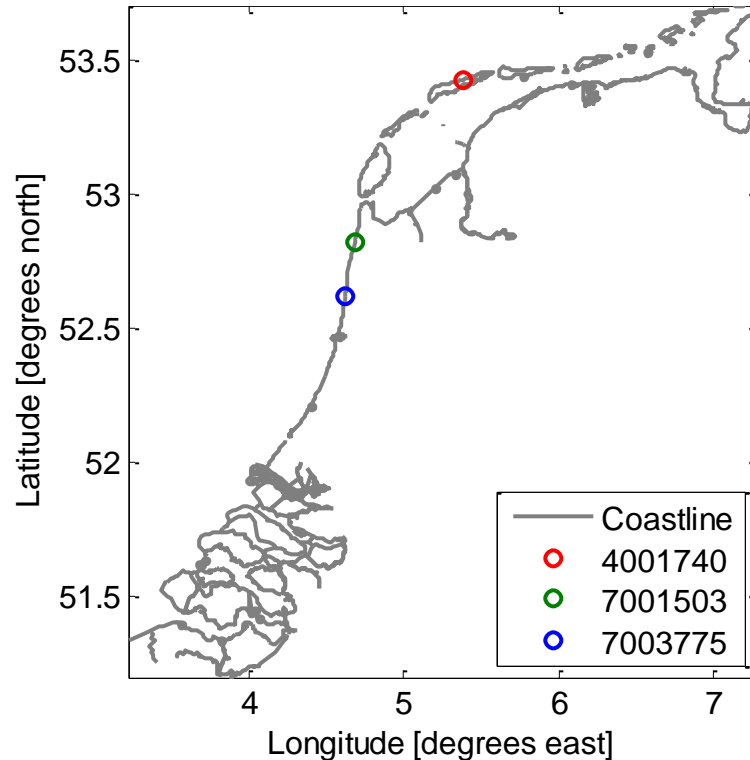


Figure 3: Map of The Netherlands with the locations mentioned in this paper indicated.

### 3. RESULTS

Figure 4 gives an overview of all combinations of landward and seaward parts of the cross-shore profiles together with an indication of the erosion volume, represented by the color of the tiles. The individual columns represent the sensitivity of the erosion volume for the seaward part of the cross-shore profile. Similarly, the individual rows represent the sensitivity for the landward part of the profile. The results show that the variation as function of the landward part of the profile (horizontal axis) is much larger than the variation as function of the seaward part of the profile (vertical axis). Figure 5 gives another representation of the influence of the seaward part on the simulated erosion volume. The erosion has been plotted as function of the seaward profile part and the markers indicate the landward part. The figure indicates that the erosion, given a particular landward profile part, only varies within a range of about 10 %. On the contrary, the similar Figure 6 that visualizes the influence of the landward profile part shows that the erosion can vary up to almost 300 %.

Corresponding DUROS+ results mainly vary as function of the landward part of the profile, since the seaward part (offshore of the toe of the sedimentation zone) is not explicitly taken into account in that model. Out of the three example profiles as presented here, only in case of (the landward part of) transect 7001503, the seaward part influences the erosion up to about 8 %. The reason is that the toe of the erosion profile in those cases reaches a bit below the MSL-4 m contour. So, a slightly different (lower) choice for the division contour between landward and seaward part would make DUROS+ be fully dependent on the landward part of the profile and insensitive to the seaward part.

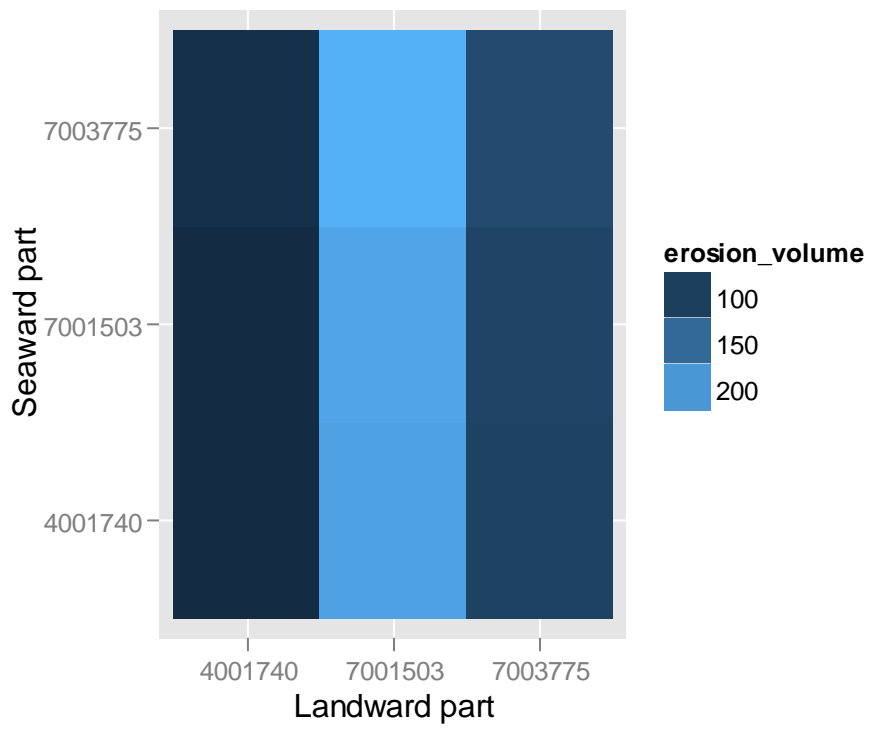


Figure 4: Matrix of combinations of landward and seaward profile parts with the color of the tiles indicating the resulting erosion volume as simulated by XBEACH.

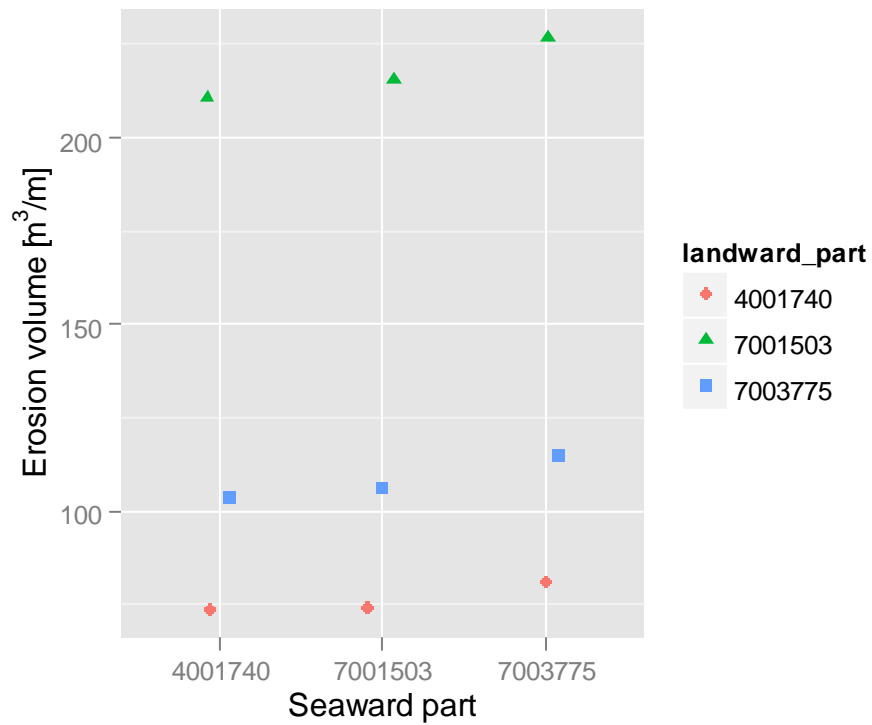


Figure 5: The XBEACH results as function of the seaward profile part.

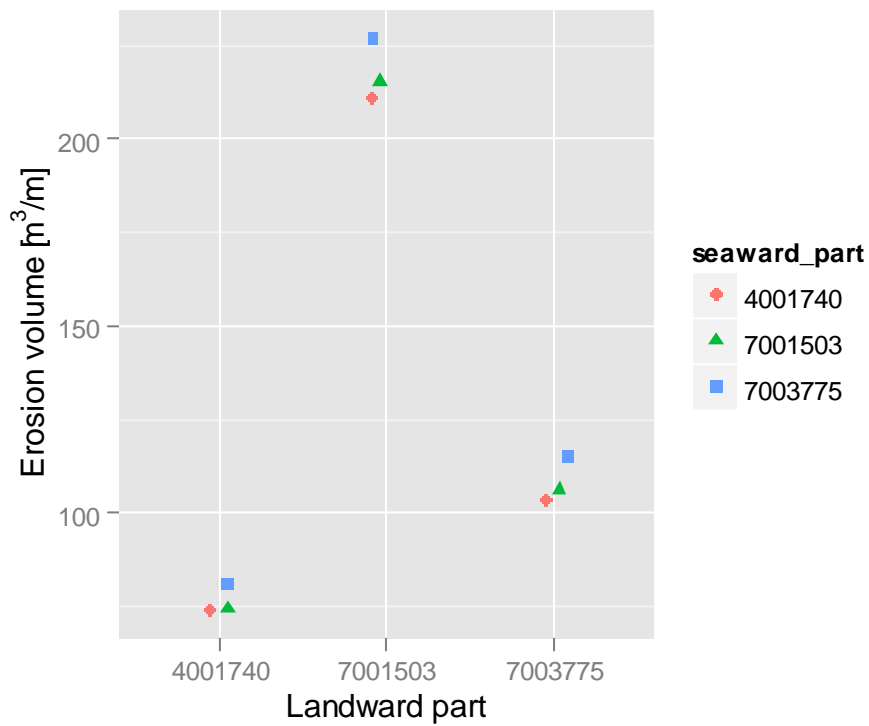


Figure 6: The XBEACH results as function of the landward profile part.

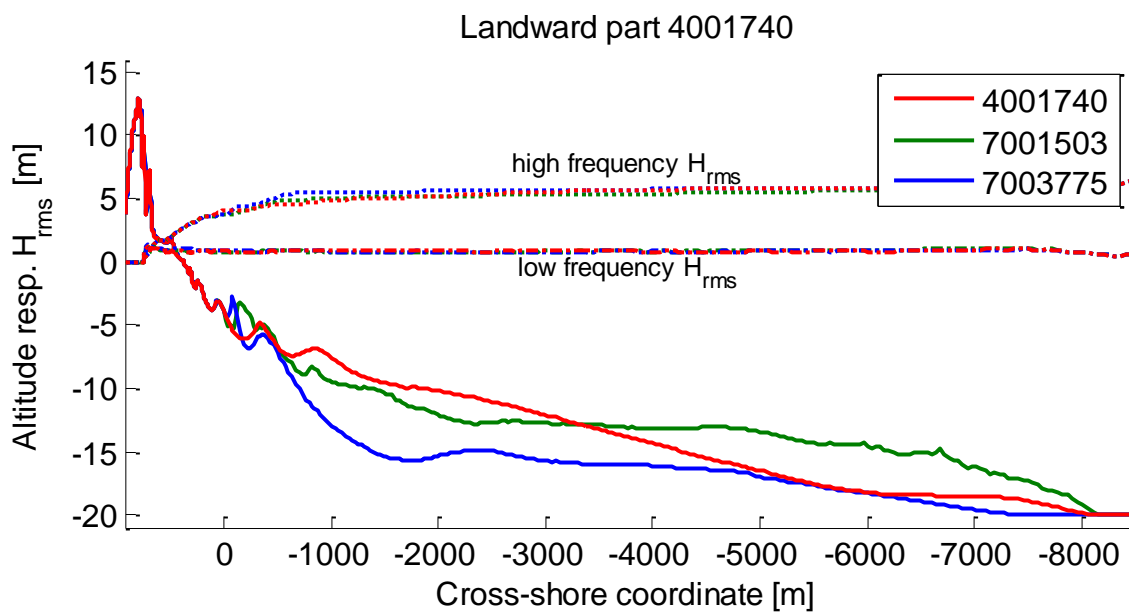


Figure 7: Example of the  $H_{rms}$  wave heights as simulated by XBEACH; three cases with different seaward profile part; the corresponding initial cross-shore profiles are included for reference purposes.

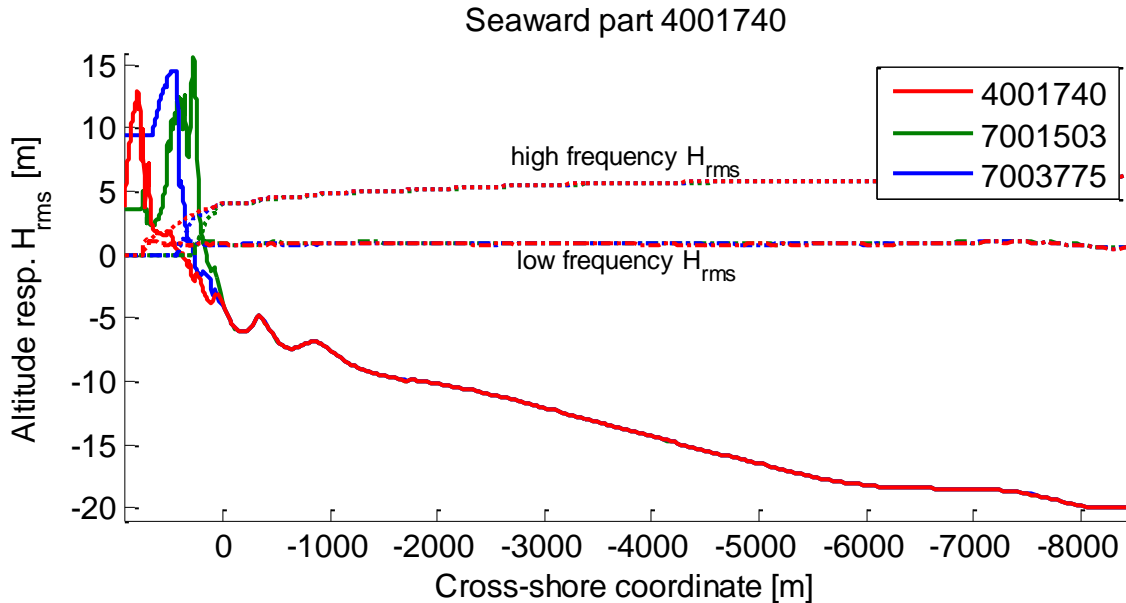


Figure 8: Example of the  $H_{rms}$  wave heights as simulated by XBEACH; three cases with different landward profile part; the corresponding initial cross-shore profiles are included for reference purposes.

The sensitivity of the dune erosion rate for the bathymetry is most likely related to the wave propagation over the cross-shore profile. Figure 7 and 8 give an indication of the high and low frequency  $H_{rms}$  wave height. These figures relate to the simulations in the left column respectively the lower row of Figure 4. The wave heights in the figures are time averaged over the total simulation. The corresponding initial cross-shore profiles are included in the figures as a reference, to be able to relate the wave height to the local depth.

In Figure 7, the distinct seaward profile parts result in a slight diversion of the wave heights towards the common landward profile part. This holds especially the high frequency and to less extent the low frequency wave heights. Landward of the profile transition, at the MSL-4 m contour, the high frequency wave heights converge fast, whereas the low frequency ones express their different origins until the shoreline. So, the low frequency waves appear to dominate the influence of the offshore profile part on the erosion rate.

The common seaward part of the profile in Figure 8 causes approximately equal high frequency wave heights until the transition at the MSL-4 m contour. Landward of the transition, the high frequency wave heights diverge clearly, since the three profiles have an obviously different shape and steepness in that area. The low frequency waves, on the other hand, show a slightly different behaviour over the entire cross-shore profile. This is likely to be related to the difference in profile shapes and in cross-shore distances to the waterline that lead to different long wave propagation and reflection.

#### 4. CONCLUSIONS

This paper describes an investigation on the sensitivity of both the upper (landward) and the lower (seaward) part of the cross-shore profile on the rate of dune erosion. The profile parts are distinguished at the MSL-4 m bottom contour. Three measured cross-shore profiles along the Dutch coast are used to create nine unique artificially combined profiles. The expected dune erosion under extreme conditions is estimated by means of XBEACH. The simulated storm events are simplified in the sense that 5 hours of stationary extreme conditions are imposed.

It can be concluded that the upper part of the cross-shore profile is of main importance to the estimated erosion rate. So, ignoring the actual shape of the offshore part of the profile can lead to an error in the order of magnitude of 10 % in terms of erosion volume, apart from the general accuracy of the applied

model. On the other hand, ignoring the actual shape of the upper part of the profile can lead to errors of a few hundred percent.

## 5. ACKNOWLEDGEMENTS

Delft University of Technology, Deltares, STW and Rijkswaterstaat Waterdienst are gratefully acknowledged for their support of the work as presented in this paper.

## 6. REFERENCES

- ENW (2007). Technical report Dune erosion; Safety assessment of dunes as water defence for the Regulation on Safety Assessment (Technisch Rapport Duinafslag; Beoordeling van de veiligheid van duinen als waterkering ten behoeve van Voorschrift Toetsing op Veiligheid 2006). Technical report, Expertisenetwerk Waterveiligheid. In Dutch.
- Roelvink, D., Reniers, A., van Dongeren, A., van Thiel de Vries, J., McCall, R., and Lescinski, J. (2009). Modelling storm impacts on beaches, dunes and barrier islands. *Coastal Engineering*, 56(11-12):1133–1152.
- van Gent, M. R. A., van Thiel de Vries, J. S. M., Coeveld, E. M., de Vroeg, J. H., and van de Graaff, J. (2008). Large-scale dune erosion tests to study the influence of wave periods. *Coastal Engineering*, 55(12):1041–1051.
- Vellinga, P. (1986). *Beach and Dune Erosion during Storm Surges*. PhD thesis, Delft University of Technology, Delft, The Netherlands. Also published as: Delft Hydraulics communications, no. 372, 1986.