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Hydraulic Boundary Conditions for Coastal Risk Management COMRISK Subproject 5

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Summary

An inventory of the methods used to determine the hydraulic boundary conditions for the sea defences in the countries participating in the North Sea Coastal Managers Group was conducted. Based on the results of this inventory the various methods have been analysed and compared for a sea dike and a dune profile on the North Sea coast in The Netherlands. Though the general approach to determine the hydraulic boundary conditions is fairly similar, the differences in details of the methods can lead to crest heights that can vary several meters for the same return period. The approaches in the safety assessment of dune coasts are quite different, though a number of methods go back on the same research from the 1980-ies.

Due to these differences results of the various conducted risk-assessments are hardly comparable. The other way around, a common approach to risk assessment might thus lead to adaptations in safety-assessment methods in the various countries. On the other hand the knowledge questions, i.e. to reduce uncertainties in risk-analysis, are rather similar in the various countries. Joint research and further exchange of knowledge can and might lead to a convergence of the methods for risk assessment used in the various countries.

Zusammenfassung

Eine Bestandsaufnahme der Methoden zur Ermittlung der hydraulischen Randbedingungen für Küstenschutzbauwerke in den in der North Sea Coastal Managers Group vertretenen Ländern wurde durchgeführt. Basierend auf der Bestandsaufnahme wurden die verschiedenen Methoden vergleichend für einen Deich und eine Düne an der niederländischen Nordseeküste analysiert. Obwohl die Verfahren zur Bestimmung der Randbedingungen generell vergleichbar sind, können die Detailunterschiede in den angewandten Methoden zu Unterschieden von mehreren Metern in der resultierenden Deichhöhe für den gleichen Wiederkehrintervall führen. Die Verfahren zur Ermittlung der Sicherheitsstandards für Dünen variieren stark, obwohl mehrere Methoden auf die gleichen Forschungsergebnisse aus den frühen 1990ern beruhen.

Wegen dieser Unterschiede sind die Ergebnisse der durchgeführten Risikoanalysen kaum vergleichbar. Umgekehrt, ein gemeinsamer Ansatz zur Risikoanalyse kann zu Anpassungen bei den Ermittlungen der Sicherheitsstandards in den verschiedenen Ländern führen. Die Forschungsfragen hinsichtlich der Reduzierung der Unsicherheiten in Risikoanalysen sind in allen Ländern vergleichbar. Gemeinsame Forschung und weiterer Austausch von Erfahrungen können zu einer Harmonisierung der angewandten Ansätze zur Risikoanalyse in den Ländern führen.

Keywords

Coast, risk management, flood defence, hydraulic boundary conditions, dike design

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1. Introduction

In 1996 national and regional coastal defence authorities in the United Kingdom, Belgium, The Netherlands, Germany and Denmark initiated a high level network of co-operation, the North Sea Coastal Managers Group (NSCMG). It was realised that, in order to achieve a transfer of knowledge and a balanced approach, a more comprehensive trans-national co-operation about risk management throughout the North Sea Region is indispensable. The NSCMG initiated a study to make an inventory of the risks, adopted safety levels and used techniques with regard to flooding of coastal areas in five countries to improve communication on this subject between the partners (DWW, 2001).

This previous study covered many aspects of flood risk in coastal areas, ranging from policy aspects and safety levels adopted in the various countries to technical aspects of dike design. One of the conclusions of this study was that the structural aspect is closely related to the way hydraulic boundary conditions are assessed. It was recommended to study the total process of hydraulic conditions together with the structural aspect to allow better comparison of the safety standards and methods applied in the various countries. In such a study the scope should include the structural aspects of dikes and dunes.

In Subproject 5 the focus is on the more technical aspects related to the design and safety assessment of the sea defences. In this subproject the way that hydraulic boundary conditions for the sea defences are derived and used is compared. The Road and Hydraulic Engineering Division (DWW) of the Directorate-General of Public Works and Water Management (in short Rijkswaterstaat) is coordinator of this subproject. DWW contracted WL | Delft Hydraulics to assist in the inventory and comparison of the methods.

2. Approach

2.1 Inventory

Subproject 5 started in 2002 with an inventory of the methodologies adopted by the various partners to assess the hydraulic boundary conditions (water level and wave conditions) and the way these are used in the design and/or safety assessment of the sea defences. This inventory was based on the response on a questionnaire that was sent to the partners together with a description of the methodology in The Netherlands. The information received from the partners has been summarized in WL | Delft Hydraulics (2005).

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2.2 Analysis for selected locations

To get some more insight in possible reasons for the differences in the methodologies to determine the hydraulic boundary conditions, the results of the inventory have been brought a step further by comparing the results of the various methods. It would be interesting to see whether the heights of sea dikes in the six North Sea countries would be different if they were designed using the methodologies from other countries when adopting the same safety level.

Ideally all methods should be applied to a typical site in each of the partner countries. In this way differences due to different geography could be detected. This would mean 36 combinations of methods and sites, which was not feasible within the framework of the COMRISK project. The closest alternative was to apply all methods to a few selected sites. For practical reasons such as easy access to relevant data regarding water level, waves, wind and bathymetry, this was limited to sites in The Netherlands. Both a sea dike and a dune section have been considered. The following sites on the North Sea coast were selected:

- Petten sea defence, the sea dike near Petten,
- Dune coast at Callantsoog.

Both sites are in the province of North-Holland, north-northwest of Amsterdam. The location of these sites is shown in Fig. 1.

The Petten sea defence (Fig. 1, top right) is a sea dike with a crest at about 12.75 m above NAP (MSL). The lower part of the seaward side has a slope of 1:4.5, the upper part a slope of 1:3. Between those slopes is a 14 m wide berm at about 5.35 m above NAP. The inner slope is 1:3.

The dunes near Callantsoog consist of a single row with a width of about 100 m and a maximum height of about 20 m above NAP (Fig. 1, lower right).

Based on the information gathered through the questionnaires, the descriptions in earlier study (DWW, 2001) and other information (e.g. found on the website of the partners),

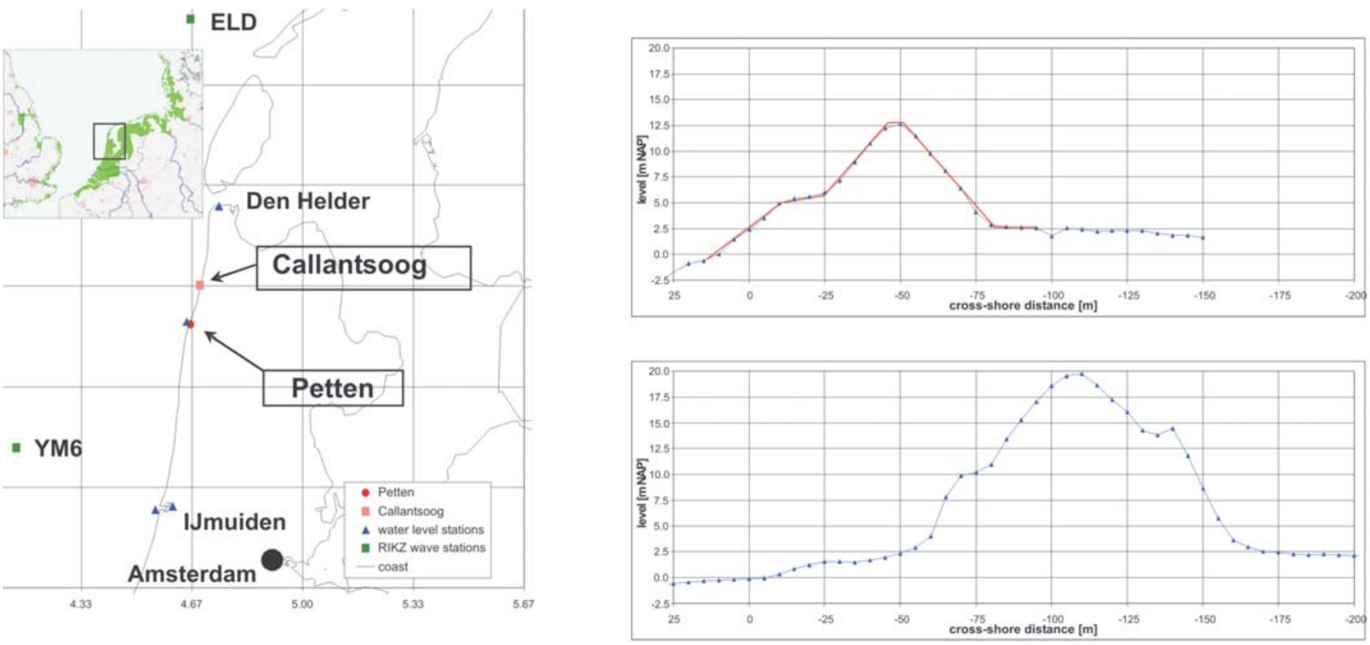

Fig. 1: Location of the selected sites (left) and typical sections of the dike at Petten (top right) and the dune at Callantsoog (lower right)

the procedures used in the six countries are described and compared based on data for the selected sites of Petten and Callantsoog. The procedure to design or evaluate a sea dike generally consists of two steps: determination of the hydraulic boundary conditions at the toe of the dike and calculation of the required crest height. The safety assessment of sandy coasts involves similar steps, the main difference being that the wave conditions are usually required in deeper water. This study therefore compares first the way the hydraulic boundary conditions are derived. Water level and wave conditions are treated separately. Then the procedures to determine the required crest height are compared. This includes a comparison of formulae for wave run-up and overtopping. These are used to assess the required crest height for the Petten sea defence according to the various methods.

The comparison presented in this study is based on a deterministic approach. All countries are developing probabilistic techniques to support assessing the risk of flooding of coastal areas. Comparing these by application to a selected case was not feasible within the present study. However, aspects such as wave run-up and overtopping formulae and criteria for these factors are also key elements in probabilistic methods. Thus, the values given in this report can not be used for actual assessment of water levels, crest levels and so on, they are indicative values to study differences between approaches in the various countries. Risk assessment using probabilistic techniques has been conducted in some of the case studies treated in the COMRISK subprojects 6 to 9.

3. Hydraulic boundary conditions

3.1 Water levels

All countries have fairly extensive networks of water level stations. These are used as basis to determine extreme water levels required as input for design and safety assessment of the sea defences. The number of stations in the countries ranges from 3 in Belgium, which has a fairly short stretch of coast along the North Sea to about 40 in the United Kingdom and even more in Germany, which has a long coast line with various estuaries. National authorities gather the data and the available information goes for some stations back for more than 100 years.

Recent data are generally stored as 10-minute averages after a quality check. Before data are used to determine design conditions by extreme value analysis the historic data are corrected for trends in sea level and/or the tidal amplitude over period of observations. In this way each record can be considered to be representative for the present situation. In most of the countries the required water levels for design and safety assessment are determined using probabilistic methods. This can be based on extrapolation of observed water levels (e.g. Denmark and The Netherlands) or on extrapolation of measured surges that are combined with the tidal component (e.g. Belgium). In the United Kingdom each of these methods may be applied as the contractor carrying out the study can use his own methods. In Niedersachsen (Germany) a deterministic method is used, which combines the tide with the highest observed surge. Schleswig-Holstein (Germany) combines this deterministic method with the probabilistic approach by using the maximum of the two. Most countries increase the design level to account for factor such as local wind set-up and relative sea level rise.

The results of the various methods to assess the design water levels are summarised in Fig. 2. The most striking in this figure is of course the single value independent from the probability of occurrence following the method Niedersachsen. This is inherent to the design

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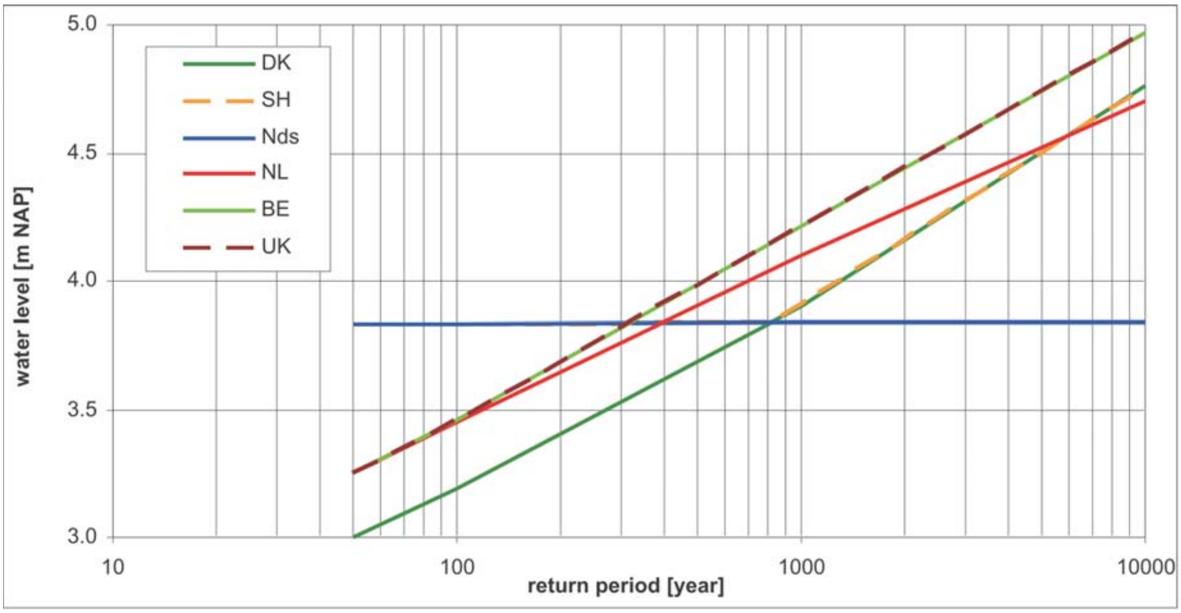

Fig. 2: Comparison of design water levels following different methods for Petten, The Netherlands

method *Einzelwert-Verfahren*, which "aims to avoid any exceedance" (quote from response to questionnaire; WL | Delft Hydraulics, 2005). It can be seen that the value for Petten following this method has a probability of occurrence between 1/400 (Dutch & Belgian method) and 1/800 (Danish method). In the comparison of methods for the Petten sea defence the results from the Belgian method have also been adopted for the United Kingdom.

It is further interesting to note that the water levels using the method of The Netherlands are for short return periods equal to those following the Belgian method, but for longer return periods closer to those from the Danish method. The differences between the results of these methods are in the order of 0.25 m, depending on the return period and method. For the longer return periods this is actually fairly small considering that the 95 %-confidence interval for the 1/10,000 year surge is in the order of 1 m. For the shorter return periods of 50 and 100 years, however, a better agreement was expected between the various methods. The difference for these return periods may be due to the use of not completely consistent data for the comparison (WL | Delft Hydraulics, 2005).

3.2 Wave conditions

Most countries use fairly similar methods to assess the wave conditions in the vicinity of the sea defences. Only Schleswig-Holstein has a quite different approach. Though deep water waves and wind are measured on a location off Sylt since 1984 (21 years) as a basis for sand nourishment, the nearshore design wave conditions are direct assessed by correlating with the still water level. The approach in the other countries is based on a statistical evaluation of deep water wave data (either from measurements or hindcast) combined with wave propagation modelling to determine the corresponding conditions near the coast. In The Netherlands and Belgium relatively long datasets of wave measurements in deep water are available (20-25 years), which allows extreme value analysis directly on the measured wave heights. In Denmark time series of 8 years are available for most of the wave gauges, while in the United Kingdom the available timeseries of wave measurements cover periods of 1 to 4 years. In these countries the wave measurements are combined with wind data that cover longer periods using hindcast techniques.

For this study the deep-water station Eierlandse Gat (ELD, see Fig. 1) is the reference relevant for the coast of Petten and Callantsoog. The official Dutch values extreme wave conditions for this station (RIKZ, 1995) have been compared with an independent analysis of the data. The resulting wave heights for the selected return periods are included Table 1. It can be seen that the difference in wave height is 0.3–0.5 m. As it appeared that this difference has no significant effect on the nearshore conditions near the Petten sea defence (the remaining difference is only 1–2 cm) other methods to assess the deep water wave conditions have not been tested. In the comparison the official values were used for the method of The Netherlands, the results of the independent analysis for all other methods.

Table 1: Extreme wave conditions at Eierlandse Gat adopted in the comparison

method	waves 1/50		waves 1/100		waves 1/1,000		waves 1/10,000	
	H_s [m]	T_m [s]	H_s [m]	T_m [s]	H_s [m]	T_m [s]	H_s [m]	T_m [s]
NL	8.05	9.5	8.37	9.7	9.24	10.2	10.00	10.6
other	7.52		7.82		8.80		9.72	

As mentioned above, all countries except Schleswig-Holstein use numerical models to determine the design wave conditions at the toe of the sea defences. Within the scope of the present comparison of methods it was not feasible to carry out wave propagation simulations with the various models used in the different countries. Instead, the wave conditions at the toe of the Petten sea defence were determined by interpolation in the results of a large number of wave runs with the model SWAN, that have been stored in a database. This database contains for a large number of locations the characteristic wave parameters (H_{m0}, T_p, T_{m02}, T_{m-2-1}, direction) of SWAN runs for 3 water levels, 14 wind directions and 5–7 combinations of wind speed and offshore wave conditions. Based on the derived water level and deep water wave height, the significant wave height H_{m0}, mean wave period T_{m02} and the peak wave period T_p near the Petten sea defence were determined by bilinear interpolation from the results for the wind and wave direction 285 °N, which is the most unfavourable direction in this location. The results are shown in Table 2. It appeared that the results were fairly insensitive to the deep water wave height and that the water level is in fact governing the nearshore wave conditions. This is illustrated by the results for Niedersachsen, for which the water level is the same for all return periods.

In Schleswig-Holstein the nearshore wave conditions are determined by correlation with the water level using the following relations:

$$H_{1/3} = (SWL - DZ) * Gr$$
$$T_z = a + b * H_{1/3}$$

where $H_{1/3}$ is the significant wave height and T_z is the mean zero-crossing wave period. The coefficients DZ, Gr, a and b are parameters determined based on measurements. For the present comparison these parameters have been derived based on measurements from the Petten site for the season 2003–2004 (RIKZ, 2004). The results are included in Table 2. It is remarkable that the wave heights are significantly higher than those based on the SWAN simulations.