Appendix 3 Denmark

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1. General description

1.1 Flood-prone areas

Individual landowners have reclaimed certain areas of land along the Wadden Sea coast in the last few decades. Most of these areas are relatively small and relatively high-lying. The towns are primarily situated on higher ground, with the exception of Tønder and Ribe, around which dikes have been built. These areas are generally 1 to 5 meters above DNN, with no land below MSL (see figure 1).

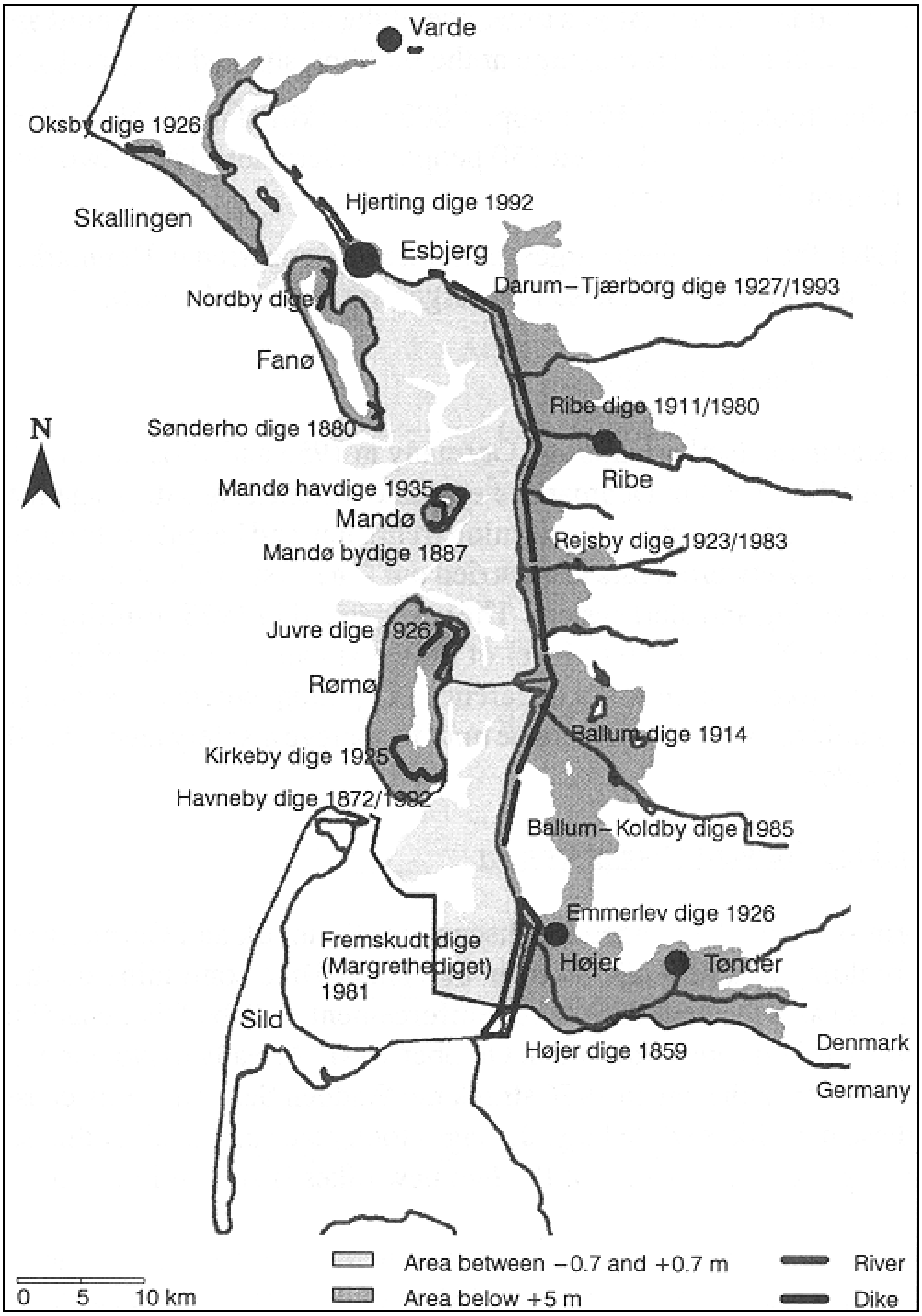

Figure 1 Low-lying areas in Denmark

1.2 Main threats

Along the Kattegat and the Baltic Sea coasts there are approximately 40 low lying area protected by a total of 350 kilometers of dike. These dikes are generally low and many of them are of poor quality. This should be considered in relation to the fact that there is nearly no tide in this part of the country and that a 50-year water level is between 1,5 and 2 meters. Most of the dikes have a turf cover layer, but no clay layers. The dike owners are normally farmers or municipalities. In some cases the dikes protect only farmland but in many cases they also protect buildings. Generally, there is no danger of loss of human life as a consequence of dike breach.

In the Wadden Sea area from Esbjerg to the German border the situation is different from the rest of the country. Here a 50-year flood is between 4 and 4.7 meters and there is a tidal amplitude of 1.5 to 2 meters. On this part of the coast stronger dikes have been built. A breach of one of the sea dikes in this area may endanger the lives of people living in the area.

1.3 Types of coastal defence

The Danish coastline is 7,300 kilometers long. Roughly speaking, there are four different types of coast (see figure 2):

- A tidal coast along the Wadden Sea with a tidal range of 1.5 - 2 meters, where approximately 100 km of dikes protect the low hinterland from flooding;
- The sandy beaches along the southern part of the North Sea coast, where dunes protect the low hinterland from flooding;
- The sand and clay cliffs of the northern part of the North Sea coast;
- The primarily clay cliffs of the Baltic Sea coasts.

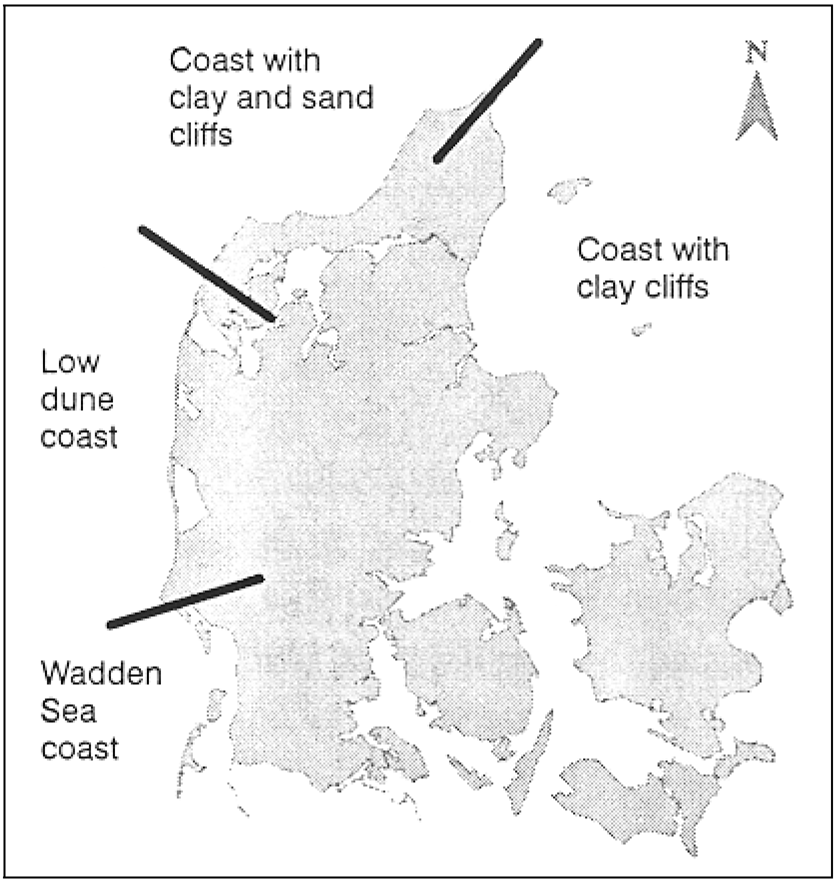

Figure 2 Classification of the Danish Coast

2. Organisational framework

2.1 Organisations / authorities involved

Kystinspektoratet (Danish Coastal Authorities, or DCA), an organisation under the Ministry of Transport, is the key authority involved in coastal defence. Established in 1973, the DCA has many more years of experience. It originated from a reorganisation of the Coastal Construction Authority, established in 1868. The principle tasks of the DCA are:

- Providing advisory services to the Ministry of Transport on protection of the Danish coast;
- Administration, construction and operation of the national coastal defence systems and the co-operation agreements on coastal protection;
- Administration of the Coastal Protection Act, which applies to all of Denmark's coasts;
- Approval of construction in waters under Danish sovereignty.

For an organisational chart, see figure 3.

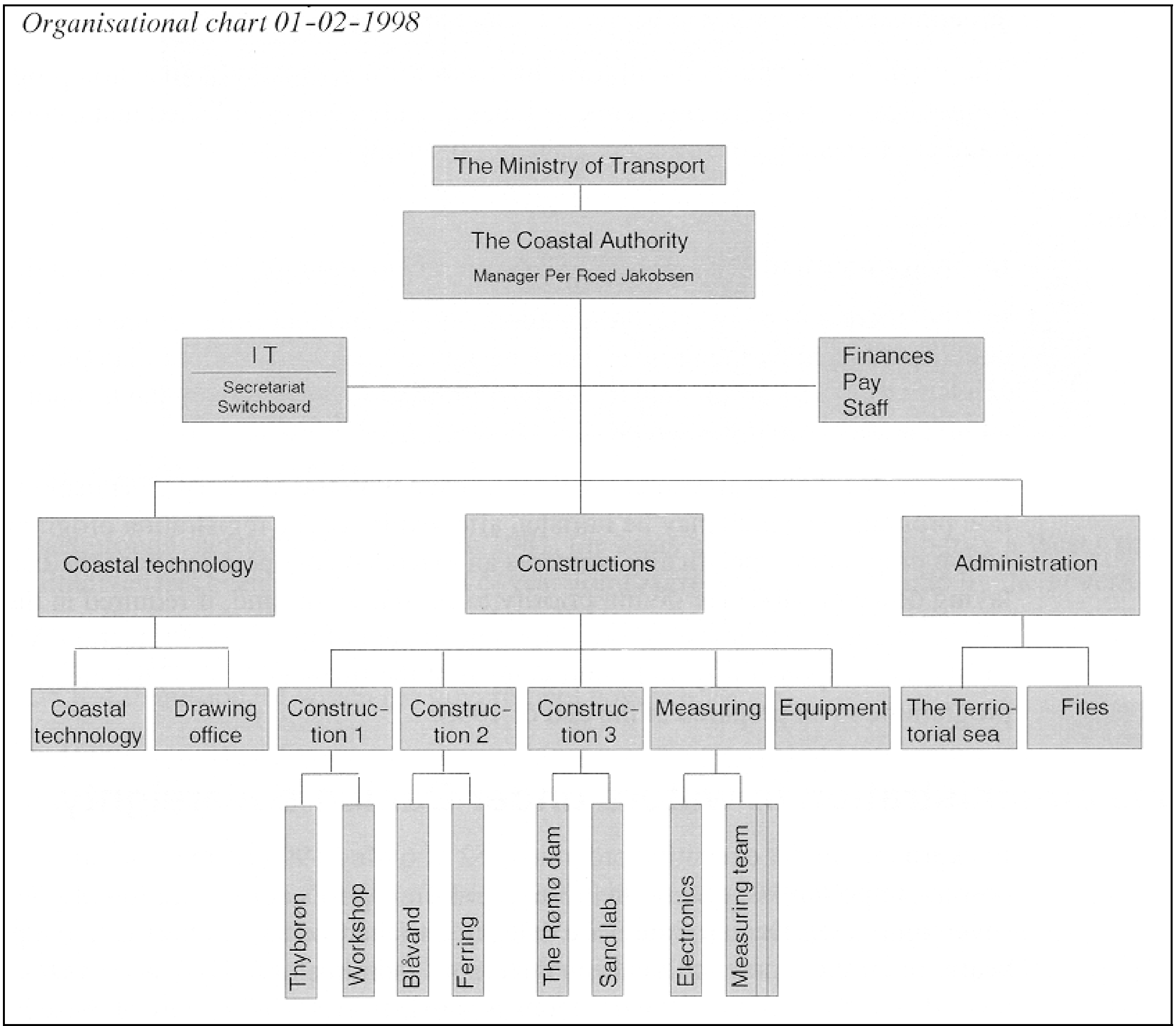

Figure 3 The organisation

Coastal defence on the Baltic Sea coasts is regulated by an act passed in 1988. According to this act, the counties are responsible for the administration of coastal defence projects. Since the counties do not possess any coastal engineering expertise, the DCA provides assistance at the planning stage and consultants provide assistance at the project stage. In general, there is little public funding of coastal defence in the Baltic Sea area.

2.2 Legislation

After the disasters in the Netherlands and Germany in 1953 and 1962, a storm flood committee was appointed in Denmark in 1964 to evaluate existing flood safety conditions. An extensive study was conducted on the frequency and height of storm surges, hydraulic conditions, and safety problems. The first result was the establishment of a warning and alert system. The work concluded in 1976 with the reinforcement of Ribe Dike to a safety level of 200 years and the construction of maintenance roads along most of the dikes.

2.3 Financing arrangements

The costs of coastal defence on the North Sea coast are shared by the central government and local authorities. The government typically pays 50-70% of costs. In some cases the government pays 100% of costs. On the Baltic Sea coasts, individual landowners must bear all costs.

2.4 Flood and coastal defence policy

The government set the dike safety level at a 200-year return period for the two major dikes in the tidal region. This safety level is based on a cost-benefit analysis. Otherwise there are no national rules for safety assessment of dikes or dunes. Safety assessment policies and erosion control policies are established through agreements between local authorities and the central government, based on the recommendations of the Danish Coastal Authority. There are probably a number of reasons for the lack of national regulation, but the main reason is the limited danger to human life and the fact that "only" land is damaged by erosion and flooding, beyond the land protected by the two main dikes

Many areas along the Wadden Sea have been designated as National Park, which makes rules for land reclamation stricter.

3. Safety levels

3.1 Background

The safety standards in Denmark are :

- At the town of Thyborøron 1,000 years;
- The dikes at Højer and Ribe in the Wadden Sea area 200 years;
- Other important dikes 50 years.

These safety standards were proposed by the DCA and approved by the Ministry of Transport. They are not based on scientific analysis, with the exception of the return period of 200 years for the main dikes at Ribe and Højer. This safety standard was based on a cost-benefit analysis.

3.2 Application

The following diagram is used to determine the return period of a dike:

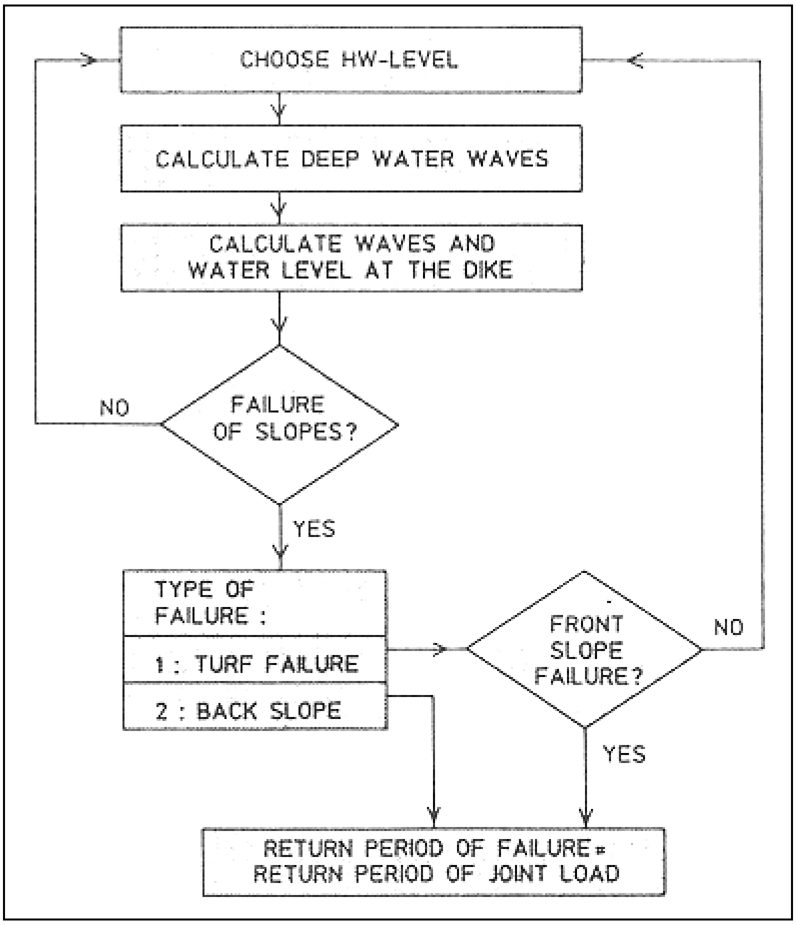

Figure 4 Calculation diagram

The calculation is based on a given water level in the deep water outside the specific dike. This water level and the corresponding wave heights are used to determine whether the situation will cause front or back slope failure of the dike. If the dike does not fail, the calculation is repeated using a higher water level. This process continues until the lowest water level is found at which the dike fails. The mean return period for this combination of water level and waves is determined and used as an expression of the dike's strength. A landowner can claim compensation for a flood if the dike is properly maintained and the probability of flooding is smaller than 1/20 per year.

4. Technical models and criteria

4.1 Hydraulic boundary conditions

Design water levels are based on an analysis of a series of extreme water levels, measured at 48 stations. The statistics are calculated using the Weibull distribution (see figure 5). In the past knowledge of waves in Denmark was poor, and the calculation of design waves was based only on theory. A study of the wave climate and dike safety level has just been completed. First, the wave climate was modeled using the Mike 21 model, calibrated with 4 years of wave recordings. This resulted in a design wave at any location in front of the dikes (these design waves vary, but typical values are H = 1.8 m and T = 4-5 sec). Second, physical model tests were conducted using the results of the wave and water level. Several combinations of water levels, waves, slopes and roughness were used to model the wave run-up.

At locations where wave statistics based on recordings are not available, the design wave is calculated using standard Shore Protection Manual procedures and based on long-term wind statistics.

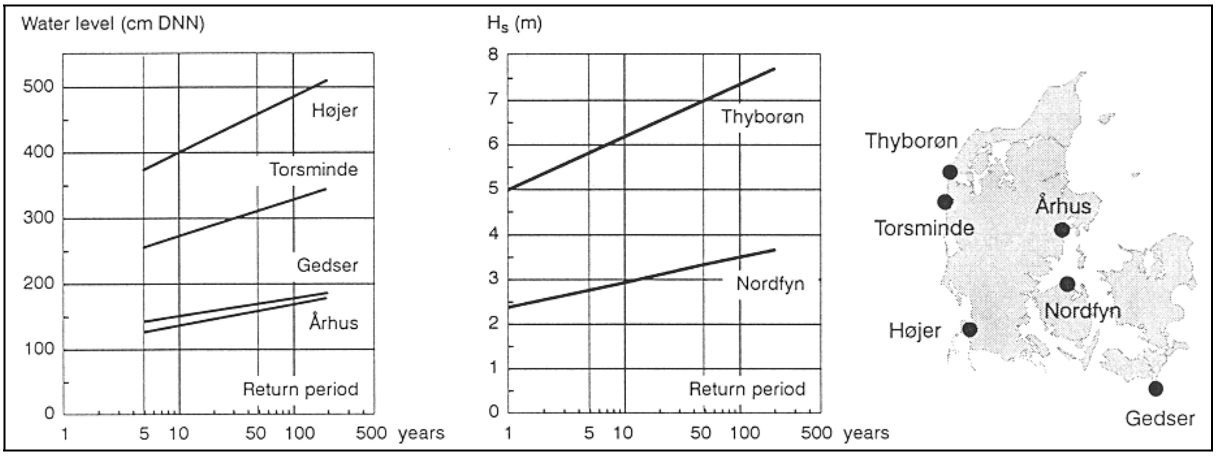

Figure 5 Water level and wave height statistics

4.2 Wave run-up, wave overtopping

The normal procedure for the design of dikes is:

- Crest level = design water level + wave run-up + additional margins (see figure 6)
- Wave run-up : $Z_n = C_n ?T_m ?\sqrt{g ?H_s} ?\tan\alpha$ (see [1])

  Where

  - Z_n = wave run-up [m]
  - C_n = $C_1 \cdot C(\varepsilon)$, see table 1 [-]
  - T_m = mean period (=peak period/1,15) [s]
  - H_s = significant wave height [m]
  - tan α = slope angle [-]

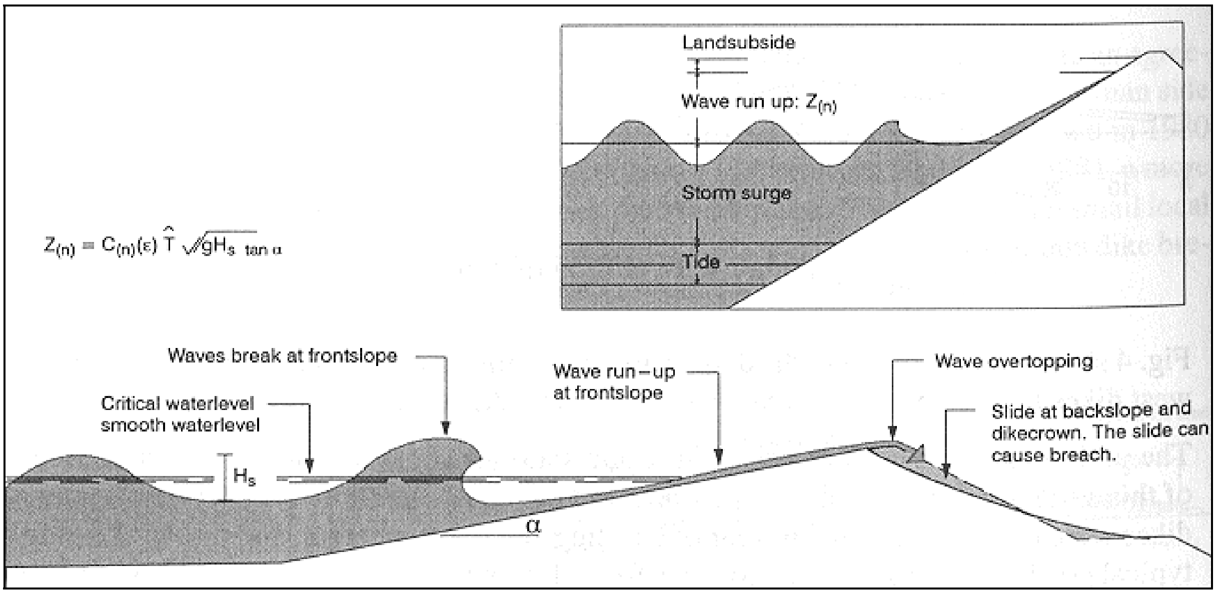

Figure 6 Design of dike height

Table 1 Critical overtopping percentages

Overtopping percentages			
	Unprotected		

Slope	Dike surface	Turf, sandy	Turf, clayey
1:1.5	2%	10%	10%
1:2	2%	20%	50%
1:3	2%	30%	90%

Table 2 Calculation of factor C_1 and C_n

Critical overtopping percentages	C_1	C_{n1}
2%	1	0,7
10%	0,77	0,54
30%	0,56	0,39

In designing the Danish Wadden Sea dikes, in the formula the critical overtopping percentage was set at 2% or 10% for back slope failure. The values in table 1 are used to determine the strength of a dike expressed as the mean return period for the critical load.
The case of the Pettemer Zeewering has been calculated for two critical overtopping percentages, 2% and 30%.

$$h_{crest} = h + C_n ? T_m ? \sqrt{g ? H_s} ? \tan\alpha ? \gamma$$

Where γ = reduction factor = 0.82. This reduction factor is the same as that used in the Dutch elaboration of the case.

The required crest level for the two critical overtopping percentages is:
h_{crest} = 4.7+0.7*12/1.15*6.7*0.2*0.82 = 12.7 m, for 2% overtopping
h_{crest} = 4.7 + 0.39*12/1.15*6.7*0.2*0.82 = 9.2 m, for 30% overtopping

The crest level for 2% critical overtopping percentage appears to be exactly the same as in the highly-developed Dutch procedure with regard to wave run-up. The Danish method is the same as the Dutch one, but the method of determining the wave height and period may vary (this has not been taken into account in this study).

4.3 Beach and dune erosion

The southern part of the North Sea coast has high rates of erosion caused by harbour breakwaters and large groyne groups. The dunes were stabilized about 100 years ago by planting marram grass. At the same time, harbours and groyne groups were built, resulting in serious downdrift erosion. The combined result of the dune stabilisation and the erosion was that the dunes had disappeared or weakened along 50 km of the coast by 1982. In that year, it was decided that a coastal defence scheme should be implemented. The objectives of this policy were :

- to re-establish a flood safety level with a minimum 100-year return period;
- to stop erosion where towns were situated near the beach;
- to reduce erosion along parts of the coast where it would reduce the flood safety level to less than 100 years in the near future.

The dunes were reinforced and new dunes were built to re-establish flood safety to a 100-year return period. A number of measures were taken. Block supports were placed to protect the dunes (due to too little space between beach and houses). On highly exposed stretches, where erosion must be stopped, low detached breakwaters were used in combination with beach nourishment. One reason for the use of breakwaters was historical, since local politicians trusted hard structures like groynes and breakwaters. A second was the high price of nourishment sand. Nourishment was applied, but only on a small scale, mainly because the principle of beach nourishment was new to the politicians.

In 1998, the coastline retreat rate was much lower than in 1982 and a safety level of at least 100 years had been re-established for the dunes.

In the period1993-1996 Denmark participated in a MAST project called Nourtec. The main conclusion of this project was that shore face nourishment is more stable than beach nourishment. The former is also cheaper and will be implemented in Denmark in the future (in combination with beach nourishment).

References

Manual on the use of rock in coastal and shoreline engineering, CUR report 154, 1991