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Coastal Flood Defence and Coastal Protection along the North Sea Coast of Schleswig-Holstein

By Jacobus Hofstede

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1. Introduction and Historical Development

Schleswig-Holstein is the most northerly Federal State in Germany. It has an area of 15,731 km² and a population of about 2,700,000 (about 172 inhabitants per km²). The State is situated between two seas, the Baltic Sea in the East and the North Sea in the West (Fig. 1). As a result, a large part of the State may be characterised as coastal zone. Within this zone, most of the population is concentrated, e.g. in the harbour cities of Kiel (about 248,000 inhabitants) and Lübeck (about 217,000 inhabitants). In all, the coastline measures 1,190 km, and about 3,800 km² of flood-prone coastal lowlands exist. In these lowlands, which represent almost 25 % of total surface area, 345,000 people live and economic assets worth of 47 billion Euros are concentrated (Hofstede, 2004). This chapter focuses on the North Sea coast, in-

Fig. 1: Overview of Schleswig-Holstein with State dikes (black bold lines), regional dikes (brown lines), and coastal lowlands

cluding the Schleswig-Holstein sector of the Elbe-estuary. For the Baltic Sea coast, the reader is referred to chapter 1.3.

The North Sea coast of Schleswig-Holstein is characterized by reclaimed coastal marshes, the Wadden Sea and the Elbe estuary (Fig. 1). The coastline measures 553 km, including 256 km of island coastlines and 77 km of estuarine shorelines. Of this coastline, 408 km have dikes, 105 km are occupied by sandy shorelines and 51 km are made up of soft cliffs. Approx. 1,700 km^2 of Wadden Sea stretch out in front of the mainland coastline. This area is a sink for coastal sediments and developed in the course of the Holocene transgression, resulting from a combination of sediment availability (mainly from the North Sea) and a hydrodynamic regime of tides and waves (HOFSTEDE, 2005). According to SPIEGEL (1997), a tidal energy input in the order of 2.2 thousand MW occurs in the Wadden Sea of Schleswig-Holstein with each flood phase. This energy input, combined with the energy impact of wind waves and storm surges, results in strong morphological processes. Outstanding are the high proportions of intertidal flats (57 %) and the 'Halligen'. These are isolated salt marsh islands in the Wadden Sea protected by low summer dikes and/or revetments. Most of them are inhabited with people living on dwelling mounds.

The history of colonization of the coastal marshlands started more than 2,000 years ago. With rising storm surge water levels, early settlers erected dwelling mounds on which they built their houses. A major change in human interference occurred at the turn of the first to the second millennium AD. At this time, farmers started to protect their cultivated land against flooding during (lower) summer storms by erecting low dikes. In the beginning, so-called "ring-dikes" were built around cultivated land. Soon afterwards, these isolated ring-

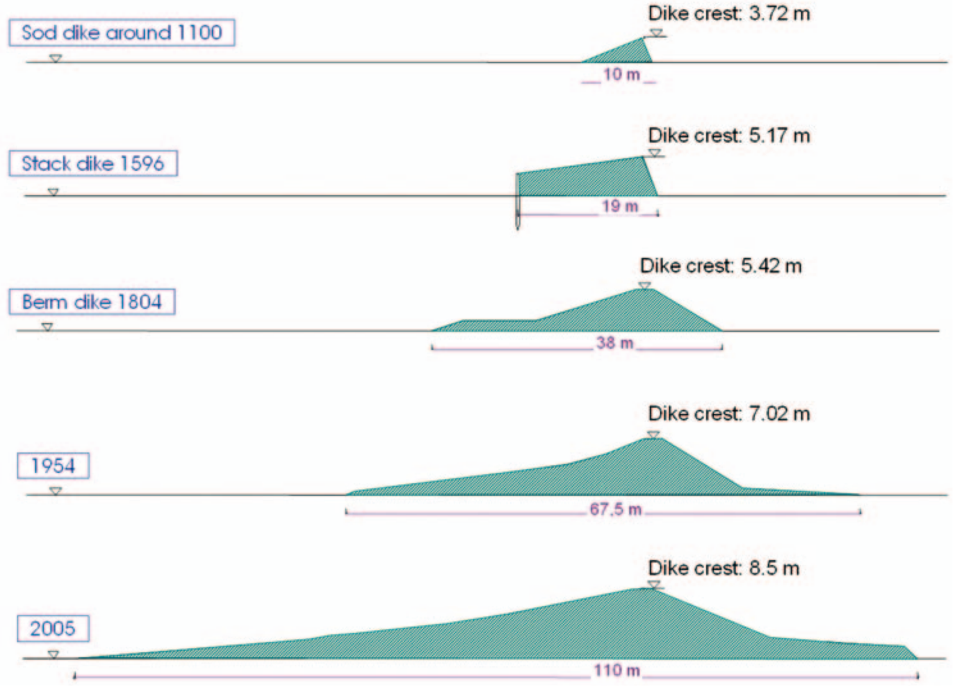

Fig. 2: Development of dikes in Schleswig-Holstein

dike systems were connected, and by the end of the 14th century, a more or less complete dike system protected the coastal marshes of the Wadden Sea. Due to the limited technical means, these early dikes were rather low and steep. Breaching of dikes frequently occurred. The following centuries were characterised by a continuous struggle of the local population against the sea. A number of catastrophic storm floods occurred in the Wadden Sea area (e.g. Oost, 1995). The greatest land loss resulted from the Second Marcellus Flood ("Erste große Mandränke") in 1362. Another catastrophic storm flood ("Zweite große Mandränke") with many fatalities occurred in 1634. During these events, thousands of people lost their lives and huge areas of marshland were permanently lost to the sea. The 'Halligen' emerged as remainders of these marshlands on the newly developed tidal flats. With increasing technical possibilities (Fig. 2), more and more salt marshes were reclaimed. Still, extreme storm surges occasionally caused the breaching of dikes, e.g. in 1717, 1825, and 1962. During the last catastrophic storm flood, in the year 1962, more than 300 people lost their lives in the greater Hamburg area.

As a result of this historical development, local population has attained a unique attitude towards their land and the sea *(trutz Blanker Hans)*. Consequently, modern coastal flood defence and coastal protection express the historically grown and justified desire of the inhabitants to protect their lives and properties from flooding and land loss. Today, the about 3,400 km^2 large coastal marshes are protected by a 408 km long dike line (364 km of state dikes and 44 km of regional dikes). In the protected area, more than 250,000 people live, and economic assets worth of 32 billion Euros are present (Hofstede, 2004). About 2,000 km^2 of the coastal marshes are protected by a second dike line. The remaining area between the first and the second dike line is divided into 75 polders (Köge) by so-called middle dikes (Fig. 1). Each of these polders represents a closed 'flood unit'.

2. Modern Coastal Defence

2.1 Strategic Considerations

Under the impression of the 1962 storm flood catastrophe, in which more than 300 people lost their lives in Hamburg, the Schleswig-Holstein State Government adopted a master plan for coastal flood defence and coastal protection. It contained the technical and financial concept for improving the standards of protection in Schleswig-Holstein. The plan was updated in 1977 and 1986. One main goal was to reduce the danger of dike breaches by shortening the primary flood defence line, amongst others through the construction of tidal locks and barrages in four river mouths. Until 1986, the primary flood defence line along the west coast was reduced by about 207 km to a length of 364 km. In the year 2000, the new master plan "Integrated coastal defence management in Schleswig-Holstein" was prepared by the responsible administration (Hofstede, 2004). After comprehensive public consultation, it was adopted in 2001 by the State Government. The master plan describes the midterm defence strategy and is based upon the principles of integrated coastal zone management (European Commission, 2002). For the first time in Germany, it considers the possible consequences of anthropogenic climate change.

2.2 Measures and Design Parameters

Coastal flood defence and coastal protection along the North Sea coast of Schleswig-Holstein mainly consists of three techniques: (1) dikes, (2) salt marsh management techniques and (3) sand nourishment. These are described below.

Dikes

Dikes constitute the main coastal flood defence in Schleswig-Holstein. The marshlands are protected by an almost continuous 408 km long primary dike line (Fig. 1). About 364 km of these are so-called state dikes, the rest are regional dikes. In contrast to state dikes, regional dikes do not have fixed safety standards. The safety standard of a state dike includes a design water level, a design wave run up, and an extra safety margin of 50 cm to account for future sea level rise (Fig. 3). The design water level should meet three basic requirements (HOFSTEDE, 2004):

1) it should have a (statistical) return period of once in a century,
2) it should not be lower than the highest water level observed in the past (incl. sea level rise since than), and
3) it should not be lower than the sum of highest spring tide water level and highest observed wind set-up.

For the North Sea coast, the statistical value delivers the highest water level. In consequence, this value represents the respective design water level to which a design wave run up is added.

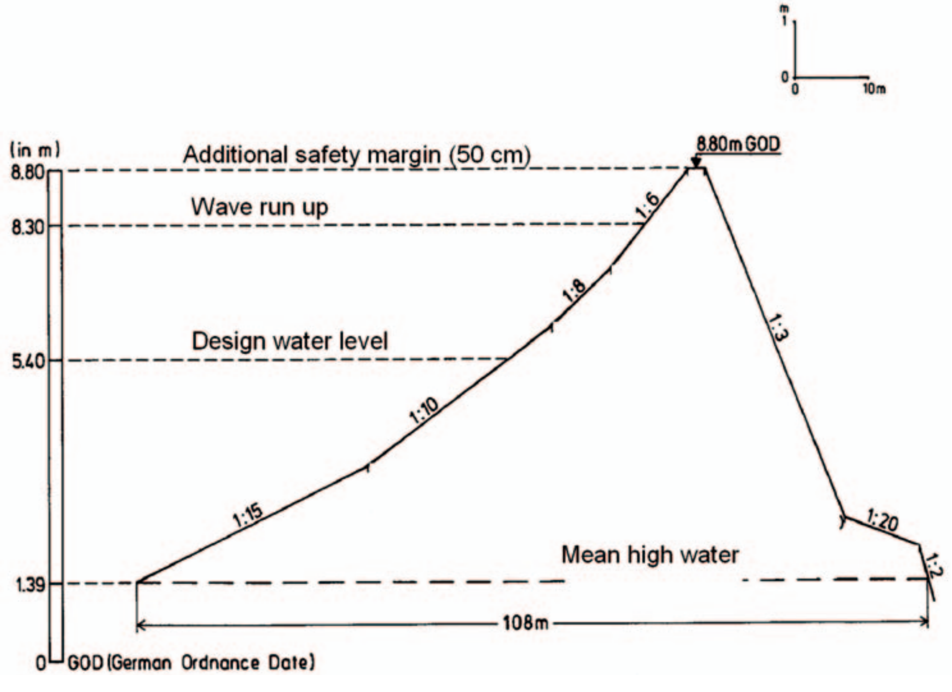

Fig. 3: Dimensions of a state dike (schematic)

With the establishment of the new coastal defence master plan, a safety check was conducted with localised values for water levels (based upon nearby tidal gauge stations) for more than 400 locations along the state dikes. Wave run up was calculated applying HUNT's formula adapted to local circumstances with empirical parameters (HUNT, 1959). If the dike is too low, wave overtopping occurs. In this case, overtopping amounts were determined using the method of VAN DER MEER (VAN DER MEER and JANSSEN, 1994). It is assumed that modern dikes are able to withstand an overflow of at least 2 l/m·s. If the calculated values exceeded this, the dike stretch was included in a priority list for dike strengthening. It turned out that, in all, 77 km of state dikes needed to be improved to meet the safety standard. From 2001 until the end of 2007, 30 km (40 %) have been enforced.

Behind the primary dike line, a 570 km long secondary dike line exists along the North Sea coast of Schleswig-Holstein (Fig. 1). These 'middle' dikes are usually older primary dikes that "shifted" into the second defence line after land reclamation. They still have a function in that they may limit the flooded area after a breach in the primary dike line occurs. The responsibility for these dikes lies with 'dike boards' (Deichverband). As with regional dikes, they do not have fixed safety standards.

On the Halligen (Fig. 4), a special form of regional dikes exists. These dikes only prevent summer floods, thereby allowing cattle grazing during summer. In winter, the 350 inhabitants on the Halligen depend on dwelling mounds for their protection. In 1962 and 1976, high storm surges caused significant damages and hazardous situations. As a consequence, all 32 inhabited dwelling mounds were strengthened between 1977 and 2007. Apart from a small ring dike around the houses, the outer slopes were flattened to reduce wave run up. Within the houses, finally, a "rescue room" was incorporated (Fig. 5). This room is deeply built into the dwelling mound, and rests independently from the house on four concrete piles. It is anticipated that, even if the whole house collapses during the surge, this one room will withstand the flood. Nevertheless, living on the Halligen remains a challenge, especially under possibly deteriorating conditions due to a climate change!

Fig. 4: Hallig Hooge

Salt marsh management techniques

Significant expenditures in coastal defence arise from salt marsh management techniques. With respect to coastal defence, salt marshes in front of dikes are, in the first place, a method to move the energy impact of storm waves from the dikes towards the outer edge of the salt marshes. Furthermore, after dike-breaching, a salt marsh can prevent the development and growth of a scour hole. It is also a source of material for dike repairs. Finally, it prevents damage at the seaward dike toe through tidal gullies migrating towards the dike. Thus, it could make the building of expensive slope revetments and groins superfluous. In recognition of these functions, the establishment and maintenance of salt marshes in front of dikes is a public obligation. At the same time, salt marshes have a high ecological value and are protected under the State Nature Protection Act. In 1995, the Coastal Defence and Environmental Administration, together with local water boards, adopted a salt marsh management concept to integrate both functions (HOFSTEDE, 2003). The results of management based on this concept are regularly evaluated by a technical board, working on principles of an Integrated Coastal Zone Management-ICZM'. The board consists of members from coastal defence and nature protection authorities together with representatives from local dike boards, NGOs and the municipalities. The success of the concept is demonstrated by the fact that, despite sea level rise, the salt marsh area in the Schleswig-Holstein sector of the Wadden Sea increased by about 16 % from 1995 to 2005.

The oldest technique to enhance salt marsh growth is the drainage of the salt marsh surface along with a narrow strip of the adjoining mud flat. With this reclamation technique, the aerated zone is shifted to a lower level in relation to mean high water, resulting in a horizontal extension of the salt marsh vegetation (DIJKEMA et al., 1990). In order to function, the

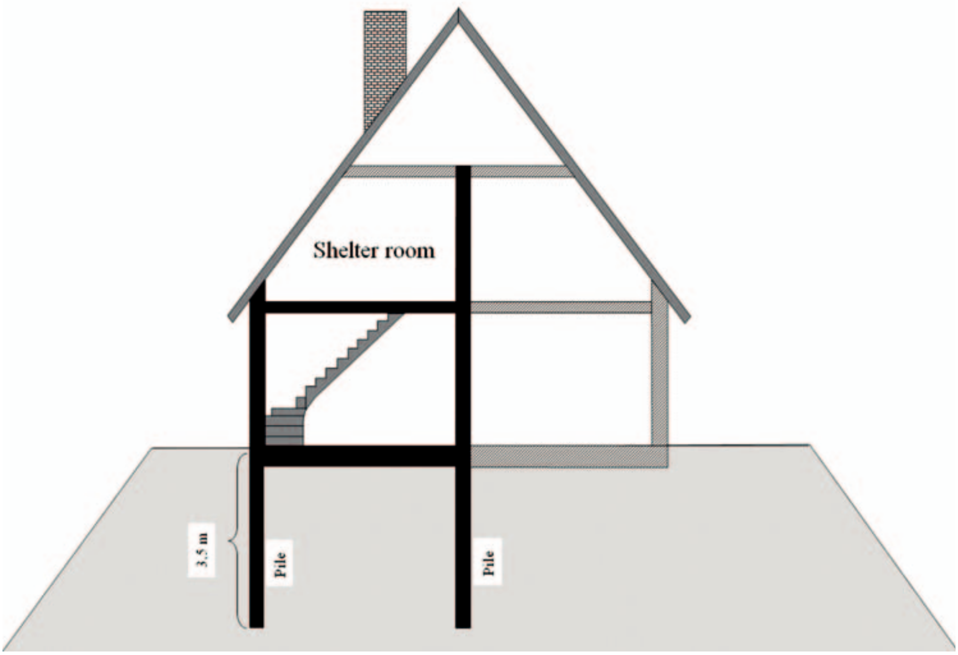

Fig. 5: Flood proof room in houses on the Halligen

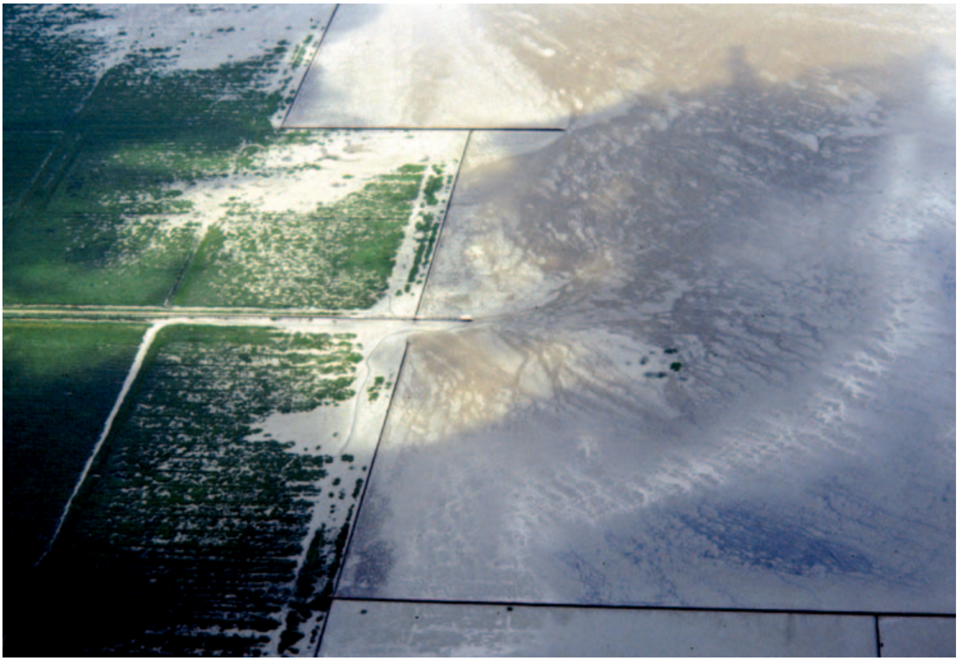

Fig. 6: Salt marsh protected by groin fields

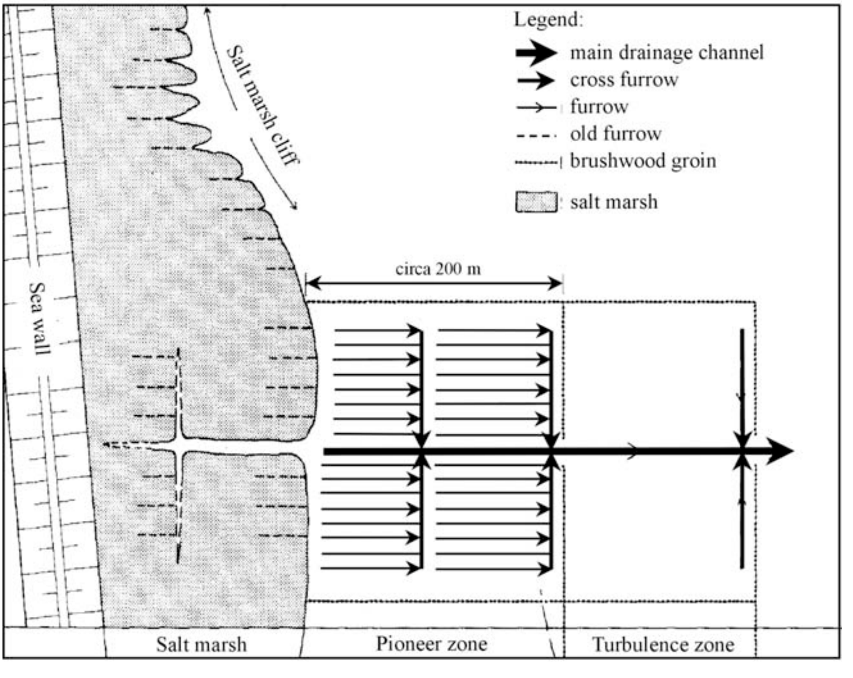

Fig. 7: Echelon system of salt marsh management

drainage needs to be cleaned on a regular basis. Another old technique is the building of brushwood groins in front of salt marshes. With this technique, wave and tidal energy, the most critical factors in salt marsh formation, are reduced significantly. As a result, sedimentation of suspended matter behind the groins and in front of the salt marsh edge is enhanced. The positive effect of the brushwood groins upon salt marsh growth is demonstrated (Fig. 6). A combination of both techniques, the so-called „Schleswig-Holstein Method“, was introduced by the Prussian government in 1900. It consists of brushwood groin fields with a size of about 200 x 200 m combined with a drainage system. The presently applied echelon system in salt marshes, as shown in Fig. 7, is based upon this Prussian method. In the turbulence zone, tidal and wave energy within the water column are reduced. Within the accretion zone, deposition of suspended matter reaches its maximum thereby stabilising the salt marsh zone (HOFSTEDE, 2003).

Sand nourishment

Sand nourishment at the islands of Sylt and Föhr constitutes the third main aspect of the coastal defence strategy along the West coast of Schleswig-Holstein (Fig. 8). Since 1963, more than 40 million m^3 of sand have been deposited at the beaches of these two islands (Sylt 37, Föhr 3.3 million m^3). With this sand, shoreline retreat could be halted. Comprehensive investigations demonstrate that this technique, the results of which are sometimes questioned, is most effective for technical as well as economic and environmental reasons. For example, the application of nourishments may make ‘hard’ coastal protection structures, which can cause negative side effects such as lee-erosion, superfluous. Hence, both islands are stabilised in a sustainable manner.

Fig 8: Sand nourishment on the isle of Sylt

Traditionally, the sand is deposited directly on the dry beaches (Fig. 8). Because of the technical equipment needed, this represents a relatively expensive method to balance coastal erosion. Furthermore, although the retreat of the shoreline can be halted, the evolution of the entire coastal profile may remain negative, causing coastal profile steepening. As a consequence, higher waves may approach the beach, inducing stronger coastal erosion during storm surges. Sediment budget analyses indicate that this was the case in front of Sylt. Hence, in 2006, major foreshore nourishment was conducted. About 850,000 m^3 of sand were dumped directly on the outer reef. In this way, about 150,000 m^3 of sand more could be deposited without extra costs. A monitoring program is under way to evaluate the effect of this technique that is already routinely being applied in Denmark and the Netherlands.

3. Outlook

About 47 km of the State dikes along the North Sea coast of Schleswig-Holstein still need to be strengthened in order to meet the safety standards as described in the master plan coastal defence. In 2007, the 'International Panel on Climatic Change – IPCC' published its fourth report on future climate change (IPCC, 2007). Although within the range of sea level rise scenarios the expected increase was slightly diminished (18 to 59 cm until 2100), significant uncertainties remained, concerning e.g. an accelerated melting of the Greenland ice cap. However, even if the Greenland ice cap melted faster than expected, the safety margin of 50 cm adopted in the master plan would be valued as being high enough. It is concluded that the situation is (still) serious, but no adaptations to the present strategy are necessary. With respect to climatic change and increasing utilization of the coastal zones, the master plan states that coastal flood defence will never end!

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