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Coastal Flood Defence and Coastal Protection along the Baltic 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 Baltic Sea coast of Schleswig-Holstein. For the North Sea coast, the reader is referred to chapter 1.2.1.

In contrast to the relatively plane North Sea coast, the Baltic Sea coastline of Schleswig-Holstein was formed during the last ice age by glaciers. They left a strongly undulating relief with moraine hills and glacier valleys. In the course of the Holocene sea level rise, the valleys were inundated and a coastal landscape developed, characterised by elongated bays (Förden) and headlands. In all, the coastline measures 637 km, 162 km of which belong to the semi-enclosed Schlei-Förde and another 87 km to the island of Fehmarn (Fig. 1). About 148 km of the coastline are occupied by soft cliffs. As a result of the Holocene sea level rise and the hydrologic forcing, the long-term morphologic development is characterised by a general retreat of the headlands. For example, the headland "Brodtener Ufer" to the North of Lübeck retreated by about 6 km in 6,000 years. The material that was eroded from the headlands was partly transported into the bays (longshore drift). Here, it accumulated in spits which in some cases almost completely cut off the bay from the Baltic Sea (e.g., Schlei-Förde). Over the time period of 1872/76 to 1951/68, almost 182 km of the coastline receded, whereas 128 km moved forward. Maximum retreat rates are registered at Heiligenhafen cliff with up to 2.5 m/a, whereas the 'Graswarder' spit situated some kilometres to the East is growing by 2 to 3 m/a (Fig. 2).

The first dike at the Baltic Sea coast of Schleswig-Holstein was erected about 30 km to the East of Flensburg in the year 1581. In the 18th and 19th century, more dikes were built due to private initiatives. These were, however, under-dimensioned and were destroyed during storm surges. The highest storm surge in the Western Baltic Sea was registered in the year

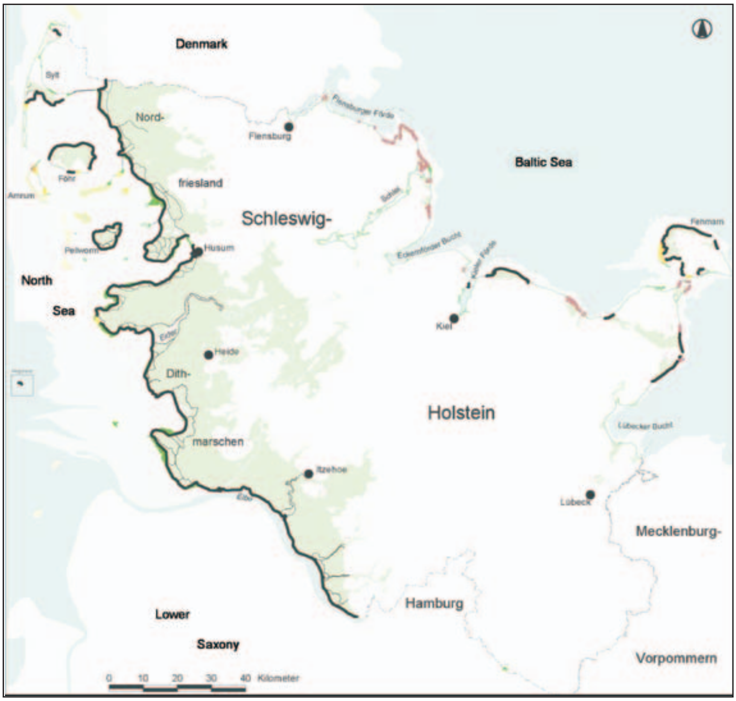

Fig. 1: Overview of Schleswig-Holstein with State dikes (black bold lines), regional dikes (brown lines), and coastal lowlands

Fig. 2: The Graswarder spit near Heiligenhafen

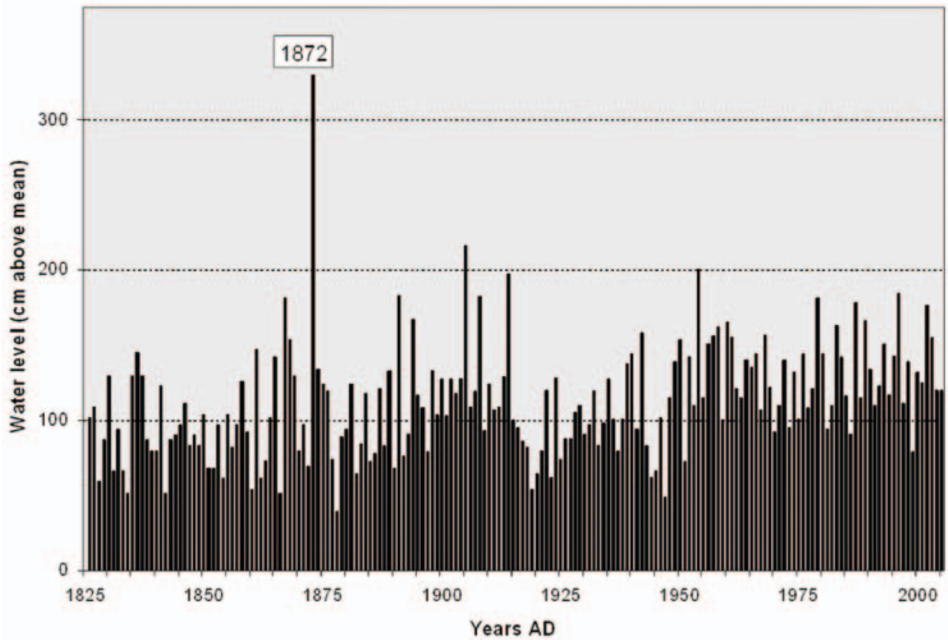

Fig. 3: Development of yearly highest water levels in Lübeck since 1826

1872. With a water level of up to 3.3 m above mean sea level, this event was almost 1 m higher than all previous and following surges (Fig. 3). This storm surge, which caused 271 fatalities, constitutes the turning point in coastal flood defence along the Baltic Sea coast of Schleswig-Holstein. From now on, the Prussian Government systematically planned flood defences. The dike profile that was developed already showed the basic characteristics of modern dikes. In the decades following 1872, the first major public defence programme was implemented.

Due to the undulating topography with bays and headlands, a large number of isolated coastal lowlands exist along the Baltic Sea coast of Schleswig-Holstein (Fig. 1). Approx. 92,000 people live in these lowlands, and economic values of 15.4 billion Euros are concentrated mainly in the port cities of Kiel and Lübeck (HOFSTEDE, 2004). Apart from the harbours, significant economic values are concentrated in a number of coastal tourist resorts such as Timmendorfer Strand (see below).

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 the greater Hamburg area, 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. In the year 2000, the new master plan "Integrated

Coastal Defence Management in Schleswig-Holstein" was prepared by the responsible administration. After comprehensive public consultations, it was adopted in 2001 by State Government (HOFSTEDE, 2004). The master plan describes the mid-term 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 climatic change.

2.2 Measures

Coastal flood defence along the Baltic Sea coast of Schleswig-Holstein mainly consists of sea dikes. In the Lübeck Bay, a flood defence scheme (sheet pile wall) of about 10 km length is presently being established. Both techniques being used are described below.

Sea dikes

In contrast to the North Sea coast of Schleswig-Holstein, a large number of isolated coastal lowlands exist along the Baltic Sea (Fig. 1). Most of these are protected by dikes. In all, 117 km of dikes protect the lowlands from flooding: 67 km are State dikes (Fig 4; Probstei), the rest are regional dikes. In contrast to State dikes, regional dikes do not have fixed safety standards and are mostly within the responsibility of dike boards. The safety standard of a state dike includes a design water level, a design wave run up and an extra safety margin to account for future sea level rise (Fig. 5). 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 then), and
3) it should not be lower than the sum of highest spring tide water level and highest observed surge.

For the Baltic Sea coast, the storm surge water level of 1872 represents the highest water level and, consequently, the respective design water level (incl. sea level rise since then), on top of which a design wave run-up is calculated.

With the establishment of the new coastal defence master plan, a safety check was conducted with localised water level values based on nearby tidal gauge stations. It turned out that, in all, 35 km of state dikes needed to be upgraded to meet the safety standard. From 2001 until the end of 2007, only 3.5 km (10 %) have been strengthened. This low achievement is a result of complex local situations and a focus on the North Sea coast (see page 134).

Other flood defences

Not in all flood prone coastal settlements along the Baltic Sea dikes are appropriate, especially in tourist resorts. Hence, alternatives have to be found. One example is the Lübeck Bight. Here, in the coastal resorts Timmendorfer Strand and Scharbeutz, almost 6,000 people live less than 3 meters above mean sea level (MSL). Capital values amounting to 1.75 billion Euros, mainly tourist infrastructure, are situated in this area. The existing flood defence for the coastal lowland is a barrier beach system with a mean elevation among 2.5 and 3.0 m above MSL. Hence, from a flood defence point of view, the situation is rather critical. It is estimated that a breaching of the barrier will occur with a water level of about 2.1 m above MSL. Fig. 6 displays the frequency distribution of the highest annual water levels for the time period between 1921 and 1996 at the gauge station Neustadt, situated about 10 km to the North.

Fig. 4: State dike with T-groins about 25 km to the Northeast of Kiel

From this diagram, it can be seen that, statistically a water level of 2.1 m above MSL has, in the present situation, a return interval of about 100 years. If MSL rises by 0.5 m, the statistical return period would be reduced to about 10 years. Considering the high capital values and human lives at stake and the long-term increase in flooding probability, it becomes evident that a sustainable flood defence solution is urgently needed.

With the last catastrophic storm surge about 135 years ago and an economic dependency on tourism (broad beaches), it is evident that the local population was rather sceptical towards coastal flood defence ("dike on the beach"). However, since the municipalities are responsible for flood defence they decide whether and what kind of sea defence is implemented. The coastal defence administration has an advisory function and may contribute to the costs. Hence, an appropriate coastal defence solution for the area can only be achieved with active involvement of and acceptance by the local population. To find a sustainable and integrated solution, an active participation procedure was conducted by external moderators (HOFSTEDE, 2001). Coastal administration did not interfere with this process; they only presented and illuminated the problem (Fig. 6). Based upon the systems theory, citizens of the two municipalities developed a model of their region. With this model and based on several coastal flood defence scenarios (e.g., "do nothing"/ "dike on the beach"), they simulated possible future developments. The model was "activated" by a step-by-step MSL rise (i.e., increase in the probability of flooding; Fig. 6). The main outcome of this procedure was:

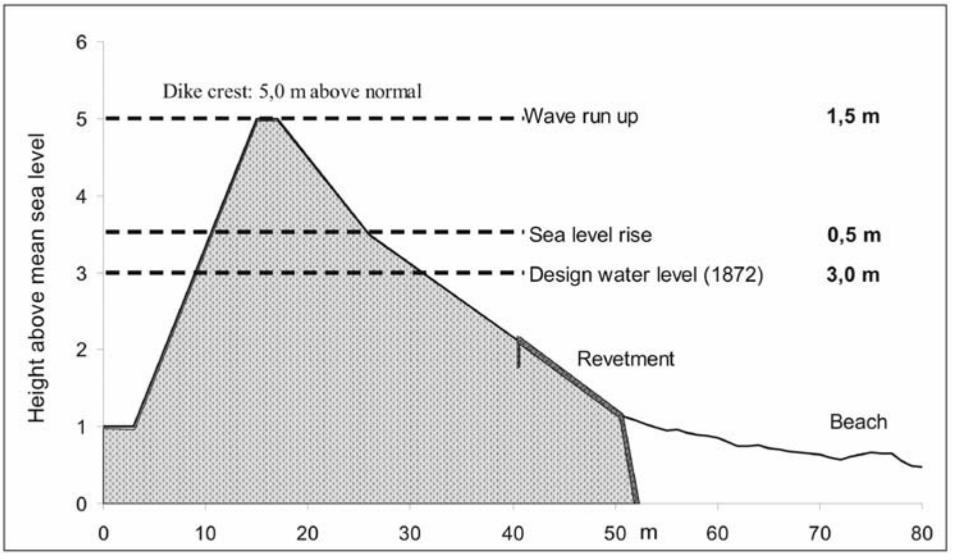

Fig. 5: Dimensions of a state dike along the Baltic Sea (schematic)

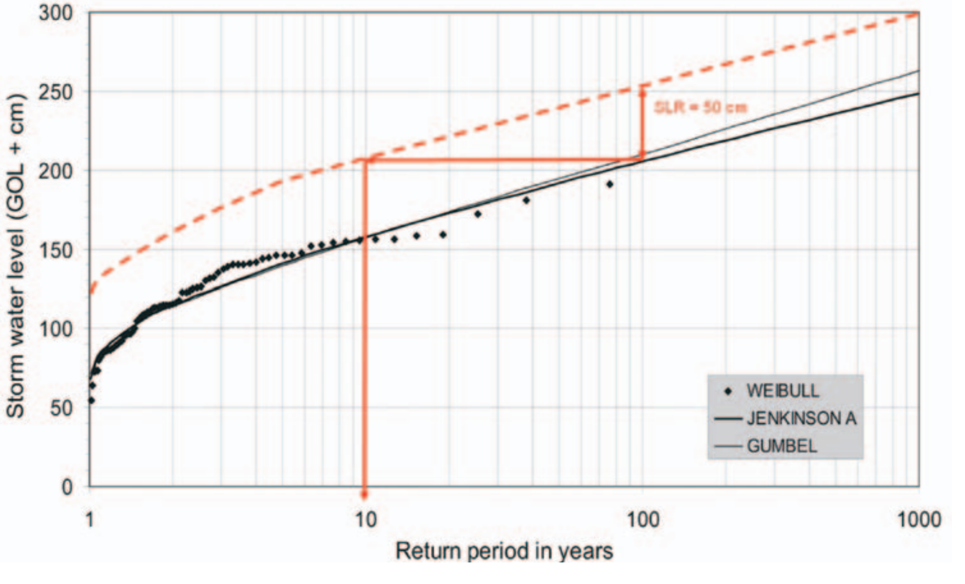

Fig. 6: Frequency distribution of the yearly highest high water levels at gauge station Neustadt for the period 1921–1996. Depicted also is the situation for a 50 cm higher sea level and its consequences for the occurrence probability

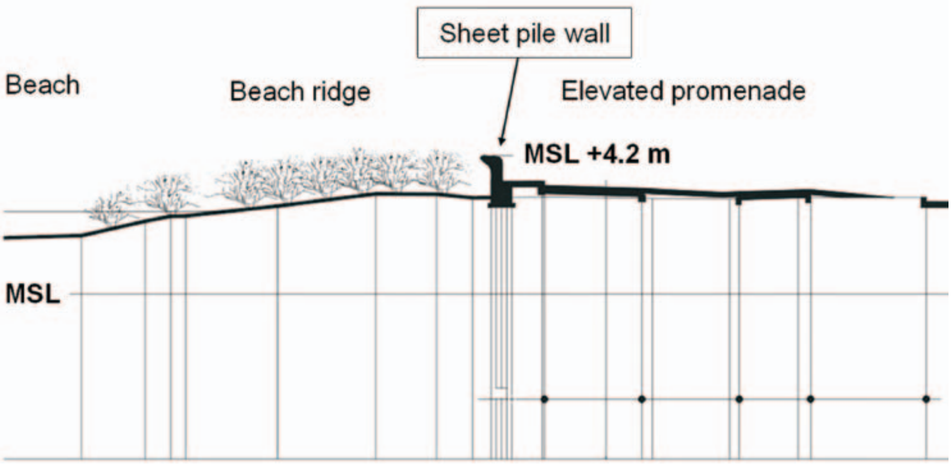

Fig. 7: Flood defence scheme for Timmendorfer Strand and Scharbeutz

Fig. 8: Sheet pile walls mounted with concrete holms and fronted by sand containers

Fig. 9: Flood defence scheme "hidden" under sand and marram grass

- the participants recognised the long-term risk for their coastal lowlands,
- they accepted their responsibility to anticipate this risk, and
- they evolved from sceptics to advocates of an integrated coastal defence concept that "fits" into the coastal landscape.

For a comprehensive description of the procedure, the reader is referred to HOFSTEDE (2001). With the basic requirement of an integrated solution, an ideas competition between selected consultants was conducted. The winning scheme is presented in Fig. 7. It consists of a sheet pile wall with concrete top rails, installed behind or within the natural beach ridge. As a toe protection, sand containers will be placed in front of the wall. Different stages of implementation are shown on Figs. 8 and 9. After completion, the structure will be buried under the beach ridge or camouflaged as a promenade wall. It should be emphasized, that the scheme does not guarantee protection against a storm surge event of 1872 dimensions (see Fig. 3). After long discussions, the municipalities decided that the costs of such a solution would be too high. Further, the interference with tourism was judged to be too intense. Thus, the citizens accepted the risks present without further protective structures.

Coastal protection

Due to its advantageous orientation to the dominant wave directions, the Baltic Sea coast of Schleswig-Holstein is, relatively stable (EIBEN, 1992). However, local erosion problems have resulted in a number of protective measures, mainly groins. The first groins were constructed in the years 1878/79. In the 1980s, 43 so-called T-groins were built near Kiel as foot protection for the new sea dike (Fig. 4). Finally, toe protection revetments were built in two locations in front of a coastal cliff and of a regional dike. These examples show that the Baltic Sea coast of Schleswig-Holstein is rather free from protective structures.

3. Outlook

About 32 km of the State dikes along the Baltic Sea coast of Schleswig-Holstein still need to be upgraded to meet the safety standards as described in the Coastal Defence Master Plan. Due to a low risk awareness of the local population and often complicated local situations, the strengthening of these dikes remains a challenge for the responsible administration. 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. At present, no acceleration in regional sea level rise can be deduced from the records. Over the last 100 years, the mean sea level along the coasts of Schleswig-Holstein rose by about 0.15 cm per year. On medium-term, however, a doubling and tripling of the present rates should be accounted for. This will have serious consequences for the sandy coasts of Schleswig-Holstein. Coastal stretches that are now stable or even accreting may become erosive. Considerations on how to adapt to this challenge are needed urgently. With respect to climate change and increasing utilization of the coastal zones, the master plan states that 'coastal protection will never end'!

4. References

EIBEN, H.: Protection of the Baltic Sea Coast of Schleswig-Holstein. In: DVWK (Ed.), Historic Coastal Defence. Verlag Conrad Witwer, Stuttgart, 517–534, 1992 (in German).

EUROPEAN COMMISSION: Recommendation of the European Parliament and of the Council of 30 May 2002 Concerning the Implementation of Integrated Coastal Zone Management in Europe (2002/413/EC), 2002.

HOFSTEDE, J. L. A.: Participatory Planning in Coastal Defence: a Pilot Study From the Baltic Sea Coast of Germany. Proceedings of the 36th MAFF Conference of River and Coastal Eng., pp. 02.2.1–02.2.12, 2001.

HOFSTEDE, J. L. A.: A New Coastal Defence Master Plan for Schleswig-Holstein. In: SCHERNEWSKI G. u. T. DOLCH (Hrsg.): Geographie der Meere und Küsten, Coastline Reports 1, 109–117, 2004.

IPCC – INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE: The Physical Science Basis – Summary for Policymakers. IPCC-secretariat, Switzerland, 21 pp., 2007.