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Coastal Protection along the Baltic Sea Coast – Mecklenburg-Vorpommern

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1. Geological and Physical Characteristics

The coast of Mecklenburg-Western Pomerania (Mecklenburg-Vorpommern) with an overall length of 1,945 km is highly structured as a result of primal glacial shaping. The coastal equilibrium processes which still persist today have resulted in extensive cordoning-off of the shallow coastal lagoons and backwaters from the Baltic Sea. The length of the external coastline is 376 km whereas the length of the coastal lagoon and backwater coastlines is 1,569 km. Especially the external coastline, which frequently alternates between steep cliff sections (128 km) and flat coastal sections (248 km), is highly dynamic. Approx. 70 % of the external coastline is in a state of recession with an average recession rate of 34 metres in 100 years, while only 7 % is subject to accumulation. The present-day coast of Mecklenburg-Vorpommern is comprised of three large morphological sections:

- The large bays of Holstein-West Mecklenburg (running from Priwall to the north-east beach of the Wismar Bight)
- Mecklenburg equilibrium-state coastline (Bugspitze to the Rostock Heath)
- Coastal lagoon equilibrium-state coastline of West Pomerania (Rostock Heath up to and including the island of Usedom/Odra bay [Oder Bucht])

Coastal evolution along the south-west coast of the Baltic Sea began about 8000 years ago following flooding of the deeper-lying glacial drift landscapes and valleys and the commencement of shoreline erosion during Litorina transgression. It was only after the cessation of the pronounced rise in sea level about 6000 years ago that a new phase with only slight sea level fluctuations began. This phase, which still persists today, was accompanied by enhanced coastal equilibrium processes. Coastal shaping and reshaping depends decisively on the already existing topography as well as on wind conditions and the resulting wave and current climate.

The present cliffs, beaches and shores of the coastal lagoons in our federal state are essentially in a delicate state of geo-morphological balance. With different objectives in mind, natural coastal equalization processes along many stretches of coastline are influenced by coastal and flood protection measures (e.g. groin construction, construction of sea walls, beach replenishment, dyke construction). This primarily concerns the external coastline, which is strongly affected by coastal dynamics. Public awareness has been and continues to be aroused by the recent dramatic changes along the steep coastal stretches of our state, especially the cliff falls on Rügen. Although the call for an effective coastal protection strategy along the cliff coastlines is understandable, these one-sided demands disregard the delicate balance between the three types of coast. It is therefore necessary to make the public aware of a coastal protection strategy which incorporates the entire coastline of the state.

2. Historical Events

Storm surges along the German Baltic Sea coast are outstanding natural events. These develop as a result of the coincidental combined action of a number of meteorological and hydrological processes which are mainly influenced by the configuration of the Baltic Sea as an elongated shallow sea with relatively narrow connections to the North Sea and the world's oceans. The reasons for the processes which may contribute to the development of storm surges in the south-western part of the Baltic Sea are low pressure regions of the westerly wind drift (storm depressions, intense low-pressure systems) which cross the Baltic Sea along characteristic paths, and especially in winter, result in strong winds with the above-mentioned consequences. Almost all storm surges, therefore, also occur during the winter months from October to March. The major factors which contribute to the development of storm surges are the degree of fill of the Baltic Sea, the setup due to seiches, and wind setup, which significantly affects water levels. In the case of small-scale domains in the form of bays, the effect of setup in bays is also of importance.

	Event	Wismar	Warnemünde	Greifswald
Heights of extreme storm surges based on historical records and geological findings (metres above the average water level at the time in question)	1044	3.35	3.15	3.35
	1134	2.85	2.45	2.55
	30. 11. 1320	2.80	2.65	2.65
	16. 10. 1449	2.60	2.50	2.70
	10. 02. 1625	3.80	3.60	3.80
	11. 01. 1694	3.38	3.01	3.08
Peak water levels of the highest measured storm surges from 1872 up to the present day (metres above NMW*)	13. 11. 1872	2.83	2.70	2.81
	31. 12. 1904	2.26	1.88	2.41
	30. 12. 1913	2.06	1.89	2.26
	02. 03. 1949	1.78	1.52	1.82
	04. 01. 1954	2.14	1.72	1.84
	03. 11. 1995	2.02	1.60	1.79
	21. 02. 2002	1.98	1.58	1.78

*) NMW = Present-day normal average water level along the coast of Mecklenburg-Vorpommern (MWP)
= 5.00 m at the tide gauge or 5.00 m above gauge datum
= 0.14 m below HN (HN = official levelling datum in the state of MWP)

The height, form and duration of storm surges depend on which of the above-mentioned factors are involved and how they are superimposed. In the most unfavourable case, i.e. when all factors coincide with their respective maximum possible increases in water level, it must be assumed that storm surge peak values of about 4.0 m above the normal average water level may result along the German Baltic Sea coast. Although such values have not as yet been measured, historical records handed down over the past 1000 years as well as the geological findings of the University of Greifswald derived from core samples of coastal and seabed deposits as well as shingle deposits on Rügen indicate that such extreme storm surges are indeed possible, as is also evident in the included table. The upper part of this short list contains the highest storm surges on the Baltic Sea coast of Mecklenburg-Vorpommern over the past 1000 years (1044 up to and including 1872) while the lower part of the list contains the highest storm surges accurately measured along our coast since 1872.

3. Design Water Level

The design high water level DHW (BHW) of a stretch of coastline is the high water level according to which the coastal protection structures for the stretch of coastline concerned are dimensioned. This constitutes the basis or fundamental base parameter for all design work in connection with coastal protection structures and also represents the safety level considered by the state as necessary and realisable in order to protect its citizens and material assets at risk in the coastal zone.

A basis for defining the BHW is the most severe storm surge of 1872 in the southern part of the Baltic Sea, as verified by measurements. The maximum water level (peak value) which occurred at that time has been scientifically checked in recent years by detailed investigations. The data recorded for the storm surges of 1625, 1872, 1874, 1904 and 1913 have also been discussed in detail, evaluated, and included where appropriate.

In Mecklenburg-Vorpommern the BHW is determined by means of the comparative value method, i.e. the secular sea level rise over two centuries subsequent to 1872 is added to the peak value up to about 2070, which corresponds to the end of the anticipated service life of many coastal protection structures. Forecasts of the relative secular sea level changes along the coast of MWP are possible due to the existence of tide gauge recordings over a period of 100 years as well as the monthly average and extreme water levels determined in recent years from a time series analysis of these data.

The past assumption of a linear change in sea level rise has been verified by investigations. The results of these investigations yield values ranging between 6 cm and 15 cm in 100 years. These results are significantly lower than those given by the scenarios of the Intergovernmental Panel on Climate Change (IPCC). The application of the IPCC values would lead to considerably higher water levels.

BHW values along the external coastline of Mecklenburg-Vorpommern are found to lie between 3.35 m below HN (Priwall) und 2.2 m below HN (North Rügen).

Based on an evaluation of recent geological data, it appears probable that the water level of the Baltic Sea along the coast of Mecklenburg-Vorpommern will rise by about 20 to 30 cm by the end of this century (2100). This will affect the external coastline as well as the coastlines of the coastal lagoons. This demands the basic continuation and upgrading of the existing "Coastal and Flood Protection Master Plan for Mecklenburg-Vorpommern" of 1994. The major work in connection with the latter may now be regarded as being completed.

4. Coastal Protection Strategy

The coastal protection strategy in Mecklenburg-Vorpommern is based on natural conditions and coastal protection engineering traditions. As far as protection requirements are concerned, the preservation of natural coastal dynamics is of top priority. Environmentally-compatible methods such as sand replenishment as well as the preferred use of natural construction materials, such as wooden posts in groin construction and natural stone in breakwater and revetment construction, are in keeping with the recommendations of the Helsinki Baltic Marine Environment Protection Commission as well as with (OK) the beach utilisation requirements posed by tourism.

Based on the state water law, the strategy is aimed at the protection of interconnected developed areas. A differentiated strategic approach is adopted according to the utilisation of those areas which are at risk of flooding or recession.

The rule along the flat stretches of the external coast is defence along the existing defence lines close to the shoreline. This also includes protection of the defence lines themselves against coastal recession. Besides the direct protection of towns and villages along the external coast, continuous chains of dunes and sea dykes prevent breaches into coastal lagoons and backwaters during storm surge events. Consequently, lower design high water levels and reduced wave loading can be applied here. Where continuous defence lines are not necessary, ring dykes are also constructed around towns and villages (adaptation) while undeveloped areas are left to the vagaries of the natural flooding process.

The realisation of coastal protection as a public obligatory task only applies to steep coasts if inner-town areas are acutely at risk due to coastal recession and/or if cliff falls are likely in the event of a design storm surge. If this is not case, the strategy of retreat is followed in order to retain the function of the cliffs as suppliers of sediment. Excluded from the latter are selected, exposed steep coastal sections which must be stabilised because of their far-reaching support function for neighbouring coastal sections.

Besides defence along existing lines, a strategy of retreat is also followed along the shorelines of backwaters and coastal lagoons, especially in the case of under-dimensioned and fairly long dykes at remote locations. If engineering efforts and costs for the upgrade and maintenance of old defence lines, intended to withstand the BHW, are not justified, these are replaced by considerably shorter new dykes in the proximity of towns. In this connection, the aim is to renaturate dyked-in areas for various reasons, e.g. as a compensation for unacceptable encroachments due to coastal protection measures. If required, the old dykes are retained in order to reduce loading on the new structures or sustain agricultural utilisation.

Special demands are posed by the necessary protection of port towns at risk of flooding, where high damage potential exists and where protection structures are often absent or inadequate at the present time. This requires intelligent solutions which suitably blend in with the urban environment. Shortened defence lines in the proximity of the coast are only possible and appropriate in exceptional circumstances, as illustrated by the storm surge protection measures for Greifswald, in which a tidal barrier in the Ryck river is planned as the central component. As this will lead to an increase in the availability of relatively flood-secure areas suitable for building development, this is in a certain sense equivalent to advancement.

The rule in urban areas is rather a strategy of adaptation. Besides the construction of linear defence structures, especially sea and embankment walls, this also includes the raising of ground levels and the construction of DWH-safe storey heights as well as suitably adapted utilisations within the framework of urban and town planning. Mobile elements should only be used in exceptional cases or for the protection of objects. The number of operational openings should be minimised.

5. Coastal Protection Structures

Coastal protection dunes constitute the major coastal protection element over a length of 106 km of coastline in the state of MWP. Along 2/3 of this length, dunes alone must be capable of withstanding storm surges without backup by dykes. For this reason, sand replenishment is a dominant coastal protection method along these stretches of coastline. During the period 1990–2005, 13 million m^3 of sand were used for dune, beach and backshore nourishment. A major component of the coastal protection system along the external coastline consists of groins (Fig. 1), whose task is to reduce natural recession or stabilise replenished sand. The total number of groins amounts to 1,129. The major proportion of these consists of single-row wooden-post groins. These are incorporated into 12 groin systems over 81 km of coastline. Exposed and heavily-loaded steep stretches of coastline which border acutely endangered inner-town areas or which have a support function for neighbouring flat coasts are nowadays effectively stabilised locally by beach-parallel breakwaters (Figs. 2, 3, 4). Rubble mound structures or sea walls in the proximity of cliffs were used for his purpose in earlier times. The total length of the state's coastal protection dyke system (1^{st} order dykes) is 150 km. Of this total, 107 km consist of coastal lagoon and backwater dykes, while 43 km consist of sea dykes (Fig. 5). These provide flood protection over a length of 33 km in combination with load-reducing dunes or rubble mound banks along the foreshore. In the event of the design storm surge, an area of about 105,000 ha is at risk of flooding because of the low natural terrain level. Without effective protection structures, about 8.7 % of the population of Mecklenburg-Vorpommern would be thereby be affected.

Over the past 15 years, the costs for the new construction and strengthening of coastal protection structures as well as for preserving their performance capability amounted to 249 million €. The relative costs for the various protection measures are shown in Fig. 6.

6. Traditional Coastal Protection System in Mecklenburg-West Pomerania: Dune – Coastal Protection Woodland – Dyke

Following the storm surge of 1872 and the subsequent storm surge events of 1904, 1913 and 1954, sea dykes were constructed on the Fischland-Darß-Zingst peninsula and the island of Usedom at a distance of 100 to 200 m from the shoreline. The purpose of these dykes was to damp waves in the foreshore zone. In order to provide continued protection in the event of dune breaching and subsequent levelling of the surrounding terrain, an additional damping element was necessary. For this reason, trees were planted on the foreshore between the dykes and the dunes in order to create so-called coastal protection woodland.

During the years 1994/95, the effectiveness of coastal protection woodland as a damping element was scientifically investigated. This investigation revealed that the wave-damping action of woodland had been overestimated in the past. Besides the roughness geometry (dependent on the woodland configuration) and the initial wave parameters, particularly the residual dune height following overtopping as well as the foreshore level were found to have a significant influence on wave heights at the dyke. Woodland widths of < 30 m, which still

Fig. 1: Groins in Rostock-Warnemünde

Fig. 2: Breakwaters in Ahrenshoop

Fig. 3: Breakwaters and sea bridge in Wustrow

Fig. 4: Breakwaters and sea wall on the Island of Usedom

Fig. 5: Groins, beach nourishment, dyke and steel wall in Markgrafenheide

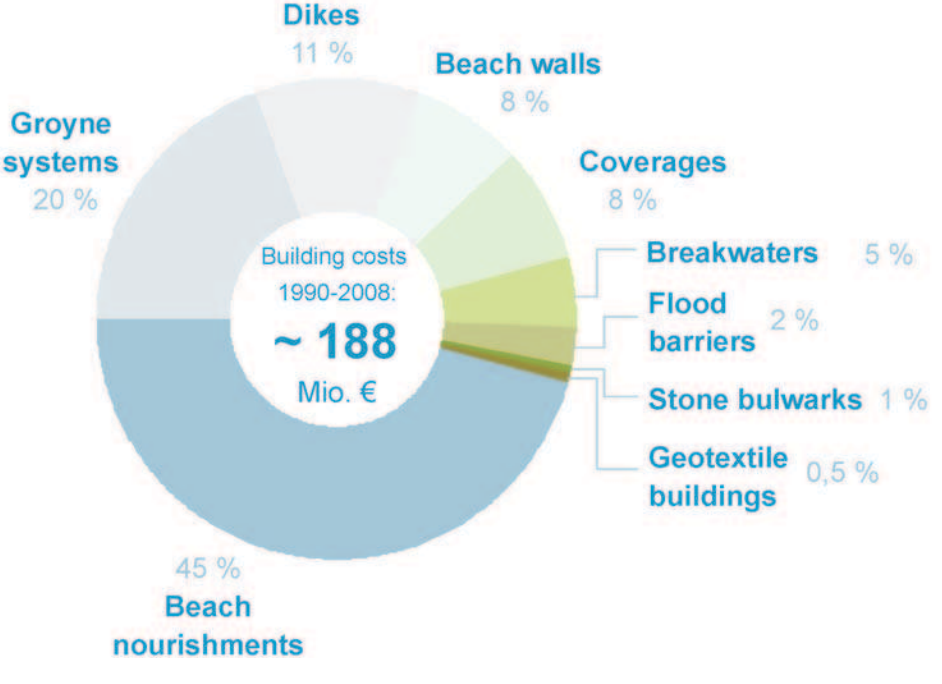

Fig. 6: Compilation of costs for coastal protection measures during the period 1990–2008

partly exist today, are unable to provide the necessary damping action. With the exception of widths > 100 m, coastal protection woodland is not included in dyke dimensioning calculations even though it is still retained as an additional wave-damping element.

The woodland does have positive functions, however, such as the promotion of aeolian dune development and preservation as well as armouring of the foreshore terrain.

7. Future Developments, Research

7.1 Continuation of the Master Plan

The Coastal Division of the State Agency for the Environment and Nature Conservation in Rostock (STAUN – Staatliches Amt für Umwelt und Natur Rostock) is currently working on the update of the existing master plan in the form of guidelines. Besides cataloguing the measures implemented so far, projects to be undertaken in the coming years have also been earmarked. At the same time, the currently valid methods applied for designing coastal protection structures are also being examined. Extensive investigations have been carried out for this purpose in recent years.

The previously adopted principle of applying a design standard for all coastal protection structures along the external coastline as well as backwater coastlines has now been formulated more flexibly: the design water level for a particular coastal section is now specified within a prescribed tolerance range, whereby economic and ecological criteria as well as communal interests are taken into account in a risk analysis.

The upper bound of the tolerance range is defined by the values corresponding to the storm surge of 1872, i.e. values based on actual measurements in the case of the external coastline, and values based on the results of numerical modelling at the University of Dresden for backwaters and coastal lagoons, taking into consideration the secular changes in sea level in each case.

7.2 Coastal Spatial Information System (Coastal SIS)

Work has now begun on the complete changeover from the ArcView projects to ArcGIS, including the conversion of all data to the official height and position reference system ETRS89/DHHN92. Further development of the present coastal SIS is also planned. Key aspects of the latter include public-relevant possibilities of presenting the results and complex intersection possibilities between the different databases of the Coastal Division and the existing spatial base data.

7.3 Coastal Digital Terrain Model (Coastal DTM)

The existing DTM has aroused a great deal of public interest in the past two years and has become an important tool for planning work in the coastal zone. Casting our sights beyond the initial versions, however, plenty of work is still necessary to update and maintain the ArcGIS-based and html-based versions of the digital terrain model "Endangerment of the Mecklenburg-Vorpommern Coast", taking into consideration different BHW levels, setup heights and flooding scenarios over a potential flooding area of about 6,500 km^2. This will primarily involve the development of new methods for computing realistic flooding areas for new coastal protection concepts as well as for computing the consequences of damage events.

7.4 Partly-Automated Dune Register (PADR)

Dunes are an essential element of the coastal protection strategy in Mecklenburg-Vorpommern. The purpose of the PADR is to promptly quantify dune break-offs following storm surge events. This involves a comparison of surveyed dune profiles (actual dune profiles) with nominal dune profiles, taking into consideration changes in the shoreline and scarps. This will permit the development of partly-automated routines, i.e. routines for incorporating new dune surveys with wide area coverage, e.g. by means of airborne laser scanning following a storm surge event.

7.5 Measurement Surveys

Land and sea surveys along the shoreline and the backshore as well as at sand extraction points will be extended by measurements using side scanners, fan echo-sounders, boomers and ammunition detectors. The survey results will provide input data for problem-oriented morphological, sedimentary and biological monitoring programmes, taking special account of the dynamics/variability of the coastal zone. With regard to the design and planning of coastal protection structures, the results of these monitoring programmes will serve to indicate the effects of coastal protection structures on the nearshore zone, thereby providing a sound basis for forecasting the influence and mode of action/effectiveness of these structures in the coastal defence system.