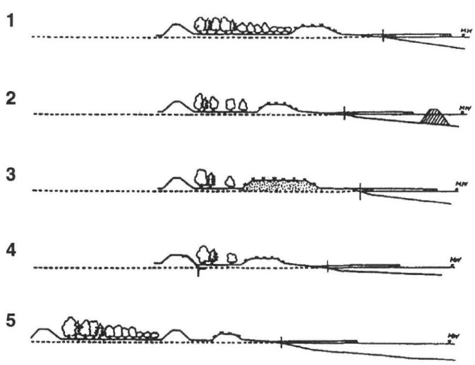
success allowing a further extension of his fields. After the Napoleon Wars which caused an interruption of these efforts KRAUSE [GERHARDT 1900] improved the scheme of BJÖRN [GERHARDT 1900] by implementation of rows of sand reed in flexible grids varying between 1,25 m and 5,65 m in dependence of dune steepness and wind action (Fig. 36). KRAUSE started furthermore the stabilization of foredunes as a direct coastal protection measure though still not realizing their function as part of the aeolian on- and offshore transport processes. Getting an insight into these processes HAGEN [1863] realized the necessity to equalize the cross-sections of the foredunes. His position as a high-ranking civil servant in the Prussian Ministry for Public Works allowed him to transfer his knowledge into practical application leading to dune reinforcements including in some cases even artificial nourishments and later the planting of sand reed. The motivation of HAGEN [1863] resulted from his insight in the crucial role of stable foredunes for the safety of the hinterland against inundation. But he did not recognize that this aim is only achievable at balanced coastal stretches. This fact was later realized by GERMELMANN [1904] describing the fate of foredunes in areas with structural erosion 'to become always a victim of the sea' which can only be avoided by an organized retreat. The state of the art then available on the basis of developments starting already in the 18th century serves still as the basis for present strategy and practice in dune stabilization at the Baltic coast into which additional materials and tools like synthetic materials and machinery equipment have been introduced.

Coastal protection forests. A unique application of natural vegetation for the purpose of coastal protection is the implementation of forest drawn up as coastal defense schemes (Fig. 37). Coastal protection forests have the function to dissipate wave energy in front of a dyke performing the most landward positioned part of the defense system for a lowland coast. It is expected though not yet proved that the coastal protection forests will absorb wave energy to such an extent that the dykes will experience neatly no wave attack and have only to keep the still water level during a storm surge. The implementation of the coastal protection forests is particularly an additional measure in areas where the capability of the foredunes is regarded as insufficient to guarantee its stability if a storm surge with long duration occurs. It is obvious that it is difficult to estimate or even to prove the effectiveness of coastal protection forest by conventional tools like hydraulic model tests or computations. Therefore, its capability can only tested in the case of a severe storm surge creating breakthroughs of the seaward parts of the system.



1 : Dyke with grass layer, wide coastal protection forest, dune at a balanced coast with or without groynes

2 : Dyke with grass layer, wide coastal protection forest, with minimum width, weak dune with offshore breakwaters and/or groynes at an eroding coast

3 : Dyke with grass layer, remnants of coastal protection forest, reinforced dune (repeated nourishments) at an eroding coast with groynes

4 : Exposed dyke with revetment; remnants of coastal protection forest, and dune at an eroding coast with groynes

5 : Retreat of the combined coastal defence system dyke - coastal protection forest - dune at an eroding coast with groynes. Dune and old dyke will merge by further coastal retreat

Figure 37. Distinct coastal defense systems with a coastal protection forest [WEISS 1992]

Coastal protection structures

Dykes. The lowlands at the Baltic Sea had in most cases a natural protection by foredunes or high beach berms. Therefore only a few dykes have been erected in the past. The first known construction at the German Baltic coast dates from 1581 at the Gelting Bay [KANNENBERG 1955]. Shape and position of this dyke are unknown, it was destroyed during storm surges in the 17th century. In this area

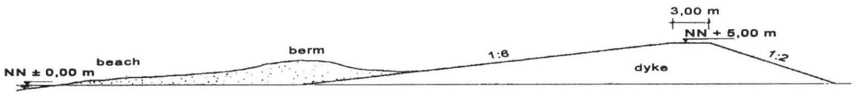


Figure 38. Cross-section of the Prussian Baltic Sea dyke of 1874 [EIBEN 1992b]

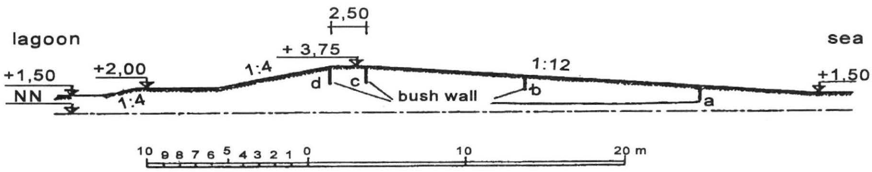


Figure 39. Cross-section of the sand dyke on the peninsula of Wustrow [WEISS 1992]

dykes have also been erected as protection of lowlands in the course of the 18th century. Further dyke construction started in other coastal areas of Schleswig-Holstein in the beginning of the 19th century. The disastrous storm surge of 1872 destroyed numerous foredunes and beach berms leading to the flooding of large areas and causing hundreds of victims. As well in the then Prussian provinces Schleswig-Holstein and Pomerania as in the Grand Duchy of Mecklenburg additional measures were regarded as necessary to keep the lowlands safe. Already 19 days after the event the Prussian government gave orders to erect dykes as additional protection of lowlands landward of foredunes or beach berms which should remained untouched but were regarded as too weak to withstand a very severe storm surge. The shape of the dykes was similar to present ones with a crest height of 5 m above mean sea level, a crest width of 3 to 4 m, an outer slope of 1:6 and an inner one of 1:2 (Fig. 38). If the position close to the shore was inevitable due to insufficient space landward of foredune or beach berm the dyke should be armoured by stone on a shingle layer and a toe protection of piles. The difference to the situations at the North Sea coast makes also the fact evident that at the Baltic coast no self-ruling communities for coastal protection existed. The Prussian government stimulated the coastal landowners to found such communities after the storm surge of 1872. In Mecklenburg dykes were unknown until the storm surge of 1872. But the lesson of this event lead also to the additional implementation of dykes in the coastal protection system. A remarkable construction was carried out in the framework of that programme on the peninsula of Wustrow in order to prevent a breakthrough: a sand dyke with an outer slope of 1:12 to withstand wave attack and an inner slope of 1:4 to reduce the sensitivity against erosion by overtopping (Fig. 39). It reflects a deep insight in the interactions of wave attack on structures

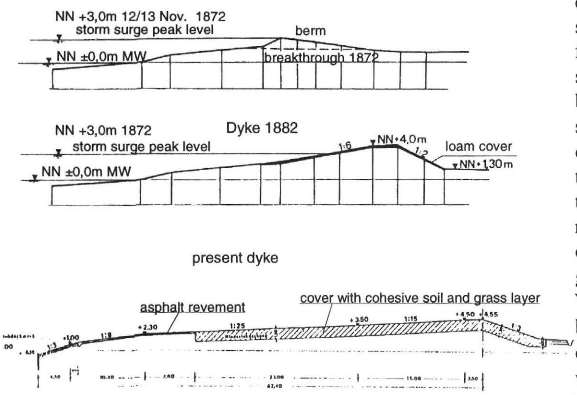


Figure 40. Initial beach berm, dyke cross-sections of 1882 and present at the Probstei coast, Schleswig-Holstein [EIBEN 1992b]

the capability of used material. Generally the design of dykes at the Baltic coast incorporated already all elements of present rules: design water level according to the highest known storm surge and empirical wave run-up in order to avoid overtopping and destruction of the steep inner slope. As well in the Prussian provinces of Schleswig-Holstein and Pomerania as in Mecklenburg in most cases the new dykes were positioned landward of the beach berm or foredune in distances between 100 and 200 m from the shoreline where wave energy was expected to be remarkably or even totally dissipated. This empirical approach proved itself as appropriate considering the fate of those dykes which had been erected close to the shoreline. The dyke in the Probstei was erected in the position of the beach berm after the storm surge of 1872 (Fig. 40). The dyke experienced a number of damages due to storm surges and needed additional armoring by revetments and toe protection before its replacement by a new construction in the beginning of the 80s of this century (Fig. 40) [EIBEN 1992b]. Already in 1898 the notes of a meeting of the local coastal protection community refers to that problem: 'Obviously the danger for the dyke due to direct interaction with the shoreface has been underestimated.' [KANNENBERG 1955]. In order to adress this problem recently the tool of beach nourishments has been introduced to reduce direct wave attack on the dyke. Nevertheless in general the programmes initialized after the storm surge of 1872 were successful, the Baltic coast experienced since then no comparable disaster. Honesty requires us to admit also that no comparable event had occurred in the meantime. Due to more recent assessments many of them would not have been able to withstand a storm surge like that one of 1872. After the World War II and particularly due to the experiences gained from the storm surges of 1954 and 1978 and 1979 reinforcements of existing or replacements by new constructions have increased the safety of lowland coasts at the Baltic Sea in the shelter of dykes.

Groynes. The first application of groynes at the German Baltic coast had the aim of reducing sedimentation at harbor entrances, e. g. at Pillau in 1811 and at Warnemünde in 1850 [GERHARDT 1900]. Later as well HAGEN [1863] as GERHARDT [1900] defined the purpose of groynes to preserve the shoreface and the beach. HAGEN [1863] regarded groynes as a part of coastal protection against storm surges: Keeping the beach as a wave energy dissipator by reducing or even minimizing erosion. He documented also the distinct construction methods of groynes in Mecklenburg and Pomerania being built in the first decades of the 19th century with lengths between about 18 and 37 m and a shore-parallel distance of about 23 m. At first groynes had only been implemented at bluff coasts but HAGEN [1863] recommended also their application at sandy lowland coasts. The design of the first groynes was purely empirical, the construction material was in the beginning fascines, later wooden piles and stones. The first known design criteria have been evaluated by GERHARDT [1900], unfortunately without explanation of their background: relation of length to distance between 1 and 1,5. In 1874 in Prussia the crest height was chosen to 0.2 m above mean water level [WEISS 1992]. In 1887 the first permeable groynes were implemented by spacing the wooden piles by 1/7 to 1/4 of their diameter. This completed the basic types of groynes still in use at the Baltic coast (Fig. 41)

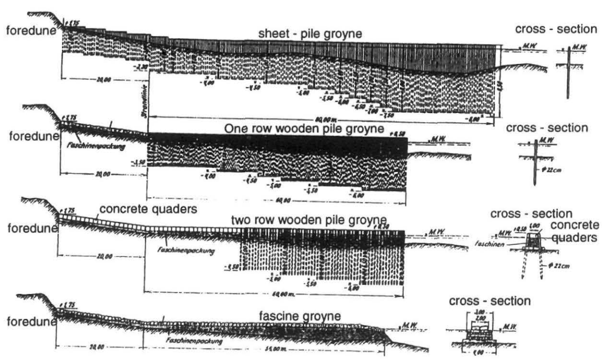


Figure 41. Types of groynes at the German Baltic coast [WEISS 1992]

COASTAL WATERWAY AND HARBOR ENGINEERING

The beginnings until the 19th century

Already in the first century A. D. Roman ships entered the estuaries of the Ems, Weser, and Elbe rivers for trading purposes. Sea trade at a larger scale started after the migration of peoples in Europe had finished in the middle of the first millennium A. D. Frisian sea traders built up settlements and trading places eastward of the Rhine along the North Sea coast but also entering the Baltic coast. In their times vessels were sufficiently small to find access to suitable coastal places by use of existing natural water depths. In the course of the 12th century A. D. by lead of the cities of Lübeck at the Baltic, of Hamburg and of Bremen close to the North Sea coast the Hanseatic League was established: a system of alliances between cities in the Northern hemisphere of Europe establishing an extended exchange of goods, particularly by seagoing vessels with a typical draft of 3,5 m. Those vessels could still get access to the large harbors by use of the existing natural waterways. In order to improve their safe traveling waterways were firstly marked by buoys, beacons and flares in the course of the 13th century.

Beside these efforts engineering activities were only necessary to install quays and similar facilities in the harbors enabling the ships to land and to take goods as easy and quick as possible. Before the 19th century engineering works in order to improve or to control waterways are only known for a few cases. The harbor of Emden had lost its access to the deep waterway in the Ems-Dollart estuary after a storm surge caused a break-through of a new channel in the 16th century and a silting up of the existing waterway. In order to give the seagoing vessels again access to the harbor the closure of this channel was at least tried in vain by erecting a wall of piles. First dredging (Weser estuary and Trave river) and implementation of groynes (Weser and Elbe estuary) is reported from the 18th century.

The operation of waterways and harbors demands for a certain standard of knowledge about available water depths and water level fluctuations. In order to meet these requirements as well survey and hydrographic mapping as water level measurements were established in the 16th and 17th century. A tidal gauge must have been available in the harbor of Hamburg in the 17th century, because since then the phase lag between high tide at London Bridge and this place is known for which a number of measurements is inevitably necessary [ROHDE 1975]. Unfortunately these data have been lost. Systematic tidal water level measurements in the harbor of Hamburg and their analysis had been initiated in 1786 by REINKE [1787] who considers them as needed for tidal compensation of soundings, information on extreme fluctuations and as design basis for engineering constructions. Other tidal gauges had been erected at the end of the 18th century at different places along the Elbe estuary, e.g., that one in Cuxhaven by WOLTMANN in 1784 who invented also an impeller for the measurement of current velocities in rivers [WOLTMANN 1790].

From the 19th century to present

In the course of the 19th century after the end of the Napoleon Wars sea trade with other continents gradually increased, particularly with Northern America which was also destination of an increasing number of emigrants from central Europe. Moreover Germany developed to an industrialized country importing raw material necessary for production and exporting goods. The use of steel instead of wood and the propulsion by steam instead of wind allowed the construction of larger vessels with larger draft demanding deeper waterways as access to the existing harbors [ROHDE 1970]. Thus in the middle of the 19th century modern waterway engineering got its driving force in Germany. The dimension of interference into the existing natural systems increased enormously and asked for a much sounder basis of process knowledge than ever before. As the theoretical knowledge was far beyond our present standard the common approach was empircal: a mixture of mostly regionally bounded observation or measurement in combination with basic process knowledge. According to that fact the history of German coastal waterway engineering will be discussed on the basis of the six most important coastal waterways: the Ems, Jade, Weser, and Elbe on the North Sea coast and Trave and Warnow on the Baltic coast.

EMS

After the already described break through of a new channel in the Ems river far away from the harbor, futile efforts for its closure and the subsequently silting up of its access channel the harbor of Emden lost its importance and position as one of the leading ports in Europe. But, during the last quarter of the 19th century, the import of ore for the industry of the Ruhr area and its coal export got shipped via a newly constructed canal to the port of Emden requiring a sufficient offshore access to the harbor which had to be established step by step. First off all a new harbor entrance was dredged and the harbor was closed off from tidal action and sedimentation by a lock acting moreover as a drainage sluice being used for concentrated outflows in order to maintain the entrance channel's cross-sections. The storm surge bay Dollart being enormously favorable with its large tidal prism for keeping cross-sections in the outer estuary stable was separated by a training wall from the waterway leading to the harbor entrance of Emden and further upstream in order to avoid import of sedimentation by the tidal ebb flow with high turbidity. Following the same purpose at least large tidal flats were enclosed and a new lock was established close to the waterway [SCHUBERT 1970]. In spite of further improvements by construction of new and enlargement of existing training walls the situation of the waterway to the harbor of Emden remained unsatisfactory in respect of the large quantities of maintenance dredging. In the 50s and 60s of this century another - at least again futile - approach to solve the problem was started: Interfering into the system by training walls and groynes in order to use the transport capacity of the flood tide for avoiding sedimentation in the Emden waterway and shifting it upstream where it would be less disadvantageous in respect of needed navigable water depth. In the 70s of this century a plan was introduced to close the Emden waterway by a new lock at both its seaward and upstream end, arranging new safe harbor areas on both shores being protected by a new dyke (Fig. 42). The river Ems should be passed through the storm surge bay Dollart [CARSJENS & CLASMEIER 1986]. Major aim of this plan was to avoid maintenance dredging in the Emden waterway and getting a smoother transition from the harbor entrance to the deeper parts of the estuary in which cross-sectional maintenance is supported by the tidal prism of the Dollart bay. Though never described this was an adaption on the basics of the concept which had been developed earlier and applied with remarkable success by KRÜGER in the Jade area. But the realization had to be postponed for years due to difficult negotiations with the neighbor country, the Netherlands. In the end, the project was abandoned for both ecological and economical reasons.

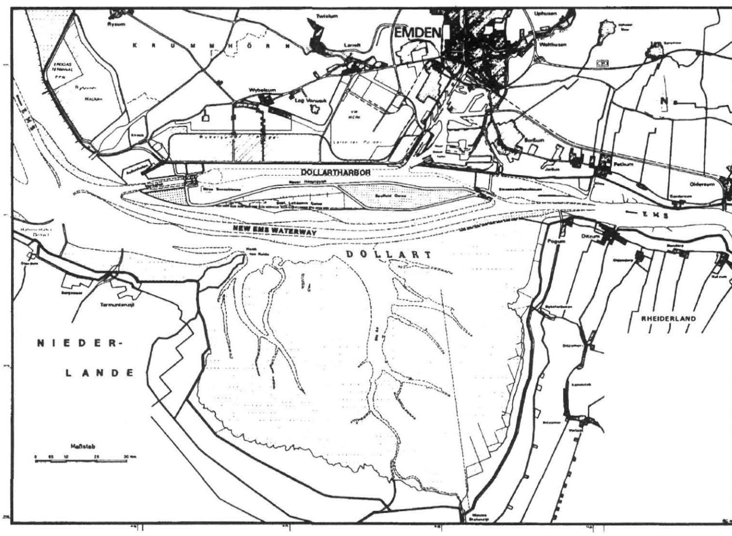


Figure 42. Dollart harbor (plan) [CARSJENS & CLASMEIER 1986]

JADE

The Jade inlet and bay were created by the erosive forces of storm surges after consecutive dyke breaks between the 13th and 16th centuries leading temporarily even to a link to the Lower Weser. The large tidal prism of the bay maintains large, stable cross-sections with remarkable water depths in the Jade inlet. Prussia though in possession of the harbor of Emden at the North Sea coast bought an area for the erection of a naval port called Wilhelmshaven at the Jade from the Grand Duchy of Oldenburg in order to use the natural advantages which became later more evident when the German Imperial Navy operated from that place large battleships of the 'Dreadnought' type.

The analysis of this area was carried out by HAGEN [1856], one of the best educated and most experienced German coastal engineers of his time. His heritage to our time beside others is the second historical record of an ordinary tide in the Jade area after that one inherited from BRAHMS about a century before [LUCK & NIEMEYER 1980]. Furthermore he combined his observations of tidal water levels with the fluctuation of silt content in the water column (Fig. 43). Later the migration of channels in the Jade and resulting occurrence of bars and shallows motivated the Imperial Navy to ask an experienced engineer of the harbor authority of Hamburg for an expertise. LENTZ [1899, 1903] recommended areal dredging in the Jade bay in order to increase the tidal prism and consequently its capacity of maintaining sufficiently large and deep cross-sections in the Jade inlet. The basics of that kind of indirect interference into the coastal processes is similar to the relation of tidal volume and channel cross-section which has become worldwide popular due to O'BRIEN [1931, 1967]. The knowledge about the important role of the bay's tidal prism for the stabilty of the Jade waterway was credited by a legal act in 1883 which forbade any land reclamation or other impacts in the Jade area leading to a reduction of the local tidal prism.

After the invention of the 'Dreadnought' battleships with enormously increasing dimensions the concept of LENTZ was no longer regarded as suitable to deliver sufficiently stable cross-sections in the Jade waterway, particularly in its offshore area. There the updrift banks were fixed by training walls and large groynes creating a small artificial island: Minseneroog. Moreover regular dredging created a stable waterway requiring only limited maintenance [KRÜGER 1922]. Before interfering into the system KRÜGER [1911] had carried out intensive investigations on the acting hydrodynamical forces and the long-term morphological development in this area in order to get a sound basis for engineering measures. He improved his concept in the course of the following decades and even after retirement until

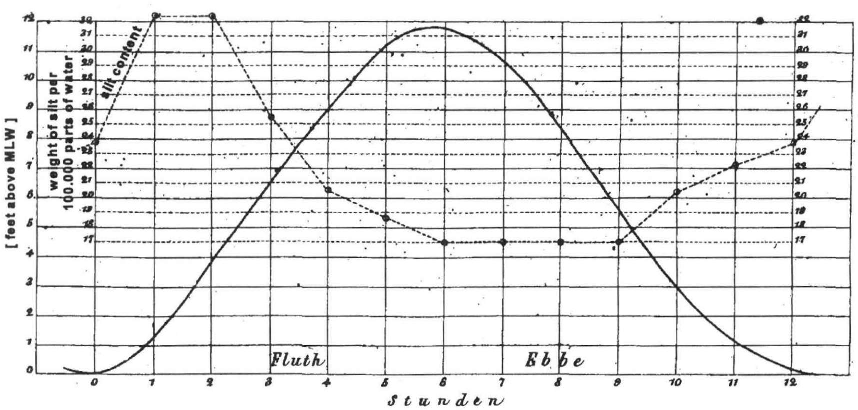


Figure 43. Tidal water level and silt content; Jade area (Fluth: flood; Ebbe: ebb; Wasserstand: waterlevel; Schlickgehalt: silt content) [HAGEN 1856]

his death incorporating an enormous number of scientists from coastal engineering and related disciplines. KRÜGER must be regarded as the initatior of interdisciplinary coastal research in Germany. Though the allied powers did not allow any maintenance of the Jade waterway after the World War II the correction of the Jade mainly inspired by KRÜGER was sufficiently successful to deliver a suitable basis for establishing at the Jade a deep water harbor for large tankers and bulk carriers step by step between 1958 and 1974. Vessels up to 250000 tdw and a maximal draft of 20 m are enabled to enter the piers at Wilhelmshaven [BRAUN & WITTE 1979].

WESER

The Weser estuary with the Outer and Lower Weser is the access for seagoing vessels to the port of Bremen. Since the 16th century the nautical conditions worsened more and more, particularly close downstream of the harbor of Bremen. In order to continue the profitable sea trade first harbor facilities were erected downstream of the existing harbor and at least in 1827 the port of Bremerhaven was founded in the transition area of Outer and Lower Weser by VAN RONZELEN [1857]. From there goods were transferred to Bremen by smaller vessels and land vehicles. For improving the safe access from the North Sea on a flat area bordering the Outer Weser a lighthouse was erected [VAN RONZELEN 1857] which is still in use as a basis for a radar based pilot system.

But still regaining an access by a sufficiently designed waterway in the Lower Weser guaranteeing sea trade as a major economical basis of the city of Bremen had political priority. The appointment of L. FRANZIUS, a very successful member of a well-known dynasty of East Frisian coastal engineers, as chief engineer of the harbor and waterway authority provided that aim with a feasible technical background: First of all the concept of FRANZIUS was contradictory to earlier local impacts the whole Lower Weser by creating a system of continuously increasing cross-sections in downstream direction with the major aim to minimize sedimentation and to achieve cross-sectional stability in the waterway requiring low maintenance efforts. As far as achievable, tidal flow was concentrated in the main channel by closing secondary ones and erecting groynes. The prospected effect was evaluated by estimated tidal curves which were expected to occur after the correction of the Lower Weser and used for computations of the tidal volumes. Applying the law of continuity an adaption of suitable cross-sections was carried out for getting nearly the same tidal current velocities along the estuary. Due to the impact of upstream freshwater a small dominance of ebb current was anticipated provoking a net seaward sediment transport [FRANZIUS 1888]. The approach of FRANZIUS was successfully carried out between 1883 and 1895 allowing ships with a draft of up to 5 m to get access to the harbor of Bremen (Fig. 44) by 'riding on the tidal wave' from Bremerhaven to Bremen. Remarkable also was that the expected effect of natural transport capacity was achieved: Only 50% of the necessary 50 million m^3 of sediment had been taken by dredging, the rest was evacuated by tidal flow. In order to stop the lowering of tidal water levels occurring after the correction of the Lower Weser further upstream in 1905 a tidal barrier was erected upstream of the harbor of Bremen [FLÜGEL 1988] reflecting the tidal wave there totally. The basic concept of FRANZIUS has been applied for a number of consecutive adaption of the Lower Weser waterway until the last one performed from 1974 to 1977 which enables ships with a draft of 12.5 m and

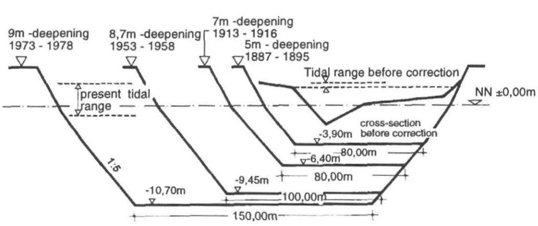


Figure 44. Cross-sections in the Lower Weser close downstream of Bremen since 1885 [WETZEL 1988]

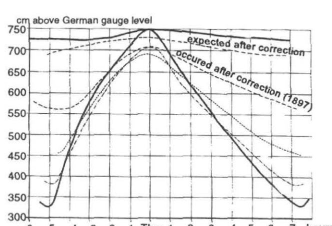


Figure 45. Tidal curves of the Lower Weser in Bremen between 1885 and 1978 [ROHDE 1970, 1980]

about 30.000 tdw to go upstream to Bremen harbor by adapting their traveling to the higher part of the tidal wave (Fig. 44). When FRANZIUS started his correction the tidal range in Bremen was about 0.3 m. As a result of the five successive deepenings tidal range has increased to about 4 m at Bremen (Fig. 45). Honesty requires us to admit that nevertheless the number of ships traveling to Bremen has been reduced in recent years and ecologists complain about the effects of the subsequent corrections demanding a restructuring of the Lower Weser to a more natural river [BUSCH et al. 1989].

Already in 1890 the growing passenger ships from the North Atlantic routes required engineering impacts in the Outer Weser which was carried out also by FRANZIUS [1895]. But this measure was less successful than the correction of the Lower Weser. The maintenance of the existing waterway required increasing efforts without gaining sufficient stability. The multiple channel system remained migrating with a tendency of changing cross-sections in its branches due to variations of local tidal volumes.

Already in 1825 the waterway had been shifted from the most westward situated channel to the eastern one. Another shift to the then deepening one was regarded by FRANZIUS as favorable, but not carried out in respect of the necessary high efforts. In 1921 PLATE [1927] started to shift the waterway from the 'Wurster Arm' in the eastern part to the central one 'Fedderwarder Arm' (Fig. 46) and fixed the then implemented system by groynes and training walls. His work was the basis for later improvements of the navigability of the Outer Weser (Fig. 46) [HOVERS 1975; WETZEL 1988] and still continues in present days for an adaption to the requirements for container vessels of the fourth generation for which a specific analysis of necessary waterway dimensions in respect of the design vessel was carried out [DIETZE 1990].

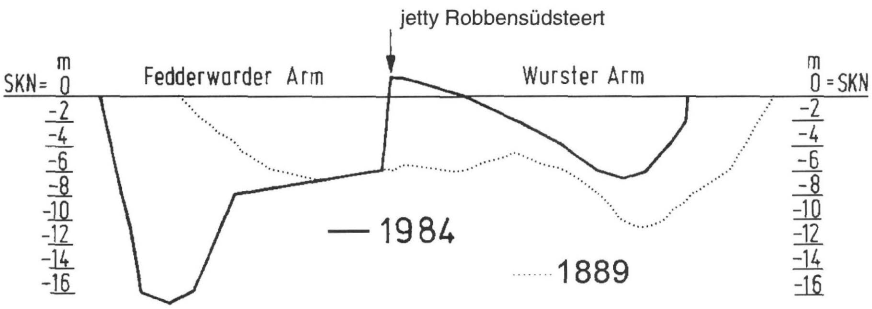


Figure 46. Cross-sections of the Outer Weser waterway in 1889 and 1984 [WETZEL 1988]

ELBE

In the beginning of the 19th century the increasing size of seagoing vessels led to difficulties in the Elbe waterway downstream of Hamburg harbor. In order to achieve a sound basis for engineering impacts HÜBBE [1842] started systematic hydrodynamical investigations. He installed e. g. permanent measuring tidal gauges in Cuxhaven at the estuarine mouth and in Hamburg between 1841 and 1843 [ROHDE 1975] which data highlighted the necessity of levelings in order to get a sound reference for the measured tidal water levels. This requirement was later fulfilled by LENTZ. River sections being critical in respect of navigability were streamlined by training walls and groynes in order to concentrate tidal flow in the navigation channel and to keep it away from tributary ones. Additionally steam dredgers were used to achieve the goal [HÜBBE 1853]. HÜBBE [1861] investigated also intensively the morphological development of the river he had to deal with; remarkable are his observations on bedforms which he already distinguished in the four classes: ripples, dunes, tidal ridges and shoals. Additionally he used tracers in order to study the migration of bedforms (Fig. 47).

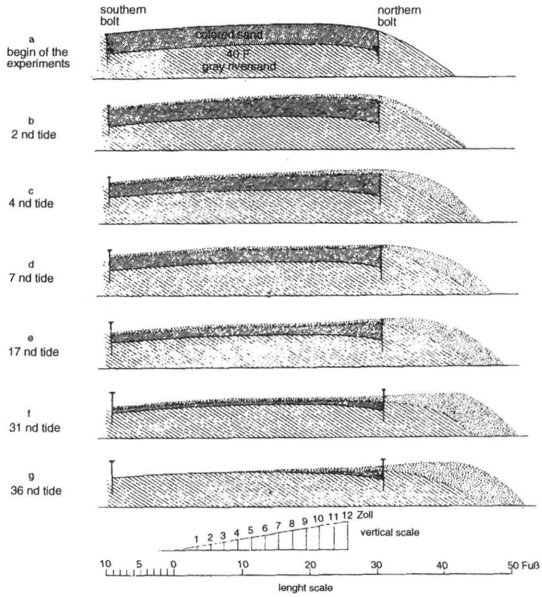


Figure 47. Results of a field experiment on bedform migration by tracer on an intertidal shoal [HÜBBE 1861]

His successor DALMANN [1856] studied the contemporary experience in coastal waterway engineering available in the neighbor countries England, France and the Netherlands. His consequence for further improvement of navigability and maintenance in the Elbe river was focussing on dredging and restriction of groyne and training wall construction on specific sections.

The increasing draft of seagoing vessels required at least dredging in the Elbe estuary, even seaward of the city of Cuxhaven [ROHDE 1971]. For the stabilization of that estuarine section between 1948 and 1966 a training wall with a length of 9.2 km was erected at the western edge of the waterway seaward of Cuxhaven due to a recommendation of HENSEN [1941]. After the 2nd World War four subsequent deepenings of the Elbe waterway have taken place. The planning for a fifth one in respect of the demands of large container vessels is presently finished [SCHLÜTER 1993]. A comparison of present and planned navigational water depths in the Elbe estuary with historical ones [ROHDE 1971] highlights the enormous changes the regime has experienced by coastal engineering interference (Fig. 48). In the meantime there had been plans to erect a deep water port at the estuarine entrance seaward of Cuxhaven. This prospects have been abandoned for economical and ecological reasons [LAUCHT 1982]. The intensive preinvestigations for that project delivered a remarkable amount of information being generally valuable for coastal engineering problems.

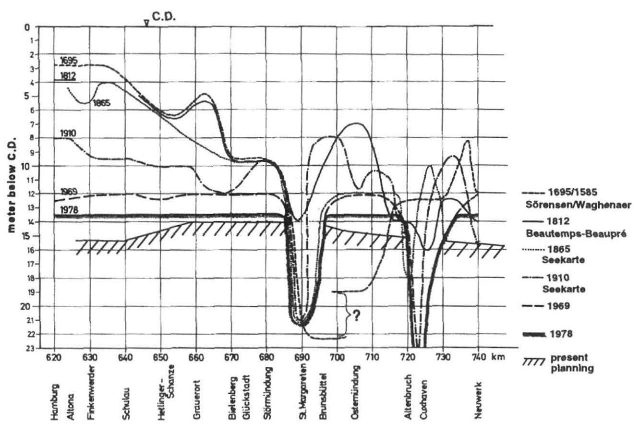


Figure 48. Change of navigational depth in the Elbe estuary and planned deepening; earlier situations adapted from ROHDE [1971]

Table 1. Coastal waterways at the German Coasts

Waterway	between	length	depth below C. D.	maxi-mum vessel	mainte-nance dredg-ing volume	1994 number of ves-sels	1994 cargo volume
		km	m	tdw	10^6 m^3		10^6 t
Elbe	North Sea-Brunsbüttel	70	13.5	110000	13.0	58450	81.5
	Brunsbüttel-Hamburg	64	13.5	100000			
Weser	North Sea-Bremerhaven	60	12.0	80000	1.3	29600	16.2
	North Sea-Brake	85	10.0	45000			6.6
	Bremerhaven-Bremen	60	9.0	35000			14.7
Jade	North Sea-Wilhelms-haven	55	18.5	250000	13.4	2760	34.5
Ems	North Sea-Emden	70	8.5	40000	10.6	1970	2.0
Trave	Baltic Sea - Lübeck (Stadt)	25	9.5	14000	0.02	23500	20.3
Warnow	Baltic Sea-Rostock	11	13.0	60000	0.06	23150	15.8

TRAVE

At the beginning of the 19th century sedimentation in the Lower Trave had led to a reduction of water depth allowing only ships with a draft of about 2 m traveling to the harbor of Lübeck. The necessary information for navigation was delivered by a gauge the data of which since 1826 are still available [JENSEN & TÖPPE 1986]. In order to improve navigability in the Lower Trave in 1835 dredging was started and in 1840 a channel passing through its barrier was established. The first river correction between 1850 and 1854 enabled vessels with a draft of about 4 m to enter the harbor of Lübeck. During the periods from 1879 to 1883 and from 1899 to 1907 the second and third correction were carried out due to plans of REHDER [1898], who was then in charge of waterway and harbor engineering. Major means were: reduction of river length by cutting bows, erection of groynes and deepening by dredging. Afterwards the waterway was navigable for vessels until Travemünde at the mouth with a draft of 8.5 m and until Lübeck with a draft of 7.5 m. After the fourth (1908 - 1961) and the fifth (1961 - 1982) correction the harbor of Lübeck is accessible by ships with a draft of 9.5m.

WARNOW

The harbor of Rostock was until the World War II of minor importance in comparison with other German harbors at the Baltic coast such as Lübeck and particularly Stettin. Nevertheless already in the