CHAPTER 81

ARTIFICIAL BEACH NOURISHMENT ON THE GERMAN NORTH SEA COAST

By Johann KRAMER*

Abstract

Several artificial beach nourishments were completed during the last twenty years on the German North Sea coast. Investigations made it possible to settle different problems connected with artificial beach nourishment and to gain additional information and experience. At present beach nourishments at Langeoog and Sylt will be realized in a way which is expected to bring the highest effectiveness. The hydrodynamic processes in connection with these beach nourishments and their change in shape will be subject to the paper.

Introduction

The East Friesian and North Friesian islands are spread along the German North Sea coast (Fig. 1). To the open sea, the islands have expansive sandy beaches, which are exposed to tidal currents and wave action. In order to maintain the beaches for the protection of the islands with their bathing resorts, people started to construct embankments and groynes more than 100 years ago. The coastal protection works, however, did not achieve the expected success on these stretches of sand, where more sand was eroded than supplied.

Thorough investigations in the years 1949/50 showed that the most economical way of carrying on the necessary island protection could be achieved by artificial beach nourishment (1). This was also a satisfactory solution for the bathing resorts in that they were provided with a beach. In this way, the "classical construction form" of island protection by means of embankments and groynes on the German North Sea coast was passed over for the first time in 1951/52 with the beach fill on Norderney.

A second beach fill followed in 1967. Beaches were also filled artificially with sand in various other islands, such as Föhr 1963, Baltrum 1968, Borkum 1969/70 and Langeoog in 1971. A further beach fill will take place on Sylt at Westerland in 1972.

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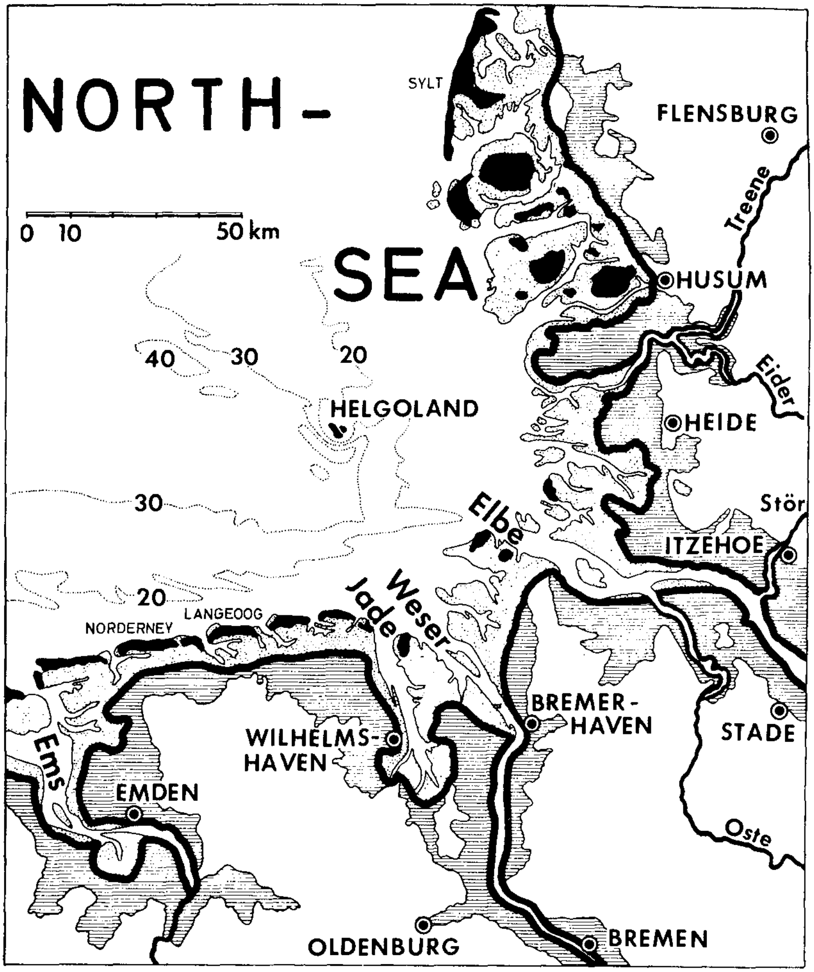

Fig. 1: The German North Sea coast

The technical development of artificial beach nourishment should be shown through the examples of Norderney 1951/52 and 1967, as well as Langeoog 1971 und Sylt 1972. The other mentioned examples of beach nourishment can go without comment as they do not differ basically from the artificial beach nourishment in Norderney. The experience gained in Norderney was taken into account when planning the beach nourishment programmes for Langeoog and Sylt.

The first Beach Nourishment in Norderney 1951/52

I have already described the planning, technical performance as well as the results of the beach fill in 1951/52 at the VIIth Conference on Coastal Engineering in Scheveningen in 1961 (2), so that it is possible to limit myself here to the basic problems.

The sand for the beach fill 1951/52 (Fig. 2) was dredged from the tidal flats south of the island and was transported by means of barges to the boster pump. From there, the sand-water mix was sucked from the barges and distributed over the beach areas through pipelines 60 - 70 cm in diameter.

Contrary to the original intention, the beach was filled with a continuous slope, as the originally planned fill dykes were destroyed very quickly by wave action. In this manner, at the end of the fill process, a high-water safe beach was created with a width of approx. 100 m, which, however, was lost in the following winter. The development of the beach fill was controlled by repeated beach surveys. In all, a total amount of 1,816,500 cubic meters (m^3) of sand was transferred in the years 1951/52. At the conclusion of the fill process, 1,245,500 m^3 of sand of the total amount still remained on the beach, giving a total fill loss of 31 % of the transferred amount of sand (2). Concerning the sand loss during and after the beach fill, it is important to note that the sand material used in the fill was finer than the sand originally present on the beach.

Behaviour of the first Beach Nourishment in Norderney after 1951/52

In the years following, a varying behaviour pattern set in in the beach areas. In the beach fill area of 1951, there was only approx. 34 % of the amount still left above the mean low water line by Spring 1959. In the beach fill area of 1952, a more

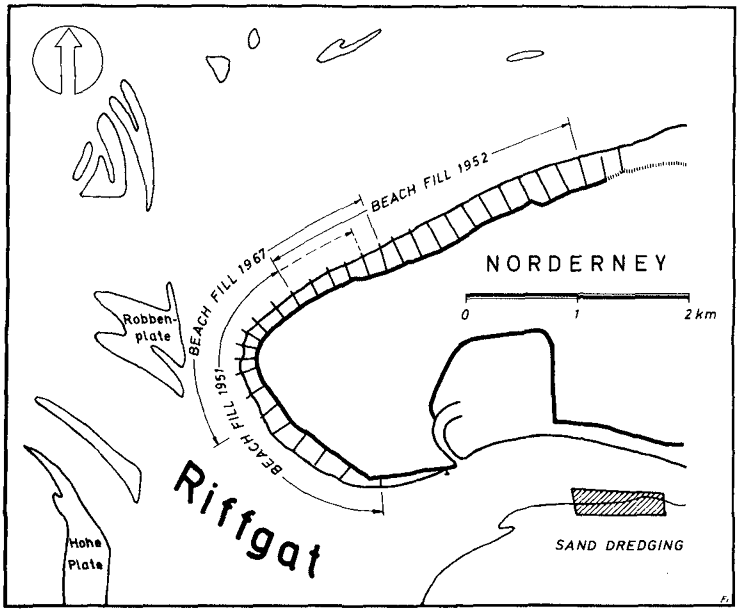

Fig. 2: Artificial beach nourishment on Norderney 1951/52 and 1967

favourable behaviour set in, which was not only attributable to the fill because further sand was added to the beach through the supply of sand deriving from sandbanks in front of the island.

It could be observed that in places where due to erosion the earlier beach height had been reached again, that the same inclination of the beach had been formed. It is therefore obvious that the beach height, incline, size of grain material, is dependent upon wave action conditions. No results were achieved in the efforts to correlate the erosion of sand to the natural parameters such as tide water levels, tidal currents and wave action. It is merely the level of the established quantities of sand in the individual groyne fields that contribute to the judgement and assessment of the beach fills.

Second Beach Fill Norderney 1967

In 1967 a new beach fill was carried out in the immediate area of the West Beach (3). Here in parts, the beach had receded so far that the tops of the sheet pilings at the foot of the embankment and the groynes had been laid free to a very great extent and also the existence of the protection works endangered.

One of the experiences gained at the beach fill in 1951/52 was not to make a fill on a beach which was too high or had too strong an incline, as such a beach was particularly exposed to wave action, and consequently, the loss of sand particularly great. Therefore, in the fill area, the beach was only filled up to NN + 0,50 m up to the height of the sheet pilings, where a uniform beach incline of 1:50 could be expected, which corresponded to the natural incline of the beach. The amount of sand necessary for this was estimated to be approx. 200,000 m^3. Reference is made to the fact that in 1951/52 356,000 m^3 of sand was filled into the same area.

At the end of the beach fill in 1967, it was established that 240,500 m^3 of sand had been filled in. The storms of October 1967 brought forth a loss of 22 % of the total reserves above the mean low water line. Favourable weather conditions in the spring of 1968 until April 1969 and wind transport from the East of the island brought a small increase, so that after three years, in the spring of 1970, the total loss amounted to merely 16 %.

The total quantities of sand on the beach above the mean low water line as a result of the beach fills 1951/52 and 1967 were:

1951/52	854 500 m^3	-	100 %
1961	444 900 m^3	-	52 %
1962	365 800 m^3	-	43 %
1963	386 600 m^3	-	45 %
1964	377 900 m^3	-	44 %
1965	389 600 m^3	-	46 %
1966	344 300 m^3	-	40 %
1967	355 900 m^3	-	42 %
1968	346 600 m^3	-	41 %
1969	381 300 m^3	-	45 %

The total balance of the beach fills at Norderney can be estimated as good. However, the experiences already gained in 1951/52 repeated themselves in that a connection between loss of sand and wind/hydrological fringe conditions could not be deduced.

Experiences and Conclusions from the Beach Fills in Norderney

The experiences made with the beach fills 1951/52 and 1967 encourage the continuation of the described form of beach preservation in the western part of the Norderney island. However, further considerations over the optimal sand supply of future artificial beach nourishments will be necessary.

The amount of sand used in the beach fill of 1951/52 was too large. The amount of sand filled in above the mean high tide water line was already lost again in the following winter. On the other hand, the amount of sand added in 1967 was too small. Even though the sand balance developed positively on a whole and the loss ration of 16 % up to 1970 for the total amount above the mean low water line is relatively low, the aims were attained short-term only.

From the experiences gained in the beach fills in Norderney, it was realized that the fills should be done in a different manner. The regional distribution of the sand proved to be of different value to the whole reach of beach protection. As a result of the effect and direction of the current, the sand in the outer fields on the edges of the areas where sand is lacking, is lost more quickly than that which is transported with the current from the middle of the area lacking sand out to the edges. Preference should therefore be given to a punctated fill rather than a regional fill. The punctated supply of sand would slowly be carried by the currents to the neighbouring fields and finally to the edges of the deficient beach, so that on the whole, it would remain effective on the beach for a longer period of time. In that way, every cubic meter of the applied sand material would be used to the utmost. Therefore, the greatest efficiency in beach fill is achieved where every cubic meter of sand stays hydraulically effective over a longer period of time, although in a different place, which is not the case with regional sand supply.

Beach Nourishment Langeoog 1971/72

Until a few years ago, enough sand was transported to the beach on the island of Langeoog through arriving sandbanks so that a sufficient beach was present from which also the dunes could replenish themselves. However, in recent years, fairly large sand losses occurred on the northern side of the island, because the sand supply stopped when the sandbanks failed to appear. The result was that the dunes too were seriously affected.

A hydromechanical investigation (4) of the sand losses showed that the dune foot lay too low and that the beach was too steep. The result is that normal beach surf changes into a cliff surf with its disadvantageous effects, even at slightly raised water levels. On a beach of normal height and shallow incline, with uninterrupted beach surf, there is a greater area at the disposal of the transformation of wave energy. When the waves break, they end in a raised swell. On the contrary, with cliff surf, the cliff suddenly brakes the raised swell, causing a reflection where high pressures are set against the cliff wall and the cliff is exposed to considerably more wave energy than with beach surf. Higher turbulence and in addition a higher transport capacity of the cliff surf are the results. At raised water levels it can happen that the waves break directly at the foot of the cliff and transfer their whole energy directly on to the cliff with impact and foam. In this case, erosion and the longitudinal transport of the sand reaches a maximum. On the other hand, with even higher water levels, it can happen that the waves do not break at the cliff, but form a stationary wave. Then the wave energy is not transposed into another form of energy, but is reflected. Although serious damage occurs to the cliff as before, the damage is not as high as when the waves break on the cliff foot. That explains the fact that an extremely high tidal wave, with full reflection on the cliff wall, is not so damaging as a series of mediumly high waves, where the waves break directly on the cliff foot.

In order to preserve the dunes, the effect of the surf action had to be withheld from their base. Therefore, beginning in 1971, the beach in front of the dune foot is being raised and widened to such an extent (Fig. 3) that even with a storm surge, a natural surf takes place on the beach in front of the dune foot. In order to estimate the necessary amount of sand, a yearly erosion rate of 77 m^3/m of the beach in the erosion area had to be taken into consideration. With an increase, this requires an amount of 100 m^3/m and per year for the erosion area of approx. 2,000 meters in length on the northern side of Langeoog. This means that the beach can be raised by one meter for every 100 meters in width. However, as long as the present sand loss continues, one must

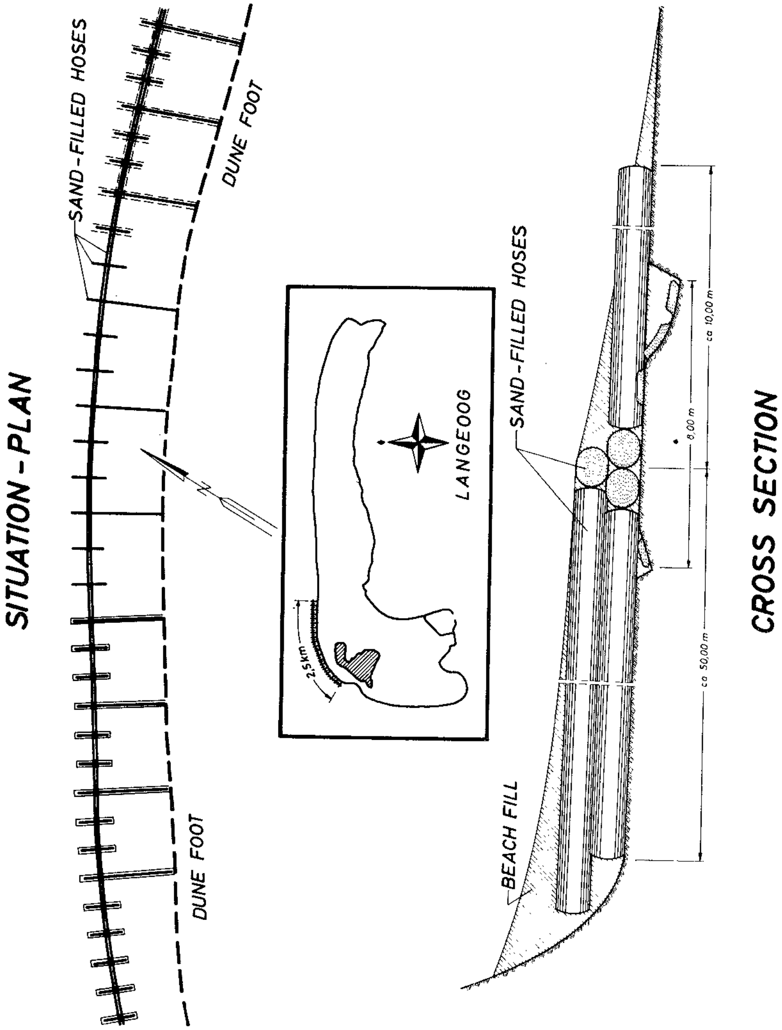

Fig. 3: Sand-filled hoses and beach nourishment at Langeoog 1971/72

reckon with a further yearly fill requirement of 200,000 cubic meters of sand. At a rough estimate, the costs for a continuous 5-yearly sand fill would be in the region of 2 Mio. DM. This is no comparison to the costs for groynes and embankments, which would be at least 50 Mio. DM, without the guarantee that they would eliminate the sand erosion.

The special purpose of this fill is to raise the dune foot and not a beach fill (4). In order to keep the filled-in sand material directly at the foot of the dunes, a longitudinal construction of sand-filled synthetik hoses has been set up (Fig. 3). This construction has been laid 50 m in front of the cliff base so that the filled area in front of it can develop into a natural beach even in raised tidal water levels. The top of the hose construction with a diameter of 1 m lies approx. NN + 2,0 m, i.e. the height of the previous cliff foot. The grain used for the fill was similar to that already on the beach (fine sand), so that by uninterrupted nourishment, the beach fill can also adjust itself to approximately 1:50.

The waves can break freely on this newly-made beach. The cliff foot, with its new high position, is only reached by incoming waves during very high storm surges, and this is only breaking surf.

As the berms are only reached by water during storm surges and for the rest of the time are in the dry, aolian sand transport can be expected with certain winds. Preliminary dunes can be won from the sand with the help of fence traps. Although these dunes are destroyed again by storm surges, they have a positive effect on sand economy.

With a difference in levels of 1,0 m in front of the longitudinal construction (Fig. 3), there is the possibility through reflection, that the beach in front of the hoses will be excavated and the construction itself in danger of being washed away. For this reason, the beach is built up so that it reaches the upper edge of the construction. This beach has to be maintained with a steady yearly refill, estimated at up to 200,000 m^3. The construction should only come into effect to protect the berms in storm surges when the beach in front of the construction is eroded.

The construction (Fig. 3) consists of two hoses laid down side-by-side and at intervals a further pipe laid on top. Washing away should be prevented by a woven mat which is 5 m long on the landward and seaward side and is buried to a depth of one meter on the seaward side.

Because longitudinal currents develop, due to the exposed construction and inclining wave action, causing erosion grooves in front of the construction as well as on the berms behind the construction, short rejectors - groynes made out of sand-filled hoses - have been installed (Fig. 3). These constructions are 10 m in length and are placed about 20 m apart and extend into the berm area. The whole berm area is intersected by sand-filled hoses with spacing of 60 m.

The work of building the hose construction and carrying out the beach fill was completed a month ago. The success of these measures will be seen in the coming years. This beach fill will still be economical in comparision to the construction of heavy embankments and groynes, even if 200,000 m^3 of sand have to be nourished yearly.

Experiences gained from the up to now Beach Nourishment Programmes

Experiences gained are as follows:

1. A minimum fill amount is necessary, otherwise no success can be expected.
2. Nourishment with sand of a coarser grain than that present on the original beach should be aimed at. Coarser grain has a higher layer stability and makes it possible to install a steeper beach where the base of the fill remains within the groyne fields.
3. The nourishment programme has to be adapted to the local currents, where the fill should take place either at lowtide or hightide, thus preventing any serious fill losses.
4. It is sufficient for a fill to be concentrated on a limited area of the beach (feeder beach) if the currents and wave action re-direct the sand material into the neighbouring areas, thus also achieving a sufficient rise in the beach level there.
5. Clay particles found in the fill material, which have to be endured in the first instance for reasons of reclamation, will soon be washed out, so that pollution of the sand beach does not occur.
6. There is no damage whatsoever to the flora and fauna in the vicinity of the beach fill.
7. Due to wave action, much higher sand losses occur on a beach built up high over the mean high water line than on a lower lying beach with a flatter profile.
8. A continual beach fill is appropriate, if it is necessary to replace the same amount of sand yearly.

Fundamentals of the artificial Beach Nourishment in Westerland/Sylt 1972

The island of Sylt, the most northerly of the North Friesian islands, extends for about 40 km north to south (Fig. 1). The island is strongly exposed to wave attack in westerly winds, which has caused, since time immemorial, erosion of the coastal area. As a result of this, the west coast of the island recedes, on an average, one meter per year. It has therefore been attempted for the past century to protect the island of Sylt from further damage by constructing groynes and embankments. It is particularly important to guard against damage to the town of Westerland, a significant bathing resort situated in the centre of the island, and to maintain a bathing beach there.

Since the 1950's, numerous hydrometrical, morphological, geological and sedimentological tests have been carried out to find the reason for this continuous recession (5). The cause lies in the negative balance of sand. A steady sand erosion is present in the middle of the island, but there is no sand supply to compensate for the loss.

The most varied methods were tried out in the construction of groynes and embankments, but although they delayed sand erosion, could not prevent it. On the basis of this knowledge and experience gained elsewhere in the meantime, the most economical solution for beach preservation at Westerland would seem to be artificial beach nourishment. The rudiments for this nourishment programme (5) were worked on by a group of experts of which the writer is a member.

The task of nourishing the beach at Westerland by the raising and widening of the beach, in order to safeguard the endangered coast protection works, will be even better accomplished, the more effectively the fill is combined in a positive sense with the natural processes. These can be characterised as follows:

On average, the beach and inshore zone extend to a width of 600 m to the seaward bar in front of the island (Fig. 4). Exposed to the power play of the currents and wave action, this stretch of the area shows the quickest changes. Re-direction of sand, diagonally and longitudinally, usually increases with the height of the waves. In this way, the sand transport on the beach is dependent upon the direction of the waves. Waves coming from the West bring little longitudinal transport. The waves, with their prevailing sloping attack, cause mass re-direction with a displacement parallel to the coast. The transport parallel to the beach is southerly with waves coming from the north-west and northerly with waves coming from the south-west. The longitudinal transport proceeds mainly in two sand flows, one in the surf region on the beach and the other in

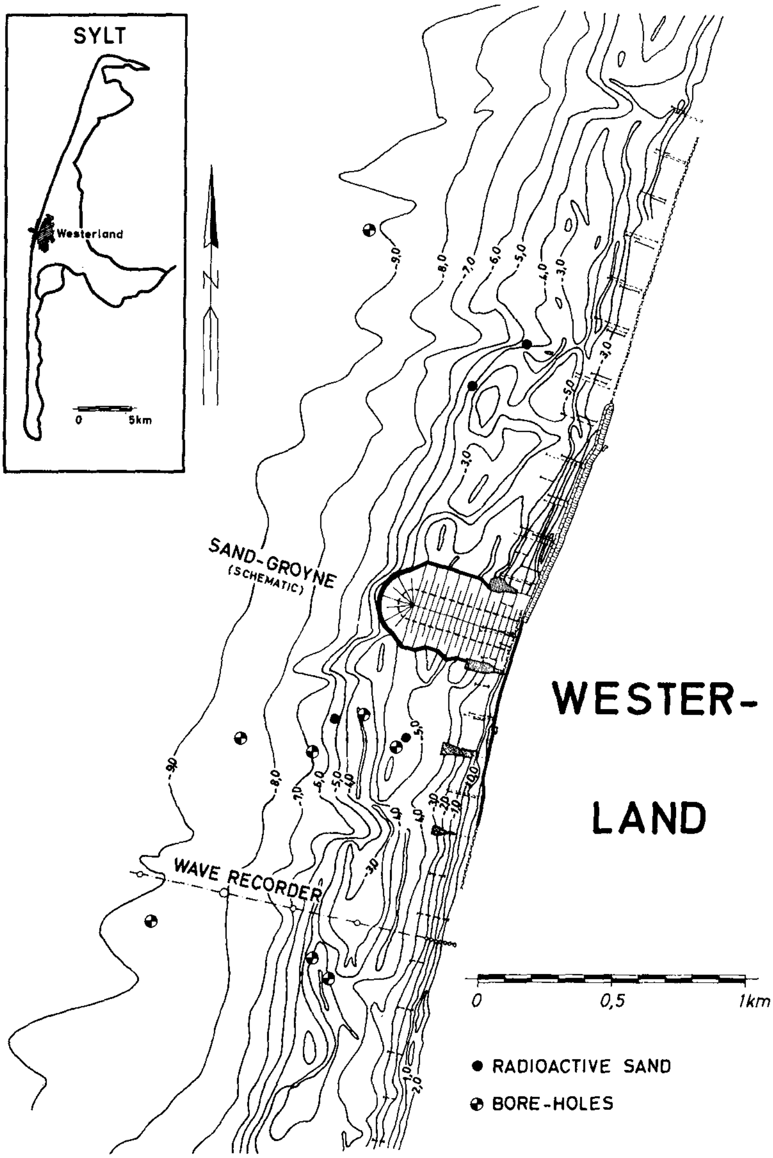

Fig. 4: The beach in front of Westerland/Sylt with the sand groyne (schematic) and investigation points

the surf region on the bar. According to the respective positions of the surf regions and their type of breakers, the sand transport also shifts its position and force. If no bar surf occurs, i. e., during high tides or with only moderately high waves, then, in the main, a sand transport only occurs on the beach, whose width extends approximately from the breaking point of the waves to their limit of uprush. On the other hand, in the case of bar surf, two sand flows are running in the same direction, one on the beach and one on the bar and the transport on the bar is the more powerful, the more wave energy is transformed into surf.

Large deviations in the height of the beach are possible, independent of weather conditions. These changes in a beach profile amounted to almost 5 m during a period of 10 months in 1954; the greatest change registered in the average beach height was 1.60 m from one day to the next. Data on the average yearly amount of sand loss on the beach of Sylt are uncertain. Specifications should be based on the many years of observation which showed a yearly average of 525,000 m^3 of sand.

Conclusions for a Beach Nourishment on Sylt with a Sand Groyne

There was a choice between four different methods of beach nourishment (5):

a) Indirect beach restoration through the build-up in layers of dredging on the offshore.

b) raising of the beach with a direct fill,

c) nourishment of locally restricted sand areas, and

d) continual fills.

Regional nourishment proves to be most suitable for the conditions on the coast of Sylt. In this way, direct protection is achieved for the beach protection works. The groyne system will probably offer no significant advantage in the nourishment programme. When the groynes are covered with sand they are ineffectual and uncovered, they give, as before, only little protection and merely lessen the effect of the surf currents.

In future planning, it should be borne in mind that there are still reliable methods for a quantative evaluation of wandering sands at present, but that qualitative theoretical models are available which can support such reflections. The fill in the form of beach widening and raising is possible. However, it is more advantageous to construct a type of sand groyne (Fig. 4). Changes and developments to this sand groyne are determined by natural occurrences, especially surf and sand transport. The aim is, therefore, to influence the present and unchangeable surf process in such a way that as little as possible of the newly added sand is lost after the fill has taken place.

Additionally, contrary to the previous regional nourishment programmes on Norderney and Langeoog, an attempt is being made on Sylt to catch additional aand from the natural longitudinal transport by means of the sand groyne (Fig. 4). The basic idea is to fill in a sand structure vertical across the channel to the bar, which, in its initial form, would have the appearance and effect of a very flat groyne.

During construction, waves affect the sand structure. Contrary to groynes of normal shape, with such flat sand constructions, not only does wave diffraction occur, but also considerable wave refraction, because the dimensions of the aand groynes and their gradients amount to a multiplication of the lengths of the arriving waves. In this manner, the appearance of the surf is completely different from that at beach groynes of traditional construction. Figure 5 A shows a sketch of wave and surf conditions on the sand structure while under construction. The sand structure is indicated by two vertical contour lines. Wave attack on the beach is perpendicular; i.e. there is no longitudinal transport in the beach surf, which runs up both sides of the sand groyne unhindered. At the sand groyne itself, one must differentiate between the head and flank surf. Greater wave heights occur in the head surf than in the simultaneous beach surf, because on the cone of the groyne head, refraction causes concentration of wave energy. On the other hand, flank surf shows lesser wave heights. By normal wave attack on the beach, only refraction is present and no diffraction.

In any case, damage occurs on the top of the groyne through the head surf, which becomes greater as wave height increases. Surf currents directed landwards develop from the flank surf, which transport the material eroded from the head of the groyne landwards. As the waves do not decrease in height on the flanks, in the course of events, this material is accumulated on the flanks (Fig. 5 A). Due to the vertical wave attack, no material is extracted from the sand construction, but merely a shifting of the sand landwarda occurs. No additional sand, however, is retained from the natural sand transport under this type of wave attack.

It is known that additional sand, that does not originate from the construction, can be expected on the luff-side of the sand groyne by diagonal wave attack (Fig. 5 B), if the groyne projects far enough out of the beach surf. Apart from that, especially on the luff-side, sand from the top of the groyne is carried landwards by the flank surf, where two surf currents meet on the luff-aide of the groyne root. The point of the heaviest wave attack is moved from the top to the flank on the luff-side; on the other hand the

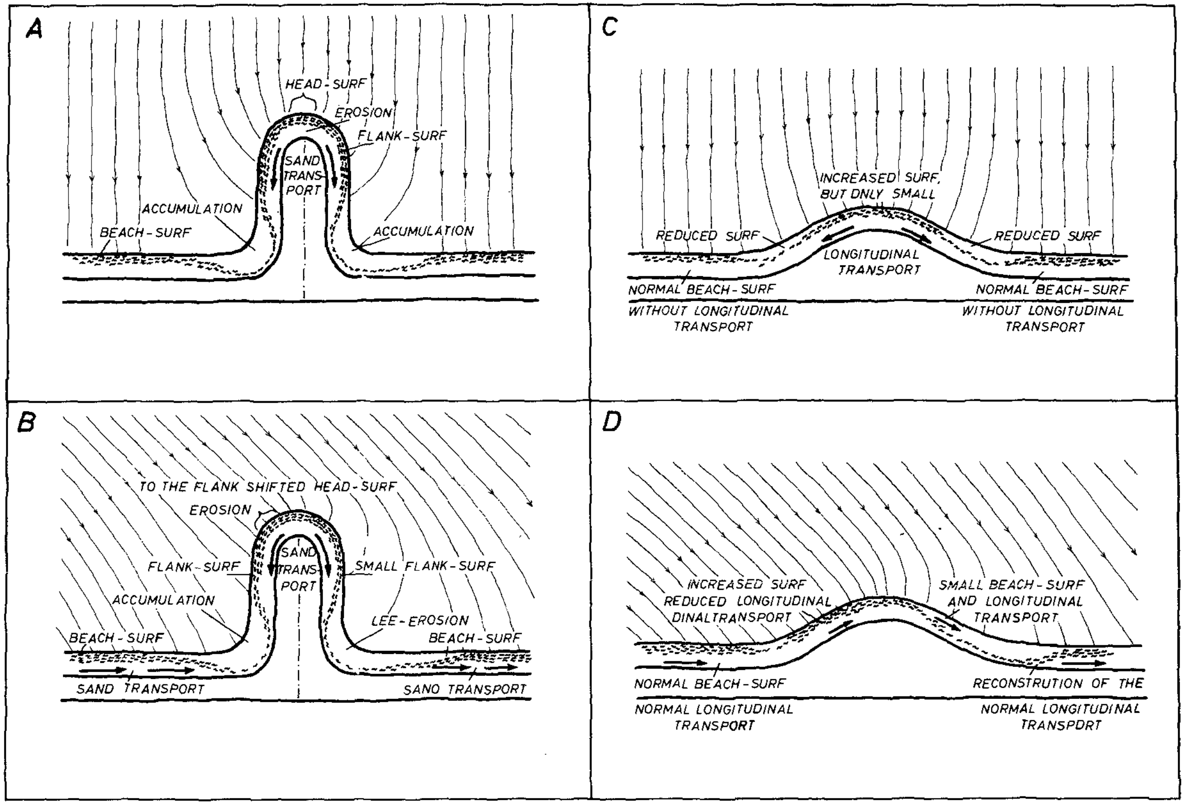

Fig. 5: Wave and surf conditions on the sand groyne

lee-side flank is exposed to much smaller wave force becsuse diffraction is added to refraction so thst here too a landwards transport dominates. On the lee-side of the beach a lee erosion is possible, but is not to be expected in the same intensity as with a solid groyne construction, because sand is supplied from the lee flank. Even diagonal wsve attack on the sand construction leads only to s landwards sand transport, although, by cutting off the surf current on the beach, additional ssnd can also be retained from the natural ssnd transport.

During the nourishment progrsmme, the sand groyne will be subject to the constsnt chsnging effects of the waves' forces. Waves from all directions have the uniform tendency of eroding the top of the sand groyne and shifting it landwards. At the same time, accumulation occurs at its root and the neighbouring flank sections, which are partly supplied from the ssnd construction and partly come from additionally retained ssnd volume.

Transformation of the Ssnd Groyne into a Sand Hoft

If the sand groyne is left to its own resources without further sand nourishment st its hesd, then s gradual transformation into a less projecting, flat ssnd construction, s "sand hoft", through the already described effect of the waves, takes place (Fig. 6 A) Later on, this ssnd hoft will extend even further along the beach while its projection snd height decrease. The speed of this trsnsformation depends upon the grsin of the sand, but mainly on the wave climate. In any case, the larger the sand mass st the beginning, the longer this process tskes. Simulsrly, the transformstion will take place more quickly at the beginning than later on, when the sand hoft has alresdy sdspted its shspe to the effect of the waves, and also when the waves have adapted themselves to the shape of the ssnd hoft.

During vertical wsve attack, the transportstion of sand landwards on the flanks of the sand hoft is light, for then the waves, due to refraction, meet the vertical contour lines practically vertically in compsrison to the ssnd groyne (Fig. 5 C). In a sloping wave sttack, the sand csn be transported around the sand hoft, as all surf currents, contrary to the sand groyne, run in the ssme direction (Fig. 5 D). The surf area on the beach extends round the whole ssnd hoft, during vertical as well as by sloping wave attack, and with its sand trsnsport, provides for an equable sand balance.

Continuous swell from only one direction over a longer period of time deforms the ssnd hoft assymetrically, whereby the luff-side flank becomes longer than that on the lee-side. A change in wsve direction then conveys a part of the ssnd transported around the

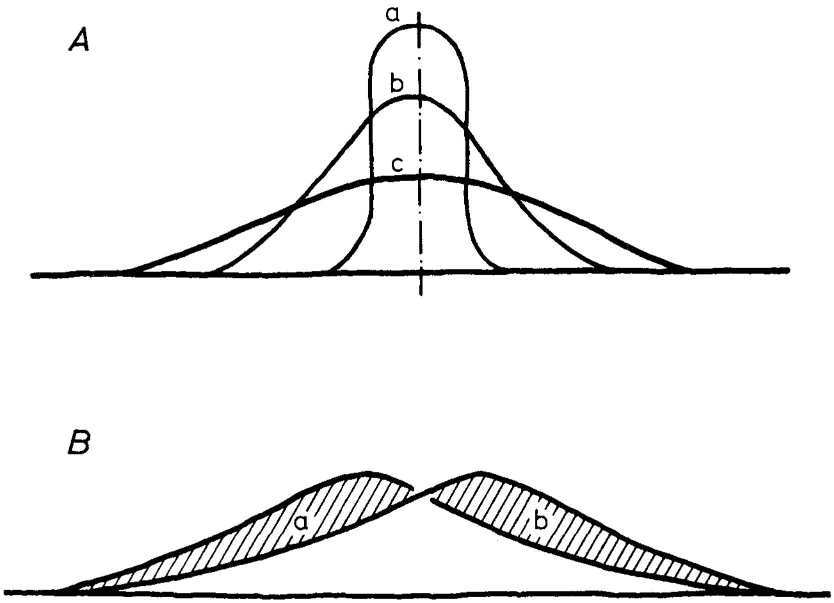

Fig. 6: A: Transformation of the sand groyne into a sand hoft (phase a-b-c)
B: Shuttled sand mass (phase a-b)

top of the sand hoft in the opposite direction, so that one can speak of a "shuttled sand mass" (Fig. 6 B). The stabilising effect that develops when part of the sand from the long-distance passes into the short-distance transport, is also very advantageous here.

The life of such a sand hoft, i.e. its stability, is longer, the more vertical the relation of the average landward current direction and energy is to the beach. It can be raised when the sand groyne is filled up to the bar, because there is already a saturated sand transport in the bar surf and therefore a decrease in the erosion at the head is conceivable. After the transformation of the sand groyne into a sand hoft, the bar surf at the top of the sand hoft changes over directly into beach surf. Because part of the wave energy reaches the lee-side flank through diffraction and refraction during a sloping wave attack on the lee-side, it is possible that the sand flow below the bar surf will be partially tapped.

Execution and Expectations of the artificial Beach Nourishment at Westerland

The construction of the sand groyne is undertaken with a daily amount of about 10,000 cubic meters of sand in order to advance the sand groyne in relation to the daily damage rate. In the favourable season, during summertime, it is possible to fill 900,000 m^3 within three months. On subtracting 1/3 of the sand volume as fill loss, 600,000 m^3 of sand remain for the sand groyne. Its length will amount to approx. 400 meters and its average width at the base approx. 300 meters with an average height of 7 meters from the bottom (Fig. 4).

The sand for the nourishment of the sand groyne is obtained from the eastern side of the island, where there is a range of Kaolin sand to a depth of 40 meters. The grain size practically corresponds with the existing sand material on the beach. The sand is conveyed from the withdrawal to the nourishment area by means of a pipeline approx. 8 km in length. Besides the suction dredge which obtains the sand, three intermediate pumping stations have been connected up in order to overcome the great distance involved in this transfer fill. The costs for the artificial beach nourishment are approx. 6,000,000- DM.

In addition, a sum of approx. DM 1,5 Mio. will be spent on investigations in order for a statement to be made under natural conditions on the success of this large effort. Numerous current and wave surveys will also be carried out in the area surrounding the sand groyne, which will be complemented by sedimentological tests (6). For that reason it is expected, that the execution of the present nourishment attempt at Sylt will lead to new and valuable knowledge of the suitability of artificial beach nourishment for island protection.

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