The Effect of Sedimentary Texture on Beach Fill Longevity

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ABSTRACT


Artificial beach nourishment is commonly used to protect coasts. Several publications have emphasized the influence of grain-size on beach fill design. Most of the works are based on theoretical considerations, but the models are rarely tested in the field. Three beach nourishment projects on the islands of Norderney and Langeoog were investigated in detail to obtain more information on the effects of sedimentary textures, such as grain-size and density, on beach fill longevity. Norderney is characterized by a number of solid coastal protection structures. In contrast, Langeoog has neither groynes nor revetments; the island is protected only by dunes. Additionally, artificial beach nourishment is necessary from time to time to compensate for the lack of natural sediment supply. The investigations on both islands and experiments on the hydrodynamic behavior of sediment particles in the laboratory demonstrate that grain-size has only a small effect on beach fill longevity; however longevity is strongly influenced by grain density.

ADDITIONAL INDEX WORDS: Coastal protection, beach nourishment, beach, shoreface, barrier island, sediment distribution, heavy minerals, North Sea.

INTRODUCTION

Shorelines are subjected to the influences of wind, waves, currents, beach morphology and sedimentary textures as well as their interactions. They are in a very sensitive equilibrium. In the past, various coastal protection and beach conservation measurements may have interfered with the balance of these active and passive forces. These measures led partly to the predicted transport and depositional conditions, but they also caused other effects. Artificial beach nourishment is a common tool of active coastal protection measures. The main aim of beach fill design was to extend the longevity of artificial beaches. The design can only be optimized by changing the morphological configuration of the beach fill or by the choice of the fill material. According to SWART (1991), the grain-size of borrow material represents an important factor for optimizing beach fills as well as the existing wave climate and the beach fill configuration. Moreover, a subordinate support of the beach nourishment may be achieved by solid coastal protection structures, e.g. groynes. In addition, the fact is that beach nourishment only treats erosional symptoms instead of eliminating the causes.

An efficient emplacement of beach fills requires a detailed knowledge of sediment processes as well as its forcing mechanisms in the nearshore zone. In this paper, the influence of sedimentary textures on the success of beach nourishment will be demonstrated.

Location of Study

The investigations were carried out on the islands of Norderney and Langeoog. Both islands are part of a barrier island chain along the North Sea coast of Germany and the Netherlands (East and West Frisian Islands, Figure 1). Sediment is transported eastward along the island shores and through the outer shoals of the ebb tidal deltas between the islands. The sediment is probably transported by alternating cross-shore currents producing a zigzag transport pattern which is a result of vector differences between seaward and landward cross-shore currents (HANISCH, 1981; WESTHOF, 1990).

Shoals and swash bars of the ebb tidal delta attach the island of Norderney at a distance of 4-5 km east from the tidal inlet (Norderneyer See). This area of the shoreline between the tidal inlet and the shoal attaching area is situated within the ebb tidal delta of the inlet and suffers from a lack of natural sand supply. A balanced sediment budget is achieved east of the shoal attaching area (Figure 2). The continuous lack of
sediment has caused an eastward migration of the tidal inlet and associated severe dune and beach erosion; this erosion threatens the settlement of Norderney. Therefore, a range of various coastal protection measures have been built within the last century. The building of seawalls, revetments and groynes was not as successful as expected, although it was possible to stop the migration of the 20 m deep channel of the Norderney Inlet with groynes founded to a depth of almost 20 m. In 1951, Europe’s first artificial beach restoration was initiated on Norderney to ensure the stability of the solid coastal protection structures.

The sediment supply to the Langeoog beach was sufficient in the past because the ebb delta of the tidal inlet of Accumer Ee attaches on the northwestern shore (Figure 3). The village on Langeoog is protected from the sea by a succession of dunes. Hence, solid coastal protection structures were not necessary. Nevertheless, artificial
refill of certain beach sections is required from time to time to broaden the beach and to protect the dunes because the supply of sediment to the western and northern beaches is not continuous.

Hydrodynamic Boundary Conditions

The hydrodynamic conditions along the southern North Sea shoreline are driven by wave and tidal currents. Both are responsible for the typical appearance of the East and West Frisian coastline with its barrier island chain. The wave climate is mainly related to the wind over the North Sea (NIEMEYER, 1986). The annual significant wave height varies between 0.7 and 1.0 m on Norderney's northwestern beach (NIEMEYER, 1992). With westerly winds, the wave-induced currents diverge in two directions along the western spit of Norderney, one in a southern direction and another in a northeastern direction. This divergence area is situated between the Groynes C and A (LUCK, 1970); although recently it seems to have shifted more eastwards recently (Figure 2). The reasons for this shift may be found in morphological changes in the ebb tidal delta, which probably generates distinctive transport directions.

The tidal range is approximately 2.4 m on Norderney and 2.7 m on Langeoog (BSH, 1993). Tidal currents can reach velocities of more than 1 m/sec in the tidal inlets (e.g. KOCH and NIEMEYER, 1978). On the beach the velocities are slower and depend on the orientation of the beach to the tidal inlet; e.g. the mean tidal current vectors reach velocities up to 0.30 m/sec on the western beach and only 0-0.05 m/sec on the northwestern beach of Norderney (NIEMEYER, 1987).

METHODS

On Norderney, the sedimentary texture of the beach sands as well as the beach profile changes were monitored for almost six years. Within this period, two beach nourishment projects were carried out: in May 1989 (EITNER et al., 1992; EITNER and RAGUTZKI, 1994) and in June 1992. During the latter, the shoreface was additionally filled for

Figure 2. Location map of Norderney (western part).
On Langeoog a sedimentological monitoring of the sediment properties of the beach sands was conducted before and after the last beach restoration in May 1993. Sedimentological data were not determined for earlier beach fills (Table 2).

Table 1. Main features of the beach restorations on Norderney in the last 40 years.

<table>
<thead>
<tr>
<th>Year</th>
<th>Volume ($\times 10^6$ m$^3$)</th>
<th>Fill Length (km)</th>
<th>Mean Grain-Size (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1951–1952</td>
<td>1.245</td>
<td>6.0</td>
<td>0.10–0.13</td>
</tr>
<tr>
<td>1961*</td>
<td>(7,000 t)</td>
<td>3–30</td>
<td></td>
</tr>
<tr>
<td>1964*</td>
<td>(10,000 t)</td>
<td>1–15</td>
<td></td>
</tr>
<tr>
<td>1967</td>
<td>0.240</td>
<td>2.0</td>
<td>0.15–0.30</td>
</tr>
<tr>
<td>1976</td>
<td>0.400</td>
<td>1.1</td>
<td>0.18–0.30</td>
</tr>
<tr>
<td>1982</td>
<td>0.470</td>
<td>1.5</td>
<td>0.17–0.25</td>
</tr>
<tr>
<td>1983†</td>
<td>0.064</td>
<td>0.6</td>
<td></td>
</tr>
<tr>
<td>1984</td>
<td>0.410</td>
<td>1.7</td>
<td>0.16–0.20</td>
</tr>
<tr>
<td>1989</td>
<td>0.447</td>
<td>1.8</td>
<td>0.15–0.20</td>
</tr>
<tr>
<td>1990†</td>
<td>0.045</td>
<td>0.5</td>
<td>0.15–0.22</td>
</tr>
<tr>
<td>1992</td>
<td>0.430</td>
<td>2.1</td>
<td>0.15–0.27</td>
</tr>
</tbody>
</table>

* = gravel fill, † = dry fill (based on data from Kramer, 1965; Kramer et al., 1963; Luck, 1970; Witte, 1970; Fatzold, 1982; Eschner, 1986; Stephan, 1988; Kneit, 1991a,b; Eitner et al., 1992; Eschner and Tillman, 1992; Eitner, 1993).

Table 2. Main features of the beach restorations on Langeoog in the last 20 years.

<table>
<thead>
<tr>
<th>Year</th>
<th>Volume ($\times 10^6$ m$^3$)</th>
<th>Fill Length (km)</th>
<th>Mean Grain-Size (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1971–1972</td>
<td>0.550</td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td>1982</td>
<td>0.290*</td>
<td>1.3</td>
<td></td>
</tr>
<tr>
<td>1984</td>
<td>0.290*</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>1987</td>
<td>0.560</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td>1993</td>
<td>0.220</td>
<td>0.5 + 0.4</td>
<td>ca. 0.20</td>
</tr>
</tbody>
</table>

* = sand dam included (based on data from Eschner, 1986 and StAIK, Norden)

Figure 3. Location map of Langeoog (western part).
Grain Size and Beach Fill Longevity

High Water Level  

Mean Water Level

Low Water Line  

Median ($d_{50}$)

Sampling Level  

Grain Size Fractions

| $<$ 0.09 mm | $<$ 0.125 mm | $<$ 0.18 mm |
| $<$ 0.25 mm | $<$ 0.5 mm | $>$ 0.5 mm |

Figure 4. Temporal grain-size distribution of the sediments within the groyne field D-E on Norderney (beach nourishment in May 1989 and June 1992).

Sediment samples were taken using 5 cm-cylinders on the low, mean and high water line along five shore-perpendicular profiles on each island (Figures 2, 3). The grain-size distribution of desalted sediments was determined by dry sieving. The carbonate content (as a parameter for the portion of shells and shell fragments in the sediments) was analysed according to the method of Scheibler (SCHULZEE and MUHS, 1967). Furthermore, the heavy mineral content was evaluated by using the Frantz Magnetic Separator (McANDREW, 1957). Heavy minerals have proved to be well-suited natural tracers for investigating transport patterns (e.g. MARTENS, 1928; VON ENGELHARDT, 1937; DECHEND, 1950; LUDWIG and FIGGE, 1979; KOMAR and WANG, 1984; CLEMENS and KOMAR, 1989; FRIHY and KOMAR, 1991; FRIHY and LOFTY, 1994). A qualitative determination by the extensive method of gravity separation was not necessary, because only the hydrodynamic properties of the minerals were important for the investigations that are presented here.

RESULTS

Temporal Grain-Size Distribution Within the Fill Areas

The sediments on Norderney are well studied (WESTHOFF, 1990; EITNER et al., 1992; EITNER, 1993; EITNER and RAGUTZKI, 1994). The sediments along the western beach are fine grained and well sorted. Tidal influences decrease with increasing distance from the tidal inlet, Norderneyer Seegat. In contrast, the influence of wave-induced currents increases and causes a coarsening of the sediments. The sediments of the northwestern beach are coarser and badly sorted because of a high content of shells and shell fragments. Generally, the grain-size increases from the low water mark to the high water mark. The sediments of the northern beach are finer grained and better sorted. In the transition of the shoal attaching area near the "Weiße Düne", the grain-size increases again. This beach section is supplied by coarser grained sediments, which were trans-
ported along the shoals of the ebb tidal delta. The increase of mean grain-size is often due to an increase in shell material. The coarser sieve fractions (>0.71 mm or 0.5 phi) mainly comprise shell and shell fragments. Generally, the heavy mineral content increases from the shoreface to the high water mark. An increase of heavy minerals can also be seen in an alongshore direction from the western beach to the northwestern beach. The increase of heavy minerals on the northwestern beach is probably due to winnowing processes, which lead to a significant loss of sediment. This relationship has also been described from other locations (RAO, 1957; KOMAR and WANG, 1984; FRiHY and KOMAR, 1991; FRiHY and LOFTY, 1994).

Both beach fills influenced the grain size (Figure 4). The finer borrow material always leads to a general refinement of the beach sediments within the fill area, but the grade of refinement differed on the three sample levels. The changes were very significant along the high water line, although the original grain-size distribution was regained after approximately one year. In contrast, the sediments along the low water line obtained the original grain-size distribution after a few months. Seasonal changes due to varying hydrodynamic boundary conditions also influenced the sediments within the fill area. Relative coarsening is associated with storms during the winter.

The beach restoration on Langeoog has not significantly influenced the grain-size as it has done on Norderney (Figure 5). This is because the sedimentary textures of the fill material did not differ greatly from the textures of the natural beach sands (Figures 9, 10).

Vertical Sediment Distribution of the Beach Fill

From the early fifties until 1992, seven beach fills were carried out on Norderney. After the last beach fill in 1992, two sediment cores were taken...
CORE I
Grain Size Distribution

Grain Size Fractions
- > 1.0 mm
- < 0.25 mm
- < 1.0 mm
- < 0.5 mm
- < 0.18 mm
- < 0.125 mm
- < 0.09 mm

CORE II
Grain Size Distribution

Grain Size Fractions
- > 1.0 mm
- < 0.25 mm
- < 1.0 mm
- < 0.5 mm
- < 0.355 mm
- < 0.09 mm

Figure 6. Core I and II within groyne field D-E, (August 1992).

to a depth of 4 m in the groyne field D-E, in order to investigate the vertical sediment distribution of the beach (Figure 6).

Cores I and II were drilled 10 m and 60 m, respectively, from the revetment in the centre of the groyne field D-E. Core I was situated above the high water level in the backshore area; Core II was located in the area between high water level and low water level on the intertidal beach (Tables 3, 4). Core I shows five layers (Figure 6). The upper layer (1A) (< 0.4 m) comprises mainly fine sand with a little carbonate content. The carbon-
The higher carbonate content is associated with the increase of grain-size. The coarser sediment particles are mainly shells and shell fragments. The following layer (2) is comprised of fine sand. Layer (3) dominantly consists of medium grained sand. A fine sand layer (4) which becomes slightly coarser with decreasing depth terminates the core. The boundary between layers (1) and (2) as well as between (3) and (4) coincides with the position of the high water level and low water level, respectively. The intermediate boundary corresponds with the height of the bottom edge of the beach fill. Thus, each layer reflects a particular depositional environment which is characterized by different hydrodynamic conditions. The vertical chronological sediment succession is equivalent to the present lateral succession.

The layers (1) and (2) represent the fill of 1992 (Table 3). The grain-size differences in layer (1) are based on varying shell contents which are reflected in the carbonate content. In the lower part of layer (1) near the former high water level, the shells and shell fragments accumulated due to hydrodynamic conditions during the dispersal of fill material. The fine sandy layers (1A) and (2) with a mean grain-size of 0.2 mm are equivalent to the fill material.

It is assumed (Table 3) that layer (3) represents the material of the beach fill in 1967. The grain-size of the sediments (0.15–0.30 mm) which were deposited on the beach at that time differ only slightly from the grain-size of the sediments of layer of the beach fill in 1992 (0.15–0.27 mm). However, the sediments of layer (3) have a mean grain-size of more than 0.3 mm; thus, it cannot be the original fill material. The fine-grained fill material was probably coarsened by deep reaching selection and sorting processes. These coarser sediments were deposited at the high water level. Thus layer (3) reflects the sedimentary textures of the original beach.

Since the boundary between layer (3) and (4) corresponds to the low water level, these layers (3) and (4) can be interpreted as deposits of a former intertidal beach and as a shoreface or subtidal sediments, respectively.

Core II shows a less distinct layering (Figure 6). Generally, there is a small increase of fine grained sediments and a decrease of the heavy mineral content with increasing depth. The carbonate content varies between 0 and 6% with no trend. In the area above the low water level, the beach is mainly characterized by beach fill (layer 1/2). The mean grain-size of approximately 0.2 mm corresponds with the texture of Core I. Also in the area below the low water level, there are no differences (Layer 4).

Hydrodynamical Properties of Sediment Particles

A detailed knowledge of the hydrodynamical properties of the sediment particles is necessary for a better understanding of the processes in the nearshore zone. Therefore, the settling velocity and critical threshold stress of heavy and light minerals has been determined (Eitner, 1993, 1995). The result of these investigations was that the grain density influences the sediment entrainment to a larger extent than the grain-size. Heavy
minerals have a much larger critical threshold stress than light minerals (e.g., quartz) with the same settling velocity (Figures 7, 8).

A study of sediment dynamics in the nearshore zone of Norderney has shown that heavy minerals were mainly enriched during storm surges and other erosional phases (EITNER, 1993). The settling velocity represents the depositional behaviour of sediment particles, dependent on grain-size, density and shape (Figure 7). The critical threshold stress quantifies the resistance of sediment grains against entrainment (Figure 8). This parameter depends mainly on density and to a lesser extent on the grain-size.

Heavy minerals are enriched due to their higher critical threshold stress. Erosional processes lead to an enrichment of heavy minerals due to these hydrodynamical properties. Depositional processes lead to a deposition of sediment grains with identical settling velocities and thus to a mixture of heavy and light minerals. A placer formation has not occurred.

Longevity Models

Several models are presently available to determine the longevity of beach fills depending on the sediment textures (e.g., Krumbein and James, 1965; James, 1975). The most commonly used model (James, 1975) estimates how much borrow material is initially required to produce a fill material with a texture similar to the native beach sand. Another model, the relative retreat rate, describes the ratio of the retreat of the filled and the native beach. Both models consider differences in grain-size distribution and sorting properties of the borrow material and the native beach.
sediments. The relative retreat rate model also regards the fill configuration as an empirical coefficient.

KRUMBEIN (1957) and KRUMBEIN and JAMES (1965) assume that fine material will be winnowed out by sorting the fill material. The grain-size distribution of the fill assimilates the sedimentary texture of the native sediments. The grain-size differences of the borrow material, and the native beach sands are shown in Figures 9 and 10.

Figure 8. Critical threshold stress in relation to different grain size fractions of heavy minerals and quartz.
Grain Size and Beach Fill Longevity

Beach Fill on Norderney in 1989 and 1992

Figure 9. Grain-size distribution of the native beach sand and the borrow material of the beach fills on Norderney in 1989 and 1992.

KRUMBEIN and JAMES (1965) give an analytical estimation of the possible fill losses on the basis of the grain-size distribution by the determination of the critical overfill ratio $R_{crit}$:

$$R_{crit} = \frac{\sigma_{borrow}}{\sigma_{native}} \exp \left(-\frac{(\phi_{borrow} - \phi_{native})^2}{2(\sigma_{native}^2 - \sigma_{borrow}^2)}\right)$$

(1)

JAMES (1975) formulated another equation based on the assumption that beach fill should halt or diminish erosion, rather than to improve a stable beach. The model is defined by the so-called renourishment factor $R_s$, which describes the ratio between the predicted erosion rate of the fill material and the real erosion rate of the native beach sands.

$$R_s = \exp \left(\frac{\phi_{borrow} - \phi_{native}}{\sigma_{native}}\right) - \frac{\Delta^2}{2} \left(\frac{\sigma_{borrow}}{\sigma_{native}} - 1\right).$$

(2)

A value of 1 means that the losses of fill material and native beach sands are equivalent. The renourishment factor, e.g. of 2.5 for the examined beach fill on Norderney in 1989, means that the beach fills have to be repeated 2.5 times more often than if a borrowed material would have been used with a grain-size distribution identical to the native beach sands.

The models were used to determine the longevity of the three beach nourishments on Norderney and Langeoog (Table 5). The model by KRUMBEIN and JAMES (1965) could not be applied because the values are less than 1. The calculation of the renourishment factor indicates that the beach fill on Norderney in 1992 had to be more...
successful than the fill in 1989, but the development of the sediment volume shows that this is not the case. The losses of the 1992 fill have even been larger. The severe storm surges in January 1993 are probably the reason. In the period between 1989 and 1992, there were only a few less severe storm surges.

**DISCUSSION AND CONCLUSIONS**

If grain-size would influence beach fill longevity (Krumbein and James, 1965; Dean, 1975; James, 1974; Swart, 1991), the sediment loss may not exceed the amount of winnowed out finer fill material; but this cannot be recognized, moreover, there is a continuous erosion (Figures 11, 12, 13). Finer as well as coarser sediment particles were winnowed out, although finer grains were eroded sooner than coarser particles. The temporal differences are very small because of minimum critical threshold stress variations, especially during storm surges when the hydrodynamic forces are so strong that grains of all sizes are suspended and transported seaward. Differences between fine and coarse sediment particles are very small because of the narrow grain-size spectra anyway. Therefore, the grain-size influence on beach fill longevity is insignificant on Norderney and Langeoog.

Recent publications suggest that the grain-size effects on beach fill longevity are limited (e.g. Larson and Kraus, 1989; Dean, 1991). Bruun (1990) has argued that basing beach fill design purely on grain-size distribution comparison is an obsolete principle. Nevertheless, this method is still acknowledged as an important basis for beach fill design (e.g. Anders and Hansen, 1990).

Larson and Kraus (1989) show the dependence between grain-size and eroded beach fill volume due to storm events. Thus, the eroded volume decreases relatively steeply as grain-size increases through the range 0.2 to 0.4 mm. Thereafter, from 0.4 to 1.0 mm, it decreases more gently. This behaviour follows from the property of the empirically determined functional dependence of the wave energy dissipation rates which rise steeply in the range of 0.1 to 0.4 mm and then increase at a lower rate with increasing grain-size. These results also demonstrate the limited influences of grain-size in order to enlarge beach fill longevity.

A beach fill will be eroded because it is not in a natural equilibrium with its boundary conditions. Therefore, a beach fill represents an erosional area. Some beaches such as those on the East Frisian Islands react with a selective enrichment of sediment grains with a higher critical threshold stress, i.e. mainly heavy minerals during erosional phases as storm surges. This passive reaction is a counteraction against erosion, although the erosion will not be terminated by this sedimentary response.

The grain-size has little effect on beach fill longevity, because the grain-size influences the critical threshold stress to a lesser extent than does the grain density. Only a significantly coarser fill material (i.e. gravel) which also has a significantly higher critical threshold stress may effectively extend beach fill longevity. Very coarse fill material such as gravel implies another problem. On Norderney, the beach was partly filled with gravel in 1961 and 1964 (Kramer et al., 1963; Muller and Ruck, 1965). The gravel increased the beach stability, especially during storm surges, but it was not integrated with the natural beach sand. Moreover, the gravel was selected by the hydrodynamic forces. A beach nourishment using gravel as fill

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**Table 5. Critical overfill ratio and renourishment factor based on grain size distribution of fill material and native beach sands.**

<table>
<thead>
<tr>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean grain size (phi)</td>
<td>φ_{min} 2.5</td>
<td>φ_{min} 2.3</td>
<td>φ_{min} 2.4</td>
</tr>
<tr>
<td>Sorting (phi)</td>
<td>φ_{max} 0.46</td>
<td>φ_{max} 0.46</td>
<td>φ_{max} 0.43</td>
</tr>
<tr>
<td>Critical overfill ratio</td>
<td>R_{crit} 0.64</td>
<td>R_{crit} 0.64</td>
<td>R_{crit} 0.37</td>
</tr>
<tr>
<td>Renourishment factor</td>
<td>R_{n} 0.39</td>
<td>R_{n} 0.45</td>
<td>R_{n} 0.36</td>
</tr>
<tr>
<td>Renourishment factor</td>
<td>R_{b} 2.5</td>
<td>R_{b} 1.8</td>
<td>R_{b} 1.5</td>
</tr>
</tbody>
</table>
material will only be successful if enough gravel is used to produce a real shingle beach. A mixture of sand and gravel, as predicted before the attempt on Norderney in the 1960's, is not possible because of different critical threshold stresses.

The use of heavy mineral sands or placers is a more suitable fill material to extend the longevity of artificial beaches. Heavy minerals have the required higher critical threshold stress without changing the structural properties of the sand beaches. Locating sufficiently heavy mineral sands could be problematical. There are several locations with heavy mineral placers in the southern North Sea (Ludwig and Figge, 1979); but the heavy mineral concentration only amounts to a maximum of 10%. This percentage is too low to provide a significant longevity extension. An alternative might be crushed volcanic rocks that have a naturally higher heavy mineral content or other particles that have a higher density. There is a need for additional investigative research to test the suitability of different materials for use as beach fill. Although this method may be neither practice nor economical for the islands in the southern North Sea, it is a possible answer for other areas dependent upon the availability of suitable resources.

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LITERATURE CITED


Kramer, J., 1960. Beach rehabilitation by use of beach fills and further plans for the protection of the island of Norderney. "Proceedings, 7th International Conference of Coastal Engineering (Richmond)."


