CHAPTER 247

ARTIFICIAL BEACH NOURISHMENT ON NORDERNEY, A CASE STUDY

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ABSTRACT

Norderney is one of the East Frisian Barrier Islands that extend along the western part of the German North Sea coastline (Fig. 1). Severe dune erosion jeopardized the health resort settlement on the west end of Norderney and necessitated the construction of solid coastal protection structures since 1857. These structures were successful in stopping the migration of the inlet and in preventing further dune erosion; but they were not able to maintain stable beaches. To protect the existing structures against damage artificial beach restoration was initiated on Norderney in 1951. Since then five further beach fills were necessary to affect an active protection by shifting the zone of wave attack seawards. The scouring from the groyne fields had been monitored. Based on these data the sand budget has been investigated. It has been proved, that on Norderney beach nourishment is an appropriate solution to protect the existing structures from failure during severe storm-floods. If we want to lower the amount of losses, we have to nourish the beach not higher than necessary to achieve the protection goals. Above a 'critical beach profile' in certain areas losses of nourished material increase considerably with height. Especially for the Norderney-case we should develop a 'low-cost-technique' for a 'low-rate-beach-nourishment'.

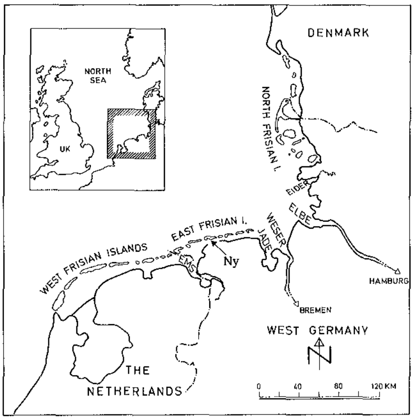


Fig. 1: Location map of the German North Sea Coast with Norderney-island (Ny)

INTRODUCTION

Like the other East Frisian Islands, the barrier-island of Norderney is formed by the coincidence of current, surf, wind (LÜDERS 1953). The migration of the islands has been well documentated for the last three hundred years (FORSCHUNGSSTELLE 1964). During the two centuries, 1850 ago, the situation between Norderney and the island to its west had changed from two hydraulically equivalent inlets, separated by a small middle island, into a single inlet. This inlet shifted to the east, eroding the core of the west end of Norderney (HOMEIER 1964, LUCK 1975). In accordance with the changed hydraulic conditions the offshore sandbars were forced seawards and therefore the west end of Norderney was no longer sufficiently supplied with sand. The development can be explained by the connection between the tidal inlet and the tidal prism; the eastward migration of the affiliated catchment area located on the tidal flat has to be considered (O'BRIEN 1969, FITZGERALD et al. 1984a/b, BRUUN 1978, LUCK 1976).

In 1857, people started to construct a combined system of shore-parallel structures and groynes on Norderney to prevent further erosion. It was necessary to extend the groynes into deep water to a depth of almost twenty meters to prevent the ongoing shifting of the inlet channel. During one century the system of protective structures was extended to a length of six kilometers. Descriptions are given by FÜLSCHER (1905), BACKHAUS (1938), PEPER (1956), KUNZ (1987). The development of the city of Norderney into a seaside health resort provided economical justification for the investment.

Even the shoreparallel structures were successful in preventing further dune erosion and the groynes were able to keep away the strong tidal currents from the core of the island, they could not stop the scouring from the beach. As the beach level progressively fell, the toe-protection of seawalls and groynes had to be extended and strengthened several times. Because of World War II the structures were not well maintained during the nineteen-fourties. The classical approach of toe protection had been reviewed by a special task group. As an alternative they recommended a restoration of the beach (ARBEITSGRUPPE NORDERNEY 1952). Thus the first artificial beach nourishment in EUROPE was implemented on Norderney in 1951/52. For the same reason five further beach fills were necessary up to now. This paper focuses on the development of the sand volume in groyne fields that ensure the safety of the structures. Results of volumetric calculations based on field data shall be presented and the question shall be discussed what we might learn from a feed-back to the monitored information concerning the technique of beach restoration on Norderney.

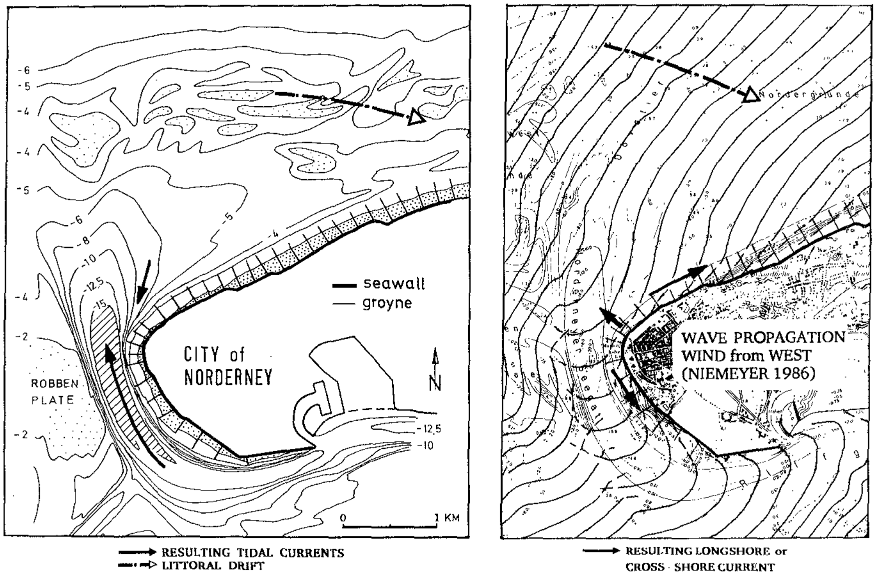


Fig. 2: Depth-contourlines, resulting currents and littoral drift (left); Wave propagation, resulting wave-induced currents (right) - Western spit of Norderney

BEACH RESTORATION SINCE 1951/52

The western spit of Norderney is displayed on Fig. 2. The left picture shows the depth-contour lines. The crescent shaped reefbow is dotted. The net littoral drift runs within the reef-bow from West to East. From time to time bars merge with the island, but only far from the western spit. For this reason there is barely sand naturally supplied to the western area. The hedged part of the tidal channel is more than fifteen meters deep. The groynes facing this part of the inlet are essential to govern the strong tidal currents. The MTR of 2,40 m leads to velocities of more than 1,50 m/s. There is a strong wave action predominantly from the west to northwest sector. An example for the wave propagation is shown in the right hand picture. The resultant longshore currents run bidirectional from an area located near the very western part. We address it as 'area of divergence'. This is the stretch where we have to face the greatest losses of sand and the strongest wave attack. Breaking waves generate high velocities in the groyne fields (NIEMEYER, 1990). The groynes which cover the easterly beach part as well as the other groynes, diminish the effects of longshore currents in the nearshore area. They are less effective the higher the water level is. The highest water level measured during storm flood (HHW) is three meters above MHW-level.

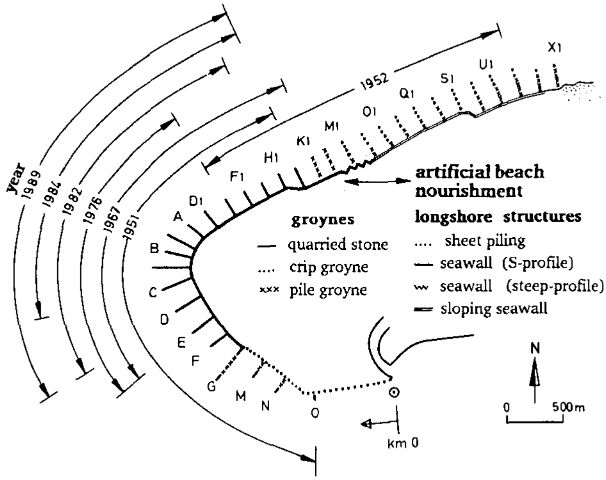
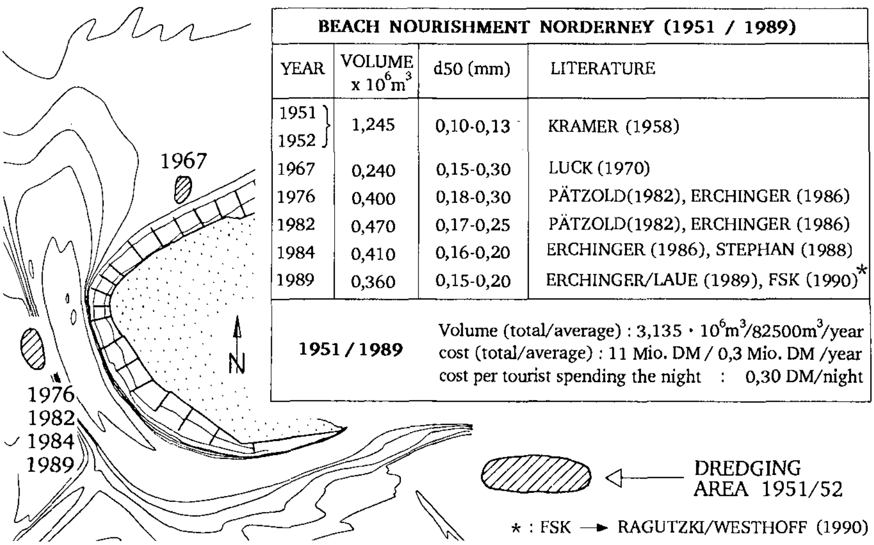


Fig. 3: Combined Protection System on Norderney-island

The combined protection system on Norderney is described by Fig. 3. Only the first artificial beach nourishment in 1951/52 covered the whole stretch.

The Fig. 4 gives some information on nourished volumes, on grain size and on literature. For the first nourishment the sand had been dredged from the tidal flat, where only fine material with a medium d_{50} of about 0,1 mm



BEACH NOURISHMENT NORDERNEY (1951 / 1989)			
YEAR	VOLUME $x 10^6 m^3$	d50 (mm)	LITERATURE
1951 1952	1,245	0,10-0,13	KRAMER (1958)
1967	0,240	0,15-0,30	LUCK (1970)
1976	0,400	0,18-0,30	PÄTZOLD(1982), ERCHINGER (1986)
1982	0,470	0,17-0,25	PÄTZOLD(1982), ERCHINGER (1986)
1984	0,410	0,16-0,20	ERCHINGER (1986), STEPHAN (1988)
1989	0,360	0,15-0,20	ERCHINGER/LAUE (1989), FSK (1990)*
1951 / 1989	Volume (total/average) : 3,135 · $10^6 m^3$/82500m^3/year cost (total/average) : 11 Mio. DM / 0,3 Mio. DM /year cost per tourist spending the night : 0,30 DM/night		

Fig. 4: Beach nourishments on Norderney (1951 to 1989)

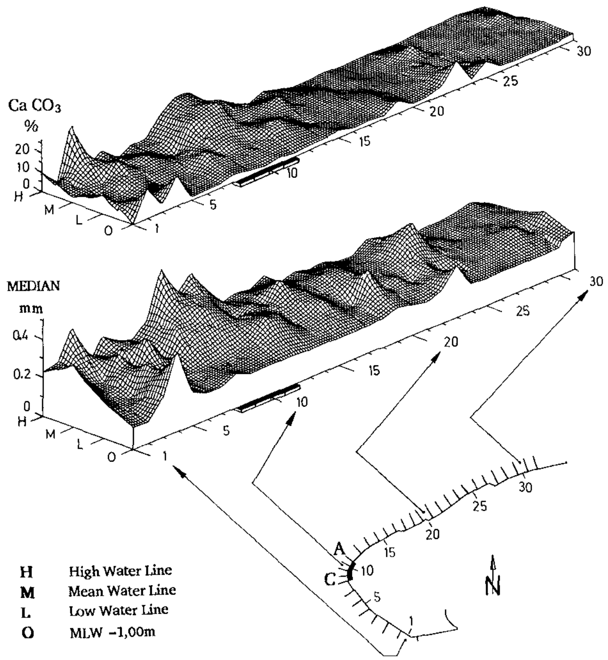


Fig. 5: Shell material and grain size in the groyne-fields of Norderney, Sept. 1987 - WESTHOFF (1990)

is available (KRAMER 1960, 1972). In 1967 the dredging of a relatively small amount of material with a medium d_{50} of about 0,25 mm was accomplished from a foreshore area (LUCK 1970). Since 1976, when the technique was available to cross the deep channel by submerged pipe-line, the sand was taken from an ebb shoal across the inlet. The material was less coarse, especially in 1989 with a medium d_{50} of about 0,17 mm (RAGUTZKI/WESTHOFF 1990). Since 1951 an average volume of 82500 m³ per year had been nourished.

The grain-size of the sand in the groyne-fields varies quite a bit. Fig. 5 pictures the situation in Sept. 1987. The convergence area (C-A) is marked by the solid line. The effects of sorting are obvious. The coarse material contains relatively more parts of broken shells, indicated by $CaCO_3$ (WESTHOFF 1990).

VOLUMETRIC CALCULATIONS AND LOSSES (1951 TO 1990)

As mentioned before, the paper is restricted to volumes to give an idea of the losses out of the vulnerable part of the groyne fields with time. The calculation focuses on the beach area where we definitly do need beach restoration for the purpose of securing groynes and shoreparallel

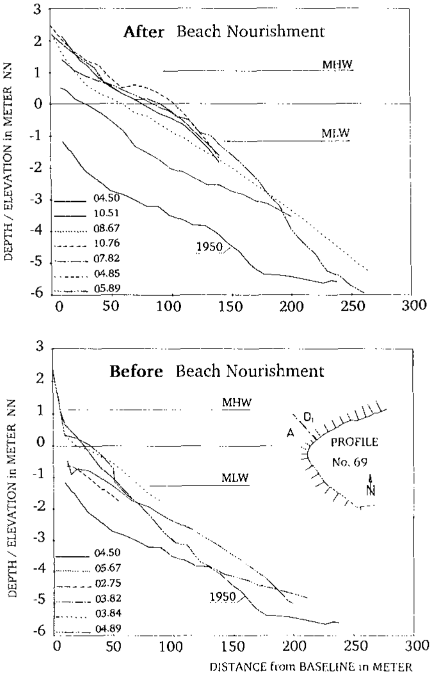


Fig. 6: Beach-Profiles in the groyne-field (A–D_1)

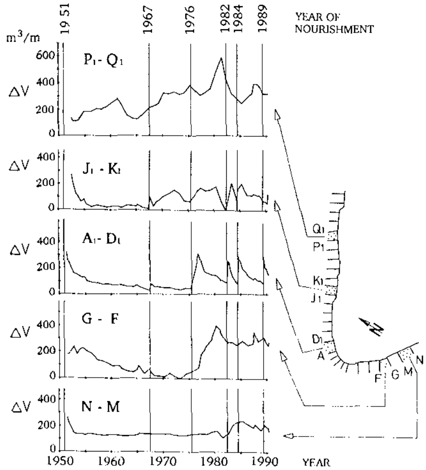


Fig. 7: Volumes above the 1950-Reference-Profile and the NN -1,50 m -level (ΔV) of five selected groyne-fields - Western spit of Norderney, 1951 to 1990

structures against failure during storm floods. To meet this target the volume calculation can be restricted to the beach part above NN -1,50 m - level, that's about MLW. This practical engineering approach is appropriate. There will be no discussion on the complicated cross- and longshore processes within enlarged boundaries.

An example for the monitored beach profiles is mapped on Fig. 6. Since the preliminary aim of the survey has been to monitor the vulnerable part of the seawall - and groyne - system, only some of the profiles extend deeper than MLW (STEPHAN 1988). The lowest profile is that of 1950, just before the first beach-restoration. We use the 1950-profile, specifically for each groyne field, as a 'reference profile' for the volumetric calculation. A restored beach would at least reach this profile if we would'nt nourish. From the lower picture we can see that the beach nourishments started off from different heights. The upper one depicts the different profiles just after the beach restoration. If we would plot the shape of the groyne into the picture, it almost would envelope the highest profiles (type of low lying groynes).

In the following, the volume-data always will be addressed as ΔV with unit cubic-meter per meter shoreline

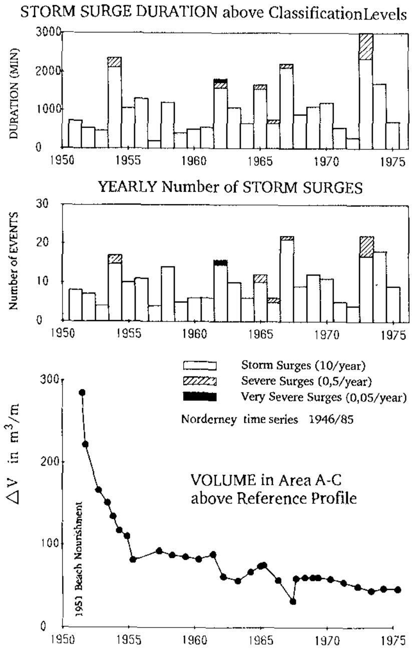


Fig. 8: Storm Duration, Number of Storm Surges, Volumes in area (A-C)

(m^3/m). The accuracy of the volume calculations has errors within the range of ± 7,5 %. The used field data for the profiles have been provided by STAIK (agency for island and coastal protection, Norden) and FORSCHUNGSSTELLE KÜSTE (research station, Norderney).

We can not expect to define a groyne-field that provides representative conditions for the whole six-kilometer stretch. The development of the volume (ΔV) over time is to be seen from Fig. 7. The field A-D_1, discussed above, is placed almost in the middle. Since it is located near the 'divergence area', each beach-nourishment indicated by the vertical solid lines, is to be recognized clearly. The deviation from the rectangular line in 1976 is an exception: the profiles after the nourishment had been monitored six month later. With greater distance from the 'divergence-area' the ΔV-graph is less immediate determined by the nourishment. The picture for the groyne-field P_1-Q_1 shows effects of sand supply from the reef-bow-bars that merged further to the East. The picture for groyne-field N-M displays an almost constant ΔV-curve, whereas the nearby-lying groyne-field G-F is obviously impacted by sand arriving from nourished parts. In general it seems to be justified to distinguish the period before 1976 with relatively moderate beach-volumes and the time after 1976 with comparably higher rates of beach nourishments. The 1967-restoration was weak and had almost no impact on the ΔV-curves. This contrast to data published by ERCHINGER (1986) can be explained by different boundaries fixed for the volumetric calculations.

1951 to 1976 is the only long-time period we can look at. The beach-nourishment of 1967 can be neglected, since it had almost no effect, that would interfere. Fig. 8 indicates how the volume (ΔV) of the divergence-area A-C decreases rapidly after the 1951-beach-nourishment. The curve does not seem to follow a kind of exponential-function (AUSSCHUSS KÜSTENSCHUTZWERKE 1977, 1988, FÜHRBÖTER et al. 1976, PÄTZOLD 1982). There are ups and downs in the ΔV-graph that might be caused by storm-surges. To prove this expectation, the storm-surge-duration and the number

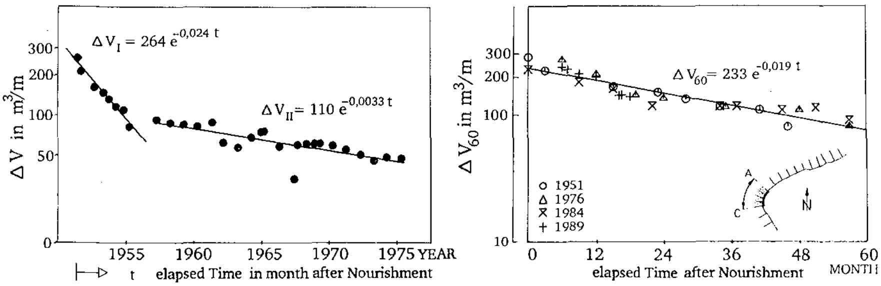


Fig. 9: Volume (ΔV) plotted over time and approximation by exponential functions. Left: 1951 to 1976. Right: periods after the nourishments of 1951, 1976, 1984, 1989

of storm-surges per year are plotted above. If we look at it carefully, we hardly will find a significant correlation; investigations on a much smaller time-scale are needed, if we want to describe the impact of storm-surge and wave action on profiles and on volumes (HOMEIER 1975). However, if we calculate and integrate wave-energy over time, we can get a relationship to the losses (PÄTZOLD 1982).

Plotting the volume ΔV against time in a semi-logarithmic scale, we come up with the results shown in Fig. 9. The elapsed time after beach-nourishment (first volumetric data) is indicated by 't'. Left hand again we have the period from 1951 to 1976. We have to distinguish at least two periods if we want to approximate by e-functions: a first one over 5 years from 1951 to 1956 and a second one for the following years. The two solid lines give the approximations (ΔV_I and ΔV_{II}). The exponent of the e-functions lead to 'half times' of 6 years, respectively 37 years. After these time periods we have lost 50% of the nourished volumes through the fixed boundaries: in cross-shore-direction into deeper parts of the beach and in long-shore-direction across the groynes.

For a time-period of 60 months we adjusted data of different nourishment-periods to a fixed scale representing the average conditions of the used periods. The results can not be compared directly with those published by PÄTZOLD (1982). The data from the 1982 beach-nourishment have been skipped: there are only two years to the nourishment and the losses are not well documented. Instead of this, the much better data from the 1989-nourishment have been used; the ΔV-function seems to behave quite similar to that one after 1982. The weak 1967-nourishment had only little impact on the ΔV-curve, as mentioned earlier. Again, the linear approximation is given in the semi-logarithmic scale. The exponent stays for a 'half-time' of 29 months. There is a substantial scattering but taking into account the different conditions (nourished material, profiles, tides, waves) we should not expect more.

From Fig. 9 we learn, that we can't describe properly the volume ΔV over the whole time-period by only one exponential function: If we use several different e-functions, the 'half-time (t_h)' of those would increase with the elapsed time (t). This leads to the non-exponential approximation as shown in the upper part of Fig. 10. The exponent of ΔV_{III} is a function of the elapsed time (t) after beach-nourishment: $t_h(\Delta V_{III})$. From this we come to the 'half-period' as function of 't'- shown below. The e-functions, as described before, are plotted into the distinguished time-periods for comparation-purpose: for the first 60 months this is $t_h(\Delta V_I)$ and $t_h(\Delta V_{60})$; the graph $t_h(\Delta V_{II})$ is representative for the time beyond the 60 months. Again, the graphs highlight that we face substantial errors, if we extrapolate a constant 'half-time' - for example from the fixed time boundaries given in Fig. 10 (dotted vertical line).

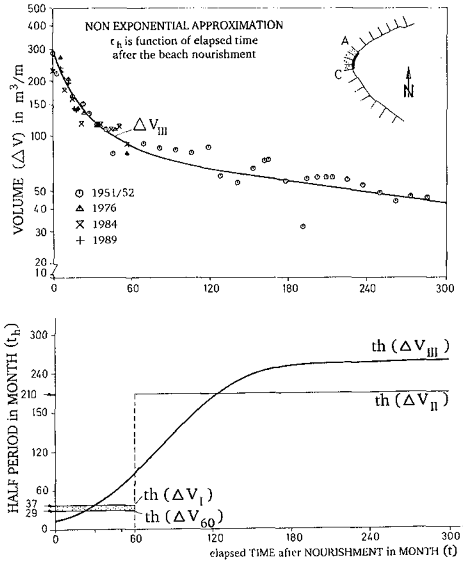


Fig. 10: Non exponential Approximation for ΔV versus time in semi-logarithmic scale (ΔV_{III}) Half-Period as function of elapsed time $t_h(\Delta V_{III})$ - Norderney (A-C)

We can convert the elapsed time into volume ΔV and come up with a curve as shown in Fig. 11. On the vertical axis again the 'half period t_h' in months; on the horizontal axis the volume ΔV. We can take this volume as nourished volume above the reference profile, landwards the fixed NN -1,50 m boundary. The curve (1) points out, how sensitive the 'half-period' reacts on the volume placed above the reference

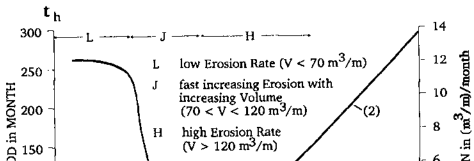


Fig. 11: Half Period and Rate of Erosion as function of nourished Volumes - Norderney, divergence-area (A-C)

profile. The rate of erosion (2) increases with decreasing half-period.

We draw as results:
If possible, we should nourish the divergent area, which determines the beach restoration-procedure, not more than 70 m³/m. In other words: we should stay in the 'L-area'. If we exceed out of the L-area the 'half time' decreases substantially with volume. This area is indicated as J. Beyond 120 m³/m the half-time gets almost constant; losses increase linear with volume.

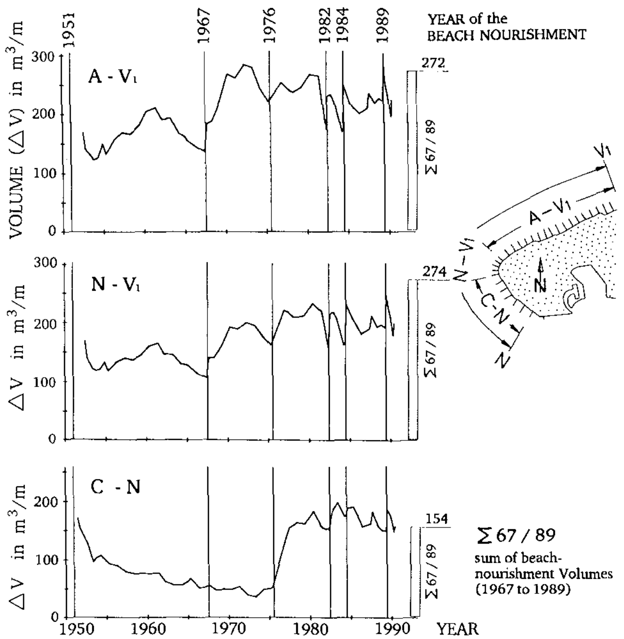


Fig. 12: Volumes (ΔV) - Norderney 1951 to 1990

Figure. 12 leads back from the 'convergence area' to the whole armoured stretch, to get an idea, how the volumes of groyne-fields on both sides of the 'convergence-area' change and how they benefit from the losses out of that area. The upper curve indicates the volume in m³/m in area 'A-V_1'. We use the same seaward boundary conditions as described earlier. The graph on the bottom is for the area 'C-N'. The curve in the middle stands for the whole stretch - that is 'N-V_1'. The beam on the right side of each picture indicates the total volume of sand in m³/m placed into the groyne fields after the first beach nourishment. If we compare the sum of nourished volumes (Σ67/89) with the difference between the 'actual ΔV' and the 'ΔV before the 1967-nourishment' we can conclude, that almost none of the material is left. The upper picture indicates, that from 1968 to 1973 substantial sandsupply must have been provided by sandbars that arrived at the beach eastwards of the groyne-fields. To address the impact of beach nourishment on the ΔV it is favorable to brake the time into two distinct periods: one 'from 1951 to 1976' and another one 'from 1976 to 1990'. Comparing the areas it is obvious, that since 1976 the average volume-level is significant higher than it had been before. With the effort of beach nourishment every 2 to 6 years a kind of volume-equilibrium is obtained, that seems to range on a higher level than needed. This encourages to look into the addressed problems, to answer the question wether we can go along with a lower volume-level, which would us enable to decrease beach nourishment-volumes substantially.

FINAL REMARKS AND CONCLUSION

The western spit of Norderney is endangered because:

there is a natural tendency of the inlet to shift eastwards to the island,
there is a negative sand budget,
there are storm surges up to more than 3 meters above MHW-level and strong wave-induced currents.

To protect Norderney, a combined system has been established since 1857. It consists of three components

shoreparallel structures
groynes with two different purposes
groynes to keep away the strong tidal currents from the core of the island
groynes to stabilize the beaches
artificial beach nourishment.

By storm surges in combination with waves the beach-profiles on Norderney are lowered, especially in front of the shoreparallel structures and groynes. Artificial beach nourishment is an appropriate solution to protect the existing structures against damage.

To achieve the protection goals we must ensure, that the beach area above MLW-level is considerably higher than the 'natural beach' would be without beach-restoration. Calculations of the beach volumes above the dynamic natural equilibrium profiles (approximated by 'reference profiles') on a long term time-period (1951 to 1990) led to relationships between the losses of nourished sand and beach volume. Above a 'critical beach profile' the losses of fulfilled material increase considerably with height (divergence area). The losses over a long time period can be calculated by an exponential function, if we use an exponent that itself depends on volume, respectivly time. The function represents the average conditions that be-sides the volume-parameter have an impact on the losses; different diameter and shape of the nourished sand and the initial profiles of the beach restoration as well as wave-energy lead to random scattering or temporary to different tendencies compared to the approximation-function. However, if we look at a long term time scale the losses out of the most vulnerable part of the Norderney-protection-system mainly depend on the calculated volumes within the fixed boundaries. If we want to lower the amount of losses, we should nourish the beach not higher than necessary to achieve the protection goals.

The efficiency of the groynes in the 'extended divergence area' against wave-induced longshore currents seems to account for one of the major reasons of this result.

We should try to approximate the natural beach slopes; however it seems to be essential that we nourish sand not finer than the natural beach.

It appears advantageous to nourish only the area from which the longshore currents are bidirectional (area of divergence) with a limited extention to the East. From the nourished area sand will be moved naturally to both directions (feeder beach).

We should try to get experiance with a deposit of sand in the foreshore-area of the easterly part of the 'extended divergence area' in combination with lower beach profiles in the area above MLW-level.

We have to look after a 'low-cost-technique' for a 'low-rate-beach-nourishment' on Norderney (KRAMER 1960). The comparison of low- and high-rate beach-nourishments will bring us to the cost-benefit-optimum.

Since the beach restoration on Norderney is part of the 'Coastline Defence System', the costs are paid by Federal and State. The enhancement of the recreational features of the beach is a welcome side-effect. Because Norderney is a highly frequented recreational beach area, there is an immediate demand for beach restoration after severe storm floods. However, we have learned that there can be a substantial amount of natural beach replenishment. There may be major savings in the cost of beach nourishment by postponing the decision on the design and quantity of sand to be placed on the beach, until the major quantity of the natural replenishment has occured.

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