CHAPTER 360

EFFECTIVENESS
OF A COMBINED BEACH AND SHOREFACE NOURISHMENT
ON THE ISLAND OF NORDERNEY/EAST FRISIA, GERMANY

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Abstract

In order to improve the effectiveness of artificial nourishments a replenishment outside of the beach itself was taken into consideration for a prototype test. Contradictory to the earlier six conventional beach nourishments the material was deposited both on the shoreface and on the beach. The fate of the combined shoreface and beach nourishment was as well as that of the preceding conventional beach replenishment intensively monitored including field investigations of bathymetry, hydro- and sediment dynamics. On the basis of these data and additional application of mathematical models the effectiveness of this new type of nourishment has been evaluated in comparison with a conventional beach replenishment.

Introduction

The East Frisian island of Norderney experiences structural erosion in its western parts since the beginning of last century which is caused primarily by large scale tidal inlet and ebb delta migration [LUCK 1977; NIEMEYER 1995]and secondary by a gradient in long shore transport in the generally west-eastern directed drift [KRAMER 1960; NIEMEYER 1991]. In addition to earlier erected solid structures eight beach nourishments have been executed here since 1951/52 [KRAMER 1960; KUNZ 1991; NIEMEYER et al. 1995a]. Hydro- and morphodynamical boundary conditions have already been described in earlier publications [NIEMEYER 1991].

In 1992 a combined beach and shoreface nourishment was chosen as an alternative to conventional beach nourishments (fig. 1) [NIEMEYER et. al 1995a]. In order to evaluate its effectiveness an intensive monitoring programme including sedimentological, morphological and hydrodynamical site

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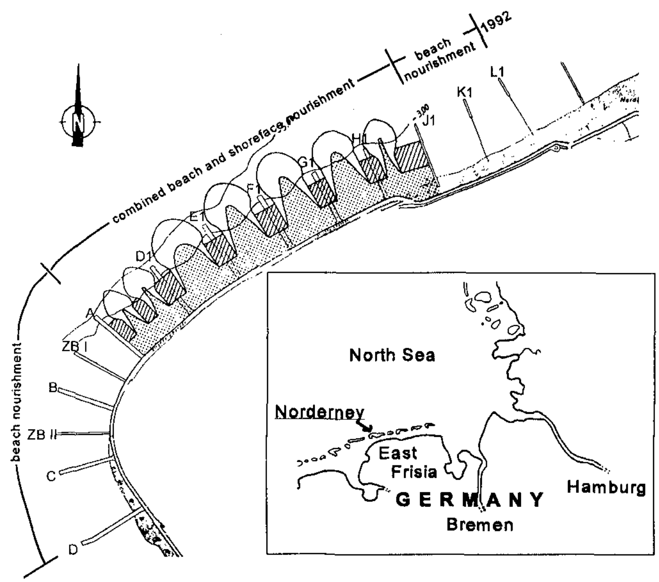


Figure 1. Island of Norderney/East Frisia in the southern North Sea; placements of the combined beach and shoreface nourishment in 1992 and of the preceding conventional beach replenishment in 1989

measurements has been carried out [KNAACK et al. 1996] as well as for the preceding conventional beach nourishment [KUNZ 1991; NIEMEYER 1991]. The investigations were carried out in cooperation with Danish and Dutch partners in the project "Innovative nourishment techniques evaluation (NOURTEC)" in the framework of the MAST II-programme of the European Communities and are additionally funded on a national basis. Results of the investigations carried out in respect to the combined shoreface and beach nourishment on the island of Norderney are subject of this paper focussing on its effectiveness by comparison with the preceding conventional one.

Design and initial behavior of the combined beach and shoreface nourishment

On the western and northwestern beaches of Norderney structural erosion is counterbalanced by artificial beach nourishments since 1951 [KRAMER 1960; KUNZ 1991; NIEMEYER 1991] though already between 1899 and 1909 dredging material has been dumped on the shoreface of the western beaches in order to improve beach stability [NIEMEYER et al. 1996]. In 1992 both nourishment techniques were combined for the replenishment of the northwestern beaches whereas on the western beaches only the beach was nourished (fig. 1). Basic idea of the deposition of material on the shoreface was to benefit from observed transport mechanisms explaining the pending of material between beach and shoreface [NIEMEYER 1991]. On the western beaches a deposition on the steep shoreface was considered as inconvenient; high initial irreversible losses into the close deep inlet channel were anticipated. A pure shoreface nourishment on the northwestern beaches was excluded because its execution by dumping or the rainbow-method on the shoreface between the groynes was regarded as dangerous for the executing vessels. Therefore the nourishment of the shoreface was carried out similar to that of the beach after finishing there the replenishment: the pipes were lengthened in the middle of the groyne fields and large humps were pumped into that area (fig. 2). It was anticipated that the local hydodynamical forces would create a dispersion of the sand stored in the artificial humps across the whole shoreface within a few weeks leading to its more or less uniform distribution.

Explanatory the reshaping of the hump in the groyne field E_1-F_1 is documented here by depth lines with reference to German datum = NN which is approximately equivelant to mean sea-level whereas mean high tide is about NN + 1,2 m and mean low tide about NN - 1,3 m (fig. 3): It is evident that the hump is lesser pronounced on the shoreface than on the beach. The highest initial losses occur therefore also on the intertidal beach and not on the shoreface which lower parts even benefit, but to a much lesser extent than the reduction of the hump's volume on the beach. A suitable explanation might be

Figure 2. Execution of the shoreface nourishment by pumping humps of sand form the shore

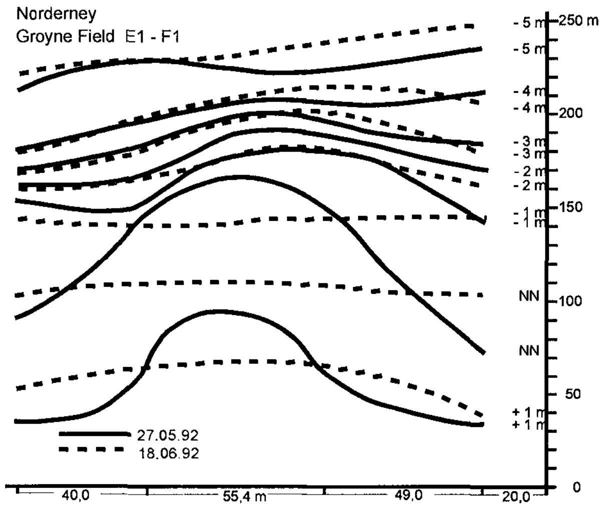


Figure 3. Reshaping of a sand hump after nourishment execution

that the geometry of the humps enforced the initilization of strong ripp currents evacuationg large amounts of the nourished material from the beach across the shoreface directly offshore being there unavailable for the anticpated pending between beach and shoreface.

Behavior of the combined beach and shoreface nourishment

Behavior of the total nourishment

The analysis of the behavior of the nourished beaches is focussed on the areas where the replenish-ment has been carried out both on the beach and on the shoreface. For this area also the corresponding data of the preceding conven-tional nourishment are taken into consideration in order to compare the effectiveness of both replenishment techniques. A comparison for the relative volumes per m beach length of the two replenishments above certain levels with reference to NN across the whole stretch between the groynes A and J_1 (fig. 1) highlights again that in the case of the combined nourishment the volumes on the shoreface below NN -1,5 m are not significantly large in relation to that ones on the beach, particularly not if compared with volumes of the preceding conventional replenishment (fig. 4a). This fact is evidently confirmed by a comparison of the volumes between the chosen levels (fig. 4b): the relative volumes on the beach of the combined nourishment are higher than those of the conventional one. But nevertheless the data highlight also that a comparison of the two distinct nourishment on the basis of their lifetime will remain insufficient, because the remaining relative volumes of the combined beach and shoreface nourishments were at the end of its lifetime in 1994 higher than those of the preceding conventional one in its final stage.

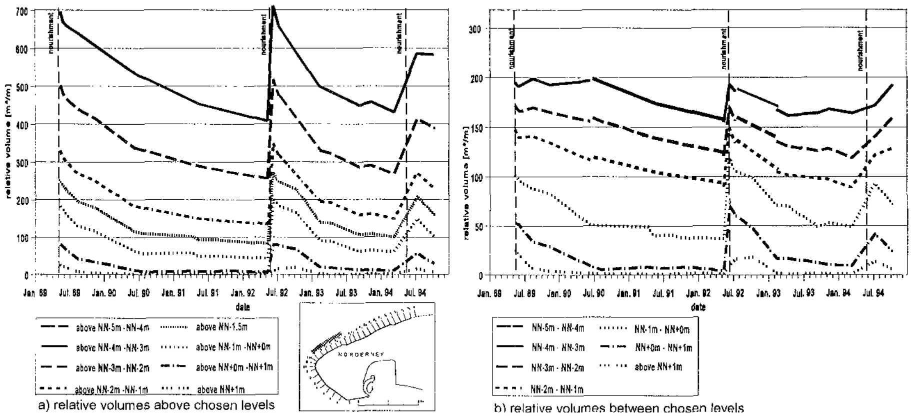


Fig. 4: Relative volumes per m beach length between the groynes A and J_1 after the conventional beach replenishment in 1989 and the combined beach and shoreface nourishment in 1992

Behavior of the nourishment in specific groyne fields

In order to get a deeper insight into the behavior of the two nourishments the development of their volumes in specific groyne fields has been evaluated with reference to the differences of shape and relative volumes. In the groyne field A-D_1 (fig. 1) at the downdrift edge of the combined beach and shoreface nourishment the relative volumes become between nearly all levels continuously smaller after the conventional beach nourishment of 1989. Only a slight increase occurred in the lower part of the shoreface in the very beginning and on the intertidal beach after a lifetime of more than two years (fig. 5). Contradictory the relative volumes of the lower shoreface increase during the whole lifetime of the combined nourishment and there is after initial erosion accretion on the upper part of the beach above mean sea-level during the first autumn and winter after implementation of the nourishment.

In the updrift succeeding groyne field D_1-E_1 (fig. 1) the intertidal beach looses relative volume immediately after the conventional beach replenishment in 1989 (fig. 6). After the first winter following the implementation of the nourishment here the relative volumes have again the same order of magnitude as before. They remain on the lower part of the intertidal beach then rather stable and decrease slightly in the final stage of the lifetime. The relative volumes on the shoreface increased during the first stage of the lifetime or experienced even a transient increase. After a period of about one year in coincidence with reduction of the relative volumes on the beach to the pre-nourishment level a continuos erosion of the shoreface started. It is itself suggesting that probable losses on the shoreface might have been compensated by eroded material from the beach as long as this source was available.

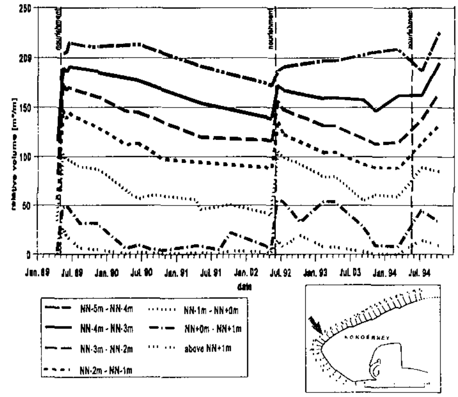


Fig. 5: Relative volumes per m beach length between the groynes A and D_1 between distinct levels after the conventional beach replenishment in 1989 and the combined beach and shoreface nourishment in 1992

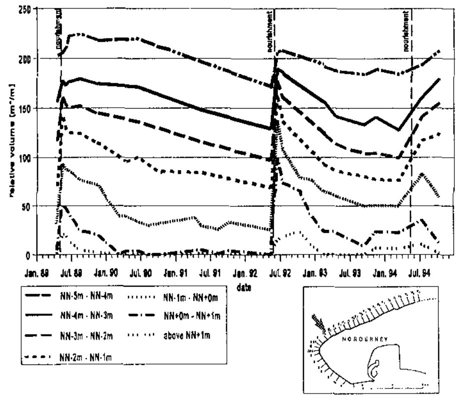


Fig. 6: Relative volumes per m beach length between the groynes D_1 and E_1 between distinct levels after the conventional beach replenishment in 1989 and the combined beach and shoreface nourishment in 1992

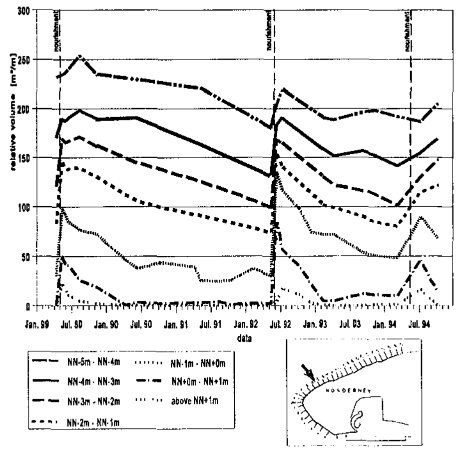


Fig. 7: Relative volumes per m beach length between the groynes E_1 and F_1 between distinct levels after the conventional beach replenishment in 1989 and the combined beach and shoreface nourishment in 1992

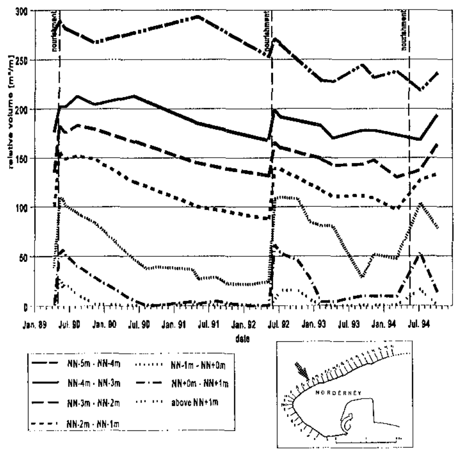


Fig. 8: Relative volumes per m beach length between the groynes F_1 and G_1 between distinct levels after the conventional beach replenishment in 1989 and the combined beach and shoreface nourishment in 1992

The nourished volumes in this groyne field have been larger for the subsequent combined nourishment leading to remarkable initial losses beside a slight increase on the highest part of the beach during the following five months. But after more than one year of lifetime a stabilization occurred on a

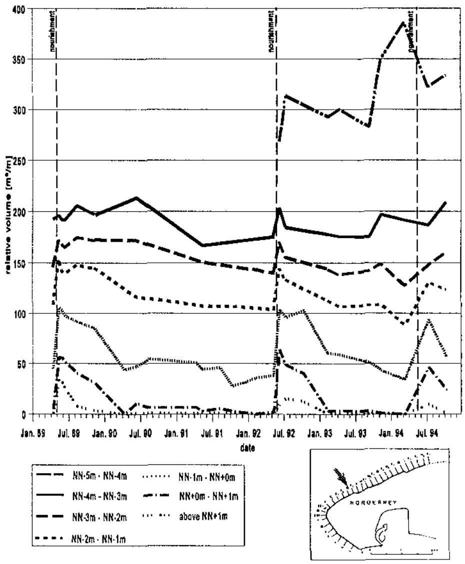


Fig. 9: Relative volumes per m beach length between the groynes G_1 and H_1 between distinct levels after the conventional beach replenishment in 1989 and the combined beach and shoreface nourishment in 1992

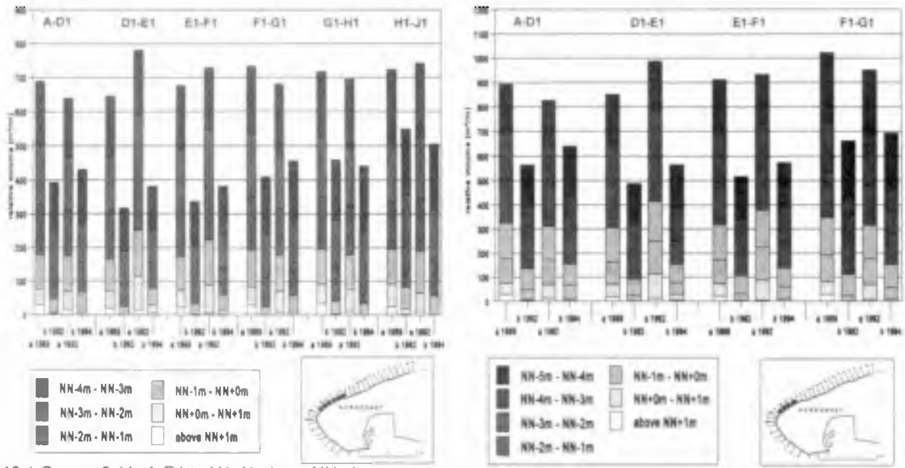
level significantly higher than the one before the implementation of the nourishment. Moreover the higher parts of the beaches recovered where the material is in respect of the primary aim to reduce wave loads more effective than anywhere else in the profile. This highlights once more that the morphological situation did not demand for the subsequent nourishment in 1994.

Similar results are gained for the next two groyne fields in updrift direction E_1 - F_1 and F_1 - G_1 (fig. 1) though less pronounced than for D_1-E_1: There are both on the upper part of the beach as well as on the lower shoreface transient phases with accretion after initial erosion (fig. 7 + 8). Particularly on the lower part of the beach the relative volumes are significant larger at the final stage of the combined beach and shoreface nourishment than before.

Contradictory the relative volumes after the combined nourishment in the groyne field G_1-H_1 follow another tendency. Whereas their values remain rather stable or increase even on the lower shoreface those on the beach reflect continuous erosion. Particularly there the preceding conventional beach replenishment has not experienced a higher amount of erosion though its lifetime lasted longer (fig. 9). This effect requires further explanation, because the behavior of the nourished beach and foreshore in this area has changed in comparison with preceding nourishments. Erosion has become relatively higher with respect to the rates in the groyne fields being located updrift.

Total balance

For all groyne fields the relative volumes between certain levels have been determined as well for the combined beach and shoreface nourishment in 1992 as for the preceding conventional beach replenishment in 1989 on the following basis: total amount before and after execution (fig. 10.1 + 10.2), losses and nourished volume (fig. 11.1 + 10.2). The relative volumes after the execution of the combined nourishment are higher than after the implementation of the preceding conventional one in the groyne field E_1-F_1, H_1-J_1 and particularly in D_1-E_1. According to the relative volumes before



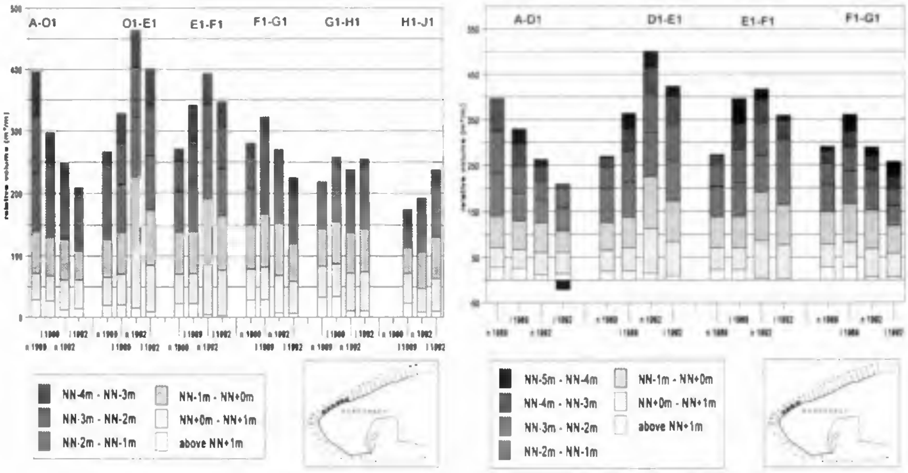
10.1 Groyne fields A-D1 to H1-J1 above NN -4m

10.2 Groyne fields A-D1 to F1-G1 above NN -5m

Fig. 10: Relative volumes per m beach length between distinct levels after implementation (a) and at the end of the lifetime (b) for the nourishments in 1989 and 1992

implementation this was aimed at counterbalancing an anticipated higher rate of erosion in these areas (fig. 10.1 + 10.2). The same design procedure has been applied for the replenishment in 1989 (fig. 11.1) for the groyne field A-D_1 which has been rather successful if the remaining relative volumes in total are taken into consideration. In the groyne fields A-D_1, F_1-G_1 and G_1-H_1 the total relative volumes have been smaller for the combined nourishment in comparison to that one in 1989. The remaining relative volumes at the end of the lifetime of the combined nourishment are higher at that of the conventional replenishment between the groynes A and G_1 and smaller in the two following groyne fields G_1-H_1 and H_1-J_1 (fig. 10). Of high importance with respect to the primary aim to reduce wave attack at the seawall are the significantly higher remaining relative volumes on the beach and there particularly in the upper part above mean sea-level in the area between the groynes A and F_1 and to a lesser extent in the groyne field F_1-G_1. With respect to the necessity of a subsequent nourishment a comparison of the remaining relative volumes at the end of the lifetime of both nourishments makes evident that the minimum values existing before the combined beach and shoreface nourishment were still by about 25% and more exceeded in any place at the end of its lifetime (fig. 10)

Beside the groyne field A-D_1 the losses after the conventional beach nourishment exceed the nourished relative volumes (fig. 11). Though the losses in A-D_1 were not compensated by the combined nourishment it delivered on overish ot which is particularly evident for the lower shoreface where instead of losses a net win has taken place (fig. 11.2). The comparison



11.1 Groyne fields A-D1 to H1-J1 above NN -4m

11.2 Groyne fields A-D1 to F1-G1 above NN -5m

Fig. 11: Relative nourished volumes (n) and afterward losses (l) per m beach length between distinct levels for the nourishments in 1989 and 1992

between nourished relative volumes and subsequent losses makes evident that particular for the stretch between the groynes A and G_1 where for both nourishments the highest losses occur the combined beach and nourishment left over an overshot of material at the end of its lifetime. In the groyne fields A-D_1, F_1-G_1, G_1-H_1 (fig. 11) and if the lower part of the shoreface is included even in the groyne field E_1-F_1 the total losses after the implementation of the combined nourishment have been remarkably smaller than for the preceding conventional beach replenishment. Only in the groyne fields D_1-E_1 and H_1-J_1 the total losses after the execution of the combined nourishment have been larger than those of the preceding one (fig. 11.1). The difference decreases by about 50 % for the groyne field D_1-E_1 if the lower shoreface is taken into consideration (fig. 11.2). With respect to of the major purpose of artificial nourishments in this place to reduce wave attack on the seawall it is of high importance to check the losses on the upper part of the beach. The behavior of combined beach and shoreface nourishment in the area with the largest losses makes evident that particularly there the relation between nourished and lost relative volumes above mean sea-level is favourable in comparison to that of the precending conventional beach replenishment (fig. 11).

Impacts of changing local wave climate

measurements in the offshore area and on the shoreface of the island of Norderney highlighted enormous changes in wave damping on the ebb delta of the tidal inlet. In comparison to results from earlier investigations [NIEMEYER 1987] waves are lesser attenuated when propagating across the ebb delta, even for conditions with no remarkable set-up on mean high tide the

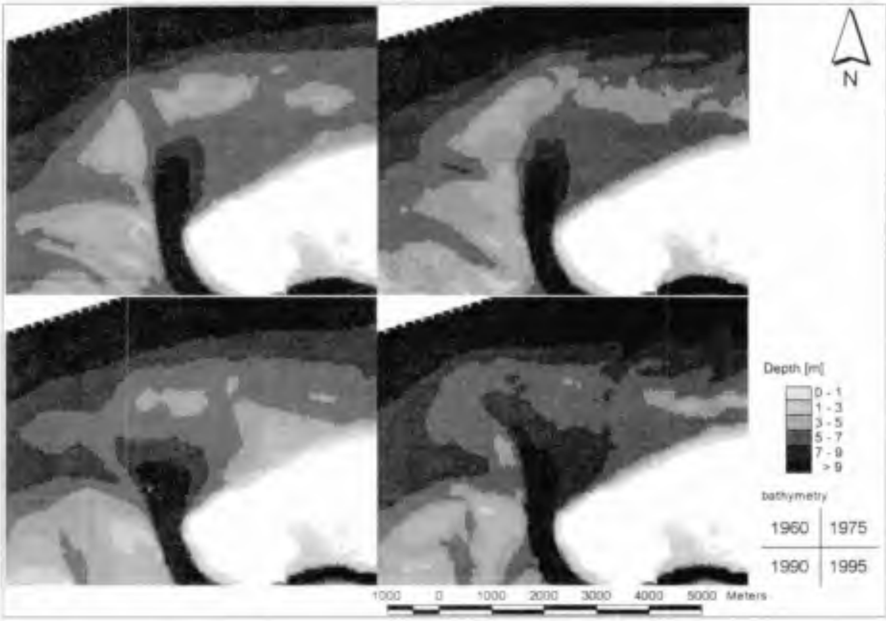


Fig. 12: Topography for the area seaward of the tidal inlet and the northwestern shore of the island of Norderney according to surveys in 1960, 1975, 1990 and 1995

shelter effect of the ebb delta for the northwestern beaches of the island of Norderney was remarkably reduced. In order to get a deeper and more systematic insight into background on these processes runs with the mathematical wave model HISWA [HOLTHUIJSEN & BOOIJ 1987; BOOIJ & HOLTHUIJSEN 1992] have been carried out for four distinct morphological situations of the area seaward of the tidal inlet and the northwestern shore of the island of Norderney (fig. 12): the bathymetries of 1960, 1975, 1990 and 1995 were used as a basis for model topography. The model HISWA has already been successfully applied to this specific area and similar ones and is regarded as a suitable tool for the anticipated purpose [DEN ADEL et al. 1991; NIEMEYER et al. 1995b].

Already the simple comparison of the topography for the disinct four situations makes signifkant morphological changes evident (fig. 12): Whereas the ebb delta is becoming even more pronounced after 1960 with a climax in 1975 the later surveys in 1990 and 1995 make a reduction of the shallows with heights above NN - m evident. Accompanied is this process by a migration and seaward directed deepening of the main channel of the inlet between 1990 and 1995: Both morphological changes enhance onshore wave penetration in direction of the island's northwestern shores.

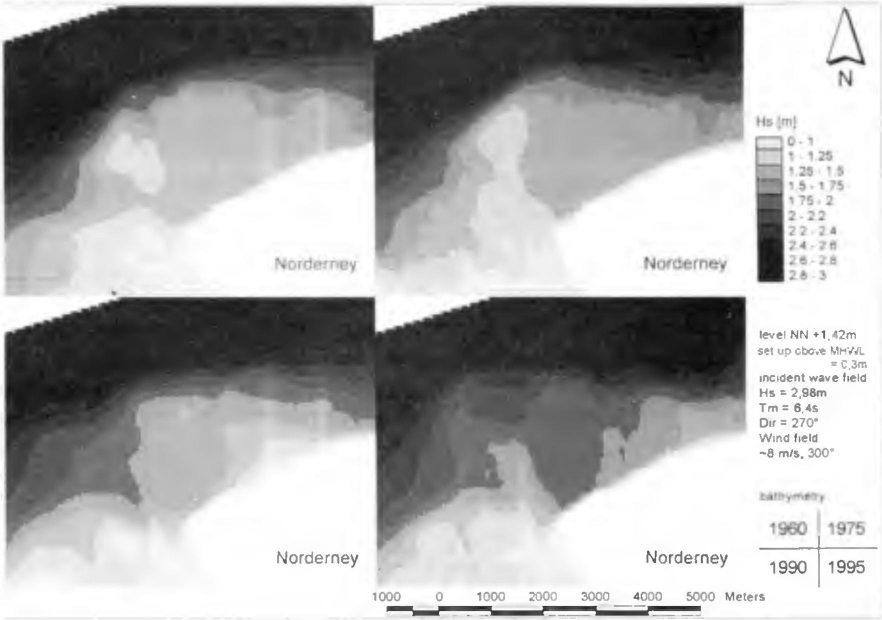


Fig. 13: Significant wave heights for the area seaward of the tidal inlet and the northwestern shore of the island of Norderney according to the bathymetry in 1960, 1975, 1990 and 1995 (computed with HISWA)

The model runs confirm this first estimate with respect to penetration of higher waves into the northwestern shoreface of the island of Norderney (fig. 13): For the situations of 1960 and 1975 no significant changes occur. But already for the topography of 1990 higher waves with 1,75 m $\leq H_s \leq$ 2,00 m propagate across the ebb delta though not appearing nearshore. For the topography of 1995 waves with heights with this order of magnitude occur on a large part of the shoreface. This increase in nearshore wave energy is not only confirmed by prototype data; the measured wave heights on the shoreface are even higher than those being computed with the model for the same offshore conditions. Additional investigations have shown that this effect does not increase for storm surges with higher set-up and higher waves. The higher waves enforce also a more intensive wave energy dissipation due to breaking in the ebb delta area.

In order to make the effect of this change in local wave climate for the dynamics on the northwestern shoreface and beaches of the island of Norderney more evident the computed significant wave heights for all four morphological situations are compared at 26 selected points at the edge of shoreface and beach parallel to the island's northwestern shore (fig. 14). For the situations of 1960 and 1975 there are no remarkable changes in wave climate. The significant wave heights are of the same order of magnitude on

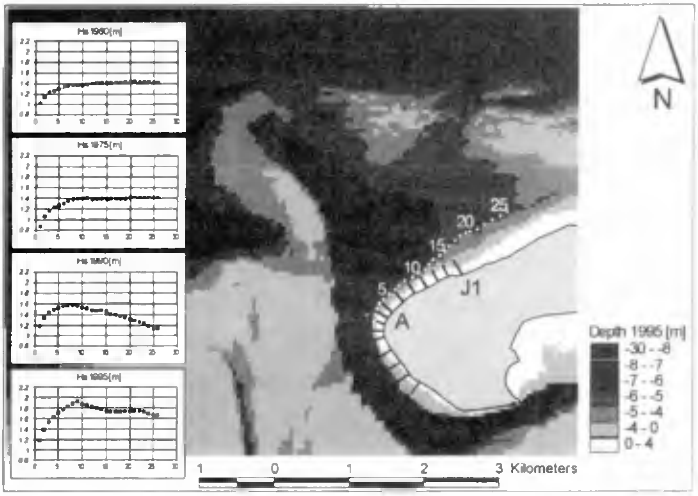


Fig. 14: Significant wave heights at the edge of shoreface and beach parallel to the northwestern shore of the island of Norderney according to the bathymetry in 1960, 1975, 1990 and 1995 (computed with HISWA)

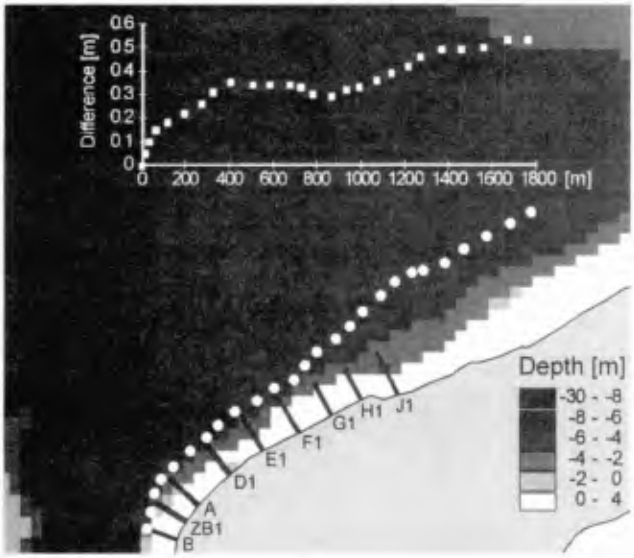


Fig. 15: Differences of significant wave heights at the edge of shoreface and beach parallel to the northwestern shore of the island of Norderney according to the bathymetry in 1990 and 1995 (computed with HISWA)

the whole stretch of the northwestern shoreface. In 1990 there is an increase of wave heights particularly in the stretch between the groynes A and F_1 but they decrease further downdrift. In 1995 wave height have increased in all places downdrift of groyne A (fig. 15). This comparison highlights that the combined nourishment experience for the same offshore conditions higher wave loads with stronger driving forces than the preceding conventional one. This unfavorable boundary conditions are another indication for the superior effectiveness of the combined nourishment. The change in wave climate explains also the higher losses occurring after the implementation of the combined beach and shoreface nourishment in the area downdrift of groyne H_1.

Conclusions

The comparison between the combined beach and shoreface nourishment and the preceding conventional replenishment with respect to their effectiveness has lead to the following conclusions:

1. Lifetime is in this case no suitable measure for comparing the effectiveness because the remaining relative volumes are for the combined nourishment in any place larger than the accepted minimum values for the preceding conventional for which no damages of the seawall occurred.

2. High initial losses of the combined nourishment might be credited to the chosen execution method with the deposition of humps which might have provoked strong ripp currents in the groyne fields. A less concentrated dumping of supply material on the shoreface could improve the measure.

3. Relatively higher losses in the downdrift part of the combined nourishment in comparison to the preceding conventional one do not occur due to the changes in the execution method. They are enforced by changes in local wave climate due to migration of the ebb delta leading to an increase of the driving forces for longshore currents and littoral drift.

4. The application of reliable mathematical wave models in combination with available actual bathymetries is suitable to make changing wave loads evident allowing an optimized adaption of the spatial distribution of relative nourished volumes in distinct groyne fields.

5. Particularly in the area with high rates of erosion the behavior of the combined nourishment delivered indications for the anticipated pending of the sand between shoreface and beach leading there to a recovery of the upper part of the beach which is beneficial with respect to the major aim of these nourishments to enforce wave energy dissipation in front of the landward placed seawall.

6. An further optimization of artificial nourishments on the northwestern shore of the island of Norderney requires a definition of acceptable wave loads for the existing seawall in order to evaluate the ultimately necessary minimum of relative volumes on the beach for sufficient wave energy dissipation.

Acknowledgement

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Lake Worth sand bypass plant, Palm Beach, Florida.
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PART VI

Case Studies

Hillsboro Inlet, Hillsboro, Florida. Photo courtesy of
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