CHAPTER 60

FIELD MEASUREMENTS AND ANALYSIS OF WAVE INDUCED NEARSHORE CURRENTS

H. D. NIEMEYER
Coastal Research Station/NLWA-Forschungsstelle Küste
Norderney/East Frisia, Federal Republic of Germany

ABSTRACT

Two data sets of field measurements of wave-induced nearshore currents are analyzed and discussed with respect to cross-shore transport phenonema and the effectiveness of beach groynes. The results are discussed in order to improve future artificial beach nourishments.

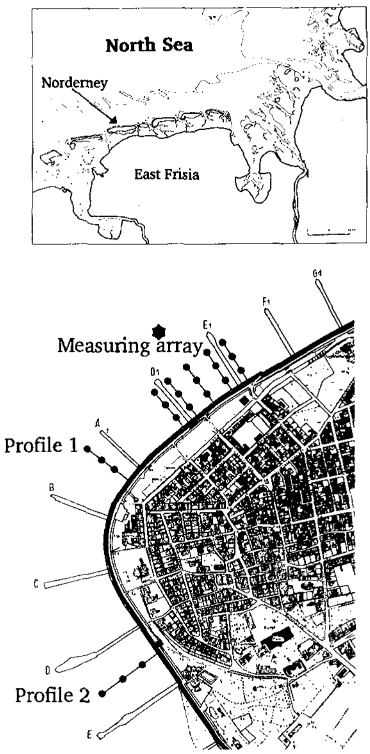


Fig. 1: Island of Norderney in the southern North Sea with measuring array and profiles

1. BACKGROUND AND SETUP OF INVESTIGATIONS

Subject of this contribution are the results of field measurements carried out on beaches of the East Frisian island of Norderney at the southern North Sea coast (FIG. 1). These investigations are part of a research programme for the optimization of future beach nourishments in the framework of interactions between hydrodynamics and existing solid structures.

In the past the East Frisian barrier islands were enforced to change their shape due to migration of tidal inlets creating a new ebb delta geometry with a furthermore updrift overleap of the ebb delta along the downdrift inlet shoreline. The sediment transport due to the eastward directed littoral drift bypasses the inlet in the form of large, migrating swash bars via the ebb delta and leads finally to a welding process of swash bars and island shore. Downdrift of their landfall the beaches suffer therefore from insufficient sediment supply causing erosion. For almost the last two centuries the morphological development of the western part of the island of Norderney was particularly governed by these processes (LUCK 1977). In order to stop further shoreline retreat solid structures have been erected since the middle of the last century. In spite of the construction of groynes, revetments and seawalls the problems remained unsolved till the introduction of repeatedly executed artificial beach nourishments as a successful tool of coastal protection which each remedied the grievance for a certain period of time (KRAMER 1960).

Though artificial beach nourishments have appeared as a rather successful tool to counterbalance the effects of continuous beach erosion, the demand for further improvements has been steadily present and has recently been more and more growing with respect to the effects of an expected acceleration of sea-level rise. Therefore in 1988 an intensive monitoring programme was started including hydrodynamical field measurements, beach and foreshore survey and sediment sampling.

Waves and currents are measured in one array with 16 and in 2 profiles with 3 measuring stations. Each station is equipped with both a pressure gage and an electromagnetic current meter, whose sensor heads are fixed closely to the bottom in order to measure velocities and directions of the currents there. First results gained from data in the measuring array (FIG. 2) are presented here. Special emphasis is laid on cross-shore transport phenomena and effectiveness of groynes. Due to limited space the discussion is focused on two data sets being representative of storm surge conditions and of swell occuring at ordinary tide water levels. In order to get a better in-

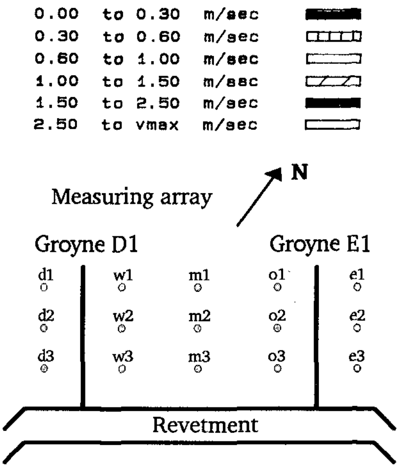


Fig. 2: Marks of measuring points in the measuring array and velocity ranges of the current roses

sight into the complex structure of the near-bottom currents on the beach the following analysis procedures were applied for this study:

- Any with a sampling rate of 11,78 Hz measured vector for a time series of twenty minutes are distinguished for sectors of 22,5° and five classes of velocity ranges and plotted as current roses (FIG. 5, 6, 14). Additionally resulting current roses are gained by the addition of any counterdirectional components of the original rose (FIG. 7).
- The total amount of spectral energy is summarized for sectors of 5° and plotted as directional spectra (FIG. 8, 10-12).

2. HYDRODYNAMICAL BOUNDARY CONDITIONS

The mean tidal range in the area of Norderney is about 2.4 m with variations of ± 0.7 m due to spring and neap. The tide is lunar semidiurnal with a mean period of 12 h 25′. Until now the highest measured storm surge set-up was some 3 m above MHWL. The averaged yearly exceedence frequencies of storm surge peaks above MHWL due to German standard classification are 10 for 0,93 m; 0,5 for 1,95 m and 0,05 for 2,86 m (NIEMEYER 1987a). Tidal currents are rather weak on the beaches with mean velocities of about 10 cm/s and a range of maximum velocities of 2,5 to 29,8 cm/s for flood and 5,1 to 39,5 cm/s for ebb tide with respect to 21 continously measured tides (NIEMEYER 1987b).

High energy wave conditions occur for winds from west to northeast generating landward traveling waves in the southern North Sea. On the island's shoreface on the average the sector of wave directions is reduced from 135° to 85° for mean conditions due to refraction. The predominantly western and northwestern directions of wind and swell create a system of longshore currents with northeastern direction on the northwestern beach and southeastward in the vicinity of the main channel of the tidal inlet (NIEMEYER 1986). The ebb delta overlaps in longshore direction the island's shoreface seaward of the beaches which have to be nourished from time to time and are now subject of this investigation. Waves propagating onshore from sea into this area have to pass the ebb delta with its shoals forcing higher waves to break. The energy dissipation due to that process effects not only a reduction of wave heights and a transformation of periods, lengths and steepness but also as well an energy shifting to higher frequencies as a decay of energy concentration leading to multi-peak spectra (NIEMEYER 1987c).

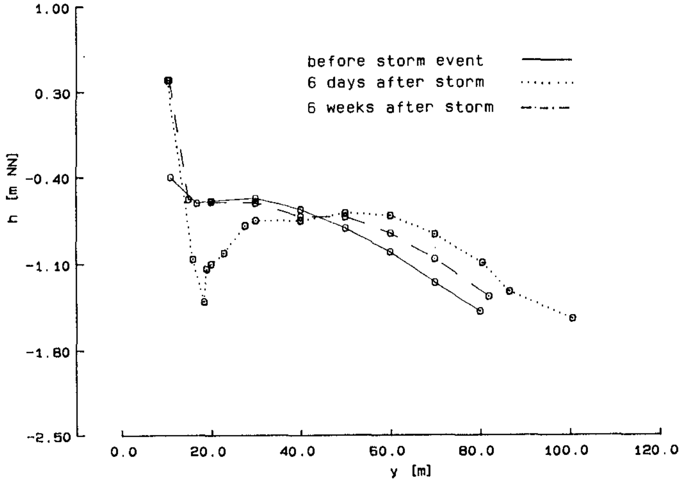


Fig. 3: Beach erosion due to storm surges and aftermath recovery

3. WAVE-INDUCED CURRENTS AND CROSS SHORE TRANSPORT PHENOMENA

3.1 Recovery of erosion profiles

The typical seasonal shift of beach profiles due to changing wave conditions is a well known as the phenonema of summer and winter profiles (BASCOM 1954). After the occurence of numbers of severe storm surges HOMEIER (1976) investigated the behaviour of beaches on the East Frisian islands including those in the suppletion area of Norderney. The most important result was that even a recovery of those beaches takes place which suffer from continuous erosion. The beach erosion due to storm surges was balanced by an accumulation of material on the shoreface which moves slightly back shoreward within a few weeks. After that period the rate of erosion has decreased to mid-term tendency. A typical example of storm surge erosion and following recovery for a beach profile in the investigation area is shown in FIGURE 3. One major subject of this study is to get to know the governing hydrodynamical processes of this phenonema in order to make eventually use with respect to the design of future beach nourishments.

3.2 Analysis of Storm Surge Current Measurements

Storm surges are usually accompanied by high energy waves. For these conditions there is a broad surf zone on the

Fig. 4: Broad surf zone with white rollers during a storm surge

beaches of the investigation area characterized by subsequently following white rollers (FIG. 4). The energy dissipation of the waves establishes a complicated secondary system superimposing the incident waves. In this study data of a storm surge at high tide with a set-up of approximately 1,5 m above MHWL are taken. Wind direction was 290° with speeds between 15 and 16 m/s within the last three hours before. Significant wave heights ranged from 1,96 m (station m3; waterdepth h = 2,6 m) close to the revetment to 2,21 m (m1; h = 3,3 m) in the most seaward row of the measuring array (FIG. 5 + 6).

The current roses for the most seaward (FIG. 5) and for the most shoreward measuring row (FIG. 6) show a shoreward increasing overbalance of seaward directed components. This effect becomes more apparent, if resulting current roses are used. The example of the inner line of the array (FIG. 7) shows evidently that at least there are only resulting components in updrift longshore and especially in offshore direction with a reasonable part of high velocities. The same results are gained if data analysis is carried out with directional spectra (FIG. 8).

This data seem to be a reasonable hydrodynamical explanation for the high erosion rates and especially the shoreward increase of seaward directed currents explains sufficiently the scouring in front of revetments due to storm surges. The deposition of eroded material on the shoreface is possible as the overbalance and intensity of offshore directed currents decreases with distance from the shore.

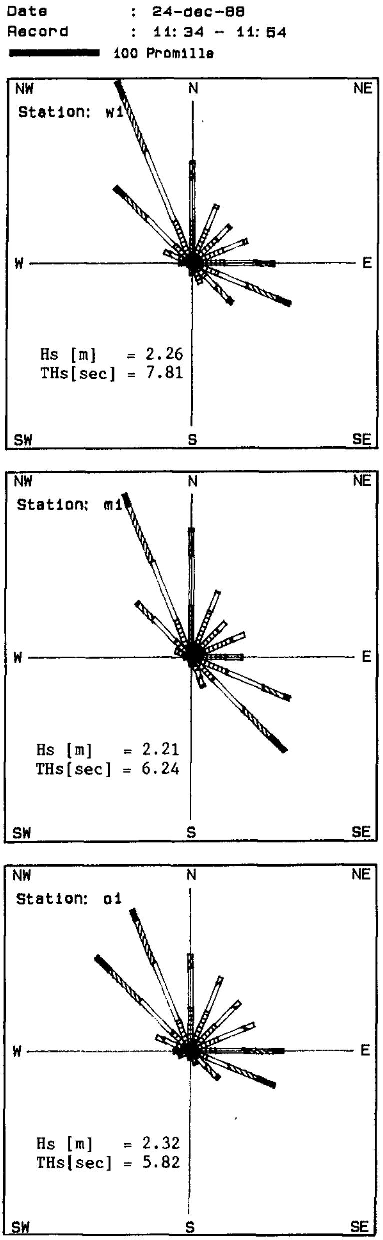


Abb. 5: Current rose of the measuring points w1, m1, o1 (storm surge)

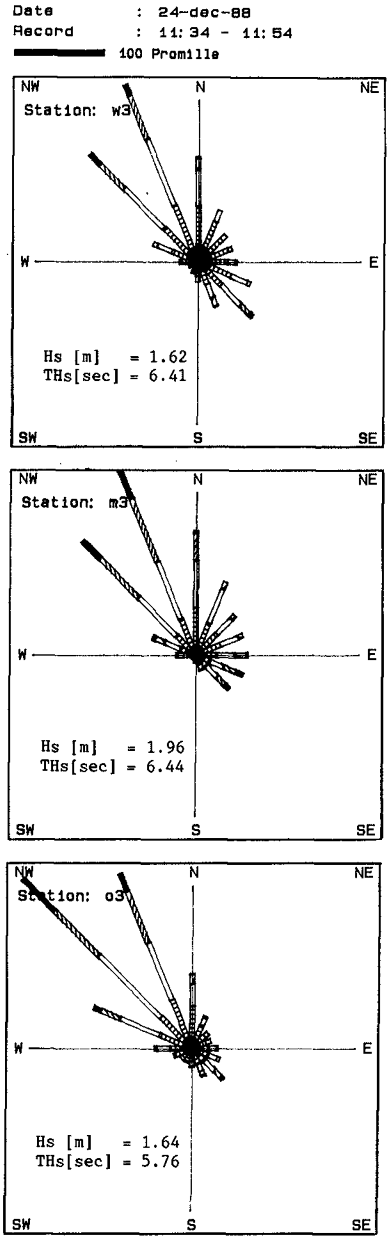


Abb. 6: Current rose of the measuring points w3, m3, o3 (storm surge)

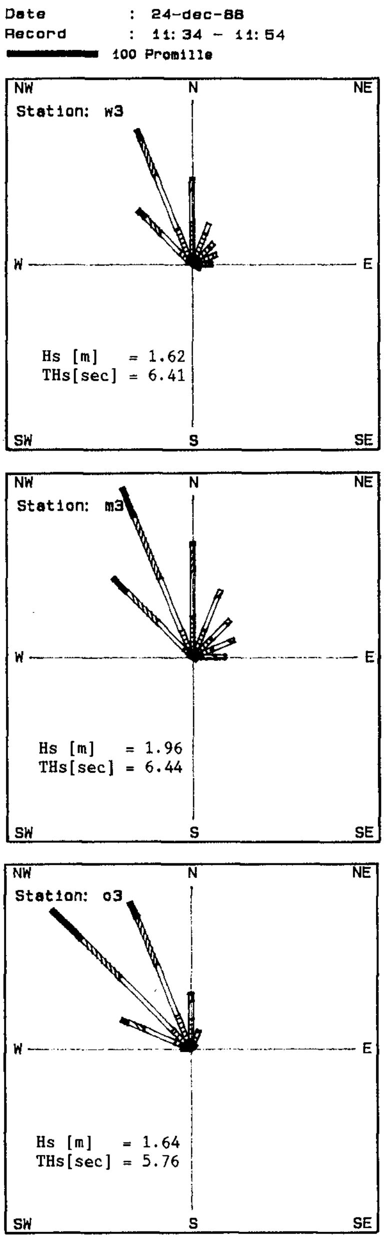


Abb. 7: Resulting current rose of the measuring stations w3, m3, o3 (storm surge)

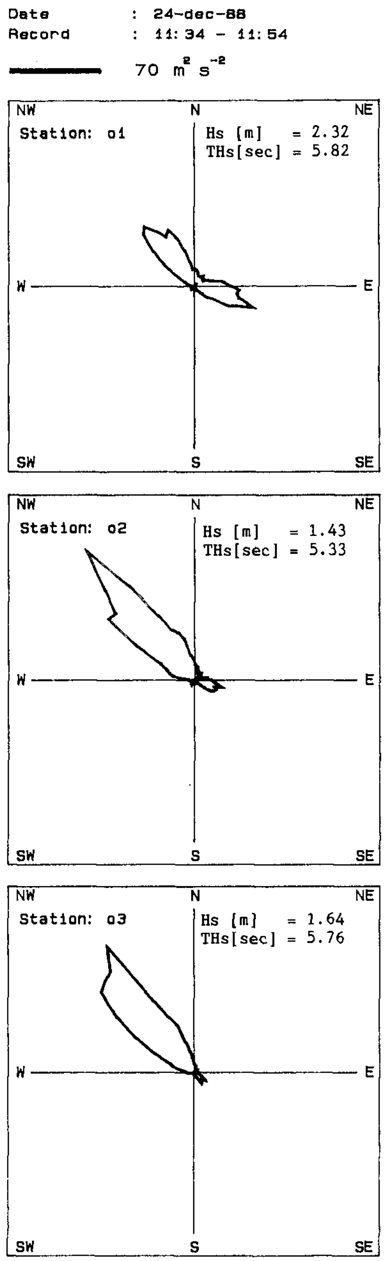


Abb. 8: Directional current spectra of the measuring stations o1, o2, o3 (storm surge)

The overbalance of seaward directed currents is expected to be an undertow effect (SVENDSEN 1984; STIVE & WIND 1986) due to breaking waves which occur -as explained before- across the whole broadth of the beach as white rollers. Their onshore directed mass flux must be compensated by a "relatively strong seaward flow below trough level" (BATTJES 1988). The high turbulence in the surf zone creates high suspension rates so that the transport capacity of the undertow does not only base on bed load. This might be a further explanation for the short term erosion created by storm surges.

3.3 Wave Induced Currents for Swell Conditions

Contradictory to storm surges with its broad surf zone for usual conditions wave breaking takes place in a narrow area in front of the revetment with a swash zone (FIG. 9). The waves on the shoreface and especially on the beach steepen due to shoaling before they break finally. Here a data set is taken from a normal tide with a peak height of 0,3 m below MHWL. There were offshore directed winds with speeds of about 5 m/s. The significant waves in the center line of the array range from 0,93 m (m1; h = 1,8 m) to 0,66 m (m3; h = 0,6 m).

The directional current spectra for the data from the array (FIG. 10-12) indicate a well established circulation in the groyne field. The primarily driving force is the overbalance of onshore directed energy along the updrift groyne E1 which is intensified by an also resulting

Abb. 9: Waves on the beach with narrow breaker line and swash zone

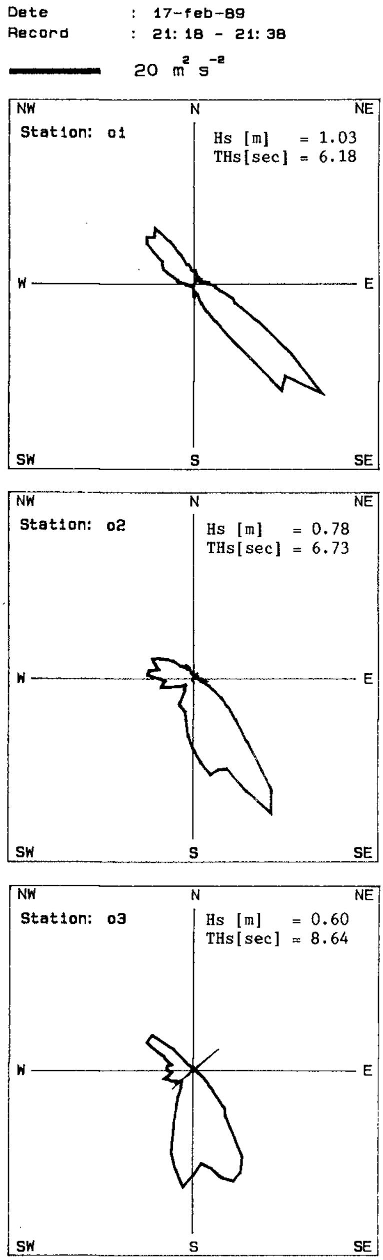


Abb. 10: Directional current spectra of the measuring stations o1, o2, o3 (normal tide)

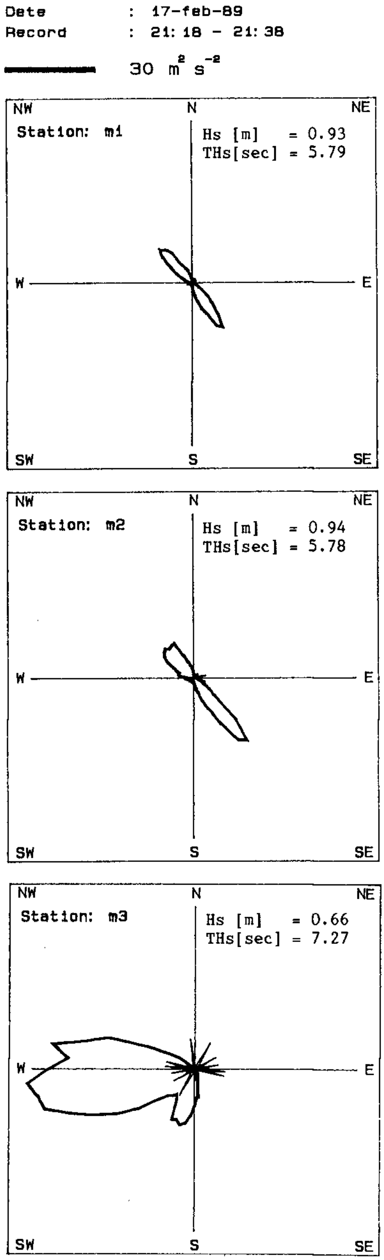


Abb. 11: Directional current spectra of the measuring stations m1, m2, m3 (normal tide)

shore-ward directed energy in the center point m2 of the array. This onshore drift creates especially close to the revetment a downdrift longshore current and due to the guiding effect of the downdrift groyne D1 concentrated seaward directed currents, which are superimposed by the return flow from the swash zone. This circulation pattern does doubtlessly depend on the geometry of the existing groyne-revetment system, especially if considered that the return flow does not occur in the place of the minimum breaker height. But its driving force must be the measured onshore near bottom drift which might be explained as an effect of very steep nonlinear waves (VAN RHIJN 1990).

As these waves are still non-breaking suspension is much lesser than in the high turbulent surf zone. Sediment transport takes place therefore mainly or even only as bed load. This explains the lower capacity in comparison with the undertow created by storm waves on the beach. If it is expected that onshore drift effects like those observed here cause the recovery of eroded beaches the longer duration of this process compared to the short period necessary for the erosion is reasonable.

In this case fortunately data of a beach profiling are avaiable for the same period (FIG. 13). A comparison of the levelling in the three measuring lines w, m and o is in good agreement with the expected transport processes:

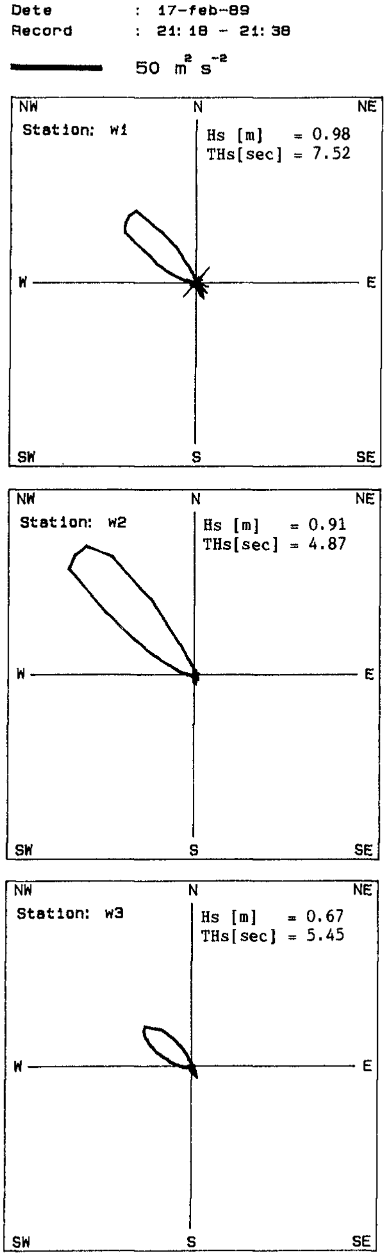


Abb. 12: Directional current spectra of the measuring stations w1, w2, w3 (normal tide)

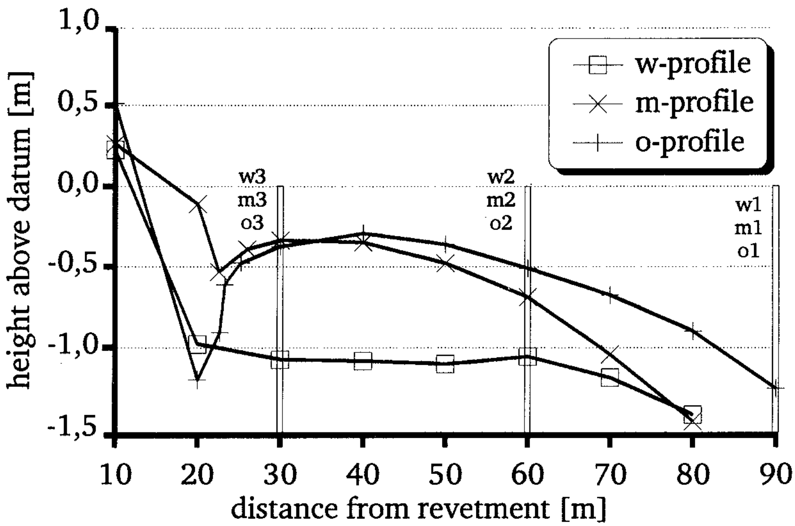


Abb. 13: Beach profiles of the measuring array

the beach is relatively high where onshore directed drift has been measured whereas it is remarkable lower in its other parts.

4. EFFECTIVENESS OF GROYNES

The purpose of beach groynes is to reduce or even to prevent longshore currents and the caused sediment transport. The effectiveness of the groyne system has already been shown by the example of forced circulation. Furthermore the two data sets will be used to get a better insight in the interactions between waves and wave-induced currents with groynes.

Exemplary the effectiveness of the updrift beach groyne E1 is investigated here. The data of the storm surge event show a remarkable longshore current both the points m1 and m3. The longshore components in the position o1 close to the updrift groyne are at least of the same order of magnitude as those measured in m1 which may be explained by the fact that the groyne has no effect on the longshore currents (FIG. 5). In contrast to position o3 the longshore components of the currents are remarkably reduced in comparison with those in m3 (FIG. 6). Obviously the greater height of the groyne in this place causes this effect.

The same effect becomes apparent for the data of the normal tide (FIG. 14) by comparison with the current roses in the measuring points o1, o2 and o3. Whereas the longshore components in the positions o2 and especially o3 are remarkably reduced, in the most seaward situated measuring point the incident waves induce significant updrift longshore components which are independent of the provoked circulation in the groyne field (FIG. 10-12).

A comparison of the geometrical boundary conditions of both data sets shows that the water depth above the groyne crest at position o3 for the storm surge is greater than in position o1 at the normal tide (FIG. 15). Apparently this parameter is not a reasonable measure for the effectiveness of groynes. Considering additionally the groyne elevation above the beach it is likely that the relative reduction of the total water column above the beach by the groyne is a more reasonable geometrical parameter for the effectiveness of groynes than the water depth above the groyne crest. In order to get a deeper insight in the physical background of the interactions between beach, groynes, waves and wave-induced currents sytematical data analysis additionally considering hydrodynamical parameters has to be carried out in the next future.

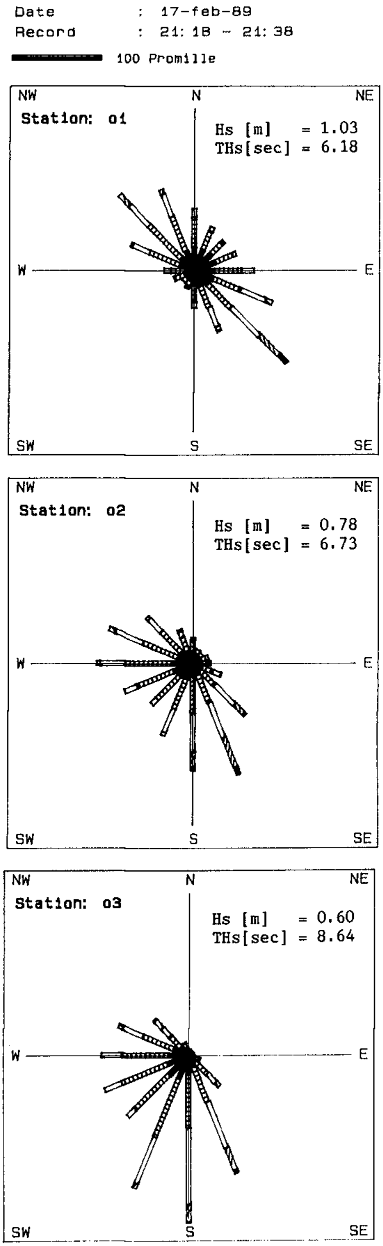
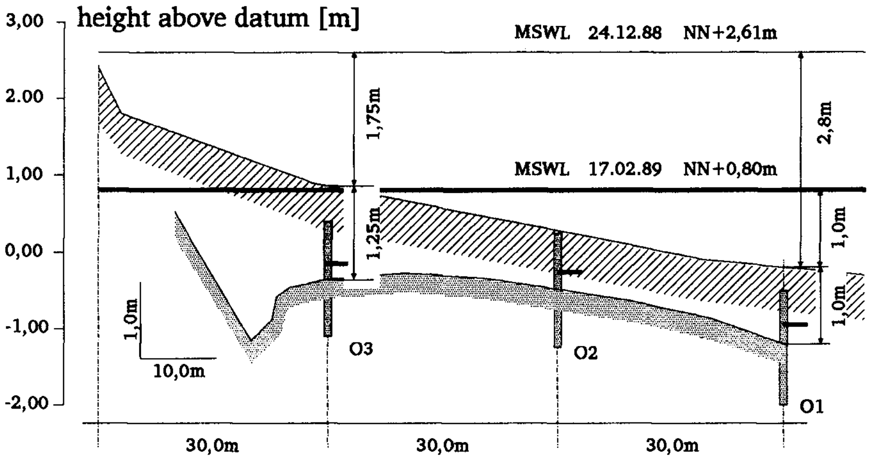


Abb. 14: Current rose of the measuring stations o1, o2, o3 (normal tide)



o-profile 17.02.1989

Abb. 15: Geometrical boundary conditions for groyne effectiveness

5. CONCLUSIONS

The results give a good indication of the driving hydrodynamical forces which govern storm surge erosion and afterward recovery of beaches with revetments and groynes. It is evident that a shoreward increasing tendency of resulting seaward directed currents effects the enormous scour which become especially visible in front of revetments after storm surges. It is also apparent that their seawardly decreasing overbalance allows the sedimentation of the eroded beach material on the shoreface. It seems to be reasonable that the overbalance of seaward directed currents could be explained as undertow effects created by breaking waves. Due to the high turbulence in the surf zone sediment transport does not only occur as bed load but also as suspension which intensifies its efficiency leading to high erosion rates on the beach and correspondently high deposition rates on the shoreface.

The high nonlinearity of steep shoaling but still non-breaking waves creates drift effects which might effect onshore directed bed load transport. But its capacity is much lesser than that of combined suspension and bed load due to undertow currents in the surf zone. This might be a sufficient explanation for the much longer duration of the recovery process compared with the short time event of storm surge erosion.

Furthermore the data discussed here give the impression that the effectiveness of groynes depends primarily on the relative reduction of the total water column due to the groyne elevation above the beach and not on the water depth above the groyne crest.

The application of these results on future beach nourishments implies that the deposition of material on the shoreface is more effective than on the beach itself. A replenishment on the beach reduces the groyne elevation above its bottom and consequently the the relative reduction of the water column. This would again lead to a diminished effectiveness of the groynes with respect to longshore transport which would effect an increase of material losses in the first period after the execution of the nourishment decreasing with the progress of erosion.

Furthermore a nourishment on the shoreface might be better adjusted to natural transport phenonema. The provoked sediment transport due to the disturbance of the existing dynamical equilibrium by artificial deposition of additional material is mainly directed onshore in the first phase after the execution of the nourishment. As this event usually takes places in late spring or early summer, there will be shift of material from the shoreface to the beach which is expected to build up a slowly growing deposit for the erosion due to harvest and winter events with strong sea conditions including storm surges. The main advantage will be that it takes a certain period of time to build up the deposit and within this period the nourished material will be mainly in a position where it is less sensitive to erosion by longshore currents. In contrast to a nourishment on the beach itself will expose the material from the beginning totally to their eroding capacity. Additionally the reduction of water depth would provoke the breaking of even relative small waves and intensify suspension and erosion. Therefore a nourishment on the shoreface might be a successful solution in order to reduce the high losses in the first phase after the execution and to extend the period of effectiveness of nourishments.

6. ACKNOWLEDGEMENT

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