

# **DESIGN REPORT: COMBINED SHOREFACE AND BEACH NOURISHMENT ISLAND OF NORDERNEY, EAST FRISIA**

## **1. STATEMENT OF THE PROBLEM**

In the past some of 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 structural erosion. For almost the last two centuries the morphological development of the western part of the East Frisian island of Norderney was particularly governed by these processes [LUCK 1977]. In order to stop further shoreline retreat and inlet migration solid structures have been erected since the middle of the last century fixing here a transitional stage being unfavourable in respect of natural sediment supply for the western and northwestern beaches of the island (Fig. 1). In spite of the construction of groynes, revetments and seawalls which appeared to be unable to stop the structural erosion of the western and northwestern beaches this problems remained unsolved. The continuing structural erosion endangered the structures by scouring and the lowering beach levels allowed beyond that the attack of higher waves. These boundary conditions forced more and more measures for the extension and strengthening of the solid structures till the introduction of repeatedly executed artificial beach nourishments as a successful tool of coastal protection [KRAMER 1960; STEPHAN 1988; KUNZ 1991; KUNZ & STEPHAN 1992] each remedying the grievance for a certain period of time.

Though artificial beach nourishments have appeared as a rather successful tool to counterbalance the effects of structural beach erosion, the demand for further improvements of its effectiveness 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 (Fig. 2). As a result of these investigations a foreshore nourishment was regarded as a suitable alternative to a conventional beach nourishment [NIEMEYER 1991, 1992]. As a final solution a combined shoreface and beach nourishment was carried out in 1992 [STAIK 1993].

## **2. OBJECTIVES OF THE NOURISHMENT**

Beach nourishments have been introduced as a measure of protection of parts of the

islands of Norderney being endangered by structural erosion on the one hand and consisting of the economically most valuable parts of that holiday resort of national importance on the other one. The choice was made in respect of higher cost effectiveness compared with the alternative to adapt the existing solid structures to eroding beaches and stronger wave attack. This initial basis of defence policy has remained unchanged until today and in fact the alternatively discussed extension of solid structures would not be accepted by nowadays public opinion. Nourishments are therefore carried out to avoid any endangerment of the stability of the existing solid structures on the beaches which still have to guarantee the safety of the most densely populated part of the island against storm surges due to scouring. Moreover nourishments are expected to have the effect of reducing damages at revetments, seawalls and groynes and therefore also of maintenance costs. Moreover beach nourishments are regarded as a more suitable tool of coastal protection in a region hosting a holiday resort and being part of an ecologically highly valuable area.

### **3. MORPHOLOGY OF THE NOURISHMENT SITE**

#### **3.1 Morphological shape**

The structural erosion of the beaches at the western beaches in the vicinity of the fixed tidal inlet and particularly of the northwestern ones of the island of Norderney in combination with the fixing of their shorelines by revetments, seawalls and groynes have led to narrow, steep beaches without bars. For that reason there is only limited space for the deposition of a nourishment volume. Therefore the life time of nourishment is also limited demanding for successive repetitions in order to compensate the losses due to structural erosion from time to time. Therefore intensive efforts have been carried out in the past in order to optimize shape and volume of the nourishment in respect to economical effectiveness.

#### **3.2 Morphological Behaviour**

After the execution of all nourishments carried out between 1951 and 1989 initial losses were rather high declining after a certain period (Fig. 3). Independently of the frequency of storm surges erosion reduced to a rather low rate and the beach levels remained always higher than they had for the minimum before the execution of the first nourishment [STEPHAN 1988; KUNZ 1991; KUNZ & STEPHAN 1992]. Initial losses are expected to be mainly a reason of disturbed equilibrium and resulting cross-shore transport. Structural erosion is predominantly effected by gradients in longshore transport [VAN DE GRAAFF et al. 1992].

The typical seasonal shift of beach profiles due to changing wave conditions is a well known as the phenomenon of summer and winter profiles [BASCOM 1954]. After the occurrence 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 (Fig. 4). These kind of transport processes have taken into consideration for favouring a nourished shoreface.

## **4. HYDRODYNAMICAL BOUNDARY CONDITIONS**

### **4.1 Tidal water levels and currents**

The mean tidal range in the area of Norderney is about 2.4 m with variations of  $\pm 0.7$  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 are 10 for 0,93 m; 0,5 for 1,95 m and 0,05 for 2,86 m due to German standard classification [NIEMEYER 1987a].

Tidal currents are particularly at the northwestern but also on the western shore rather weak on the beaches itself 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 continuously measured tides. On the foreshore slope of the inlet velocities are reasonably higher with maximum velocities of 43,6 to 56,4 cm/s for flood and 48,8 to 69,1 cm/s for ebb tide [NIEMEYER 1987b]. In the ebb channel of the inlet maximum velocities are in the order of magnitude of 1,5 m/s for ebb tide reaching extreme values of 2 m/s for storm surges and ebb durations of more than twenty hours for storms from southwest to west [KOCH & NIEMEYER 1978].

### **4.2 Waves and wave-induced currents**

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  $135^\circ$  to  $85^\circ$  for mean conditions due to refraction (Fig. 5): The predominantly western and northwestern directions of wind, sea 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. 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 (Fig. 6) [NIEMEYER 1987c].

Wave-induced currents on the beach effect sediment transport more than the tide-generated ones, because their velocities are remarkably higher: Even for normal conditions and moderate wave climate there is a remarkably percentage of wave induced currents exceeding the levels of 0,6 and even 1,5 m/s increasing significantly for the occurrence of storm surges. Highest velocities occur for undertows, longshore

currents have lower velocities [NIEMEYER 1991, 1992]. It was possible to expail erosion during and recovery of beaches after storm surges as an effect of undertows and landward directed bottom drift due to shoaling waves [NIEMEYER 1991, 1992].

## **5. DESIGN AND EXECUTION ALTERNATIVES**

### **5.1 Nourishment type**

Under discussion have been three design alternatives of the nourishment:

1. Conventional beach nourishment,
2. shoreface nourishment,
3. combined beach and shoreface nourishment.

A conventional beach nourishment like those ones carried out between 1951 and 1989 taking the gained experience into consideration was regarded as a conservative solution without special risks but also without a chance getting remarkable improvements for future nourishments. A pure shoreface nourishment is impossible because in the vicinity of the tidal inlet that kind of solution would not work. But also at the northwestern beaches the execution of a shoreface nourishment faces problems. The dumping by a hopper dredger in the groyne fields or the pumping there by the "rainbow-method" was regarded as to risky for the vessels. Placing of the nourishment outside of the groyne fields was expected as insufficiently effective in respect of the objectives. At least a compromise was carried out (Fig. 7): a beach nourishment on the beaches in the vicinity of the tidal inlet, a combination of beach and shoreface nourishment on the northwestern beaches of the island providing the longshore transport with material and suffering mostly from structural erosion and a beach nourishment on their downdrift beaches which benefit already from longshore transport.

### **5.2 Borrow area**

As well as shape and execution methods the choice of a suitable borrow area was thoroughly dicussed. For the first beach nourishment in 1951/52 the material has been taken from the flat area landward from the island [KRAMER 1960], for the second one in 1967 from the shoreface [LUCK 1970] and for those in 1976, 1982, 1984 and 1989 from the shoal "Robbenplate" of the ebb delta close to the nourishment site on the island across the ebb channel of the inlet. In 1989 additionally coarser material was taken from offshore. A study on possibilities of borrowing material for future nourishments was carried out by WESTHOFF [1991] taking into consideration also other parts of the ebb delta consisting of suitable sand. But there the borrowing is much more sensitive to rough weather conditions than at the shoal "Robbenplate".

### **5.3 Execution tools**

All nourishments carried out on the island of Norderney since 1951 were only executed

by use of cutter dredgers pumping the material from the borrow area to the nourishment site. In 1989 additionally hopper dredgers have borrowed material offshore and pumped onto the beach by the rainbow-method. For the beach nourishment itself there was no alternative being competitive to the method used until now in respect of costs. Borrowing offshore and in other parts by hopper dredgers and dumping of the material on the shoreface or pumping to the shoreface was discussed as an alternative for the shoreface nourishment. As another possibility the pumping of the material to the shoreface via the pipe network used for the beach nourishment and borrowed by the same cutter dredger at the same borrow area was taken into account.

## 6. FINAL DESIGN AND EXECUTION

For the execution the use of hopper dredgers and of alternative borrow areas was regarded as not suitable, because of higher risk for contractor in respect of rough weather conditions and expected increase of costs. The material was therefore borrowed by a cutter dredger from the shoal situated across the ebb channel of the tidal inlet which was crossed by a dived pipe. The material was distributed on the beaches by pumping via a pipe network which at least was ranging across the whole nourishment site. Afterwards it was profiled by bulldozers according to a simplified equilibrium profile after DEAN [1983]. The material for the shoreface was placed by consecutive lengthening of the pipeline performing a sand body similar to a groyne. The distribution of the material on the shoreface occurred due to tidal and wave action.

Choice of borrow area, execution and shaping of the nourishment could not be carried out independently, because there is doubtless a high grade of interference. In this case the execution method was predominantly chosen for expected economical benefits which have to be proven in the future by using the results of the investigations following the execution in the framework of the MAST II - NOURTEC programme.

## 7. LITERATURE

**BASCOM, W. H. [1954]:** Characteristics of Natural Beaches. Proc. 4th Conf. o. Coast. Eng., ASCE

**BATTJES, J. [1988]:** Surf-Zone Dynamics. Ann. Rev. Fluid Mech. 1988, 20

**DEAN, R. G. [1983]:** Principles of Beach Nourishment. in: CRC Handbook of Coastal Processes and Erosion (ed. P. KOMAR); CRC Press, Boca Raton/Fl.

**GRAAFF, J. VAN DE; NIEMEYER, H.D. & OVEREEM, J. VAN: Beach Nourishment, Philosophy and Coastal Protection Policy.** in: J. van de Graaff, H.D. Niemeyer & J. van Overeem: Special issue artificial beach nourishments. Coast. Eng., Vol 16, No. 1

**HOMEIER, H. [1976]:** Effects of Severe Storm Surges on East Frisian Island Beaches and Dunes (in German: Die Auswirkungen schwerer Sturmtiden auf die ostfriesischen Inselstrände und Randdünen). Jber. 1975 Forsch.-Stelle f. Insel- u. Küstenschutz, 27

**KOCH, M. & NIEMEYER, H.D. [1978]:** Storm Surge Current Measurements in the Tidal Inlet Norderneyer Seegat (in German: Sturmtiden-Strommessungen Im Bereich des Norderneyer Seegats). Jber. 1977

Forsch.-Stelle f. Insel- u. Küstenschutz, Bd. 29

**KUNZ, H. [1991]:** Artificial Beach Nourishment on Norderney, a Case Study. Proc. 22nd Int. Conf. o. Coast. Eng. Delft, ASCE, New York

**KUNZ, H. & STEPHAN, H.-J. [1992]:** Results of Morphological Investigations Concerning the Beach Nourishments on Norderney (in German: Ergebnisse morphologischer Untersuchungen zu den Strandaufspülungen auf Norderney). Die Küste, H. 54

**KRAMER, J. [1960]:** Beach Rehabilitation by Use of Beach Fills and Further Plans for the Protection of the Island of Norderney. Proc. 7th Conf. o. Coast. Eng. Richmond, ASCE

**LUCK, G. [1970]:** Second Beach Nourishment on the Western Beaches of Norderney (in German: Die zweite Strandaufspülung am Weststrand Norderney). Jber. 1968 Forsch.-Stelle f. Insel- und Küstenschutz, Bd. 20

**LUCK, G. [1977]:** Long-termed Development of Tidal Inlets between Eastfrisian Islands. Proc. 15th Intern. Conf. o. Coast. Eng. Honolulu, ASCE, New York

**NIEMEYER, H.D. [1986]:** Wave Propagation and Damping in the Offshore and Wadden Sea area of Norderney (in German: Ausbreitung und Dämpfung des Seegangs im See- und Wattengebiet von Norderney). Jber. 1985 Forsch.-Stelle Küste, 37

**NIEMEYER, H.D. [1987a]:** Classification and Frequency of Storm Surges (in German: Zur Klassifikation und Häufigkeit von Sturmtiden) Jber. 1986 Forsch.-Stelle Küste, 38

**NIEMEYER, H.D. [1987b]:** Measurements of Tidal Currents in Groyne Fields (in German: Tidestrommessungen in Bühnenfeldern). Jber. 1986 Forsch.-Stelle Küste, 38

**NIEMEYER, H.D. [1987c]:** Changing of Wave Climate due to Breaking on a Tidal Inlet Bar. Proc. 20th Intern. Conf. o. Coast. Eng. Taipei, ASCE, New York

**NIEMEYER, H.D. [1991]:** Field Measurements and Analysis of Wave-induced Nearshore Currents. Proc. 22nd Int. Conf. o. Coast. Eng. Delft, ASCE, New York

**NIEMEYER, H.D. [1992]:** Causal Interpretation of Transport Phenonima as a basis for Nourishment Design (in German: Die ursächliche Deutung von Transportphänomenen als Gestaltungsgrundlage für Strandauffüllungen). Die Küste, H. 54

**SVENDSEN, I. A. [1984]:** Mass Flux and Undertow in a Surf Zone. Coast. Eng., Vol. 8, No. 4

**STAIK [1993]:** Test Nourishment - Development and Execution, Unpublished Rep. (in German: Versuchsaufspülung - Entwicklung und Technik, unveröff. Bericht). Staatl. Amt f. Insel- u. Küstenschutz

**STEPHAN, H.-J. [1988]:** Five Beach Nourishments on Norderney - Results of Morphological Investigations (in German: Fünf Strandaufspülungen auf Norderney - Ergebnisse morphologischer Untersuchungen). Arb. Forsch.-Stelle Küste, Nr. 11

**STIVE, M. J. F. & WIND, H. G. [1986]:** Cross-Shore Mean Flow in the Surf Zone. Coast. Eng., Vol. 10, No. 4

**VAN RHIJN, L. [1990]:** Sediment Transport by Currents and Waves. Civ. Eng. Europ. Courses Progr. o. Europ. Comm. Cont. Educ., Syllabus Delft Univ. o. Techn. - Int. Civ. Eng.

**WESTHOFF, T. [199]:** Study on Borrow Material and Sites