CHAPTER 227

COMPARISON OF BEACH AND SHOREFACE NOURISHMENT

TORSMINDE TANGE, DENMARK

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Abstract

Within the framework of the EU–sponsored programme Marine Science and Technology (MAST), a full–scale test was implemented in 1993 in Denmark, Germany and the Netherlands with the aim of evaluating the use of shoreface nourishment.

In this paper the background, the set–up and the results of the Danish part of the NOURTEC project are presented.

1. Introduction

Nourishment has been used by the Danish Coastal Authority (DCA) on the Danish North Sea coast since 1974. The volume of sand has been gradually increased and has now reached a level of about 3 mill. m^3/year distributed along 150 km of the coast. Most of the nourishment has been beach nourishment but shoreface nourishment has also been used occasionally.

There has always been and there still is a considerable difference in the unit price of the two ways to protect the coast. The inevitable question is therefore which nourishment method has the best benefit/cost ratio.

Qualitatively, the following relative advantages are seen for the two nourishment methods:

Beach nourishment

– gives a better dune foot protection

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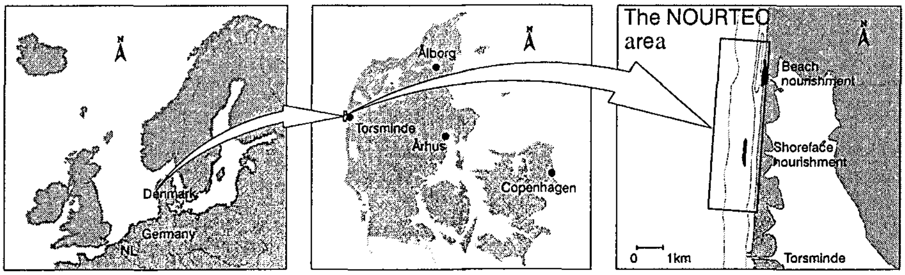

Fig. 1 Nourtec site, Torsminde Tange.

- gives a more well–defined local effect within the problem area
- is politically more attractive because a direct result of the nourishment can easily be seen

Shoreface nourishment

- is about 30% cheaper per m^3
- can be carried out without machinery on the beach
- is applicable to small nourishment projects because the mobilization costs are low

However, to our knowledge no quantitative methods exist which can be used to make a rational choice in the design situation. The design has been based on experience and on the use of rules of thumb.

The Danish Coastal Authority therefore decided to initiate a full–scale test on beach and shoreface nourishment, see Fig. 1. Together with similar projects in the Netherlands and Germany, the Danish project constitutes the NOURTEC project.

2. Research questions

In the planning and design of the test nourishment projects, the three NOURTEC partners agreed upon the following general design objectives [Niemeyer et al. 1995]:

- stabilization of the coastline
- coastal protection
- widening of the beach

Each of the design objectives is evaluated in terms of a corresponding design parameter, see section 4.2. The evaluation should end up giving the answers to these research questions:

- Does the nourishment fulfil the design objectives?

– What is the relative effect of the two nourishment projects? Here the benefit/cost ratio should be included.

– What is the importance of the grain size of the nourishment sand?

Besides, the project should give an improved understanding of the morphological changes induced by placing large volumes of sand in a coastal environment.

3. Experimental set–up

3.1 Test site description

Torsminde Tange is a 300 – 500 m wide barrier located north and south of Torsminde on the North Sea coast of Denmark, see Fig. 1. The barrier is a sand dune system on a clay layer. The top of the dunes is at +8 m DNN (Danish normal zero). The top of the clay layer is found at approximately –4 m DNN along the beach. The beach is 100 m wide and consists of sediment ranging from fine sand to pebbles. The beach slope is 1:20. A 2 – 3 bar system is found offshore and the sediment D_{50} range is from 0.3 to 0.8 mm. The closure depth is at –16 m DNN. The depth contours are straight and parallel to the coastline and the profile slope is 1:100. The average coastal retreat is 2.6 m/year.

3.2 Nourishment and survey programme

The shoreface nourishment is located on the outside of the outer bar in the southern sector and the beach nourishment is located from the dune foot to the shoreline in the northern sector. The nourishment volume in both nourishment projects was 250,000 m^3 of sand distributed with 250 m^3/m. Each of the stretches was 1 km long and 2 km apart from each other. The D_{50} of the beach nourishment sediment was 0.32 mm while the D_{50} of the shoreface nourishment was 0.57 mm. A red fluorescent tracer was mixed with the shoreface nourishment in a ratio of 1:100,000. Similarly, a blue tracer was mixed into the beach nourishment [Madsen et al. 1995].

The survey area is 7 km long and 1.5 km wide located symmetrically around the nourishment projects. The survey lines span from dune top to –12 m DNN with a mutual spacing of 100 m giving a total of 70 survey lines. A single beam echo sounder was used to survey the bathymetry and GPS was used to survey the topography and the zone from 0 to –2 m DNN. The survey accuracy was 0.04 m. A total of 17 survey campaigns were carried out during the 2–year NOURTEC period.

In every fifth of the survey lines 9 – 10 sediment samples were taken by hand on the beach and by a Van Veen grab offshore in predefined positions. All samples were sieved and analysed for content of tracer grains.

3.3 Boundary conditions

The water level is recorded at a groyne at Torsminde and at a groyne 5 km north of the survey area once every 15 min. The tidal range is 0.6 m and the 100 year water level is 3.40 m DNN. Wind speed and direction are recorded at Torsminde once every 15 min. Wind from the north west is dominant and the 100–year wind speed is 33 m/s. Wave height and direction are recorded by a waverider just north of the survey area at 18 m depth. Wave characteristics have also been recorded by a current meter, at first placed at 14 m depth just seaward of the NOURTEC area. Later it was placed at 4 m depth on the shoreface nourishment. Waves were recorded once every 3 hours. The dominant deep water waves come from NW and the 100–year significant wave height is 8.1 m. Current has been measured at the above described locations once every 15 min. At both locations the current meter was placed 1 m above the bottom. At 14 m depth the dominant current is the tidal current with an amplitude of 0.2 m/s. At 4 m depth the current is also significantly influenced by waves but still the tidal current is dominant.

4. Effectiveness analysis

4.1 Introduction

The surveys showed that the beach nourishment was eroded after about 3/4 year while the shoreface nourishment only lost about 40% of its volume in the whole monitoring period. The morphological description and interpretation of the development in the monitoring area is presented in section 6.

Here the results are presented of a strictly mechanistic method to analyse the survey data. This so–called effectiveness analysis gives objective results easy to compare with the results produced by the other two partners in the NOURTEC project.

The analysis is based on the use of a number of common design parameters. The parameters are calculated for each bathymetry and the development of the parameters is compared to the estimated development of the parameters in the absence of the nourishment projects. The difference between this so–called autonomous development and the actual development represents the net effect of the nourishment. Here it is assumed that the autonomous development and the nourishment effect can be superimposed.

4.2 Definition of the design parameters

In section 2, the general design objectives were presented. Each of these objectives is evaluated by means of one of the following three common design parameters:

- position of the coastline
- position of the upper part of the profile
- beach width

In Fig. 2 it is shown how the design parameters are calculated. Apart from the "beach width" the parameters are calculated on the basis of a volume divided by the height of the zone used in the volume calculation. The result is a horizontal distance to the reference line. The level DNN +4 m is considered to be representative of the beach level at the dune foot.

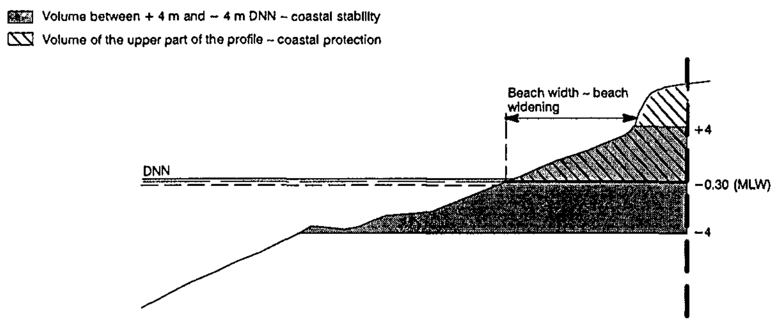

Fig. 2 Definition of the common design parameters.

4.3 The autonomous development

For practical reasons it was not possible to estimate the autonomous development in the monitoring area for the NOURTEC period 1993 – 95 from the development of a nearby reference stretch. So instead, historical data were used.

The wind rose for the monitoring period 1993 – 95 is nearly identical to the wind rose for the period 1985 – 92. This indicates that the meteorological boundary conditions are about the same for the two periods. On this basis it was decided to calculate the design parameters for the period 1985 – 92 and consider the slope of the corresponding trend lines as good estimates for the autonomous development in the monitoring period.

4.4 Results

The effect of the nourishment projects can be calculated for any section along the coast. Here it has been chosen to show the results for 3 km stretches located symmetrically around the two project areas. The reason for this choice is that the analyses have shown that the effect of the nourishment projects is not limited to the nourished 1 km stretches themselves.

The development of the three design parameters for the southern and the northern 3 km stretches is shown in Fig. 3. The autonomous development is shown as well.

From the figure it appears that in the 2–year monitoring period the beach nourishment stabilizes the coastline and improves the coastal protection level. On the other hand, the beach width has not been improved. For the shoreface nourishment there is a positive net effect on all three design parameters. Hence, the shoreface nourishment has fulfilled all the design objectives.

Quantitatively speaking the shoreface nourishment has an effect on the coastal stability of 10.4 m or 250,000 m^3 for the 3 km stretch while the similar effect of the beach nourishment is 2.8 m or 67,000 m^3. The effect on the coastal protection is 9.0 m or 189,000 m^3 for the 3 km stretch for the shoreface nourishment and 5.4 m or 113,000 m^3 for the beach nourishment.

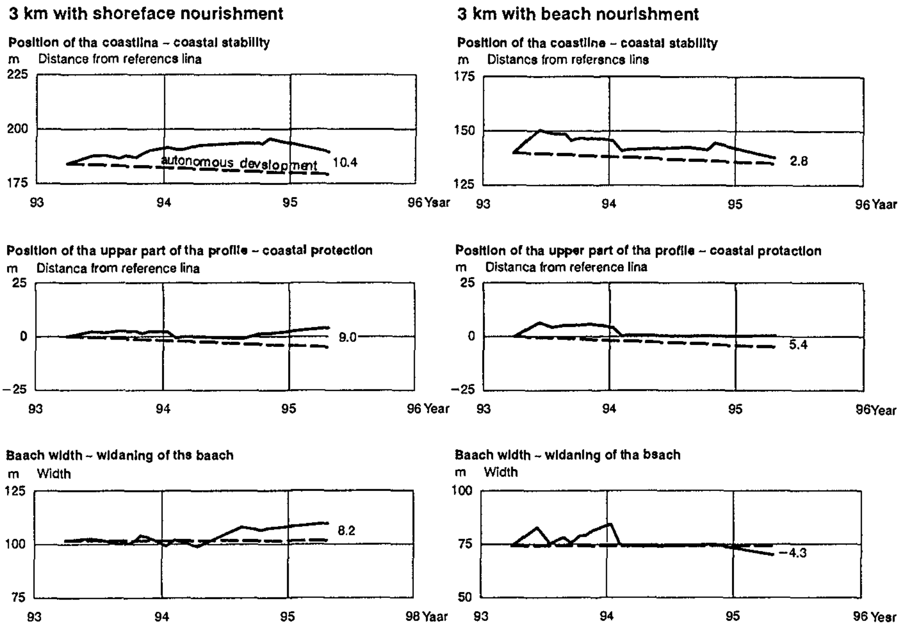

Fig. 3 Nourishment effect on the design parameters.

A direct comparison of the two nourishment projects is shown in Fig. 4. It appears that the shoreface nourishment gives the better stabilization of the coastline over the whole period. However, in the first 3/4 year the beach nourishment is the more effective. Concerning coastal protection the shoreface nourishment is the better option. Again the beach nourishment is the better option at the beginning of the period. For the beach width the result is similar. At the beginning, the beach nourishment is better but over the whole period the shoreface nourishment ends up being better.

Also in Fig. 4 the benefit/cost ratios are shown for the effect of the nourishment projects. Because it is about 30% cheaper to nourish on the shoreface than on the beach, the better relative effect of the shoreface nourishment mentioned before is increased when the costs are included in the evaluation.

5. Modelling

The 1–dimensional numerical model LITPACK and a 2–dimensional numerical model MIKE 21 have been used. Both models have been developed by the Danish Hydraulic Institute. The purpose of using the models is to analyse the effect of using coarse sand in the shoreface nourishment and to extrapolate the results to other boundary conditions.

5.1 1–dimensional modelling

LITPACK has been used to calculate the longshore sediment transport during the entire NOURTEC period and the results have been used in the calibration of MIKE 21. The

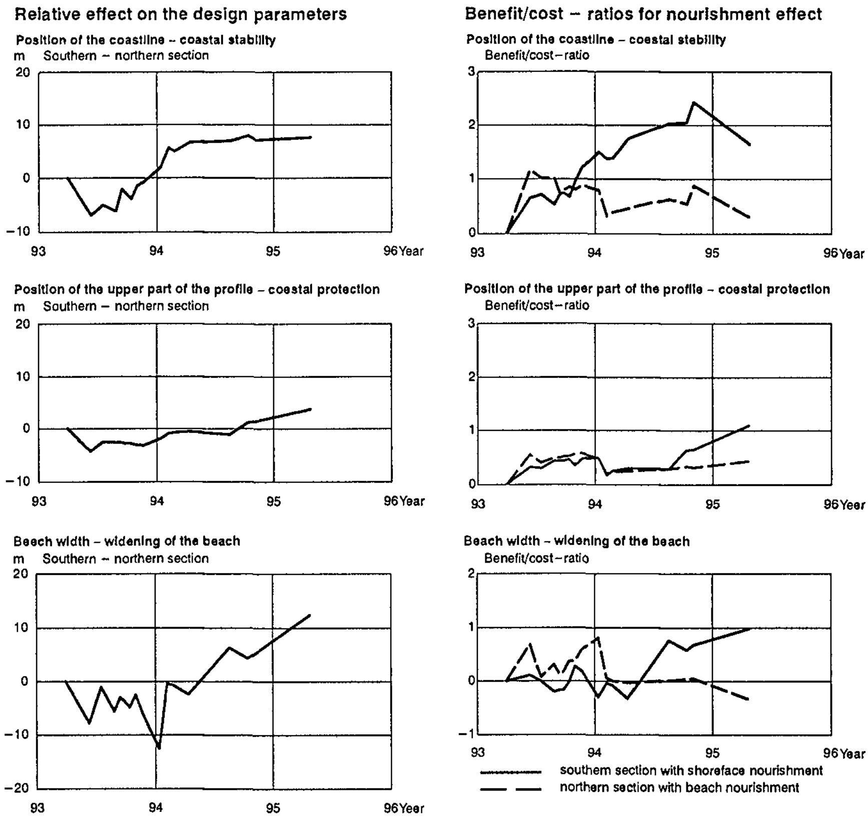

Fig. 4 Relative effect of the two nourishment methods and benefit/cost ratios for the nourishment effect.

nourishment projects are included in the two areas S(horeface nourishment) and B(each nourishment), see Fig. 5. For each area there is one survey line on both sides of the nourishment and 3 lines which include the nourishment.

First, LITPACK was calibrated to the annual littoral drift. The annual littoral drift has been calculated by accumulating the profile erosion from the nodal point for the littoral drift to the NOURTEC area by using three different approaches. Based on these calculations the south–going net littoral drift was estimated to be in the interval of 550,000 – 850,000 m^3/year. Secondly, LITPACK was calibrated to the measured volume changes in the areas S and B in the entire NOURTEC period, including the variation intervals due to survey inaccuracy.

In LITPACK, uniformity of the coastal profiles is a basic assumption. The applicability of LITPACK for quantification of erosion/accretion along a coastline depends entirely on the fulfillment of this assumption. This assumption was not completely met, which was confirmed by the 2–dimensional modelling, and must be taken into account when the results are analysed.

In Fig. 5 the results of the calibration are shown. It appears that the calibration is good for the area S and less good for the area B but still within the variation intervals which are given by the measured data. The problems with area B are caused by an extremely large erosion that took place during the winter of 1994 – 95 outside the beach nourishment.

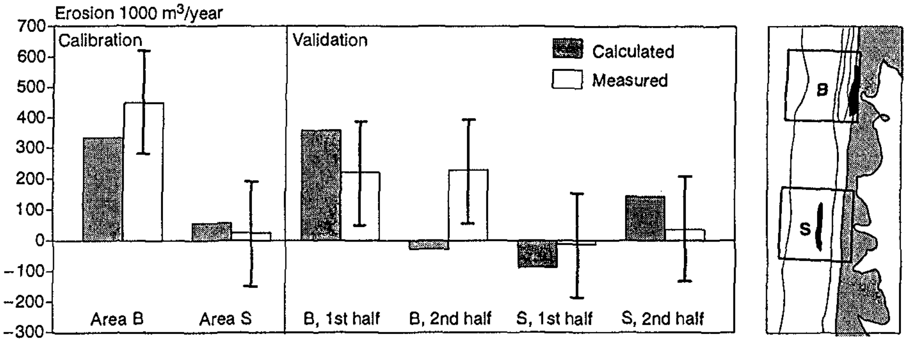

Fig. 5 Calibration and validation of LITPACK.

After the calibration, the model set–up has been verified for the two halves of the monitoring period, each about 1 year long. The results are also shown in Fig. 5. Again good agreement is seen for area S and for area B, less agreement is seen for the second half of the period. Although the results have not been quite perfect, the model set–up is assumed to be calibrated and validated as far as possible and the model set–up can be used in a descriptive and prognostic mode.

The cross–shore distribution of the longshore sediment transport in the NOURTEC period has been analysed and it is found to be very sensitive to the local shape of the shoreface nourishment on the outer bar. A decrease in the water depth above the nourishment causes extensive wave breaking and hence increased sediment transport on the bar and decreased transport near the coastline. The sediment transport distribution is not particularly affected by the the beach nourishment because only a small part of the nourishment is under influence of waves.

For both the shoreface and the beach nourishment area it is found that during the NOURTEC period waves with a significant wave height of 1 to 2 m cause most of the sediment transport and the net sediment transport direction is southward.

In order to quantify the effect of nourishment sediment characteristics on the sediment transport, the dependence of D_{50} is analysed. For the shoreface nourishment $D_{50} = 0.57$ mm and for the beach nourishment $D_{50} = 0.32$ mm. It is done by averaging the longshore sediment transport for the NOURTEC period in each of the areas S and B for each D_{50}. For the shoreface nourishment the ratio between $D_{50} = 0.32$ mm and $D_{50} = 0.57$ mm was found to be 2.3. Similarly for the beach nourishment, the ratio was found to be 1.2.

5.2 2–dimensional modelling

MIKE 21 is a 2–dimensional modelling complex. In the present case a parametrised wind wave model, a depth integrated hydrodynamic model and a deterministic, intra wave period sediment transport have been applied. The intention of using MIKE 21 is to calibrate the model so that it will reproduce the sediment transport in the NOURTEC period.

The simulated conditions had to be limited to 3 wave heights and corresponding water levels, 2 wave directions, 3 bathymetries and 4 different types of sediments due to computer time consumption and with that the costs. The wave heights are chosen from knowledge gained in the LITPACK study about which waves are significant for the sediment transport. Wave directions from south– and northwest were chosen as a minimum. Both are 40° off the coast normal. As a minimum, a bathymetry taken prior to the nourishing, one describing a "summer" bathymetry and one describing a "winter" bathymetry were chosen. Finally, the sediment range from natural sand to the coarse shoreface nourishment sand was described by the D_{50} parameter. The same sediment spreading was used to reduce the number of variables. These parameters were combined in 18 sets of data, each set representing a typical combination of boundary conditions.

The 2–dimensional modelling complex consists of a large wind wave model with a resolution of 20 by 100 m, which gives boundary conditions to the local model area. Here the resolution of the wave modelling is 4 by 20 m. The resolution of the hydrodynamic and sediment transport model is 20 by 20 m.

The results show that even small morphological changes are reflected in the sediment transport pattern so it was difficult to distinguish between the sediment transport caused by natural variations and the sediment transport caused by the nourishment volumes. An attempt has been made to eliminate all other changes but the ones caused by the nourishments by integrating the longshore transport in depth intervals of +4 m to –4 m ("coastline") and of –4 m to –8 m ("6 m depth"). It was found that the changes introduced by the nourishments are nearly insignificant compared to the natural variations both in space and time.

Fig. 6 shows examples of sediment transport fields calculated for 3 different bathymetries. Here the 2–dimensional effect of the nourishments are clearly seen. The longshore sediment transport components have been integrated within the intervals "coastline" and "6 m depth". The calculated integrated sediment transport rates are compared for a) the bathymetry just before nourishment and the "before nourishment bathymetry" supplemented with the "after nourishment bathymetry" within the area S and B, and b) for a "summer" bathymetry and a "winter" bathymetry.

Another result was that of migrating bed forms on deep water (15 – 20 m) influence the direction of the incoming waves and effect the longshore sediment transport. The effect is most pronounced in the most seaward part of the NOURTEC area.

The effect on the integrated longshore transport of using coarse sand for the shoreface nourishment was calculated. For the shoreface nourishment the ratio between the longshore sediment transport rates for D_{50} = 0.32 and 0.57 mm was found to be 1.17. Similarly for the beach nourishment, the ratio was found to be 1.11.

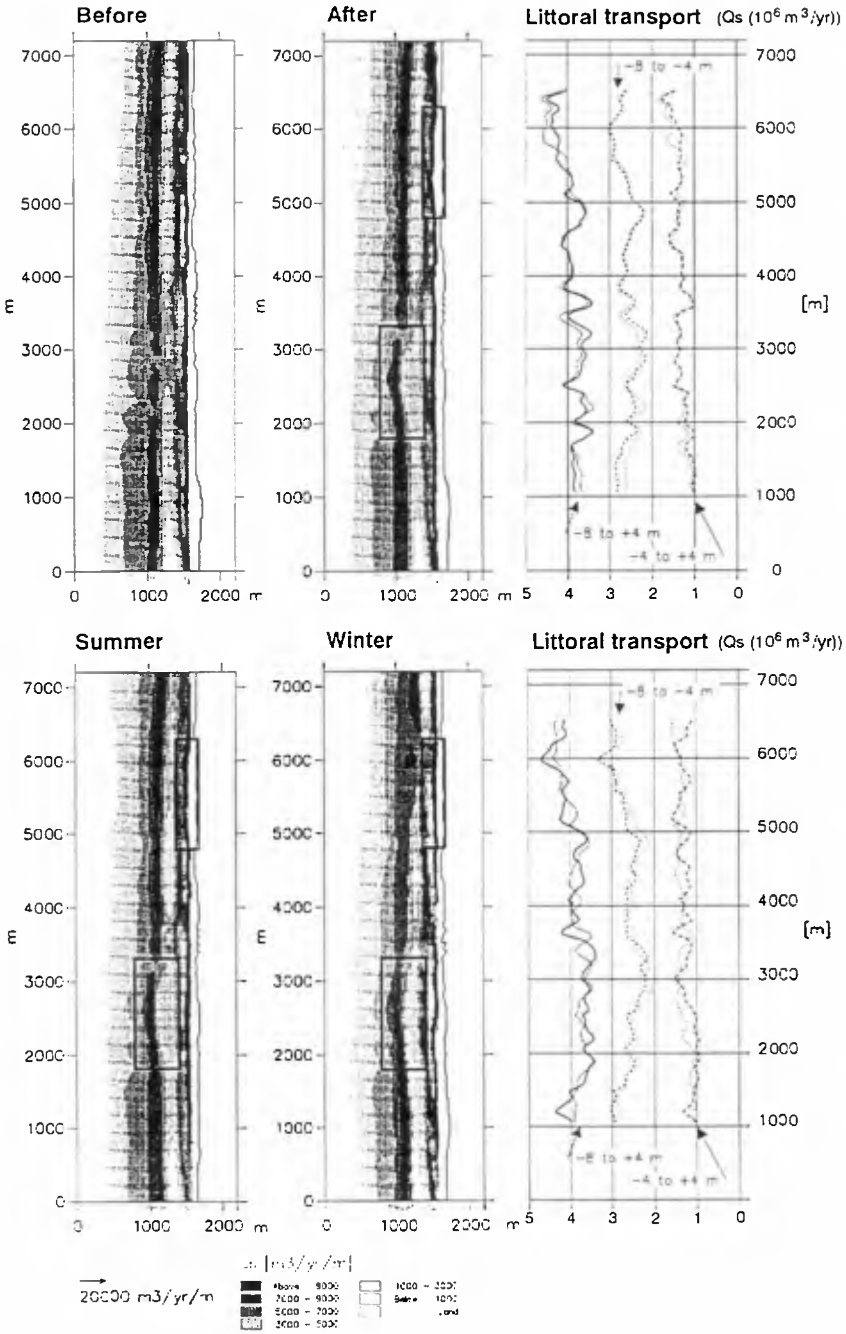

Fig. 6 Calculated, 2–dimensional sediment transport fields and integrated longshore sediment transport components for the intervals +4 m to –4 m, and –4 m to –8 m.

Finally, attempts were made to combine the MIKE 21 calculated volume changes in a system of 12 boxes by which the NOURTEC area is described to reproduce the development in the NOURTEC period. The longshore sediment transport variation with wave direction calculated by LITPACK was used to extrapolate the volume changes. The morphological changes were taken into account by using the "summer" or "winter" bathymetry. Fig. 7 shows the MIKE 21 weighted and measured accretion in 1 km long boxes. In 3 of the 6 boxes good agreement is seen but poor agreement is seen in the other boxes.

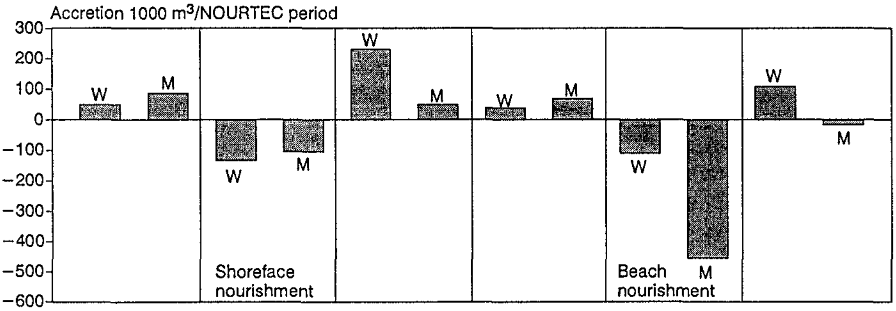

Fig. 7 Weighted Mike 21 and Measured volumes from south to north.

6. Morphological analysis

The volume changes in the monitoring area have been analysed by use of a system of cells with fixed horizontal boundaries. For each cell the volume development has been calculated.

In Fig. 8 the system of cells is shown together with the volume curves for selected cells and combinations of cells. The shoreface nourishment is located in cell H. For this cell there is a volume increase just after completion of the nourishment. From here the volume is stable with some fluctuations. In the cells A–B–C landward the shoreface nourishment there is a gradual volume increase over the whole monitoring period. For the beach nourishment in cell E a gradual volume decrease is seen over the monitoring period. After about 3/4 year the beach nourishment has been eroded. Tracer results indicate that part of this sand migrates towards south in the coastline zone.

Although the volume is constant in cell H, some morphological changes are seen. Over the monitoring period the nourishment migrates about 50 m onshore and the level of the top of the nourishment is reduced by about 0.5 m.

In Fig. 9 an overview is given of the horizontal development of the bar system. Just south of the shoreface nourishment the bar becomes continuous shortly after completion of the nourishment, probably because of the surplus of sand transported on the bar at the nourishment. It can also be seen that a weakening starts after a year at the northern end of the nourishment. Corings in the nourishment area show that about 60% of the nourishment sand is still in the initial position at the end of the monitoring period.

The 40% loss of the nourishment sand is only about 1/3 of the total accretion landward of the nourishment. It means that the accretion effect of the shoreface nourishment is

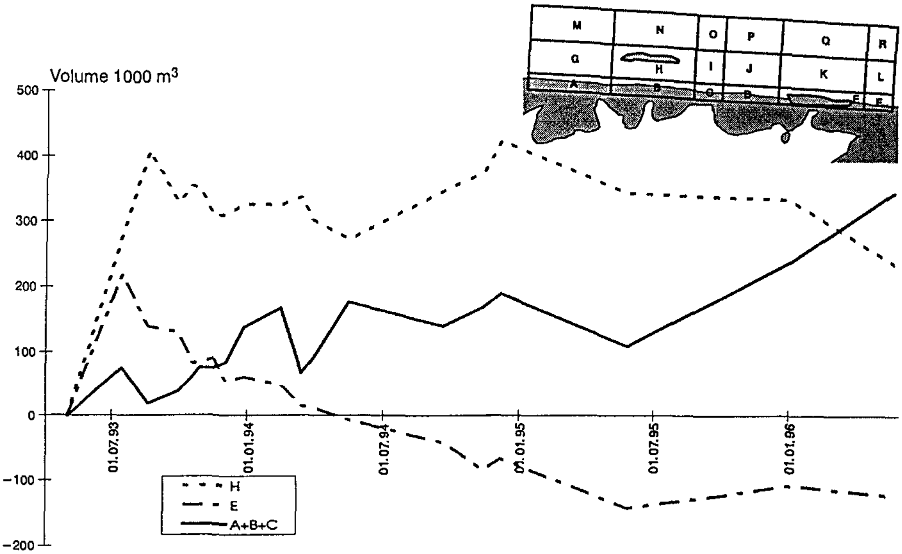

Fig. 8 Volume development in selected cells.

much larger than the nourishment volume itself. The reason is the breakwater effect of the nourishment. Like a breakwater, the nourishment reduces the longshore transport landward with an accretion as result.

An interesting result of this project is the better stability of the shoreface nourishment compared to the beach nourishment. Part of the explanation of this fact is the coarser sand in the shoreface nourishment. However, a reason which is even as important is the specific position of the shoreface nourishment. The position in the bar zone is a natural position for a perturbation so to say. Therefore the nourishment quickly becomes an integrated part of the bar system instead of being eroded away.

Outside the monitoring area migrating bed forms have been observed. However, it has not been possible to verify if the bed forms cause a longshore variation in the sand transport from the outer to the inner part of the profile.

7. Conclusions

The effects of a beach nourishment and a shoreface nourishment have been analysed and compared. Because the weather conditions in the monitoring period were about average, the results are considered to be valid for average weather conditions.

By use of a mechanistic analysis approach it has been determined if the nourishment projects fulfil three design objectives: stabilization of the coastline, coastal protection and widening of the beach. It was found that the beach nourishment stabilizes the coastline and improves the coastal protection but the beach width has not been improved. On the other hand, the shoreface nourishment fulfils all the design objectives.

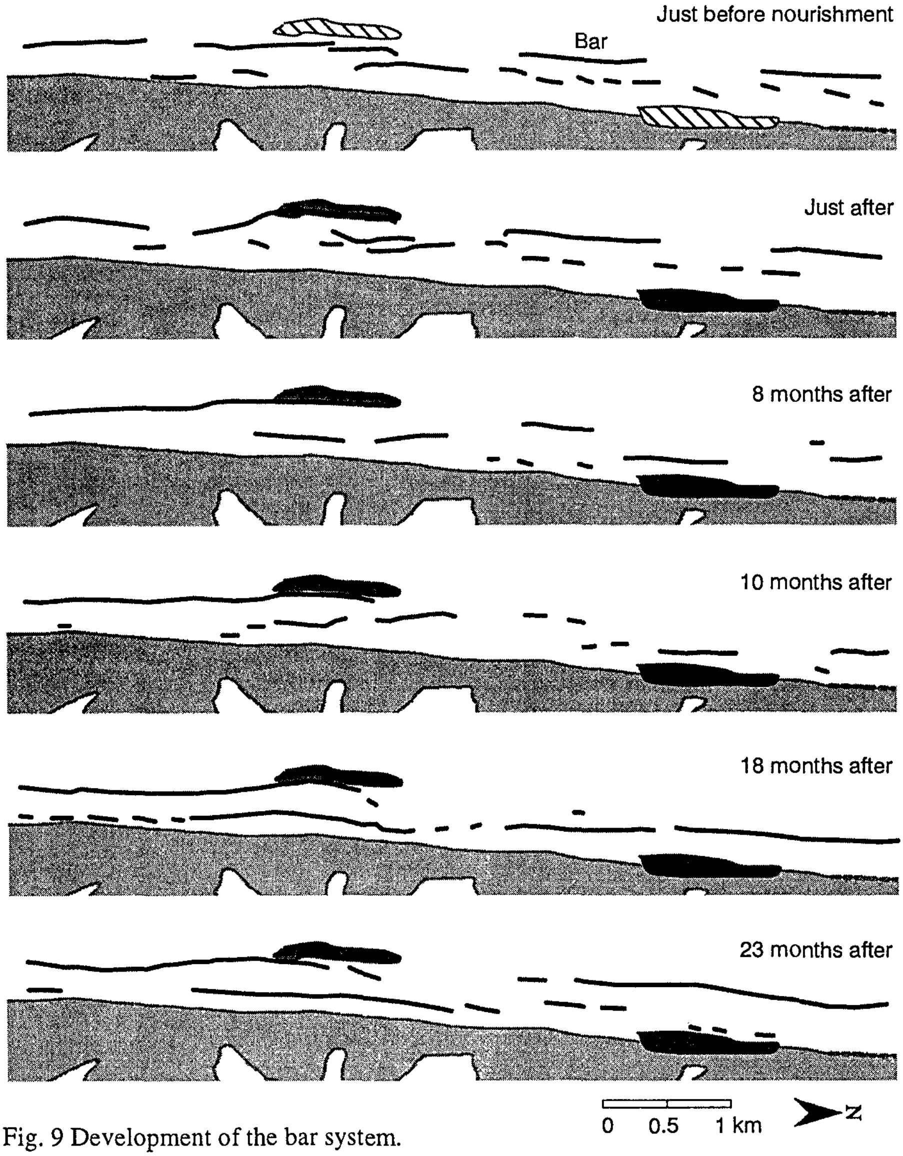

Fig. 9 Development of the bar system.

The relative effect of the two types of nourishment has also been analysed. For all three design objectives, shoreface nourishment is the better option at the end of the monitoring period but beach nourishment is the better option at the beginning. When the price of the nourishment sand is taken into account, the relative effect of the shoreface nourishment is improved because this nourishment type is cheaper.

The 1–dimensional model LITPACK has been calibrated and verified to the monitoring data. LITPACK was then used to calculate the sediment budget and the effect of grain size.

The 2–dimensional model MIKE 21 has shown that the processes in the surf zone are highly 3–dimensional and that the natural variations of the longshore transport are large compared to the changes introduced by the nourishment.

It was concluded that the 2–dimensional calculations of 6 wave conditions combined with 3 bathymetries have been helpful in understanding details of some of the processes which contribute to the natural re–shaping of the investigated area. However, partly due to a limited number of simulated conditions and partly due to the fact that the processes in the surf zone are highly three dimensional, the results cannot be combined in such a way that the observed losses and gains of sediment are reproduced.

The two nourishment volumes have shown a clear difference in stability. The beach nourishment was eroded after 3/4 year. For the shoreface nourishment about 60% of the sand was still in the initial position two years after completion of the nourishment. One reason for the stability is the coarser sand. It was found that the shoreface nourishment sand with $D_{50} = 0.57$ mm is about 2.3 times as stable as sand with $D_{50} = 0.32$ mm. However, a reason which is probably just as important is the position of the nourishment in the bar zone.

The accretion effect of the shoreface nourishment is much larger than the nourishment volume itself. The reason is the breakwater effect of the nourishment. Like a breakwater, the nourishment reduces the longshore transport landward resulting in an accretion.

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