CHAPTER 221

EVALUATION OF SHOREFACE NOURISHMENTS BY LINE MODELLING

Martin D. Groenewoud[1], Willem T. Bakker[2,3], Jan van de Graaff[1],
Ruud Spanhoff[3] and Christian Laustrup[4]

ABSTRACT

Shoreface nourishments are sometimes used as an alternative for ordinary beach nourishments. Many aspects of the behaviour of shoreface nourishments are still unknown. Shoreface nourishments affect the morphological behaviour of a coast. Line modelling might be used to study and to predict the behaviour of shoreface nourishments after execution. Although not every detail of the real behaviour can be dealt with, line modelling is still a rather simple but powerful tool. The recent application is discussed of the line modelling technique to study several shoreface nourishments carried out in the NOURTEC framework.

INTRODUCTION

Coastal zone managers may fight undesired structural erosion of coasts either by 'hard' or by 'soft' measures.

With 'hard' measures the basic idea is to interfere in the sediment transports involved in such a manner that the erosion in the stretch of coast under consideration is stopped, or at least reduced. With a well-tuned system of groynes or a number of shore-parallel detached breakwaters this aim can in principle be achieved. That often the erosion problem is shifted to the adjacent lee side beaches is a serious draw-back of these types of countermeasures.

With 'soft' methods (e.g. a beach nourishment [further: BN]) this adverse lee side effect is avoided. The basic idea of artificial nourishments is to accept the losses as observed (no attempts to interfere in the processes which cause the erosion) but replenish from time to time the apparent losses. Often life times in the range of 5 till 10 years are striven after. Although artificial BN's have to be repeated, it often turns out to be a very cost effective method in comparison with 'hard' alternatives.

Structural erosion of a stretch of coast means that the stretch loses sediments at a regular basis. Often a gradient in the longshore sediment transports is the main cause of the erosion problem. In a cross-shore profile the volume of sediments (m^3/m) in that profile in a predefined (fixed) area, diminishes as a function of time. All parts of such a profile (dunes; beach; shoreface) suffer eventually from this type of

[1] Delft University of Technology; Stevinweg 1; 2628 CN Delft; the Netherlands
[2] Netherlands Center for Coastal Research; Delft University of Technology; Stevinweg 1; 2628 CN Delft; the Netherlands
[3] Rijkswaterstaat, National Institute for Coastal and Marine Management; P.O. Box 20907; 2500 EX the Hague; the Netherlands
[4] Kystinspektoratet; Høbovej 1; 7620 Lemvig; Denmark

erosion. However, the upper part of the profile (beach and dunes) is often considered as the most important part of the entire profile; many important functions of a coast to mankind are concentrated in just this part. Because structural erosion manifests itself most clearly in the upper part of the profile, artificial nourishments are often applied just there. With a BN the 'health' of a beach is directly improved; one clearly can notice the improvements for the time being; e.g. the beach is widened which is favourable for recreational use.

Many methods exist to execute artificial BN's [see e.g. CUR (1987)]; most of them are, however, rather cumbersome in practice. The handling of the sediments from borrow area to fill site is often complicated and thus costly. Because of the recreational use of beaches often the summer period is excluded as execution time.

Instead of applying (cumbersome) artificial BN's, nourishing just the shoreface seems an (easy) alternative. Sediment handling is quite simple; the dredge sails from the borrow area and dumps the load at the shoreface and starts with a new cycle. Because of no (or less) hindrance to the recreational use of the beaches also the summer time can be used for execution. Large cost savings are expected to be achieved with shoreface nourishments [further: SN] in comparison with classical BN's.

In the scope of the NOURTEC project [Mulder *et al.* (1994)] at 3 sites (Terschelling, the Netherlands; Norderney, Germany; and Torsminde, Denmark; see Fig.1) sand has been supplied on the shoreface. The NOURTEC project implies evaluation and comparison of the coastal behaviour at those sites after the SN's.

Bakker *et al.* (1994) made a prediction of the expected coastal behaviour after the SN at the Dutch Wadden island of Terschelling; furthermore the coastal behaviour after the supply at the German Wadden island of Norderney was evaluated. They used the 3-line modelling technique. Later on the nourishments in Denmark and Terschelling have been evaluated with the same technique (Groenewoud 1996a and 1996b). The study has been finished with an overall evaluation of the 3-line modelling technique as a design and evaluation tool (Groenewoud 1996c).

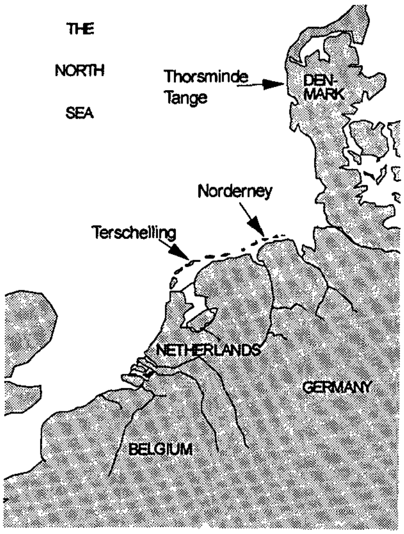

Fig.1 Location of the 3 NOURTEC test sites

In the present paper the application of the 3-line modelling technique in the 3 NOURTEC cases is discussed; strong and weak points of the method are revealed.

SHOREFACE NOURISHMENTS IN PRACTICE

Fig.2 shows in plan view a (shore parallel) SN along a sandy coast. Because a SN is meant to be a substitute of an ordinary BN it is expected that a part of the supplied volume is transported towards the coast. With the notion of the existence of equilibrium profiles one can indeed expect that because of cross-shore transports the extra volume of sand is eventually spread over the entire profile (in onshore as well in offshore direction). Consequently also a part of the supplied volume is thought to reach eventually the beach. For the judgment of the effectiveness of SN's in comparison to BN's it is of course important to know which part of the volume of SN's reaches the beaches, and which time scales are involved. With detailed cross-shore transport calculations these topics are to be evaluated.

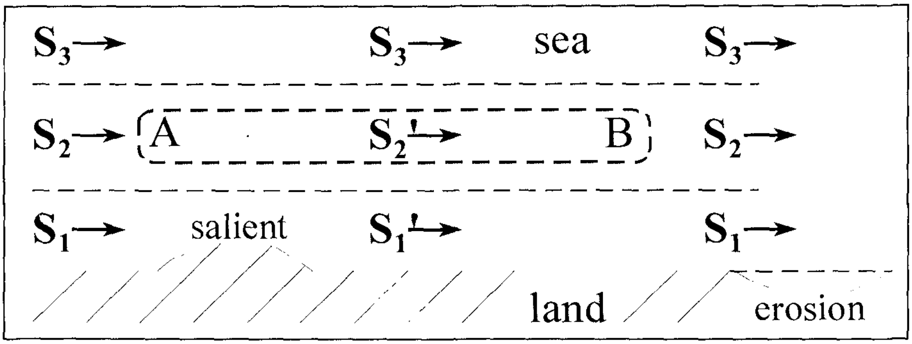

Fig.2 (Arbitrary) shoreface nourishment in plan view

In plan view (see Fig.2) a SN is limited; between points A and B the depths contours are just after the execution locally shifted in seaward direction. In the neighbourhood of the points A and B the orientation of the depth contours has changed. With a description of the (local) longshore transport depending on the orientation of the depth contours it is easily understood that near the points A and B a redistribution of the volume of sediments of the SN in longshore direction will take place. Also in the upper part of the profile, as soon as some sediment has reached that part of the profile by cross-shore transports, a similar reorientation of the local depth contours will occur with a consequent redistribution of sediments in longshore direction in the upper part of the profiles of the stretch of coast.

A SN acts, however, also as a (mobile) submerged breakwater. The presence of a SN will affect (reduce) the wave heights in the zone between the SN and the waterline. Consequently the longshore sediment transports in this zone are reduced compared to the original transports along the non-supplied coast at the left-hand side of A and at the right-hand side of B (see Fig.2). Assuming a net longshore transport in the zone behind the SN as indicated in Fig.2 from left to right, it is expected that behind the left side of the SN some accumulation of sediments will occur (salient formation). Right from B it is expected that (additional) erosion of the beaches will occur.

Especially the expected salient formation at the up-drift side behind the SN will confuse phenomenological studies based on bathymetric data. Is the observed accumulation of sediments in this area because of cross-shore sediment transport effects or because of longshore transport effects?

If a SN is applied in a zone with water depths where in the non-supplied situation still substantial yearly net longshore sediment transports do occur (either wave or tide driven or due to a combination of waves and tidal currents), the mere sudden uplift of the bottom because of the presence of the SN will cause increased sediment transports above the SN (see Fig.2). Induced gradients in the local longshore transport will cause erosion of the SN just right of point A and accumulation of sediments just right of point B. It seems that the entire SN is moving (within the schematization of Fig.2) from left to right along the coast.

In the brief discussion of the different morphological effects of a SN it was presumed that the borrow material of the SN is equal to the native material. In practical applications, however, this presumption might not be true; the borrow material may differ from the native material. It is for sure that consequently the sediment transports involved, will change.

In the previous part 4 morphological effects of a SN have been briefly discussed, viz.:

> i) (straightforward) cross-shore redistribution of the volume of a SN over the entire cross-section; ii) longshore redistribution of the volume of a SN due to reorientation of the depth contours in the zone of the SN itself (starts immediately after execution) and in the upper part of the profile (starts when after some time sediments have reached the upper part of the profile); iii) salient formation at the up drift side (and erosion at the down drift side) in the zone between SN and waterline because of reduction of the yearly net longshore sediment transport in this zone; iv) integral movement of the SN in longshore direction because of yearly net longshore sediment transports in the SN zone.

In the next section the 3-line modelling technique is discussed. It will turn out that the effects i) and ii) can in principle be properly modelled with the present technique; the effects iii) and iv) cannot be accounted for with the present model set up. In the present 3-line modelling approach it is also assumed that borrow and native material are the same. Additional effects due to differences in borrow and native material are not accounted for.

3-LINE MODELLING TECHNIQUE

General

In the present study 3 lines have been used to represent a cross-shore profile. More, or only 2 lines are in principle also possible. The 3-line modelling technique is a rather simple technique which can be used to study the behaviour of a morphological system with time. The approach relies on the assumption that the actual behaviour of a morphological system can be considered as a linear superposition of different sub-systems. In the present application for instance, the autonomous behaviour of the system is assumed to be the same before and after a SN application. Only the additional effect of the SN is modelled. So if the behaviour of the SN with time is modelled reliably, the eventual behaviour of the system with time is found by adding both sub-systems (autonomous behaviour + behaviour because of the SN).

Schematization of cross-shore profile and cross-shore transports

In a 3-line model the cross-shore profile is schematized by 3 zones with horizontal separation planes (see Fig.3). The volumes of sand in the zones (layers) are characterized by 3 lines which may, contrary to equilibrium profile approaches, develop 'freely' with time. It is assumed that in each zone the mutual distance between the upper and the lower limit remains the same and (thus) that the part of a profile coinciding with the zone moves only horizontally.

The characterizing lines each have a distance to an arbitrary vertical reference line which for L_1 can be defined as (see Fig.3):

$$L_1 = \frac{1}{h_1} \int_{-d_1}^{0} y(z)dz \qquad (1)$$

For lines L_2 and L_3 similar formulae can be derived.

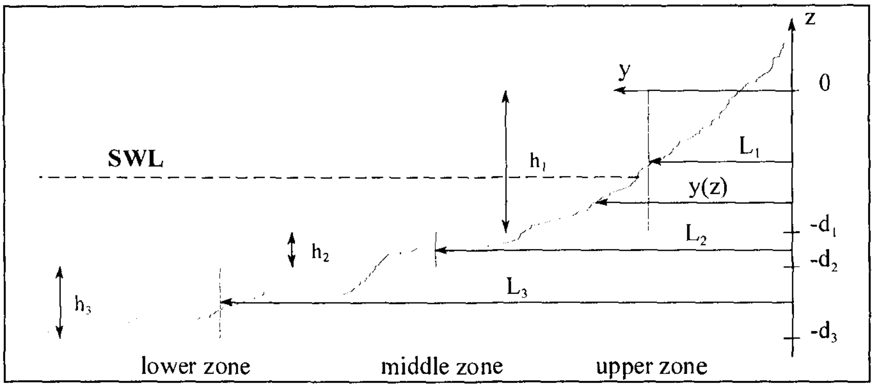

Fig.3 Schematization of cross-section

The parameters of Eq.1 and Fig.3 are:

d_1,d_2 = depth of separation plane between zone 1 and 2; zone 2 and 3;
d_3 = depth of lower limit of zone 3;
h_1,h_2,h_3 = height of zone 1; zone 2; zone 3;
L_1,L_2,L_3 = characterizing mean line of upper zone; middle zone; lower zone;
y(z) = distance of point of profile at depth z to a reference line;
z = height above the y-axis.

The cross-shore sediment transport rate between the zones is assumed to be proportional to the difference between the actual distances and the equilibrium distance between the characterizing lines. This method of describing cross-shore sediment transports was originally proposed by Bakker (1968) and further developed by Swart (1974).

Since in the present application the profiles before the SN application are assumed to be equilibrium profiles, the use of L_1, L_2 and L_3 can be avoided; only perturbations from the initial equilibrium profile are considered. These perturbations are expressed as (see Fig.4) y_1, y_2 and y_3 respectively.

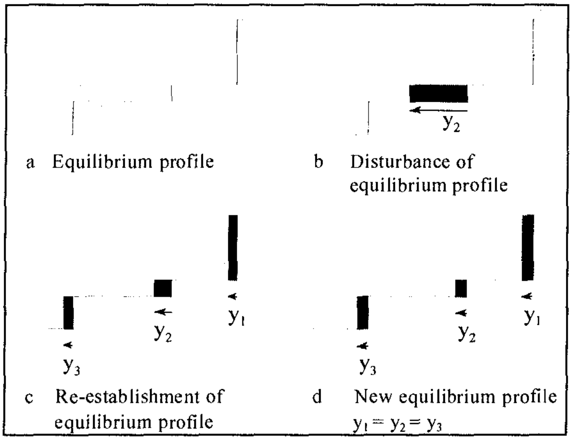

Fig.4 Schematized equilibrium profile (a); disturbance in middle layer (b) and behaviour (c and d)

If the transport rates S_{y1} [and S_{y2}] are assumed to be proportional to the differences (y_1-y_2) for S_{y1} [and (y_2-y_3) for S_{y2}], then the following equation for S_{y1} can be written:

$$S_{y_1} = s_{y_1}(y_1 - y_2) \tag{2}$$

(For S_{y2} similar formula.)

with: S_{y1} = cross-shore transport from the upper to the middle zone [m^3/m/year] (positive in seaward direction)
s_{y1} = cross-shore coastal constant [m/year]

The description of the cross-shore sediment transport relies on a proper estimate of the cross-shore coastal constants. It can be proved that these coastal constants can be rewritten as:

$$s_{y1} = \frac{1}{T_{01}} * \left(\frac{h_1 * h_2}{h_1 + h_2} \right) \tag{3}$$

with: T_{01} = time constant for diffusivity between upper and middle zone (year)

(For the time constant for diffusivity between the middle and lower zone T_{02} a similar formula can be derived.)

The T_0 period is the lapse of time in which a certain value of deviation from the equilibrium distance will decrease with a factor e. The problem of estimating proper values for the cross-shore constants is now shifted to the proper estimate of the T_0 periods.

Schematization of longshore transport

In each zone of the schematized cross-shore profile longshore sediment transports will occur. These longshore transports are indicated by S_1, S_2 and S_3 for the upper, middle and lower zone, respectively. In the following discussion S_x is generally used.

In the present NOURTEC cases the total longshore transport, and the distribution over the different zones, is calculated with the CERC formula; the possible contribution of tidal currents is consequently ignored. The method can, however, also be used if tidal currents are taken into account; the preparatory calculations are only somewhat more complicated in that case.

A gradient in the longshore transport results in the following equation of continuity:

$$\frac{\partial S_x}{\partial x} + h\frac{\partial y}{\partial t} = 0 \tag{4}$$

with h being the thickness of the layer over which erosion or accumulation takes place. The gradient of the longshore sediment transport is due to changes in angle of wave approach.

The wave climate is assumed to be constant along the coast. With small changes of the angle, the longshore transport is assumed to depend linearly on the angle of wave approach.

$$\frac{\partial S_x}{\partial \varphi} = s_x \tag{5}$$

with: s_x = longshore coastal constant

The chain rule gives:

$$\frac{\partial S_x}{\partial x} = \frac{\partial S_x}{\partial \varphi} * \frac{\partial \varphi}{\partial x} \tag{6}$$

Substitution of Eqs.5 and 6 in Eq.4 and assuming small angles ultimately yields:

$$-s_x\frac{\partial^2 y}{\partial x^2} + h\frac{\partial y}{\partial t} = 0 \tag{7}$$

The change of the position of the coastline ($\partial y/\partial t$) due to longshore transport is proportional to the curvature of the coastline. This also applies if the profile is divided into several zones. The equation for the upper zone then becomes:

$$\left[\frac{dy_1}{dt}\right]_{long} = \frac{s_1}{h_1} * \frac{\partial^2 y_1}{\partial x^2} \tag{8}$$

with: s_1 = longshore coastal constant

Combination of both cross-shore and longshore processes with linear addition gives:

$$\frac{dy_1}{dt} = \frac{s_1}{h_1} * \frac{\partial^2 y_1}{\partial x^2} - \frac{s_{y1}}{h_1}(y_1 - y_2) \tag{9}$$

$$\frac{dy_2}{dt} = \frac{s_2}{h_2} * \frac{\partial^2 y_2}{\partial x^2} + \frac{s_{y1}}{h_2}(y_1 - y_2) - \frac{s_{y2}}{h_2}(y_2 - y_3) \tag{10}$$

$$\frac{dy_3}{dt} = \frac{s_3}{h_3} * \frac{\partial^2 y_3}{\partial x^2} + \frac{s_{y2}}{h_3}(y_2 - y_3) \tag{11}$$

In these equations the longshore transport is determined by the constants s_1, s_2 and s_3 and the direction of the coast. The cross-shore transport is determined by the constants s_{y1} and s_{y2} and the deviation from the equilibrium position.
These three equations determine the development of y_1, y_2 and y_3 in time and position along the coast.

Numerical solution
The numerical method used to solve Eqs.9, 10 and 11 is the Euler Explicit Time Forward Central Space method. Time and space steps have to be carefully linked in order to fulfil the stability criterion.

Example
In Fig.5 the results of an arbitrary example are given. Along 2 km a shore-parallel SN is placed in the middle layer. The thicknesses of the layers are respectively: upper: 6 m; middle: 3 m and lower: 3 m. The cross-shore constants are s_{y1} = 1.33 m/year and s_{y2} = 0.3 m/year. The longshore coastal constants read: s_1 = $2.65*10^6$ m^3/year/rad; s_2 = $0.22*10^6$ m^3/year/rad and s_3 = 0 m^3/year/rad. The volume as nourished is 300 m^3/m; because of the nourishment just after the nourishment the y_2 values shifted with 100 m in seaward direction.

From Fig.5 it becomes clear that the SN diffuses in all directions. With the constants as used indeed a large part of the SN reaches the upper part of the profile.
The lower zone just seaward of the SN gets some sand directly from the middle zone because of cross-shore transports. In the adjacent lower zones also some sedimentation is noticed. Since the longshore coastal constant s_3 in the present

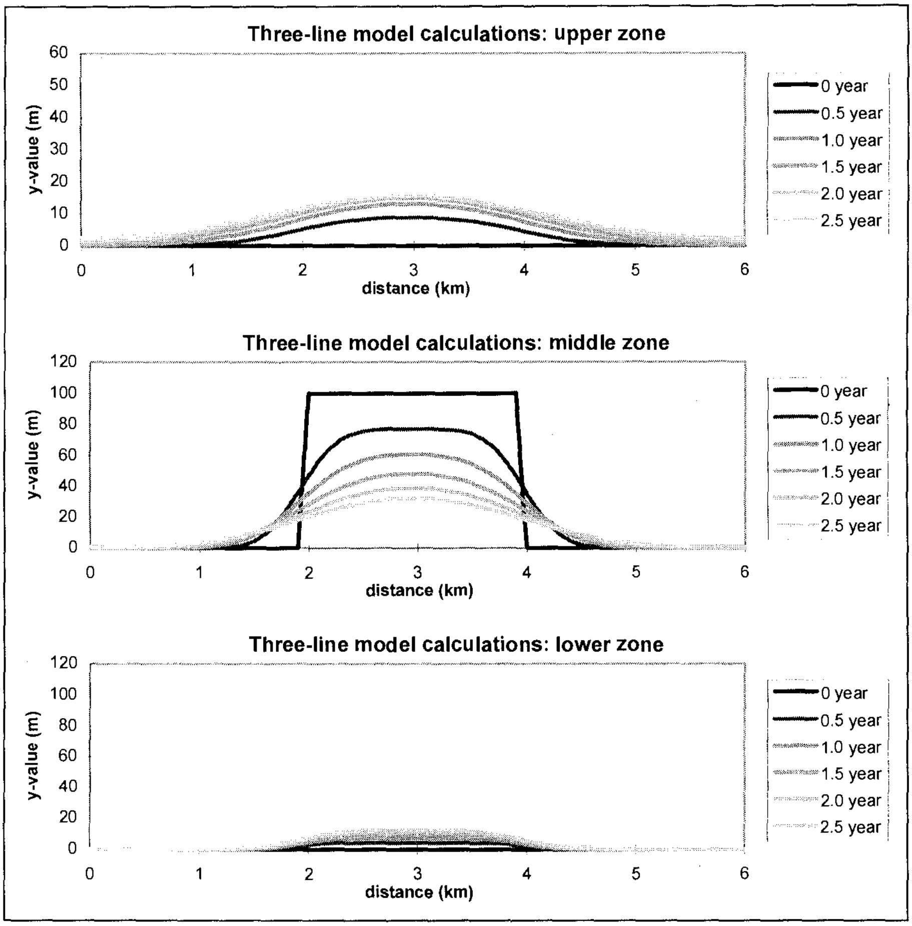

Fig.5 Development with time of a shoreface nourishment in middle layer

example is zero, this material has reached these zones first via the adjacent middle layers and next by cross-shore transport.

In the present example the autonomous behaviour of the coast is not taken into account; in real life problems the autonomous behaviour has to be added to the computation results. To determine the autonomous behaviour in real cases turns out to be a cumbersome task (see NOURTEC examples next section).

NOURTEC EXAMPLES

Torsminde

The Torsminde test side is located along the west coast of Denmark (see Fig.6). Fig.7 shows two typical cross-shore profiles; 1 to 3 offshore bars are present. The site is located in front of a sand dike. A typical value of D_{50} for the sand in the profile is 0.4 mm.

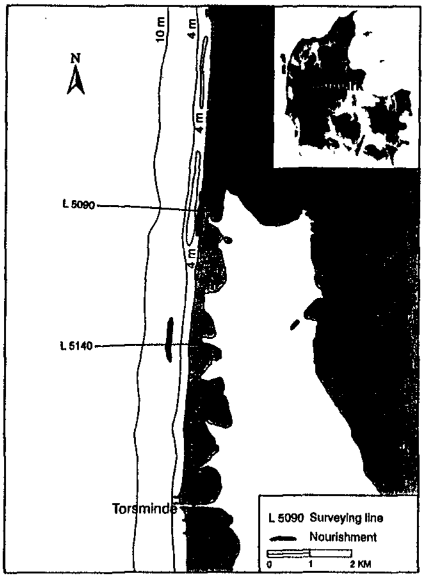

Fig. 6 Location Torsminde test site

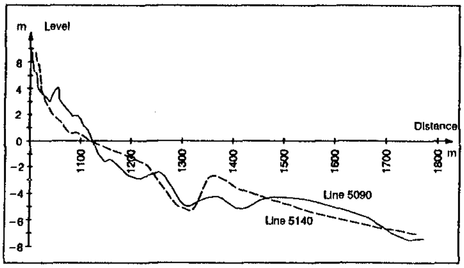

Fig. 7 Typical cross-shore profiles

Separate beach and shoreface nourishments took place in 1993. Over longshore stretches of one km each, approximately 250,000 m^3 sand has been nourished in both cases; so approximately 250 m^3/m. The D_{50} of the borrow sand (D_{50} = 0.34 mm) for the BN was slightly less than the native sand; the borrow sand (D_{50} = 0.58 mm) for the SN was coarser than the native material.
The BN was placed between DNN +4 m and DNN -1 m (DNN = Danish Normal Zero); the SN between DNN -4 m and DNN -6 m. The cross-shore profiles have been divided in 3 layers: upper: DNN +4 m to DNN -4 m; middle: DNN -4 m to DNN -6 m; lower DNN -6 m to DNN -10 m.

Estimates of the longshore coastal constants have been calculated using the CERC formula; the distribution of the transport over the different zones have been found by using the Svašek and Bijker (1969) method.

In the modelling the determination of the cross-shore coastal constants is a vital item. In the Torsminde case different sets have been tested using the observed behaviour as criterion. A reasonable set was eventually found.

To judge the quality of the computation, a comparison with the observed behaviour was made. The autonomous behaviour was set on an average coastline retreat of 6.7 m/year. This value was based on measurements in the period 1978 - 1988.

In the example case of Fig.5 y-values are computed for each 100 m along the coast. In the Torsminde case also a 100 m spacing was used in the computations. In order to facilitate comparison of measurements with computations, averaged values for stretches of coast of 1 km length (so-called boxes) have been used.

The fluctuations of the measured y-values turned out to be relatively large compared to the calculated development of the y-values. It is not expected that these large fluctuations are mainly due to the two nourishments.

Overall the comparison between the calculated and the observed development showed in some cases similarities and in some other cases considerable differences. One of the shortcomings of the present model is that the model can not cope with the effects of the different grain sizes on the morphological development.

Norderney

As already discussed by Bakker *et al.* (1994), the Norderney case is in fact too complicated to be modelled properly with a 3-line modelling technique. The complicated bottom topography in front of the test site and the presence of a number of groynes made this site in fact unsuitable for a simple line-modelling technique.

Terschelling

In the Terschelling case (see Figs.8 and 9) the shoreface was nourished in 1993 with a volume of 2.1 million m^3 over a length of 4.6 km at a depth of Datum -7m to -5m. In fact the most seaward trough of the bar system was filled. The SN was located in the middle part of a 12 km long study area.

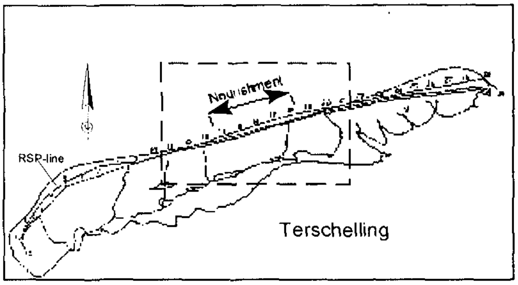

Fig.8 Location Terschelling test site

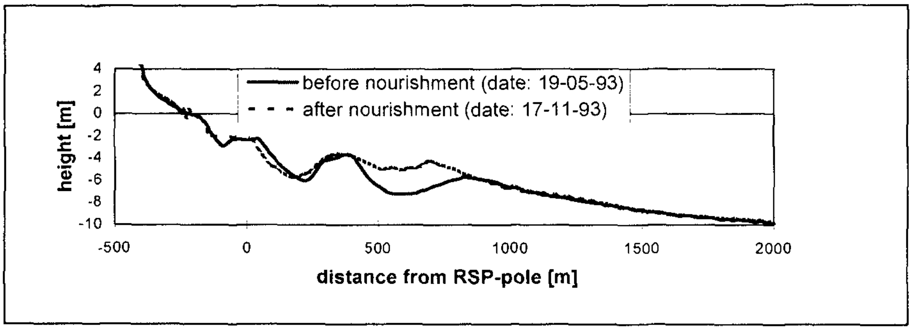

Fig.9 Typical cross-shore profiles

The native bed material shows a typical distribution over the cross-shore profile: D_{50}= 0.24 mm at the beach and gradually decreasing to D_{50}= 0.16 mm at the deeper shoreface. The D_{50} value of the borrow material was 0.20 mm.
Apart from the yearly profile measurements (since 1964; 200 m spacing), just before and after the execution of the SN many more profile measurements have been carried out. After the nourishment e.g. in a lapse of time of 2 years 11 series of measurements have been carried out.

The shape of the cross-shore profile was schematized in 3 layers. Normally (fixed) depth contours are chosen as layer limits. In the Terschelling case because of the bar system, the upper layer was defined from Datum +3 m to Datum -3 m (most landward contour); the lower layer was defined from Datum -6 m (most seaward contour) to Datum -9 m. All the sediment between the most landward Datum -3 m depth contour and the most seaward Datum -6 m depth contour was considered to belong to the middle layer. So even if a trough of the bar system is deeper than Datum -6 m or a crest is higher than Datum -3 m the sediments (or the lack of sediments) involved belong to the middle layer. With this procedure the entire (with time moving) bar system is confined in the middle layer.
The 3-line model is based on the hypothesis that an equilibrium profile exists in cross-shore direction. It might be questioned whether this concept holds as well in case of a bar system with a cyclic behaviour as for Terschelling.

The longshore coastal constants have been derived with the CERC formula. The cross-shore coastal constants have been derived by trial and error, taking the observed behaviour after the SN into account. Rather short T_0 (time constant for diffusitivity) values had to be adopted (T_{01} = 1.5 years upper to middle zone; T_{02} = 5 years middle to lower zone). It is felt that the rather small value T_{01} of only 1.5 years is partly 'artificially'. As discussed in section 'Shoreface nourishments in practice' some salient formation landward of the SN is expected because of gradients in longshore transport. Although this phenomenon can not be properly modelled with the present technique, the effects are accounted for by the relatively small T_{01} value.

The study area was divided in several (8 in this case) boxes (1.2 km each).
Prior to the SN the autonomous behaviour of each box could be determined since many profile measurements are available. In the final judgment of the observed and calculated behaviour of the coast, the calculated autonomous behaviour of each box was taken into account.

The calculated development of the y-values of the upper zones was very similar to the measured development after the application of the SN. The large observed volume increase in the upper zone is, in the present simulation, almost entirely caused by cross-shore transports from the middle zones. It might be questioned whether this is physically correct.
The simulation results for the middle zones were less good. E.g. the observed general movement of the SN in eastward direction could not be properly modelled. The differences between the measured and modelled behaviour of the lower zone were in some cases large.

ESTIMATES OF COEFFICIENTS

In the preceding section the modelling results of the 3 NOURTEC cases have been briefly discussed. Thc Torsminde and Terschelling cases could be modelled more or less successfully. The Norderney case has been reported by Bakker *et al.* (1994); the complexity of that problem was demonstrated.

The quality of the modelling results depends to a large extent on a proper choice of the coastal constants. Reliable longshore constants could be determined with the CERC formula. The proper choice of the cross-shore constants turned out to be more difficult. Till now a sound theoretical basis is lacking for the determination of these constants. By trial and error (using the observed behaviour after execution of the SN's) useful estimates have been found. With these estimates at least some essential characteristics of the behaviour could be modelled. This procedure makes it difficult to use the model in an *a priori* predictive mode in other cases.
In Table 1 the constants as used in the Torsminde and Terschelling cases have been summarized.

	Torsminde	**Terschelling**
T_{01}	5.0 years (s_{y1} = 0.32 m/year)	1.5 years (s_{y1} = 1.33 m/year)
T_{02}	5.0 years (s_{y2} = 0.27 m/year)	5.0 years (s_{y2} = 0.30 m/year)
s_1	2.65 * 10^6 m^3/year/rad	3.63 * 10^6 m^3/year/rad
s_2	0.23 * 10^6 m^3/year/rad	0.96 * 10^6 m^3/year/rad
s_3	0.00 * 10^6 m^3/year/rad	0.00 * 10^6 m^3/year/rad

Table 1 Coastal constants Torsminde and Terschelling cases

The longshore constants for the upper zone for Torsminde and Terschelling are of the same order of magnitude; in the middle zone the constants for Torsminde are somewhat smaller than for Terschelling. This is partly caused by the difference of the height of the upper limit of the middle zone; DNN -4 m for Torsminde and Datum -3 m for Terschelling. Both in Torsminde and in Terschelling no longshore sediment transports are assumed to occur in the lower zone.

The time constants for diffusivity in cross-shore direction are generally 5 years, except for the Terschelling case between upper and middle zone (T_{01} = 1.5 years). There is no reliable theory available yet to predict time constants. In the Terschelling case the observed cycle for the (offshore) movement of the bar system is 10 - 15 years. It is felt that the time constants should have the same order of magnitude; 5 years is in this respect not too strange. The rather small value of T_{01} = 1.5 years for Terschelling is probably because in this value also the (not modelled) effects of longshore sediment transport gradients are accounted for.

With the use of mathematical cross-shore transport (and morphological) models in principle estimates of cross-shore constants could be derived. Although this procedure has not yet followed in the present NOURTEC cases, promising results have already been achieved in other Dutch research cases. [See Steetzel (1996).]

CONCLUSIONS

The 3-line modelling technique has proved to be a powerful method to represent the most important characteristics of the behaviour of SN's after placement. Different design alternatives can be easily compared. It is certainly not a technique to answer all questions which might be raised related to the application of SN's.

A serious problem in analyzing the behaviour of SN's after placement is the distinction between the SN-induced behaviour and the autonomous behaviour. Much of the observed differences between model results (added to the estimated autonomous behaviour) and the measured behaviour, is caused by uncertainties about the estimated autonomous behaviour.

The present 3-line modelling technique is not able to cope with differences between borrow and native material.

Although the modelling results were in some respects not fully successful, the study has revealed that modelling attemps can serve as a very fruitful focus point for better understanding of the complex behaviour of shoreface nourishments.

ACKNOWLEDGEMENTS

The study was sponsored by partners in the NOURTEC project: Rijkswaterstaat, National Institute for Coastal and Marine Management/RIKZ; the Netherlands (Terschelling case), Coastal Research Station Norderney; Germany (Norderney case) and Danish Coastal Authority; Denmark (Torsminde case). The NOURTEC project was co-sponsored by the Commission of the European Union, Directorate General XII, Marine Science and Technology (MaST II) Programme under contract MAS2-CT93-0049.

REFERENCES

Bakker, W.T. (1968) The dynamics of a coast with a groyne system. Proc. 11th Int. Conf. on Coastal Eng., London, UK.

Bakker, W.T, N.F. Kersting and H.D. Niemeyer (1994) Line-modeling of Shoreface Nourishment. Proc. 24th Int. Conf. on Coastal Eng., Kobe, Japan.

CUR (Centre for Civil Engineering Research, codes and specifications) (1987) Manual on Artificial Beach Nourishment. Report 130; Rijkswaterstaat and DELFT HYDRAULICS; Gouda, the Netherlands.

Groenewoud, M.D. (1996a) Three-line modelling of the Torsminde supplies. Delft University of Technology, Fac. of Civil Eng., May 1996.

Groenewoud, M.D. (1996b) Three-line modelling of the Terschelling supply. Delft University of Technology, Fac. of Civil Eng., October 1996.

Groenewoud, M.D. (1996c) Summary of the three-line modelling of the NOURTEC supplies. Delft University of Technology, Fac. of Civil Eng., October 1996.

Mulder, J.P.M., J. van der Kreeke and P. van Vessem (1994) Experimental Shoreface Nourishment, Terschelling (NL). Proc. 24th Int. Conf. on Coastal Eng., Kobe, Japan.

Steetzel, H.J. (1996) Beach nourishment and rock structures; behaviour oriented modelling of the combination of beach nourishment and rigid shore parallel structures. DELFT HYDRAULICS, Delft (in preparation).

Svašek, J.N. and E.W. Bijker (1969) Two methods for determination of morphological changes induced by coastal structures. XXIInd Int. Nav. Congress Paris, section II, item 4.

Swart, D.H. (1974) Offshore sediment transport and equilibrium beach profiles. PhD thesis Delft University of Technology.