CHAPTER 190

METHOD FOR ARTIFICIAL BEACH NOURISHMENT

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Why beach nourishment

For a good design, the purpose of the nourishment has to be clearly defined. In general, there are three reasons for beach nourishment:

1. combatting coastal erosion (chronic erosion)
2. preventing flooding (safety)
3. maintaining a wide recreational beach.

In the Netherlands a political decision has been made to maintain the coastline of 1990. Also, the required funds are available to do so. Thus the main purpose of nourishment in the Netherlands is to combat chronic erosion.

Available tools

For the design, several tools are available. In general one can distinguish three kinds of tools:

1. mathematical models
2. field observations
3. physical models

Physical models are <u>not</u> recommended for the design of beach nourishment. This is because the process of beach change is caused primarily by irregularities in wave conditions. It is very difficult to accurately model this in a scale model. Mathematical models seem to overcome this problem but in fact they only change the problem. To use these models one needs good input data (waves, etc) and good calibration methods. In order to get them, one needs many years' measurements.

Because of the highly irregular wave climate, the predictive value of mathematical models in the Netherlands is rather low. Mathematical models are therefore used mainly for understanding coastal behaviour and comparing alternatives, and not for the quantitative design of artificial beach nourishment. A more direct design method has proved to be more effective.

When beach data (measured profiles) are used, one does not have the problem of defining a good wave climate or other boundary conditions. They are automatically correct. The main problem is that for a good statistical analysis, one needs much data. Consequently one needs a number of years' measurements. This kind of information is abundant for the Dutch coast.

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The Dutch Design Method

Beach nourishment in the Netherlands is designed in an extremely simple way. Experience has shown that this is a very reliable method. The method is very trustworthy, if applicable.

step 1: Perform coastal measurements (for at least 10 years).
step 2: Calculate the "loss of sand" in m^3/year per coastal section.
step 3: Add 40 % loss.
step 4: Multiply this quantity with a convenient lifetime (for example five years).
step 5: Put this quantity somewhere on the beach between the low-water-minus-1-meter line and the dune foot.

This method is simple and straightforward. It does not require mathematical models, but good quality profile measurements are absolutely necessary.

Problems

Of course, there are also problems with the Dutch Design Method. There is one very important general assumption:

The beach nourishment has no influence on the long-term natural behaviour of the coast. Or, in other words, the erosion rate before nourishment equals the erosion rate after nourishment.

This general assumption is true in The Netherlands when beach nourishment is relatively long and the seaward displacement of the water line because of the nourishment is not too great. In The Netherlands the ratio between length of a nourishment (L) and seaward movement of the water line (width of the nourishment, w), L/w, is in the order of 20 - 40. Of course, one should realise that the Dutch coast is a coast with a tidal difference of 2 - 4 meters, a tidal current along the coastline and an almost perpendicular wave attack. Provided the L/w ratio is in the order of 20 or more, this assumption is valid in most areas of the world.

The erosion rate has to be calculated as a volume per unit of time (e.g. m^3/year per m of coastline) In cases were no profile data are available, one may also use the retreat of the high-waterline, but then one implicitly assumes that also the coastal profile is constant in time. That is usually not so. Apart from that the variation in the measured data is also significantly more if one uses coastline retreat instead of volume retreat.

So in fact the first step is to measure the coastal profile for a number of years, and calculate the volume in the profile (see fig. 1). Important is to define good boundaries. The landward boundary has to be placed far enough landward that erosion (also storm-erosion) will "never" pass this boundary. "Never" has to be interpreted as: possible not in the observation period and extrapolation period. The offshore boundary has to be far enough into the sea, that no significant onshore/offshore transports take place over this boundary during normal situations. In any case one should try to place this boundary seaward of possible breaker-bars.

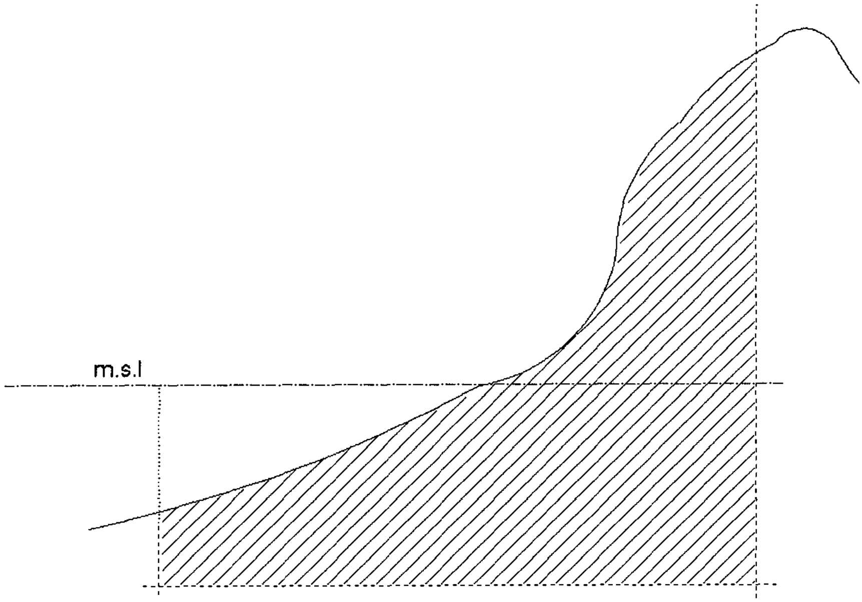

Figure 1: control profile

It is usually a problem to match the terrestric levelling of the beach with the offshore soundings. In case of a big tidal difference this is no problem. The soundings (during H.W.) may overlap the levellings (during L.W.). In case of a smaller tidal difference this might become a problem. In such a situation nearshore sounding with the use of a Hoovercraft may solve the problem.

The next step is plotting the volume data as a function of time (see fig. 2a). Through the data in this figure one may draw a regression line. Usually a linear trend can be assumed, especially when the regression-period is in the order of ten years. This period is recommended for this type of analysis. In very special cases non-linear regression has to be applied. The slope of the regression-line indicates the erosion-rate, e.g. Q_m (m^3/year).

As next step a nice lifetime for a nourishment is selected, for example 5 years. One may select any figure, and optimize this later on. Experience however, has shown that such an optimization usually is completely overrun by non-technical issues, like available budget, available sand, execution schemes, etc. We call this lifetime T.
The volume to be nourished is thus $V_N = Q_m * T$ (m^3). (see fig. 2b).
However "losses" in longshore direction are not considered. These "losses" occur, because the nourishment has always a limited length. Also there is a wash-out of finer particles (the grain-size distribution of the nourished sand is new equal to the original beach sand).

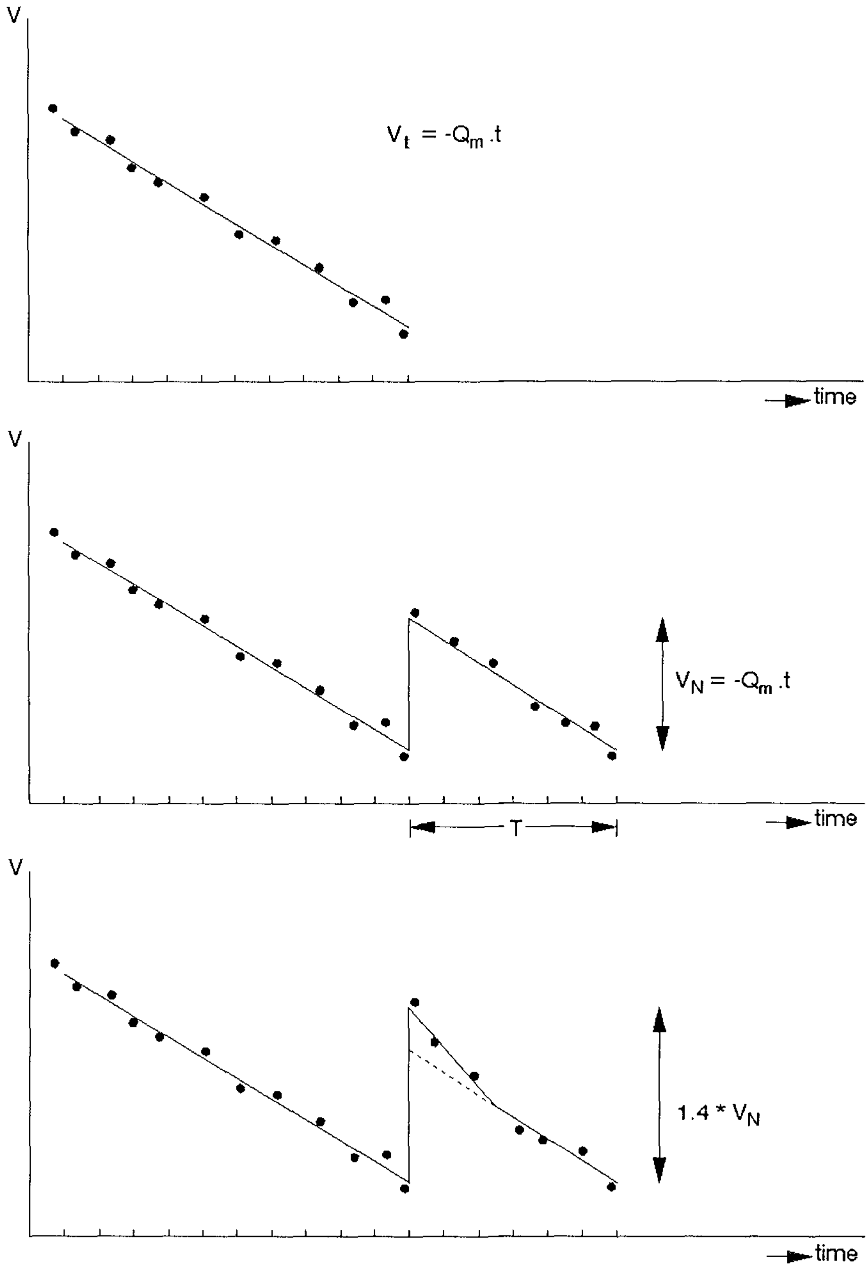

Figure 2: principle of beach nourishment design

Because the beach is somewhat further into the sea, the wave-attack is heavier, and, last-but-not-least their might be a profile adaptation outside our control volume. This last effect becomes less when we place our seaward boundary farther in a seaward direction.

For all these losses we should add something. A first estimate of this surcharge is 40%. This percentage is covering all type of losses (see fig.2c). This percentage can be fine-tuned by using measured data from the evaluation of previous nourishments in the region. We found in the Netherlands that we usually could use a somewhat lower percentage.

As an example the beach nourishment of Texel is presented [Rakhorst, 1989]. The quantity of the nourishments was determined, using linear regression, see fig. 3. As can be seen the yearly erosion-rate increased somewhat after was started with the nourishment schemes. However this change is negligible on the total quantities to be nourished. In this case the surcharge is very small (due to a wide control profile, long nourishment, correct sand).

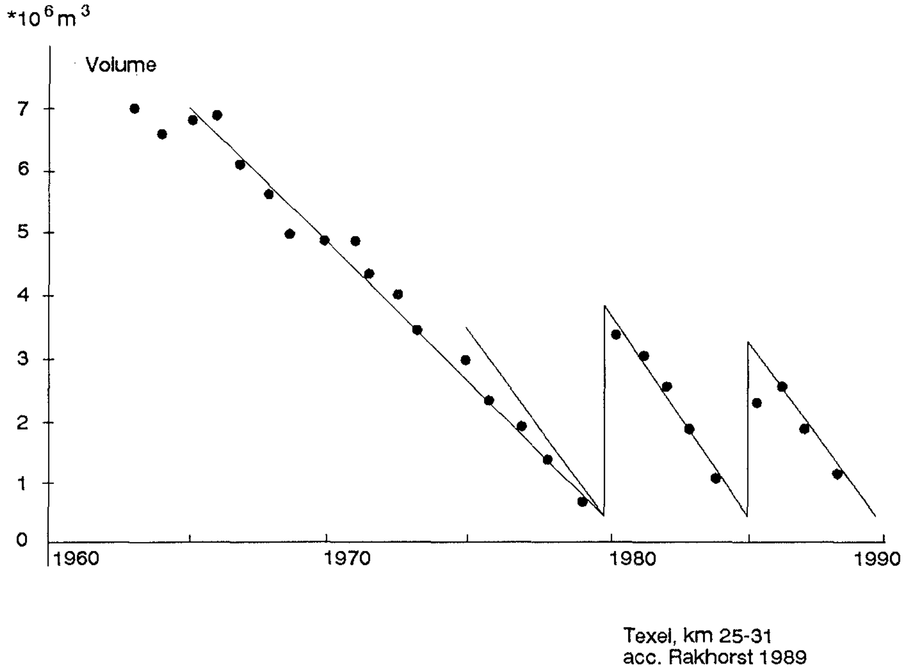

Figure 3: Coastal volumes at Texel

An other example can be found in the nourishments on Westerland, Sylt (Führböter, 1991, and Führböter & Dette, 1992). See figure 4. One can see clearly that, after a short adaption period, the regression before nourishment. The surcharges, however, vary very much. Also they are quite big. This is mainly caused by the fact that the control volume, is only measured to the MSL-1m line, which is approx, the Low Water Line. This underlines the necessity to make the control volume wide enough.

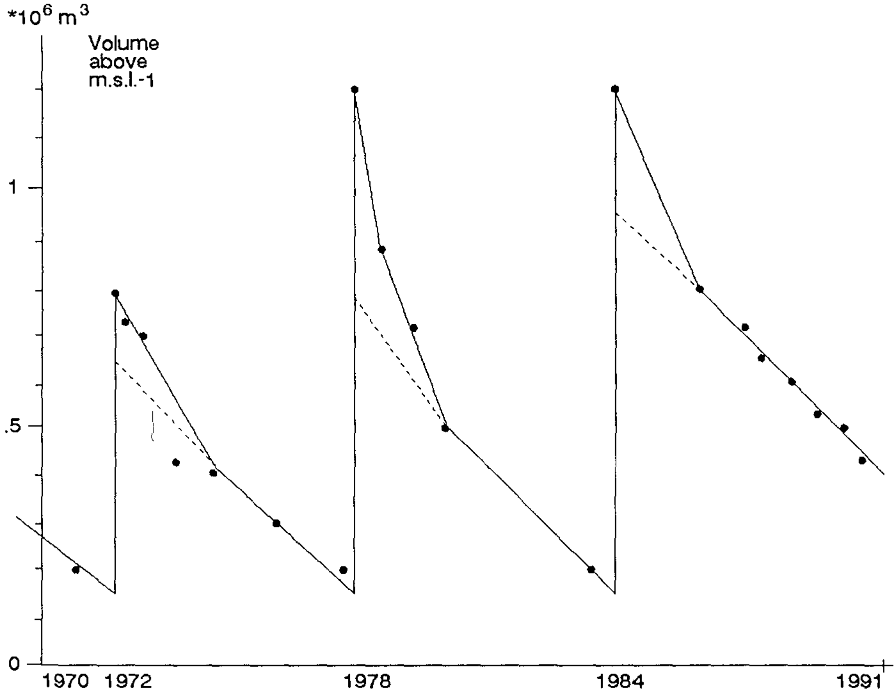

Figure 4: Coastal volumes at Sylt (Westerland)

Westerland [Sylt]
acc. Fuhrboter 1991

The erosion can be described using :

$$V_t = k_2 \, e^{k_1 t} + Q_m \cdot t$$

The paper of Dette and Führböter describes a mathematical method to optimize the term K_2 exp (k_1t) in this equation. For practical reasons we do not try to optimize this in the Netherlands, because practice has learned that the effect of other aspects (available budget, time planning, etc.) have a much bigger impact than optimization of this term. Also the fact that using a wider control volume decreases the magnitude of this surcharge is a reason not to focus too much on this point.

The data from Westerland are very interesting when they are plotted in a slightly different way. In fig. 5 the same data are plotted, but now on the vertical axis the deviation from the linear trend is plotted. So in fact only the k_2 exp (k_1t) - part is plotted. The exponential functions can be observed very clear in the 1978 and 1984 nourishments.

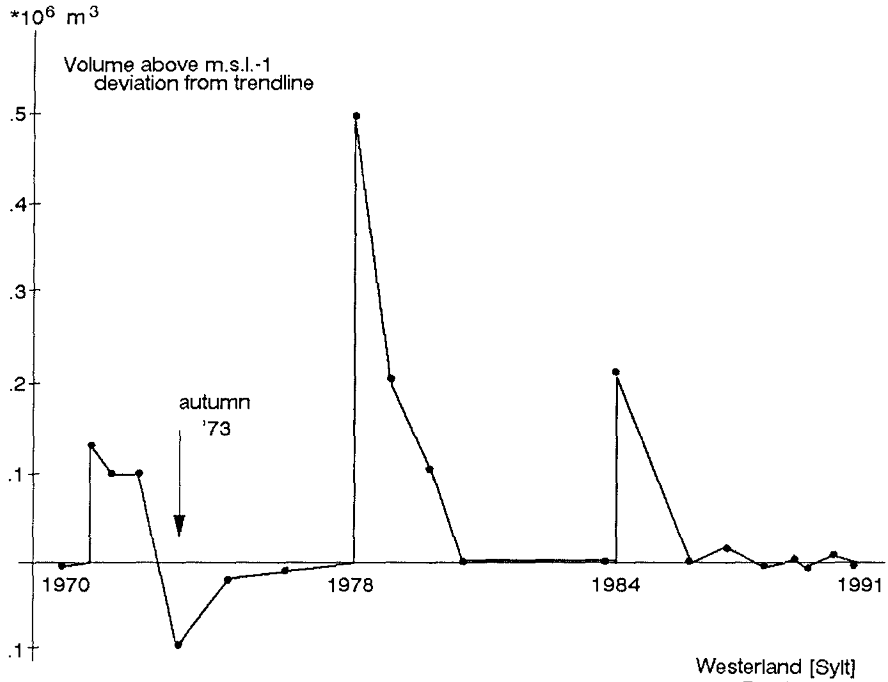

Figure 5: Volume difference from linear trend (Sylt)

In autumn 1973 there was a big storm on this coast. Due to this storm much sand eroded from the higher part of the beach and was deposited below the low-water line. Because this deposition was outside the control-volume, it is indicated as a loss. In the calm period after the storm this sand was transported back. The erosion-line comes back to the expected e-power-line. When a wider control volume had been used, one could probably not find this storm in the record. This shows very clear that individual storms like the autumn 1973-storm, not really contribute to the slow and chronic erosion of a beach. Storms do not cause extra erosion to nourished beaches.

Of course, the design-procedure described above is not very exact. One run the risk of making two types of "design errors".

"design error 1"

The yearly erosion was not determined correctly, like in the Texel case. See figure 6. Because the real erosion (= slope of regression line) is more than anticipated, the life-time of the nourishment is also shorter than anticipated. So next time one has to nourish somewhat more sand, or define the life-time somewhat shorter (if one wants to use the same nourishment volume)
However one has also to conclude that every grain of the first nourishment has done his job. Only we expected too much. So every dollar invested in the nourishment was invested very well. Therefore one has to conclude that this "design error" does not lead to financial problems.

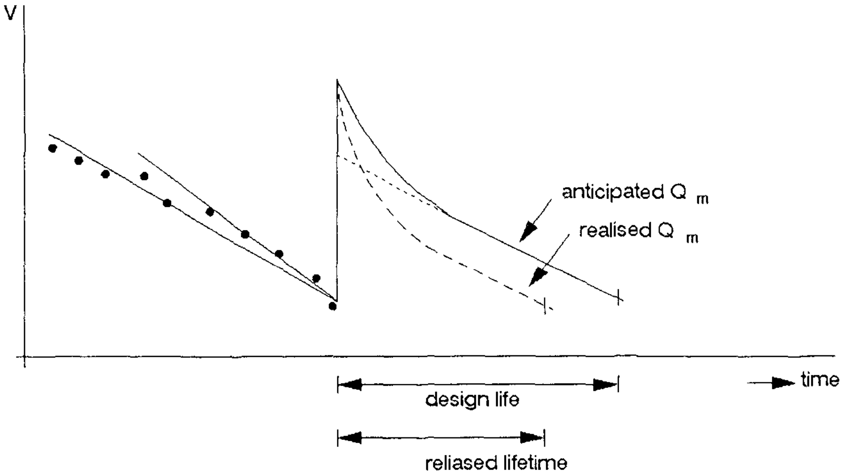

Figure 6: Design error type 1   Design error type 1 : Q_m was not determined correctly

"design error 2"

The yearly erosion trend is determined correct, but the surcharge was somewhat too small, see figure 7. This also leads to a shorter lifetime than anticipated, and next time the design can be easily adapted by using the correct surcharge percentage. But also in this case one has to conclude that all nourished sand worked very well, and that one can not speak of a bad investment. This "design error" too does not have considerable financial consequences.

From the above one has to conclude that artificial beach nourishment has, from a financial point of view, a very big advantage. It is in fact an investment on which one has hardly any risk. Every grain of nourished sand is effective. Artificial Beach Nourishment may prove to be somewhat cheaper or more expensive than anticipated,

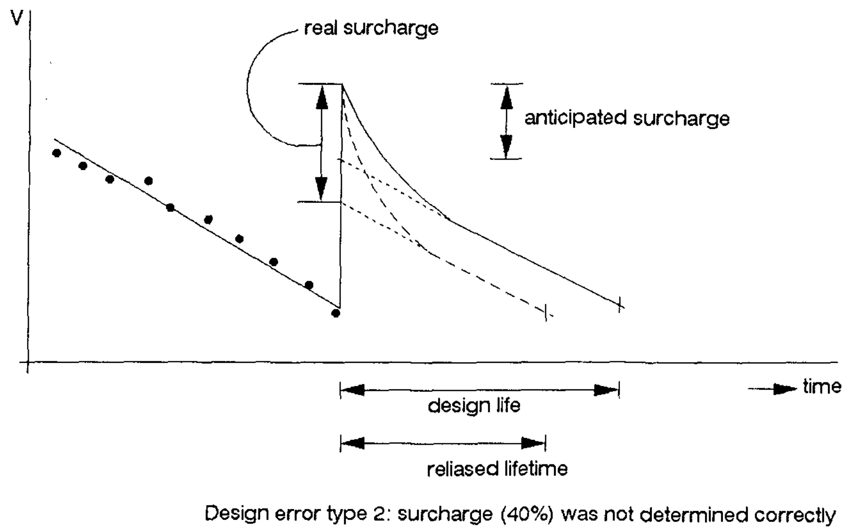

Figure 7: Design error type 2

but what has been invested is not lost.

Placing the sand

From a morphological point of view there is not much preference where the sand is placed in the beach profile (provided it is between the breakerline and dune-foot or swash-line). Placement outside the breakerzone might be attractive in some cases, but that is outside the scope of this paper.
The first minor storm after the placement of the nourishment will adapt the profile to the natural profile. And nature can do this much better than bulldozers and scrapers.

Experience in the Netherlands has indicated that so-called profile nourishment (i.e. try to make a natural stable profile) does not has any influence on the erosion-rate. It was only found that at very steep, relatively fast eroding beaches, a high placement lasted somewhat longer, because the profile could not adapt quickly enough to the erosion. In fact, because of high nourishment the profile was constantly too steep, and the next nourishment was due before the profile could adapt.

From an economic point of view a placement just above H.W is preferably. Usually dumping from split-barges in the breakerzone can not be realized, and one has to pump the sand ashore. The cheapest way is placing the discharge pipes just out of the reach of the waves, which implies a nourishment-level just above H.W. The seaward slope is formed by the free flowing sand. No bunds are used.

The consequence of this method is that one has just after the nourishment a beautiful, wide, high and dry beach, but with a seaward slope which is to steep to survive the stormy season. So, the first storm in autumn will rework the profile until it reaches its natural shape, and much sand is transported from the H.W-line to just below L.W. From a morphological point of view this a absolutely no erosion. In general the public has a different opinion. They see only the dry beach, and they see that it "disappears" after a minor storm. So they regard the nourishment as a failure.

Because of this psychological reason (for funding nourishments one needs public support) it is wise to make the shape of a nourished beach in such a way that the changes in autumn are not too big. In this way one will have more public support for nourishments.

The beach profile

It is very difficult to design the new beach profile. A very good assumption is that the profile after the nourishment will eventually be the same as before the nourishment, provided the same type of sediment has been used.

Nature will form that profile. Therefore it does not matter very much where the sand is placed in the profile. After one or two small storms the complete profile is reworked by nature and the natural (stable) profile is formed. From this one may conclude that one should dump the sand where dumping is the cheapest, as long as it is landward of the breaker line.

In The Netherlands, the cheapest way is placing the sand on the beach, preferably on the higher section. All discharge pipes can be placed out of reach of the waves, and after the nourishment a beautiful, wide beach is formed. However, because the slope just under the low water line is too steep, the first storm in autumn transports sand from the beach towards the underwater shore. From a morphological point of view, this is no problem. From an economical point of view, this is the optimal solution. A number of nourishment projects in the Netherlands have been designed in this way.

However, from a political point of view this is not a good solution. The public has a beautiful beach in the summer, directly after the nourishment. But in autumn, during a minor storm, the public observes that the beach largely disappears. They do <u>not</u> observe that the sand is deposited just below the low water line. The public draws the incorrect conclusion that the nourishment was not successful at all. The wide beach has disappeared.

Because beach nourishment is generally paid for by a public authority, public opinion is important in acquiring sufficient funds. Therefore it is wise to design beach nourishment in such a way that the public sees that the beach is somewhat wider after the nourishment, but that there is no major adaption in the beach shape during the first storms in autumn. If the purpose of the nourishment is to make a wide recreational beach, this is very important. If the purpose is to prevent flooding, the best place is as high as possible on the beach. If the purpose is to combat chronic erosion, the best place is in the breaker zone.

Sediment size

The size of the sediment is important. If the sediment is finer that the original material, the equilibrium slope will be more gentle. Some researchers also assume that finer material causes bigger losses. However it is not clear whether these bigger losses are caused by the more gentle beach profile or whether they are a real loss.

In order to get an impression of the effect of the grain size on the beach slope, one may use a general diagram as made by Dalrymple and Thompson [1976]. However, many beaches have slopes of 1:50 or less, and they are not in this diagram. Also the scatter of the data is too wide for practical application.
It is therefore recommended to start from the existing beach slope and use scale relations to derive the change in beach slope. These scale-relations have been developed by Vellinga [1982] and used for calculating the overfill ratio by Pilarczyk, Van Overeem and Bakker [1986]. The formula to be used is $(l1/l2) = (w1/w2)^{0.56}$. In this formula l is a characteristic length and w is the fall velocity of the beach material.

Suppose the volume to be nourished per meter of coastline is 500 m^2, and the nourishment height is 5 m. The used sand is 250 micron instead of the original 275 micron. When the original slope was 1:75, the new slope will be 1:80. Because of the more gentle slope an extra volume of ½ x 5 x 5x(80-75) = 60 m^2 is necessary. This is an overfill of 12 %.
If one applies the technique of James, as presented in the US Shore Protection Manual, which is based upon the sorting out of fine particles, in this example one finds a overfill ratio of 20 %. Experience in Holland shows that the SPM method gives relatively high overfill ratios. Also it is expected that the mechanism of sorting out is not the governing mechanism, but only the fact that a more gentle slope will occur.

However, detailed research in this field, based upon a good set of prototype data is not available at this moment.

Conclusion

From the above one can conclude that the presented design method for artificial beach nourishment is simple, straight forward and very reliable. No advanced models are required. The disadvantage is that beach profile data have to be available. Because of this, it is always good to have a good beach monitoring programme (profile measurements to be made once a year, at fixed profiles).

In the Netherlands all nourishment have in fact been designed using this method, except one. That nourishment was for an artificial peninsula, where (of course) no beach data were available. In that case mathematical models were used.

Directly after the nourishment, the shape of the beach is not optimal. Nature will adapt the shape of the nourishment. Also, because the nourishment protrudes into the sea, the current attack will be more. So, some extra loss has to be expected. It is difficult to calculate this loss exactly. Our experience shows that an extra surcharge of 40 % on the designed quantity covers all losses, also the loss because of the extra current attack. A more mathematical approach to determining this loss is presented by Führböter [1991], although his assumption that an initial loss rate is proportional to the volume of sand available on the beach might not always be true.

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