

Groin height determination with an empirical parametric method

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Introduction

The dutch coast is over a great length protected by groins, some of them are rather old (from the 19<sup>th</sup> century) and need to be refurbished. Because of this work, it is necessary to decide whether to keep the groins in their original shape, or to change the lay-out. Along the most southern stretch of the dutch coast (near the border with Belgium) the crest level of the groins is rather high above the beach level, because of continuous erosion of the shoreline. Because of the height of these groins, they suffer severely from wave attack, and local authorities wish to lower the groins in order to decrease the maintenance costs.

The groins in this coastal section are very wide, and made of natural stone, see fig. 1.

The question was to find the optimal height of stone groins along a coast with strong tidal currents. The location and the length of the groins were fixed and should not be altered. A review of the available literature showed that no ready-made answer was available to this problem. The general conclusion was that most authors state that a height of 1 m or less above the beach is optimal in order to catch sand, because higher groins cause reflection of waves, which results in erosion of the beach near the groin. However this conclusion is based upon visual observations and lab tests in non-tidal situations with relatively short groins.

The literature-review also revealed that no reliable mathematical models for the design of groins were available.

From the review it was concluded that a different approach to the problem was required. It has been decided to do an empiric parametric investigation to solve the problem.

A number of parameters have been defined to describe how effective a groin works. Besides that, the financial consequences of decreasing/increasing the height of a groin were determined (both building costs, as well as capitalised maintenance costs). With the first set of parameters the minimal and optimal height of a groin can be determined from a view point of coastal engineering. Comparison with the costs give the overall optimum.



Fig 1. Stone groin with two rows of piles

In order to evaluate the quality of a groin as a coastal defence work, the following steps can be made:

1. Determine how well the groin can fulfil the separate functions. This follows from the geometry of the groin.
2. Determine how well on the given location a groin has to fulfil this functions. This follows from the hydro-morfological situation.
3. Determine how important it is that a groin on this location completely fulfils the functions required.

This can be illustrated with the following example:

1. A groin decreases the wave-driven current to a maximum, if the groin always is higher than the water level. This is often not so. From the geometry of a given groin can be calculated that the wave-driven current is decreased to certain part, for example, reduction to 60%.
2. In order to prevent beach erosion near the groin a strong reduction of the current is required. From a morfological evaluation follows, for example, that 80% current reduction is necessary to keep the beach in stable position.
3. From 1 and 2 follows that the groin does not satisfies as surf-groin, and that consequently beach erosion will occur. There may be reasons why, at this location the potential erosion is accepted, for example because it is known that within a short period there will be a supply of sand from a moving sand bank, fully compensating the expected erosion. An other reason may be that erosion is no problem because the dunes are relatively wide, and dune erosion can be allowed to a certain extend.

The parameters mentioned under 1 can be calculated from the geometry of the groins. In order to estimate the attack of tidal currents and wave-driven currents, an analysis has to be made of the distribution of surf-energy along the coast and the depth of current erosion holes in front of the groins. From the analysis follow the minimum value of the parameters.

#### The hydraulic factors

Because it is not possible with the present knowledge of hydraulics and morfology of groins, to give unambiguous quantitative findings of the influence of lowering existing groins on the erosion of beaches, one has to compare the groins from an hydraulic point of view.

The idea behind it is that the morfological effect of a groin (reduction of longshore transport capacity and the harmful effect of sand loss in seaward direction) can be described applying separately hydraulic factors.

Longshore transport is determined by the factors: tidal current, wave-driven current, turbulence due to breaking waves (and in an indirect way by: the lee-zone behind the groin).

When for all the groins along the coastline these factors are available, it is possible to draw conclusions on the desirable magnitude of the factors for each groin.

Six factors have been defined, which are supposed to describe the morfological effect of a groin. They are split to the main functions "current groin" and "beach groin".

#### Current groin:

##### Factor 1: tidal current reduction

The presence of a groin, with or without piles, has a direct restraining influence on the tidal current in this zone, and consequently a reducing effect on the sediment transport along the coast.

##### Factor 2: head-effect

Due to the current reduction over the length of the groin there will be a current-contraction just in front of the head of the groin. Due to this erosion an increase loss of sand in offshore direction may occur.

##### Factor 3: current turbulence

Because of the current between the piles and over the crest of the groin, due to difference in sand transport and sand transportcapacity, the extra turbulence may cause an erosion pit at the downstream side of the groin.

#### Beach groin

##### Factor 4: wave-current reduction

The presence of a groin causes an extra resistance in the surf zone against the wave-driven current. This has a direct influence on the magnitude of the longshore transport

##### Factor 5: wave turbulence

When a groin is relatively high above the beach, there will be wave reflection against the groin, causing extra turbulence on the weather side. In combination with a seaward directed surf-induced current (rip current) this may cause considerable erosion on the wather side.

##### Factor 6: lee-factor

If a groin has an oblique direction with respect to the incoming waves, then there will be a shadow area behind the groin. The wave attack in this area will decrease, which has a reducing effect on the longshore transport.

For each factor a mathematical description is given, based upon the geometry of the groin. The parameters describing the factors have been chosen in such a way that the calculated value is always between 0 and 1, in which 0 means "bad" (no current reduction, big head effect) and 1 means a "good" groin.

### Computation of the various factors

#### Factor 1: tidal current reduction

The velocity on the beach  $v_1$  is compared with the velocity on the beach at the same location, if the groin was not present ( $v_0$ ). A streamline with the length of the average distance between the groins is regarded (see fig. 1).

In a situation without a groin the velocity is:

$$v_0 = C \sqrt{h \left( \frac{\Delta H}{L} \right)}$$

(for the used symbols see appendix I)

The current velocity with presence of a groin is:

$$v_1 = C \sqrt{h \left( \frac{\Delta H_1}{L} \right)}$$

in which:

$$\Delta H_1 = \Delta H - \Delta H_2 - \Delta H_p$$

The resistance due to the groin without piles:

$$\Delta H_2 = \mu \frac{(v_2 - v_1)^2}{2g} = \mu \frac{v_1^2}{2g} \left( \frac{h}{h^2} - 1 \right)^2 = \mu \frac{v_1^2}{2g} \left( \frac{d}{h-d} \right)^2$$

and the resistance due to the piles is:

$$\Delta H_p = \eta \frac{v_2^2}{2g} = \eta \frac{v_1^2}{2g} \left( \frac{h}{h_2} \right)^2 = \eta \frac{v_1^2}{2g} \left( \frac{h}{h-d} \right)^2$$

and:

$$\Delta H = \frac{v_0^2 L}{C^2 h}$$

The dimensionless current reduction in a streamline is:

$$\frac{v_1}{v_0} = \frac{(\Delta H_1)^{1/2}}{H} = \sqrt{1 - \frac{\Delta H_2 + \Delta H_p}{\Delta H}}$$

or:

$$\frac{v_1}{v_0} = \sqrt{1 - \frac{\mu \frac{v_1^2}{2g} \left(\frac{d}{h-d}\right)^2 + \eta \frac{v_1^2}{2g} \left(\frac{h}{h-d}\right)^2}{\frac{v_0^2 * L}{C^2 h}}}$$

or:

$$\frac{v_1}{v_0} = \sqrt{\frac{1}{1 + \frac{C^2 h \left[ \mu \left(\frac{d}{h-d}\right)^2 + \eta \left(\frac{h}{h-d}\right)^2 \right]}{2gL}}}$$

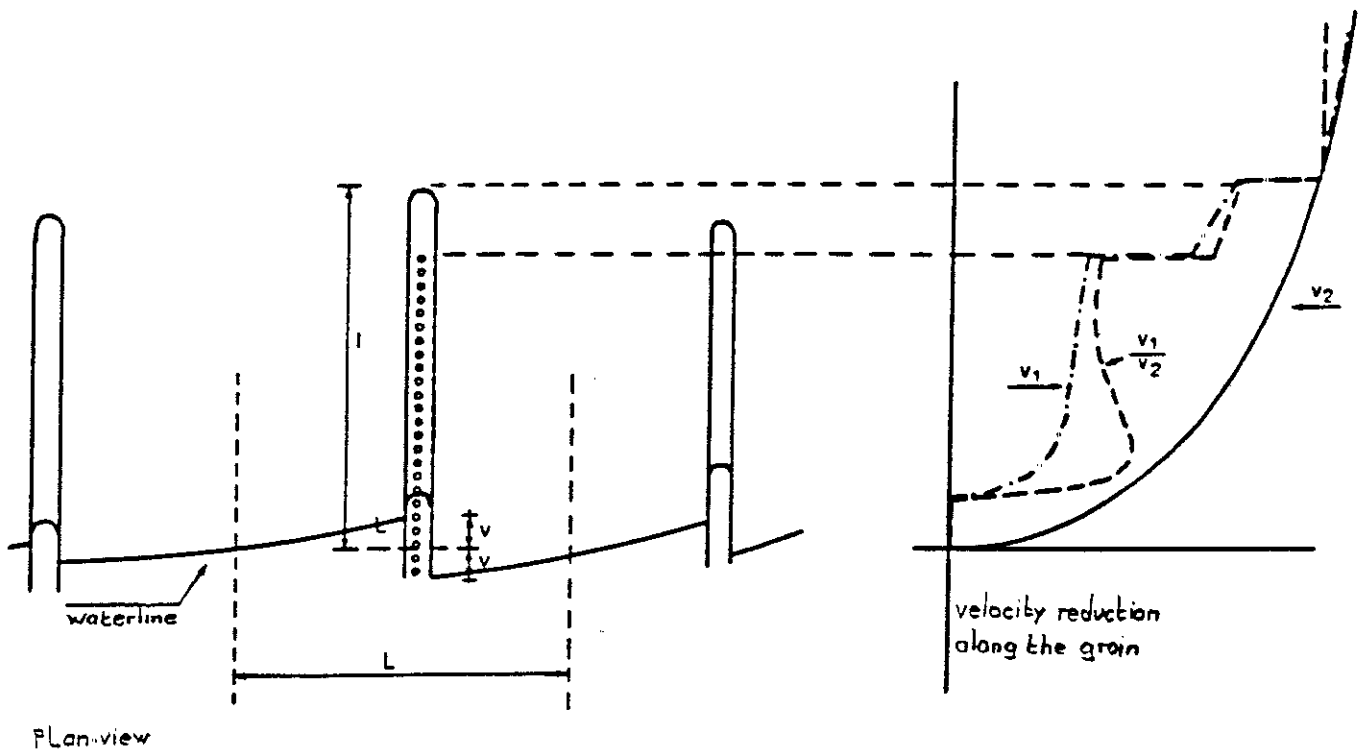
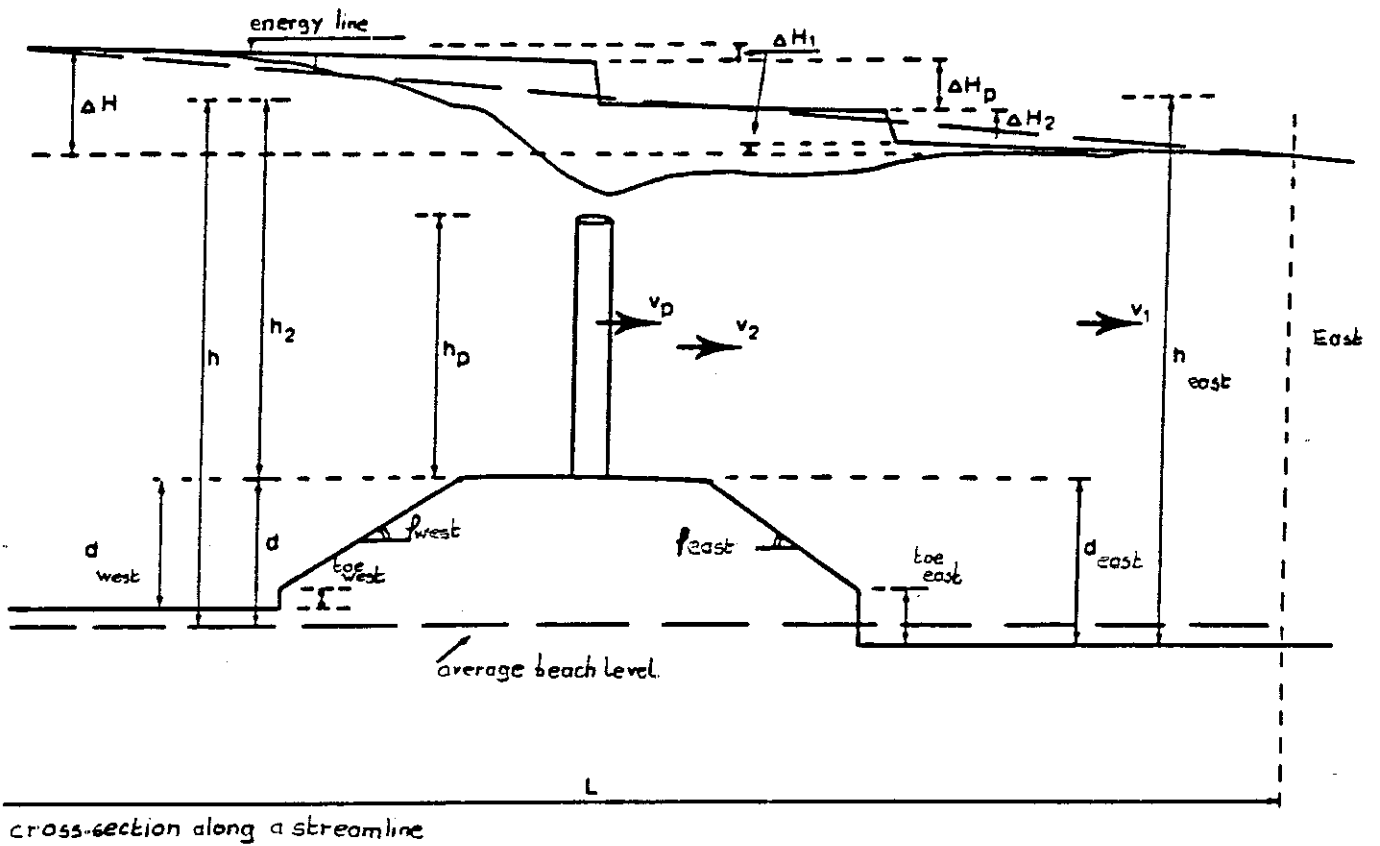


Fig. 2 schematisation of a grain

The average current reduction over the total wet length  $L$  of the groin is:

$$\left(\frac{v_1}{v_0}\right)_{ov} = \frac{\int_0^L \left(\frac{v_1}{v_0}\right) dl}{L}$$

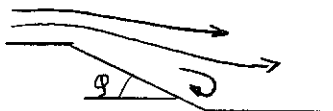
And the parameter describing the factor "tidal current reduction", is:

$$\text{factor } l = 1 - \frac{\int_0^L \left(\frac{v_1}{v_0}\right) dl}{L}$$

The factor  $v_1/v_0$  indicates the current reduction. To calculate the current velocity in a streamlane, this value has to be multiplied with the undisturbed velocity  $v_0$ . This is indicated in fig. 2.

The coefficients  $\mu$ ,  $\eta$  and  $C$  require some explanation:

- The loss-coefficient  $\mu$  at sudden reduction in velocity depends on the abruptness of the increase of profile.



$\phi$	6°	10°	15°	20°	30°	60°	90°
$\mu$	0,14	0,20	0,30	0,40	0,70	1,10	1,10

For the groins in this study  $\phi$  varies between 4° and 20°:

- The loss  $\eta$  for current through a pile-screen is:

$$\eta = R \cdot \frac{h_p^{2/3}}{h-d} * 1.7 \left(\frac{D}{B}\right)^{4/3}$$

in which  $R$  is the number of pile-rows. The formula is based upon research of the Delft Hydraulics Laboratory,



Factor 2: head-effect

The contraction of flow-lines around the head of a groin can be described by the velocity-gradient over the head if the pile-row is terminated near the head, this effect will be stronger.

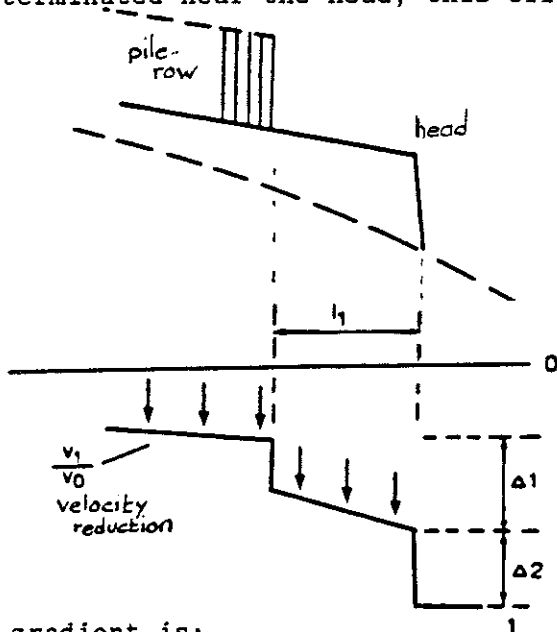


fig. 3: schematisation of head effect

The gradient is:

$$\Delta v = \Delta_2 = \Delta_1 \exp(-l_1/20)$$

in which  $\Delta_1$  = difference in velocity reduction between the head of the groin the end of the piles

$\Delta_2$  = difference in velocity reduction over the head of the groin

$l_1$  = distance between the head and the end of the pile-row.

Turbulence due to contraction is supposed to be quadratic function of the velocity gradient. Thus:

$$\text{factor 2} = 1 - \Delta v^2$$

Factor 3: current turbulence

The amount of turbulence at the downstream side of the groin can be described by the energy loss over the crest (see fig. 2).

$$\Delta H_2 = \mu_2 \frac{(v_2 - v_1)^2}{2g} = \mu_2 \frac{v_1^2}{2g} \left( \frac{d}{h-d} \right)^2$$

It is supposed that the turbulence due to the current between the piles ( $\Delta H_p$ ) is situated above the protected part of the groin, and is therefore disregarded. Compare the energy loss  $\Delta H_2$  with the maximum loss in this flow lane  $\Delta H_{\max} = v_2/2g$ , thus:

$$\frac{\Delta H_2}{\Delta H_{\max}} = \mu_2 \left( \frac{v_1}{v_2} \right)^2 * \left( \frac{d}{h-d} \right)^2 = \mu_2 * \left( \frac{d}{h} \right)^2$$

The coefficient  $\mu_2$  gives the extra turbulence due to a vertical wall and rubble flanking the groin.

This value has to be averaged over the length of the groin, applying the squareroot of the waterdepth as a weighing factor:

$$\text{factor 3} = 1 - \frac{\int_0^1 \frac{\Delta H_2}{\Delta H_{\max}} * \sqrt{h} \cdot dl}{\int_0^1 \sqrt{h} \cdot dl}$$

#### Factor 4: wave-current reduction

A breaking wave is the generating power for the surf-current, the bottom shear stress is the dissipating power. A groin will increase the resistance, and thus the dissipating power. The surf-current is a linear function of the bottom shear stress, so a linear change in shear stress causes a linear change in the velocity.

In the definition of factor 4 it is assumed that the increase in resistance is equal to the quotient of groin-height/waterdepth. Averaged over the length of the groin this is:

$$\text{factor 4} = \frac{\int_0^1 \frac{d}{h} \cdot dl}{1}$$

#### Factor 5: wave turbulence

Waves reflected by the vertical side of a groin are causing turbulence at the upstream side. It is assumed that the amount of turbulence is a function of the wave reflection:

- wave reflection increases linearly with the groin-height
- wave reflection is maximal for a vertical groin

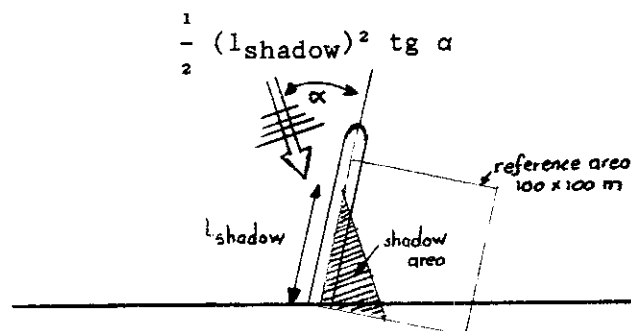
- wave reflection on a sloping groin is a function of the slope  $\phi$ , according to  $\sin^2 \phi$
- oblique waves have a turbulence as function of the angle of approach  $\alpha$  according to  $\sqrt{\sin \alpha}$

$$\text{factor 5} = 1 - \int_0^l \frac{(d-t) \sin^2 \phi + t}{h} dl \sqrt{\sin \alpha}$$

#### Factor 6: lee factor

The presence of a groin will cause a lee area in the wave field. The size of this area depends on the groin height, wave height and the orientation of the groin.

The size of the lee-area is estimated as:



The point  $l_{\text{shadow}}$  is a point on the groin where  $h-d = 0.5$  m. The lee-area is compared with a standard area of  $100 \times 100 \text{ m}^2$  to find factor 6.

For the execution of the computation of the various factors a computer-program is available.

For a coastal section in the south-west of the Netherlands, near Breskens, various factors have been calculated. In figure 4 the factors 1, 4 and 6 are plotted as a function of their height above the beach. Also the factors for a normalised "testgroin" are given, with one and with two rows of piles ( $R = 1$  and  $R = 2$ ) are presented.

For the design of groin-reconstruction, with this technique a number of alternative designs can be evaluated. As an example groin number 8 near Breskens is worked out. For this groin, using the computer program, all six factors have been calculated, with varying crest heights, one and two rows of piles and a varying pile-length. Figure 5 gives the results of these calculations. Also has been determined the costs of reconstruction capitalized maintenance costs.

This has been done for refurbishment within the actual profile (df1 690.000) and for reconstruction with varying crest heights. Reconstruction at the actual crest height costs df1 770.000 (level at 1.20 m). Reconstruction at a height of only 0.50 m above the beach costs df1 555.000. Assumed is that the slopes of the groin are continued in stone until 0.20 m below the beach. For crests in between costs are linearly interpolated.

From these two aspects:

1. costs at varying crestheight
2. hydraulic factors at varying crestheight

diagrams can be composed, which give the relation between costs and the hydraulic factors. See figures 5 and 6. These diagrams show a discontinuity at a crestheight of 0.80 m because at lower crest heights, the slopes have to be continued at greater depth into the beach sand, in order to prevent undermining by scour.

From morfologic investigations followed that in this area the tidal current reduction (factor 1) is most dominating. In order to work properly, this factor should be at least 0.65, preferably higher. From figure 5 follows that cost increase significantly, if it is tried to raise this factor above 0.67. Refurbishment of the groin, keeping the crestheight at the present height ( $d = 0.80$  m) costs df1 645.000. Factor 1 is in that case 0.66.

The application of a second pilerow makes it possible to lower the groin with 0.10 m, keeping factor 1 at the same level. Financially this lowering of the groin with 0.10 m is no improvement; the groin becomes df1 55.000 more expensive. Refurbish the existing groin with the present geometry is also possible. It gives a factor 1 of 0.78, but costs df1 45.000 more than construct a new groin.

It might be possible that the "optimal current groin" is not so good regarding the other factors. From the diagrams of the other factors follows that with respect to wave-current reduction the "optimal groin" is not so good. However, surf-induced currents are of minor importance in this area, and consequently a factor fo 0.6 can be accepted. Making the groin lower and applying two rows of piles not only makes the groin more expensive, but also is worse regarding the surf-induced current. Doubling the pile-rows is only profitable for the wave-turbulence factor. The improvement to gain (factor 5 increases from 0.55 to 0.58) is too small to balance the increase in cost (with df1 55.000) and the lowering of factor 4 and 2.



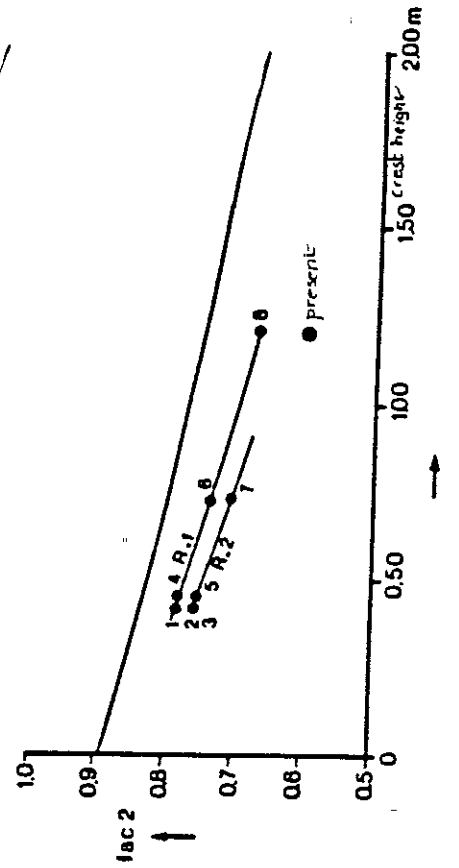
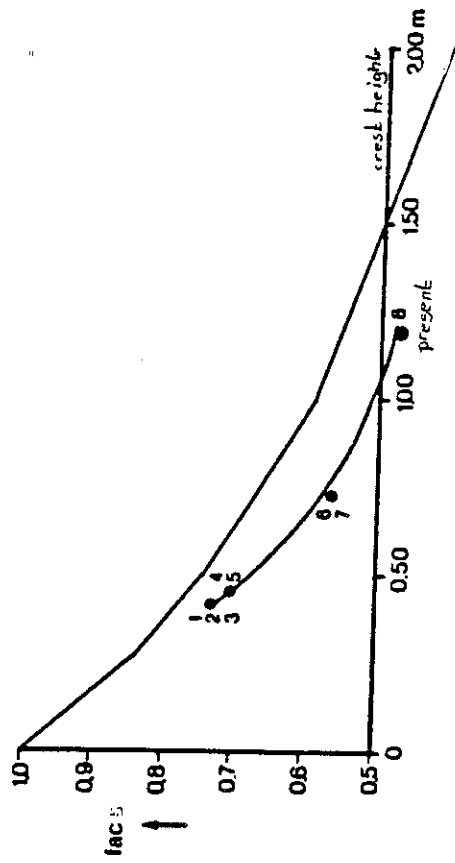
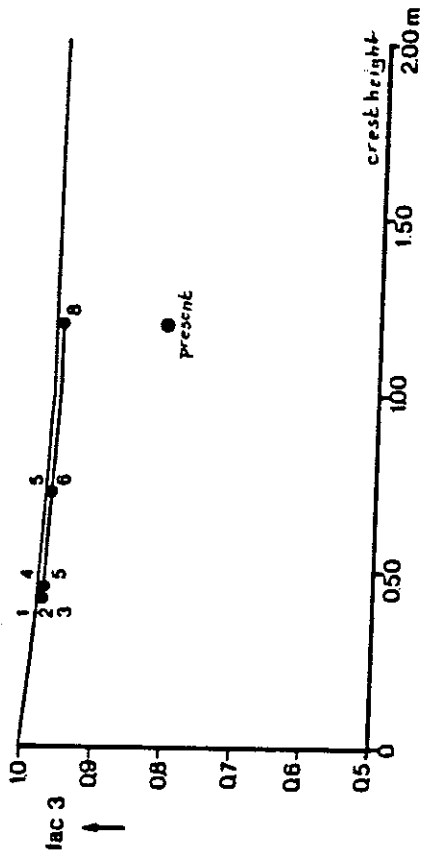
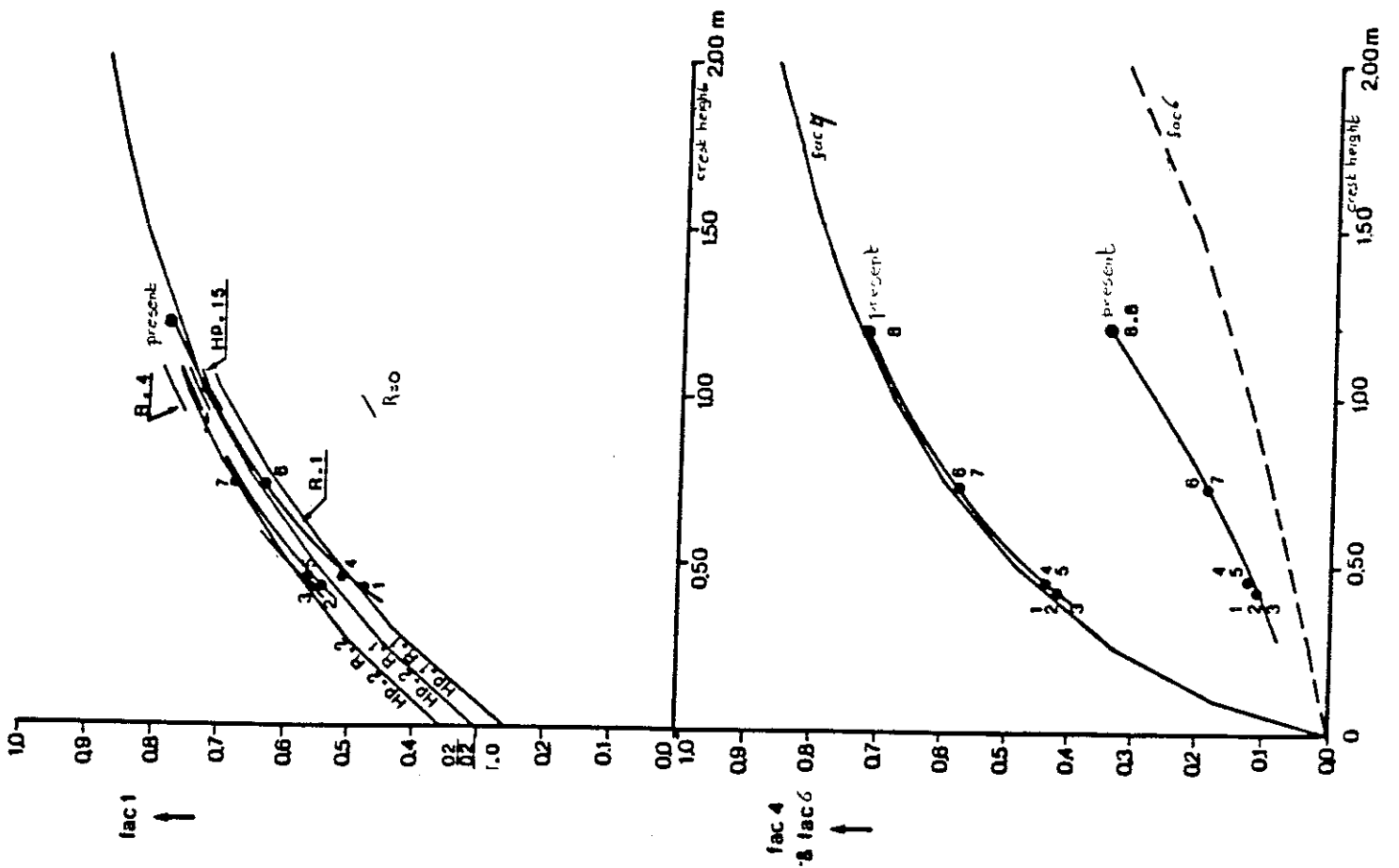


Fig 5 Hydraulic factors for various alternatives  
Groin #8, near Breskens

So, there remain two realistic options:

1. reconstruction at a crest level of 0.80 m above the beach, using one pile-row
2. refurbishment of the groin, keeping the existing geometry.

Summarised this has the following consequences:

	present situation	refurbishment within present geometry	reconstruction at d = 0.80 m
factor 1, current reduction	0.78	0.78	0.66
factor 4, wave-current reduction	0.72	0.72	0.61
factor 6, lee-factor	0.35	0.35	0.21
factor 3, current turbulence	0.80	0.96	0.96
factor 2, head effect	0.61	0.68	0.72
factor 5, wave turbulence	0.47	0.48	0.55
costs		df1 690.000	df1 645.000

In this case no simple decision can be made; there are about as many advantages as disadvantages. A decision can be made by studying also the neighbouring groins. The geometry of the subsequent groins along one coastal section should not vary too much.

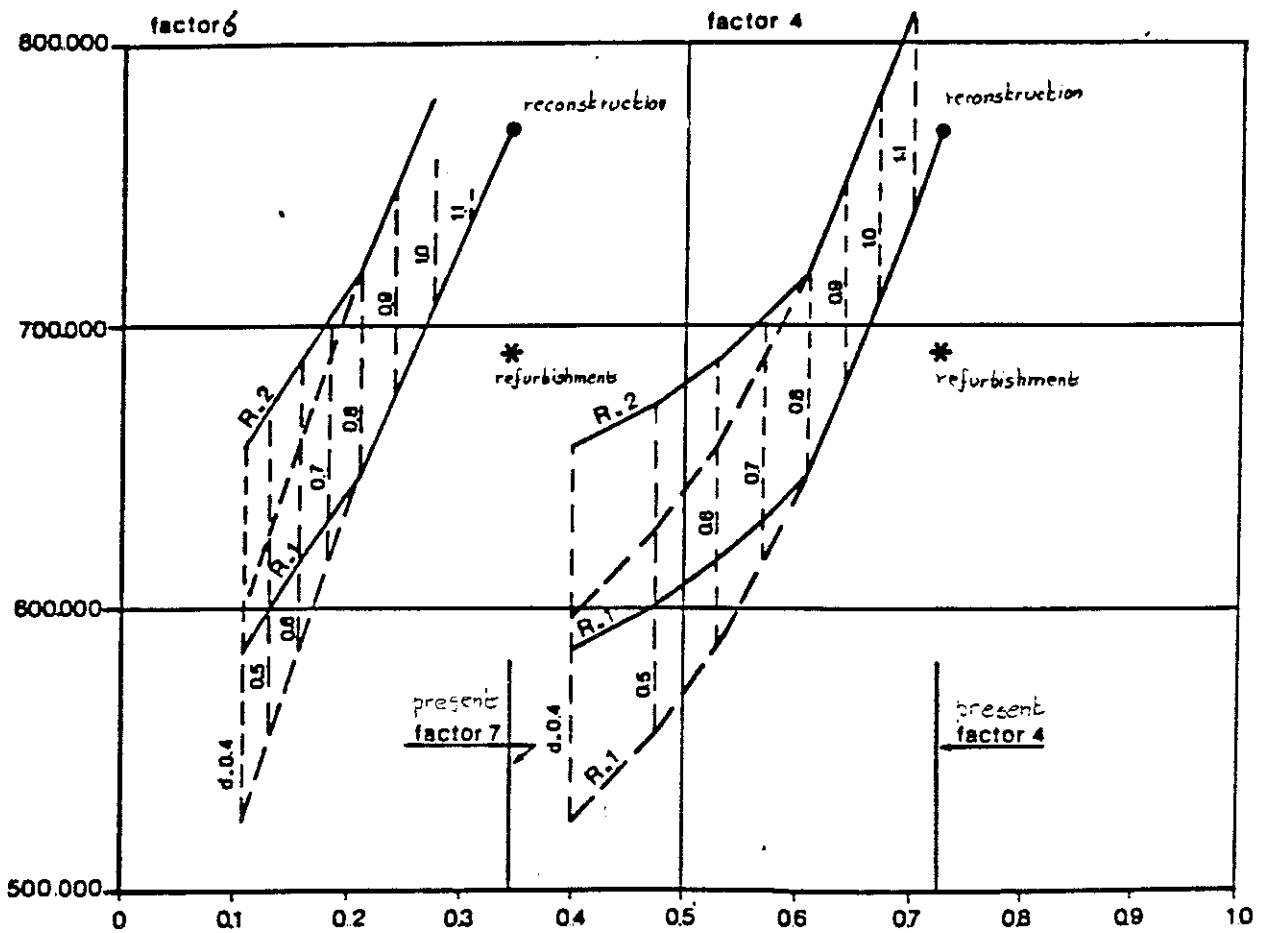
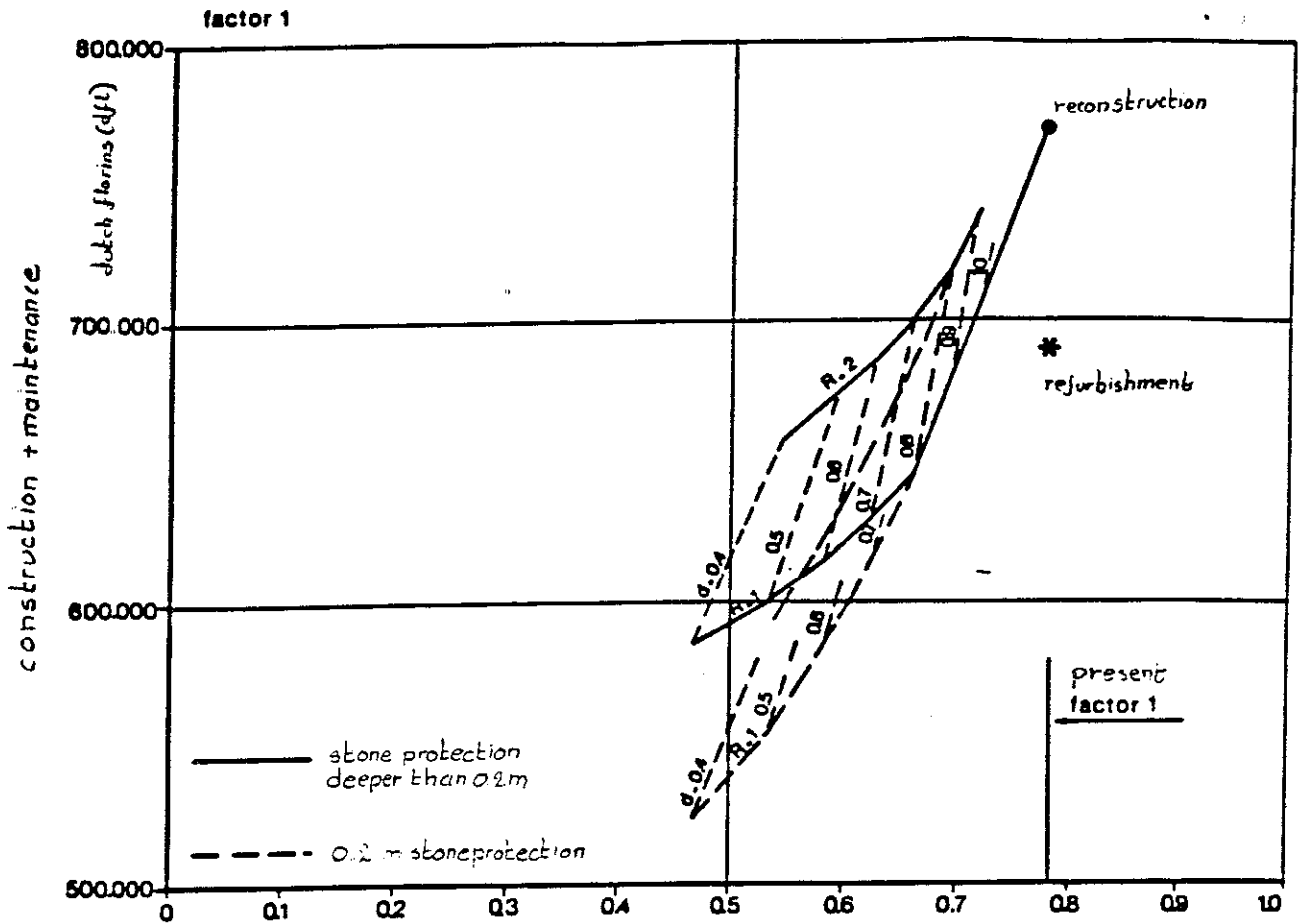
In this way every individual groin can be judged. If the whole group of groins is judged, reconstruction has to be planned in such a way that the group becomes rather homogeneous.

#### Morphological considerations

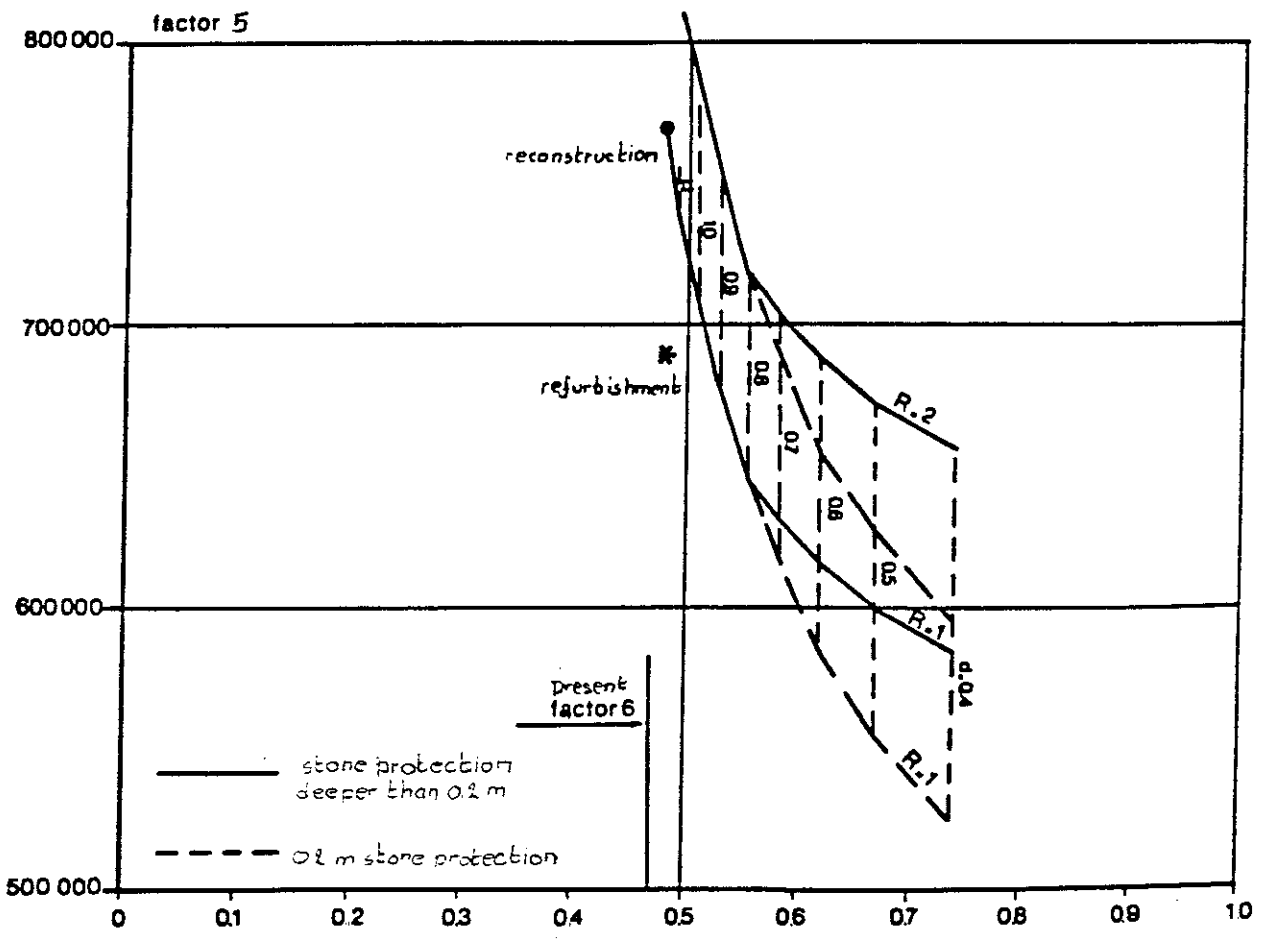
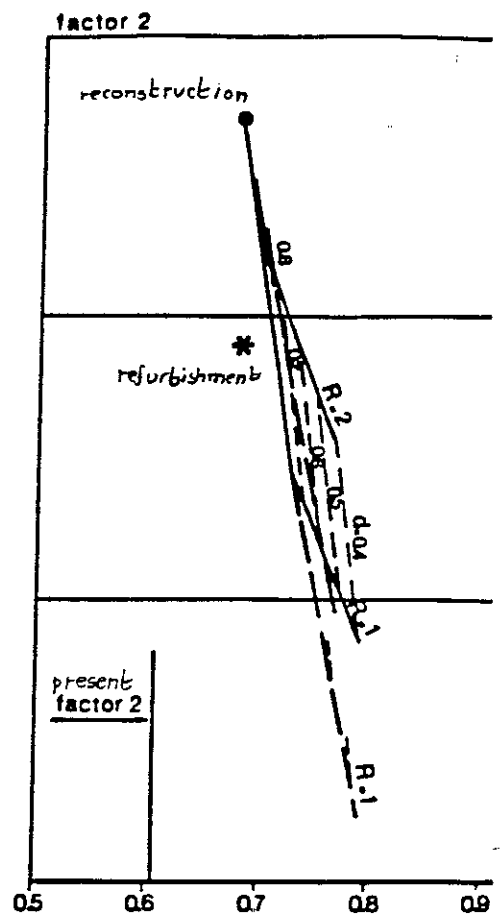
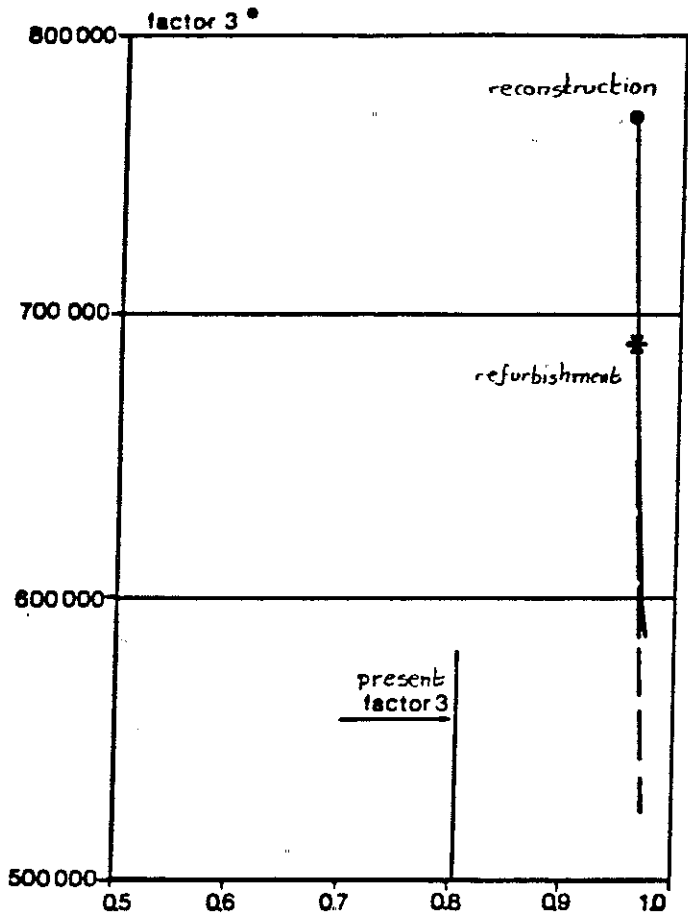
A few paragraphs ago it was mentioned that "from morphological considerations followed that factor 1 should be at least 0.65". The problem is always to develop these considerations.

In case of this example a full analysis of the whole coastal stretch has been made and, among others, the following parameters have been determined for each groin:

- difference in beach-height at left/right side of the groin
- measured head-effect (= depth of scouring hole in front of the groin)
- potential erosion/accretion.







The last parameter was determined by calculating sediment transport with the CERC-formule (assuming absence of groins) and using the differences in potential sediment transport to calculate the potential erosion

Also the actual coastal regression was determined, as well as the six-factors for all the 70 groins in the area.

From these data followed that, in cases with heavy current attack (deep scouring holes) groins with a factor 1 value lower than 0.65 were not effective.

In those cases with relatively high potential erosion groins were effective with a factor 4 - value of 0.75 and higher.

These figures are only valid for this coastal stretch. Universal application of the given values 0.65 and 0.75 is not possible. They have to be determined for every coastal stretch.

### Conclusions

In many parts of the world groins are applied. For groins which do not simply work as sandtransport-blockers, there are not mathematical methods to calculate the optimal geometry.

In many cases the groins were build in the past, based upon experience only. When erosion is not completely stopped, groins are rising above the beach level, and maintenance becomes expensive. Because of high maintenance costs the coastal manager wants to lower the crest levels (sometimes even below the beach level, because there are no maintenance costs any more).

From a viewpoint of coastal morphology high groins are attractive.

Using the technique described in this paper it is possible to determine the optimal groin-height for existing groin-fields in tidal areas. This technique cannot be used to design new groin fields.

## appendix. Notation

- $\Delta H$  energy loss in current without groins
- $\Delta H_1$  energy loss over the beach, while a groin is present
- $\Delta H_2$  energy loss over the ~~piles~~ crest of the groin
- $\Delta H_p$  energy loss over the piles
- $h$  average water depth on the beach
- $h_2$  water depth above the crest of the groin
- $d$  height of the groin above the beach
- $h_p$  length of the piles
- $v_0$  undisturbed current without groins
- $v_1$  reduced currents
- $L$  length of the groin
- $L$  distance between two groins
- $g$  9.81 m/s<sup>2</sup>
- $C$  Chézy-coefficient
- $D$  diameter of the piles
- $B$  distance between de piles
- $\eta$  loss-coefficient by current through the piles
- $\mu$  loss-coefficient by current over the crest
- $\theta$  slope of the groin
- $\alpha$  angle of incidence of the waves
- $R_1$  number of pilerows