CHAPTER 71

EROSION PROBLEMS OF THE DUTCH ISLAND OF GOEREE

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ABSTRACT

At many places along the dutch coast especially at the West side of the islands, erosion occurs.
One of the islands where the erosion is severe, is Goeree, situated in the Delta area in the South-West of the Netherlands. (see fig. 1). This isle is recently connected with other islands by dams. (see fig.2). These dams built within the scope of the Deltaproject plans closing the tidal estuaries and to shorten the length of the coastline thus reducing the wave attack. This paper examines how the influences of the closure of the estuaries affect on the erosion of the neighbouring coast. To this end, the changes in vertical and horizontal tide caused by the closure as well as the wave induced littoral drift and the sandtransport caused by a combination of tidal currents and waves before and after the closure, are computed. On the basis of this computations, a few suitable solutions for the reduction of erosion are discussed.

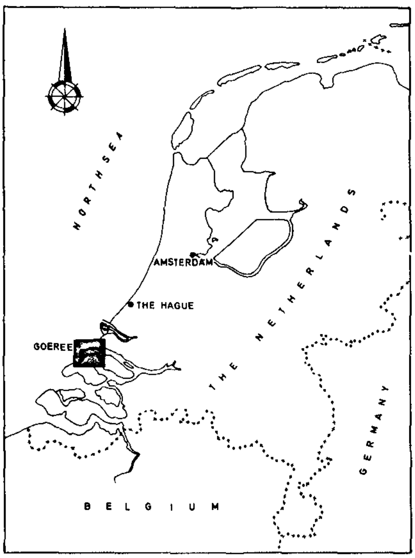


Figure 1 MAP OF THE NETHERLANDS SHOWING THE LOCATION OF THE ISLE OF GOEREE

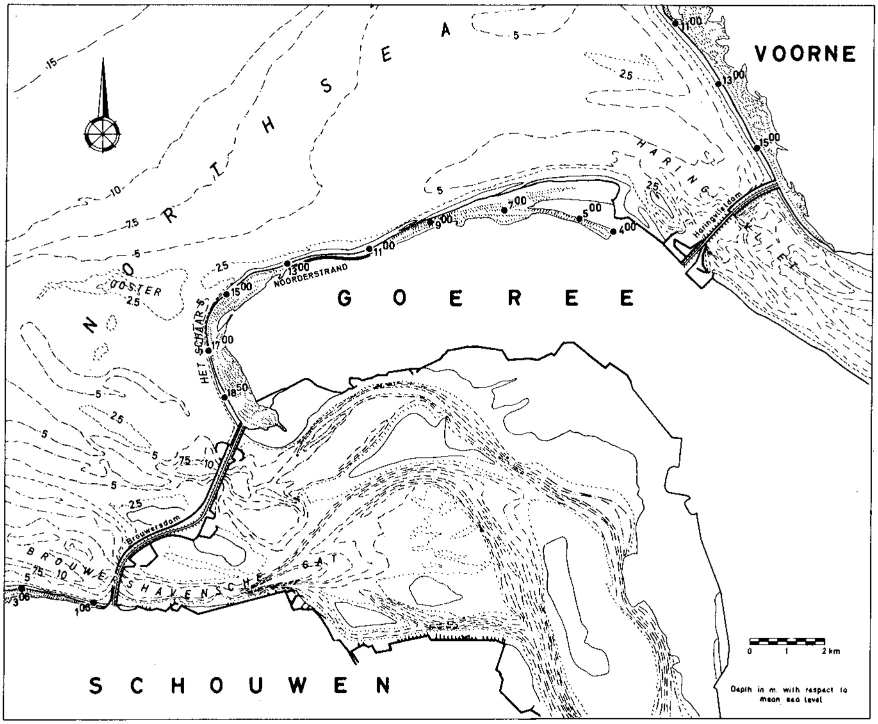


Figure 2 MAP OF THE WESTERN PART OF GOEREE WITH DEPTH CONTOURS

INTRODUCTION

Prior to the closure of the tidal estuaries, Haringvliet and the Brouwershavensche Gat estuaries (see fig. 2), the westcoast of the isle had already been subjected to severe erosion. In 1968 the regression of the dunes reached a maximum of about 20 m per year with an annual loss of sand of about 400.000 m^3 whereas the former mean loss was approximately 200.000 m^3. Because of this alarming regression the following three sandsupplies have been carried out since 1969.

1. In the winter of 1969, 400.000 m^3;
2. In the summer of 1971, 610.000 m^3;
3. At the beginning of 1974, 3.500.000 m^3 sand,

which 800.000 m^3 sand were used for the enforcement of the dunes. (see also fig. 8).

It is obvious that with sandsupplies the regression of the original dune ridge or coastline can be slowed down or even been halted. The disadvantage of these supplies is the need for supplying sand over such a long time. Up till now sand that was used for the above mentioned beach nourishment was pumped from a neighbouring lake over a distance of maximum six kilometers, for this reason the costs per m^3 sand were low. In the future, because of environmental objections, no more sand can be pumped from this lake, but has to be taken from attracting the sea, against relative high costs. Because of the above mentioned reasons the optimal solution to reduce the erosion is to be found.

In order to determine the best measures against this severe erosion the direction, distribution and order of magnitude of the littoral drift along the island before and after the closure of the Brouwershavensche Gat has to be known. Only the closure of the Brouwershavensche Gat is mentioned here inasmuch as closing of the Haringvliet did not influence the westcoast erosion. Erosion problems have been solved by means of model tests, here however the sandmovement is calculated by means of mathematical formulas.

WAVE INDUCED LITTORAL DRIFT ALONG THE ISLAND

Calculations are only possible if wind, wave and tidal data are available.

The wind and wave data are based on data collected at the dutch lightvessel Goeree [1]*. On this lightvessel the wave height, periods and directions are estimated visually. The wave directions are combined into 30 degree sectors, (see fig. 3), the wave heights are pat in groups with a half meter difference between each and finally the wave periods are grouped into the categories of duration shorter than 5 sec., between 5 and 7 sec., between 7 and 9 sec. and longer than 9 sec.

*) See list of references.

The number and percentages of the observations in each of the above mentioned classes (categories) are known. As mentioned before the wave heights are estimated visually on board of this lightvessel. Measured wave height data acquired by means of a wave recorder on board of the former drilling platform "Triton" near The Hague are also available. A correlation is made between the wave height recorded on the drilling platform by means of a step gauge. For onshore winds (fetch limited)(see fig. 3) the wave heights are calculated by means of wave generation graphs from Thysse [2] and Bretschneider [3].

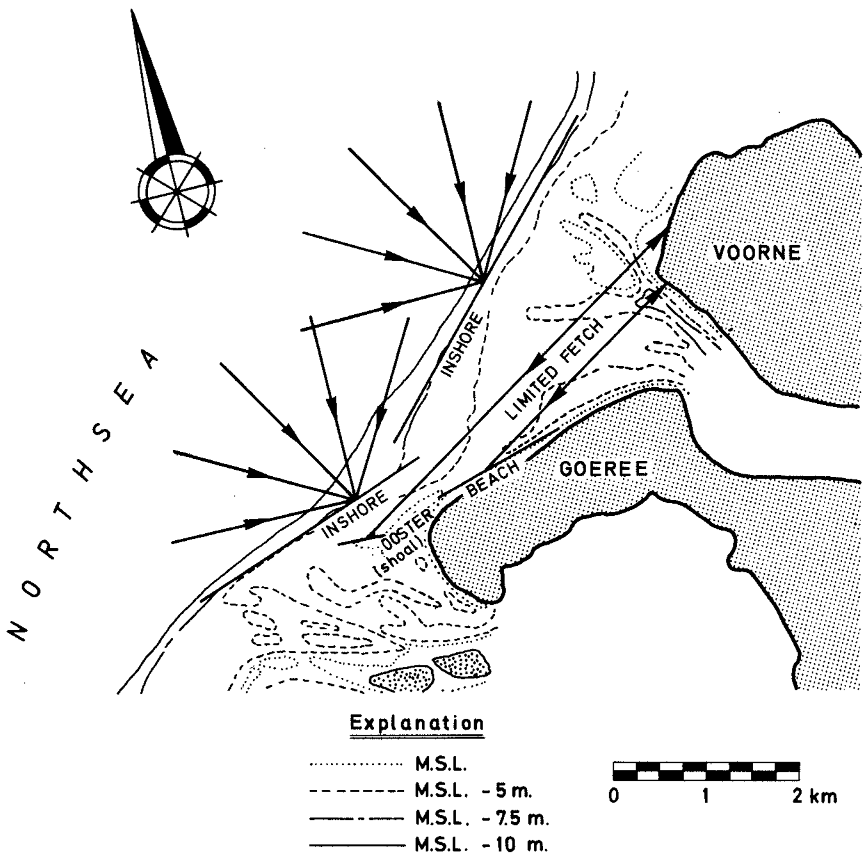


Figure 3 DIRECTION OF THE WAVE RAYS FOR WHICH THE WAVE INDUCED LITTORAL DRIFT IS COMPUTED ALONG OOSTERSHOAL AND NOORDERSTRAND

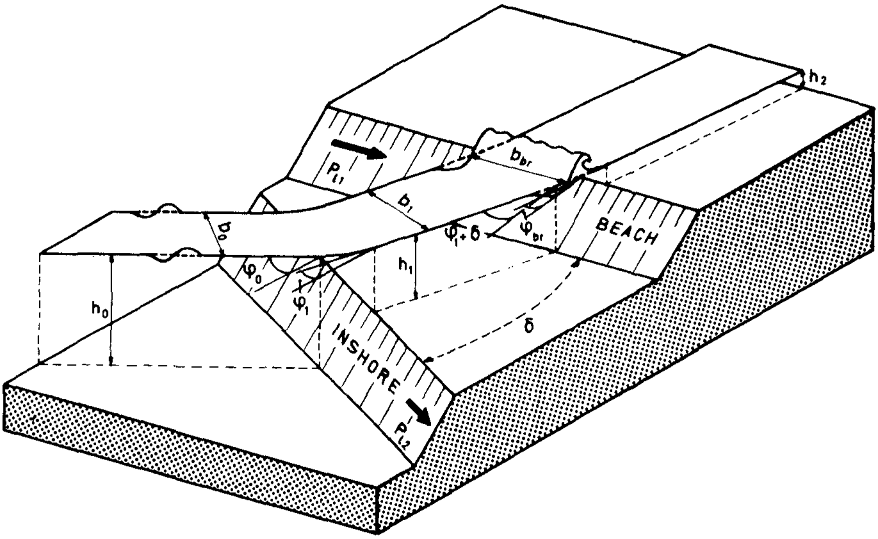


Figure 4 THREE DIMENSIONAL VIEW OF A BEACH PROFILE WITH A WAVE RAY APPROACHING THE BEACH
P_{l1} = LONGSHORE COMPONENT OF THE WAVE ENERGY ALONG THE BEACH
P_{l2} = LONGSHORE COMPONENT OF THE WAVE ENERGY ALONG THE INSHORE

For the computation of the wave induced littoral drift the vertical tide is also introduced. To this end the mean tide measured by tide gauge is used. From the correlation between wave data from the drilling platform "Triton" and the light-vessel "Goeree" it is found that the wave period estimated on the lightvessel is one and a half times the measured mean period on "Triton". The period showing the wave pattern as good as possible seems to be that period where the energy/unit of area and the energy transport/m' of the singular wave equals that of the wave pattern (T_{eq}). Battjes [4] found that this period is 1,23 times the mean period. In this way the observed periods can be substituted by $T_{eq} = 0{,}82\ T_{ge}$, where T_{eq} = equivalent wave period and T_{ge} = observed wave period on the lightvessel "Goeree".

It is assumed that the waves are known at a depth of about 15 m minus mean sea level (depth at the drilling platform). From this depth the changing of the waves as a result of refraction and shoaling at the breakerline is computed by assuming two groups of parallel depth contours in front of the Noorderstrand (north-coast) and the Ooster shoal, in this case called "inshore" and "beach". (See fig. 3 and 4).

Along "inshore" and "beach" the longshore component of the energy flux is computed with a simplified version of the Svasek method. [5]. Svasek's method, a variation of the C.E.R.C. method [6], assumes the littoral drift between two adjacent depth contours to be proportional to the longshore component of energy loss between these contours. The above mentioned simplification is the reduction of depth contours to two groups of parallel depth contours. [7] [8].

For this computation the following assumptions are made:

a) The sediment transport along a sandy coast is directly proportional to the longshore component of the loss of energy;
b) The sediment transport between two depth contours is directly proportional to the longshore component of energy loss between those contours;*
c) The waves are spilling breakers inside the breakerzone;
d) Refraction proceeds inside the breakerzone;
e) The loss of the wave energy is caused by breaking of the wave;
f) The loss of energy between deep water to breaking depth is negligible relative to the losses in the breakerzone;
g) The waves will be taken into consideration while ripcurrents are not considered;

* Although mathematically the given formulation is not correct as it is not even possible to take the longshore component of a scalar [9]. The meaning of the expression i.e. $\sin\varphi$ times the loss of wave energy (φ being the breaker angle) will be clear.

h) Wave phase velocity in the breakerzone is equal to wave group velocity and is dependent on depth only;

i) The depth contours are schematized to two groups of parallel depth contours that make an angle with each other;

j) When φ is angle of wave incidence, it is assumed that $\cos\varphi_{br}$ equals 1 in the breakerzone. This assumption is based upon the consideration that in the case where the angle of wave incidence in deep water is 75°, the wave period is 7 seconds and the wave height 3,5 m, then the cosine of the angle at breaking point will be 0,867. This number is one of the smallest values this cosine can attain.

The longshore component of the flux of energy per m' along the coast at the edge of the breakerzone can be given by:

$$Pl = nE_{br} \; c_{br} \; \sin\varphi_{br} \; \cos\varphi_{br} \qquad \ldots\ldots\ldots (1)$$

where
n = group velocity/phase velocity
$E_{br} = \frac{1}{8}\rho g \overline{H_{br}^{2}}$ = energy per unit of water surface area [10].
ρ = density of the water
g = acceleration of gravity
H_{br} = breaker height
c_{br} = wave celerity in the breakerzone
φ_{br} = angle of wave incidence at the breakerline

According to assumption j) we put $\cos\varphi_{br} = 1$

By assuming a narrow spectrum of frequency

$$\overline{H_{br}^{2}} = \frac{1}{2}(H_{sign})_{br}^{2} \qquad \ldots\ldots\ldots (2)$$

where $(H_{sign})_{br}$ = significant breakerheight

Further more is assumed that the ratio significant wave height in the breakerzone and breakerdepth is a constant value (γ).

$$(H_{sign})_{br} = \gamma h_{br} \qquad \dots\dots\dots (3)$$

where h_{br} = breakerdepth

To compute the celerity in the breakerzone use is made of the theory of Bernoulli, i.e. the second order approximation of the solitary wave is used [11] and it is assumed that the wave celerity is equal to the group velocity in the breakerzone.

$$c_{br} = \sqrt{g(h_{br} + H_{br})} \qquad \dots\dots\dots (4)$$

For parallel depth contours Snell's law is valid

$$\frac{\sin \varphi_o}{c_o} = \frac{\sin \varphi_{br}}{c_{br}} \qquad \dots\dots\dots (5)$$

where φ_o = angle of wave incidence in deep water

c_o = celerity of the waves in deep water

Using the assumptions a).....j) and the mentioned formulas, the longshore component of energy flux can be found.

a) If no shoals are present (h_2 = 0) and all depth contours are parallel (δ = 0)(see fig. 4 for declaration of symbols) then from formulas (1)....(5)

$$Pl_1 = K\, h_{br}^3 \frac{\sin \varphi_o}{c_o} \qquad \dots\dots\dots (6)$$

where $K = \frac{1}{16} \rho g^2 \gamma^2 (1 + \gamma)$

However if $h_2 > 0$ then a part of the energy passes the shoal and is lost for the longshore component of energy flux along the "beach".

Using the assumptions b), c) and d) one finds for the magnitude of this energy loss:

$$K\, h_2^{\,3}\, \frac{\sin \varphi_o}{c_o} \qquad \ldots\ldots\ldots\ldots (7)$$

The wave energy flux Pl_1 along the beach is:

$$Pl_1 = K(h_{br}^{\,3} - h_2^{\,3})\, \frac{\sin \varphi_o}{c_o} \qquad \ldots\ldots\ldots\ldots (8)$$

For two groups of parallel depth contours that make an angle δ with each other the equations will be slightly different because the longshore component of the energy flux is computed along the "inshore" as well as the "beach". Moreover is the angle of wave incidence at the "beach" ($= \varphi_1'$) not to be calculated directly with Snell's law. $\varphi_1' = \varphi_1 + \delta$ (see fig. 4) where φ_1 is computed with Snell's law and δ can be positive as well as negative. In figure 4 δ is positive.

b. If $h_{br} > h_1$, the waves are breaking from the "inshore" till the "beach".

The longshore component of wave energy flux along the "beach" is

$$Pl_1 = K(h_1^{\,3} - h_2^{\,3})\, \frac{\sin(\varphi_1 + \delta)}{c_1} \qquad \ldots\ldots\ldots (9)$$

and along the "inshore":

$$Pl_2 = K(h_{br}^{\,3} - h_1^{\,3})\, \frac{\sin \varphi_o}{c_o} \qquad \ldots\ldots\ldots (10)$$

c. If $h_2 < h_{br} < h_1$ then the waves only break on the "beach":

$$Pl_1 = K(h_{br}^{\,3} - h_2)^3\, \frac{\sin (\varphi_1 + \delta)}{c_1} \qquad \ldots\ldots\ldots (11)$$

and

$$Pl_2 = o$$

d. If $h_{br} < h_2$ then $Pl_1 = Pl_2 = o$

As can be seen from these formulas the breakerdepth has to be known to compute this longshore component of energy flux.

Computation of breakerdepth:

Take two wave rays lying a distance of 1 m apart from each other at the coastline. The flux of energy between these rays is:

$$n_o c_o b_o E_o = n_1 c_1 b_1 E_1 = n_{br} c_{br} b_{br} E_{br} \qquad \ldots\ldots (12)$$

where b = distance between two wave rays

indexes o = at deep water

1 = at depth h_1

br = at breakerdepth

from equation (12):

$$\frac{1}{2}\, c_o b_o\, \frac{1}{8}\, \rho g H_o^2 = c_{br} b_{br}\, \frac{1}{8} \rho g H_{br}^2 \qquad \ldots\ldots (13)$$

If h_{br} is smaller than h_1 the waves break on the beach and making the same assumptions as mentioned before one finds for h_{br}:

$$h_{br} = \left[\frac{H^2_{\text{sign}}\, c_o}{2\gamma^2 \sqrt{(1+\gamma)g}} \cdot \frac{b_o}{b_{br}} \right]^{2/5}$$

where for two groups of parallel depth contours:

$$\frac{b_o}{b_1} = \frac{\cos\varphi_o}{\cos\varphi_1} \text{ and } \frac{b_1}{b_{br}} = \frac{\cos(\varphi_1 + \delta)}{\cos\varphi_{br}}$$

(see fig. 4)

so $$\frac{b_o}{b_{br}} = \frac{\cos\varphi_o}{\cos\varphi_1} \; \frac{\cos(\varphi_1 + \delta)}{\cos\varphi_{br}}$$

If $h_{br} > h_1$ i.e. when the waves are breaking on the inshore the result is:

$$h_{br} = \left[\frac{H_{sign}^{2} \cdot c_o}{2\gamma^2 \sqrt{(1+\gamma)g}} \cdot \frac{\cos \varphi_o}{\cos \varphi_{br}} \right]^{2/5}$$

In both cases $\cos \varphi_{br}$ is found by an iteration procedure.

For each occurring wave height, period, angle of wave incidence and waterlevel the breakerdepth and so the longshore component of wave energy is to be computed.
The resultant littoral drift is computed under the assumption that Q (=littoral drift) = 2000 Pl [m^3 sand/year] . [5]
A computerprogram is developed to compute the resultant sand-drift with aid of the mentioned formulas in a relative short time.
Only along the Ooster(shoal) and the Noorderstrand (beach) this wave induced littoral drift is computed.

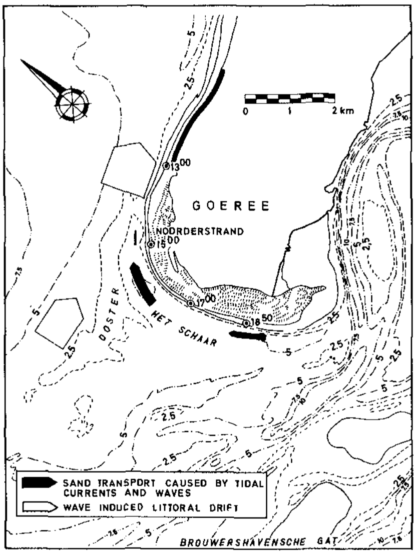


Figure 5 CALCULATED SEDIMENT TRANSPORT ALONG THE ISLE OF GOEREE BEFORE THE CLOSURE OF THE BROUWERSHAVENSCHE GAT

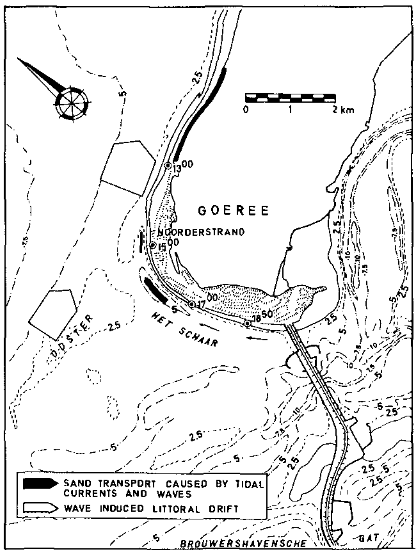


Figure 6 CALCULATED SEDIMENT TRANSPORT ALONG THE ISLE OF GOEREE AFTER THE CLOSURE OF THE BROUWERSHAVENSCHE GAT

In front of the beaches and shoals more to the south the depth contours are too freakish to expect reliable results. However here the transports are relatively small. The resultant drift turned out to be more than 1 million m^3 sand/year along the Ooster and about half a million more along the Noorderstrand going in eastward direction (see fig. 5 and 6).

SAND TRANSPORT CAUSED BY TIDAL CURRENTS AND WAVES

While the order of magnitude of the wave induced littoral drift is more or less independent of the closure of the estuaries there is a big difference in the sandtransport caused by tidal currents and waves before and after this closure.
A numerical two dimensional tidal computation according to the Leendertse method [12] is made to compute the horizontal and vertical tide round the westside of the island, before and after closure of the Brouwershavensche Gat. Some data obtained from this computation are used as boundary conditions for a more detailed one dimensional tidal computation in the Schaar channel. This is a channel with a maximum depth of 8 m in front of the Westcoast (see fig. 2). For this purpose the Schaar channel is schematized into five sections of different depth. In the sections the mean horizontal tide is computed. Between the two sections the waterlevel is known. Figure 7 shows the horizontal tide before and after the closure. The biggest velocities are in both cases directed to the north. After the closure however the velocities are less, especially in the neighbourhood of the Brouwersdam. The longshore transport caused by the interaction of tidal currents and wave induced orbital velocities is approached with Bijker's formula [13].
This formula is derived from the Kalinske-Frijlink formula [14].

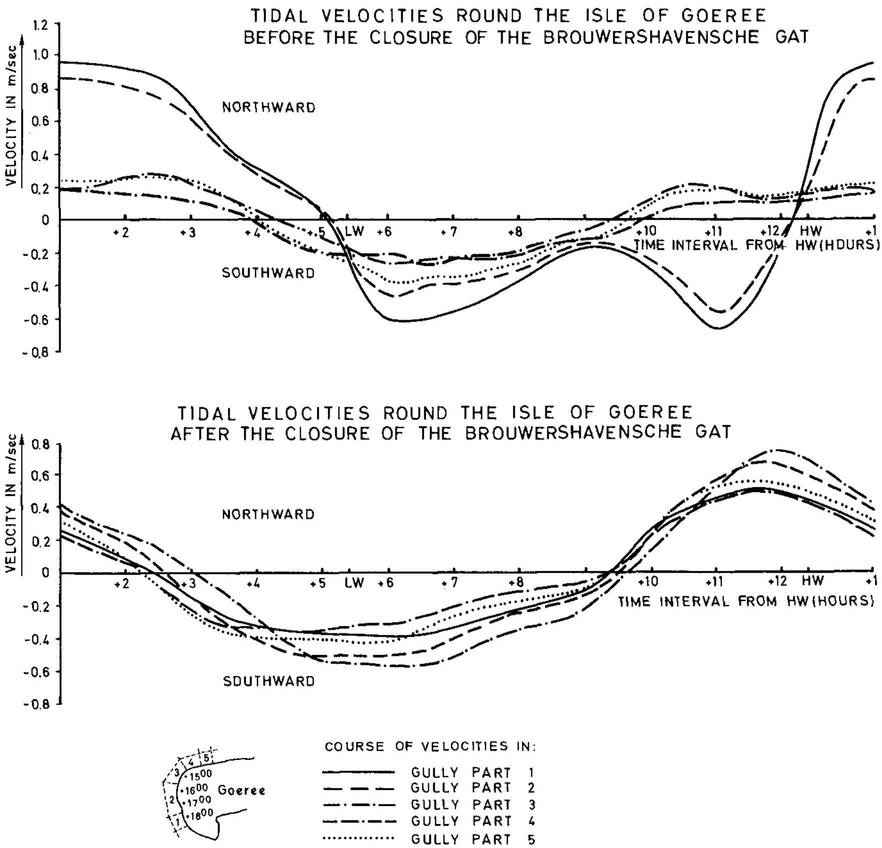


Figure 7

Bottom load:

$$S_b = 5\,D\,\frac{v}{C_r}\sqrt{g}\;e^{-0{,}27\,\dfrac{\Delta D C_r^{2}}{\mu v^{2}\left\{1+\frac{1}{2}\left(\xi\frac{u_b}{v}\right)^{2}\right\}}}$$

where S_b = bottom load per unit of time

D = grain diameter

v = current velocity

C_r = resistance coefficient

g = accelaration of gravity

Δ = relative apparent density

μ = ripple coefficient

ξ = parameter

u_b = orbital velocity near the bottom

Suspended load:

$$S_s = 1.83\ S_b\ (I_1 \ln \frac{33h}{k} + I_2)$$

where S_s = suspended load per unit of time

I_1 en I_2 = Einstein integrals [15]

h = depth

k = half the ripple height

By means of Bijker's formula, it is found that the transport rate is increasing to the north (see fig. 5 and 6). From this computations of the sandtransport in the Schaar channel the magnitude as well as the location of the observed erosion in prototype can be explained.

Before the closure of the Brouwershavensche Gat sand used to come from this estuary. After the closure the sandfeed to the Schaar channel coming from the estuary was cut off.
Though the sandtransport capacities after the closure are smaller the erosion is larger because of the change in difference of capacities. The order of magnitude of the mean sandlosses in the erosion area found from the computation are about 200.000 to 300.000 m^3/year after the closure and about 150.000 to 200.000 m^3/year before the closure of the estuary. That is about the same amount as the mean yearly losses in the prototype. This resultant sanddrift feeds the Noorderstrand.

SOLUTIONS FOR REDUCING THE EROSION

Up till now sandsupplies have been carried out to reduce the erosion. Figure 8 shows a cross section of the beach after the sandsupply and the enforcement of the dunes in 1974.

See also the aerial photograph made a year after the sandsupply in 1971.

By a very large sand nourishment the streamprofile of the Schaar channel narrows down. This in turn causes higher flow velocities resulting in an increasing loss of sand. Because of this a closure of the channel is considered in the future. This should be done with a dam made of sand because the channel stops the sandfeed of the Noorderstrand. The littoral drift along the sanddam however can replace the sand that used to come from the Schaar channel. This sanddam can be considered like a big sandsupply (about 10 million m^3). Figure 9 shows a possible solution of such a dam.

It will be clear that such a solution only has effect if one does not prevent erosion of the sanddam, otherwise the erosion would be replaced from the Westcoast of the island to the Noorderstrand.

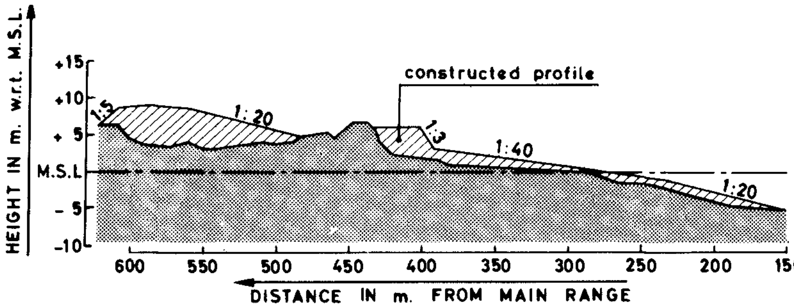


Figure 8 PROFILE OF THE DUNES AFTER THE SANDSUPPLY IN 1974

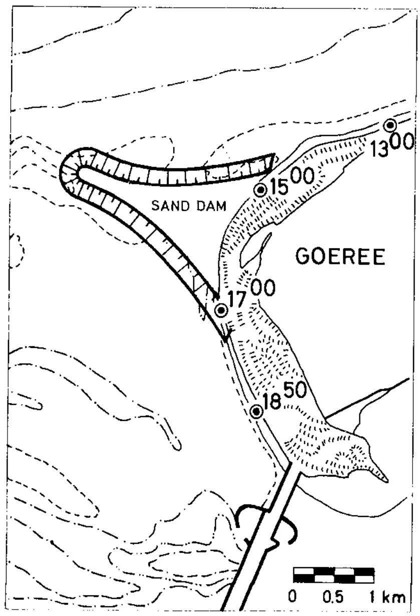
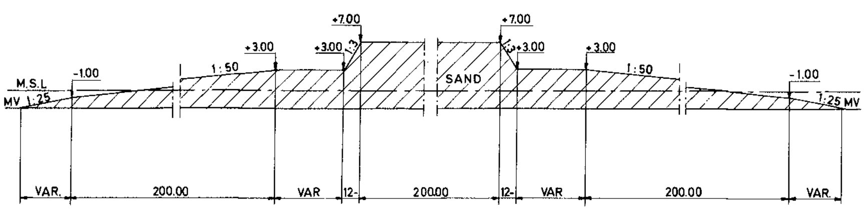


Figure 9[a] Location of the sand dam



Measures in m.

Figure 9[b] Cross section of the sand dam

Figure 9 EXAMPLE OF THE LOCATION AND THE DESIGN OF A SAND DAM TO CLOSE THE SCHAAR-GULLY

AERIAL PHOTOGRAPH OF THE WEST-COAST OF GOEREE. TAKEN 3 May 1972
(area where the sand supply was carried out)

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