CHAPTER 41

SOME CHARACTERISTICS OF THE DUTCH COAST

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1. INTRODUCTION

The Dutch coast is over its whole length a sandy coast. Along such a coast the changes in shape of the coast-line are determined by transport of sediments, in casu sand, along the coast. This transport is brought about by water and by air. The latter, the eolian transport, though it may have some importance, has been neglected in this study. The marine transport along the Dutch coast is caused by currents and by waves; we do not know which is the most important.

In this study the transport by waves is considered to be the effect of waves, moving in one predominant direction; the transport by currents is taken into account as a transport by tidal currents only.

We should like to underline here the very general character of the following considerations.

2. GENERAL TRANSPORT-FORMULAE

From the continuity-condition it follows that

$$\frac{\partial y}{\partial t} = A \ \frac{\partial Q}{\partial x}$$

where Q = the quantity of transported material per unit of time
t = the time
A = a constant.

The x-axis has been taken along the coast-line.

The factor $\frac{\partial y}{\partial t}$ is the velocity, with which the coast-line moves. Erosion will occur if $\frac{\partial y}{\partial t}$ is positive, accretion if $\frac{\partial y}{\partial t}$ is negative.

If $\frac{\partial y}{\partial t} = 0$, the coast-line will not alter its situation. The equilibrium-condition of the coast-line, therefore is:

$$\frac{\partial Q}{\partial x} = 0$$

or: the coast-line is in equilibrium if in every cross-section of the coast the same quantity of material is transported.

If the quantity transported increases in the transport-direction, $\frac{\partial Q}{\partial x}$ is positive, and thus $\frac{\partial y}{\partial t}$ is positive, so erosion occurs. If the quantity transported decreases in the transport-direction, there will be accretion.

It may be allowed to suppose that along a non-disturbed coast (i.e. a coast without inlets, groins, jetties etc.) in each cross-section the quantity Q transported equals the transport-capacity Q_c. In that case the changes in the shape of the coast-line depend only on the changes in the transport-capacity along the coast, i.e. on changes in wave-direction or wave-intensity, or on changes in the tidal capacity.

This does not hold good along a disturbed coast, where in some parts a difference may exist between the quantity actually transported and the transport-capacity. A certain stretch (the length of which we do not know) is needed to bring Q into accordance with Q_c. If $Q > Q_c$ accretion occurs, if $Q < Q_c$ there will be erosion along the stretch of disturbance. The erosion stretch may be relatively longer than the accretion stretch, since a surplus may be deposited quicker than a deficit is supplied.

We assume that it is allowed to superimpose the $\frac{\partial y}{\partial t}$ curves of the disturbances linearly on the general $\frac{\partial y}{\partial t}$ curve of Q_c.

3. EFFECT OF A TIDAL CURRENT ON A NON-DISTURBED COAST

The transport-capacity of a tidal current will increase with the tidal range. If, therefore, the tidal range increases along the coast in the direction of propagation of the tidal wave the coast will be eroded. A decreasing tidal range in that direction will cause an accretion.

4. EFFECT OF WAVES ON A NON-DISTURBED COAST

Along large stretches of a coast the average intensity and the average dominant direction of the waves will not change very much. The angle α, between the wave direction and the perpendicular on the coast-line, however, does change if the coast-line is not a straight line. Therefore, Q_c will be a function of α.

$$Q_c = Q_m \; f(\alpha) \quad .$$

If we put $f(\alpha) = \sin 2\alpha$, then

$$Q_c = Q_m \sin 2\alpha \quad .$$

$Q_c = Q_m$ if $\alpha = \frac{\pi}{4}$. $Q_c = 0$ if $\alpha = 0$ and if $\alpha = \frac{\pi}{2}$.

Along a concave coast (see figure I^A) $Q_c = Q_m$ in M_1 and M_2 ; $Q_c = 0$ in A, B_1 and B_2, Therefore, the waves will cause an erosion along the stretches $B_1 M_1$ and $B_2 M_2$ and an accretion along $M_1 A M_2$.

Along a convex coast (see figure I^B) it is the opposite. Along $B_1 M_1$ and $B_2 M_2$ accretion occurs and $M_1 A M_2$ will be eroded. We see that waves tend to straighten a curved coast-line.

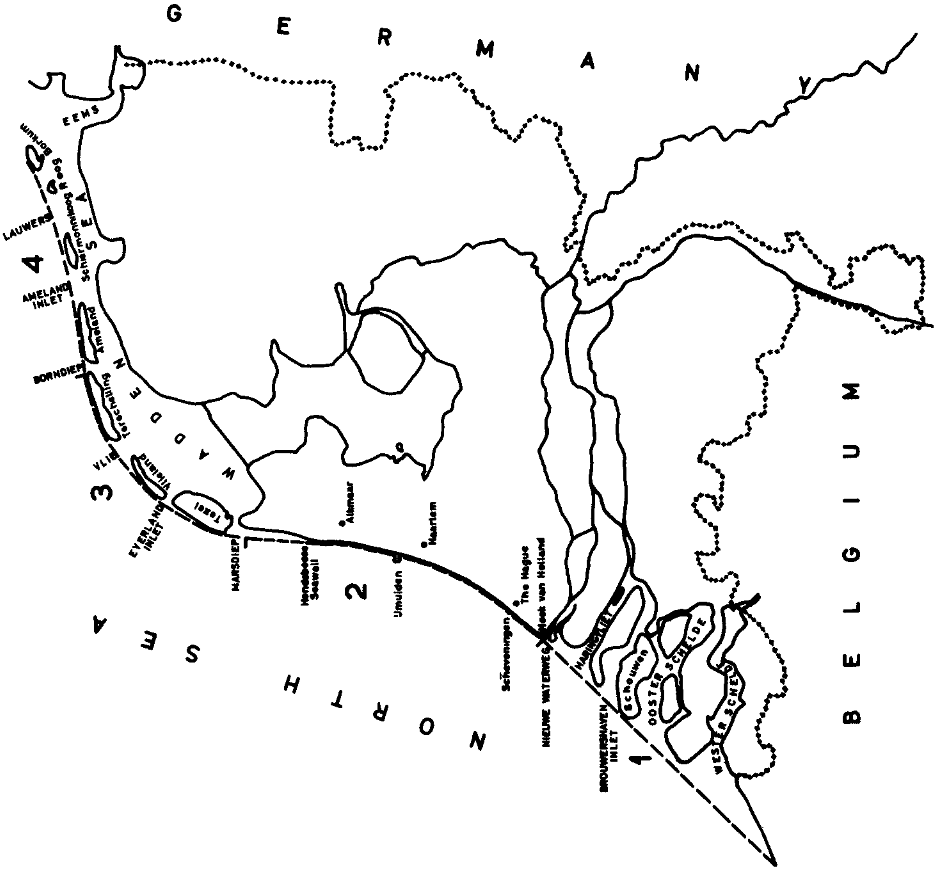

Fig. 2. The Dutch coast-line.

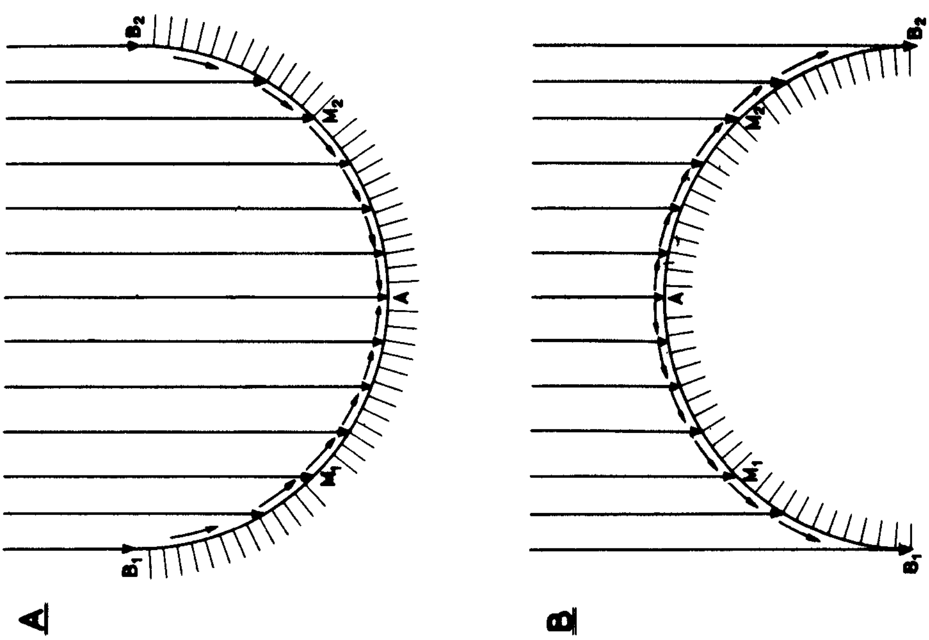

Fig. 1. Effect of waves on a concave and on a convex coast.

5. EFFECT OF DISTURBANCES

Tidal currents mostly cause erosion on both sides of a disturbance. The eroded material moves into deeper water, where shoals are formed.

The effect of waves on both sides of an inlet is similar. Jetties, groins and such disturbances, however, mostly show an accretion on the lee-side and an erosion on the windwardside.

6. THE DUTCH COAST-LINE

As a whole, the Dutch coast-line consists of four parts (see figure II).

1. A straight line, from the Belgian frontier to Hoek van Holland.
2. A concave part between Hoek van Holland and the Marsdiep-inlet.
3. A convex part from Marsdiep to Borndiep.
4. A faintly curved concave part from Borndiep towards Germany.

Part 1 is disturbed by 5 inlets: Westerschelde, Oosterschelde, Brouwershaven-inlet, Haringvliet and Nieuwe Waterweg. A real coast-line hardly exists here.

Between Hoek van Holland and Marsdiep there are no inlets, but some disturbances are caused by the harbour jetties of Scheveningen and IJmuiden, and by the bulwark (groins) of the Hondsbosse Seawall.

The curves of the Wadden-islands (part 3 and 4) are disturbed by large inlets: Marsdiep, Eyerland-inlet, Vlie, Borndiep, Ameland-inlet, Lauwers and Eems.

7. EFFECT OF TIDAL CURRENTS

The tidal range decreases from the Belgian frontier until the Marsdiep-inlet and increases from Marsdiep to Germany. Since the direction of propagation of the tide is from Belgium towards Germany, the tidal currents tend to bring about an accretion along part 1 and 2, and an erosion along part 3 and 4.

8. EFFECT OF WAVES

The effect of waves on the Dutch coast depends mainly on what may be considered as the dominant wave direction with regard to the transport of sediments. In figure III we have constructed the effect of waves if the dominant wave direction would be N.W. and W., respectively.

9. EFFECT OF DISTURBANCES

By the simplified and general method applied, it will be impossible to analyse the changes of the coast-line in part 1 and part 4, since on these parts of the coast the disturbances caused by the many large inlets will surpass by far the normal effects of waves and tidal currents.

On the islands Texel, Vlieland or Terschelling perhaps some stretches may be found on which the influence of the tidal inlets may be neglected.

With the disturbances along the concave part between Hoek van Holland and Marsdiep we are dealing in more detail in paragraph 12.

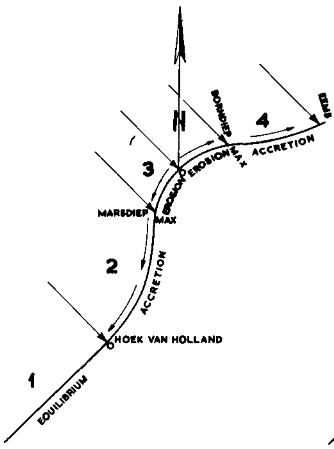

Fig. 3. Effect of waves on the Dutch coast-line.

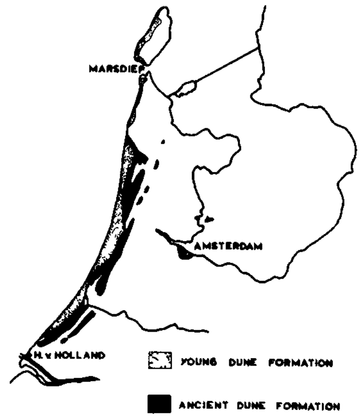

Fig. 4. The "ancient dune formation" between Hoek van Holland and Marsdiep.

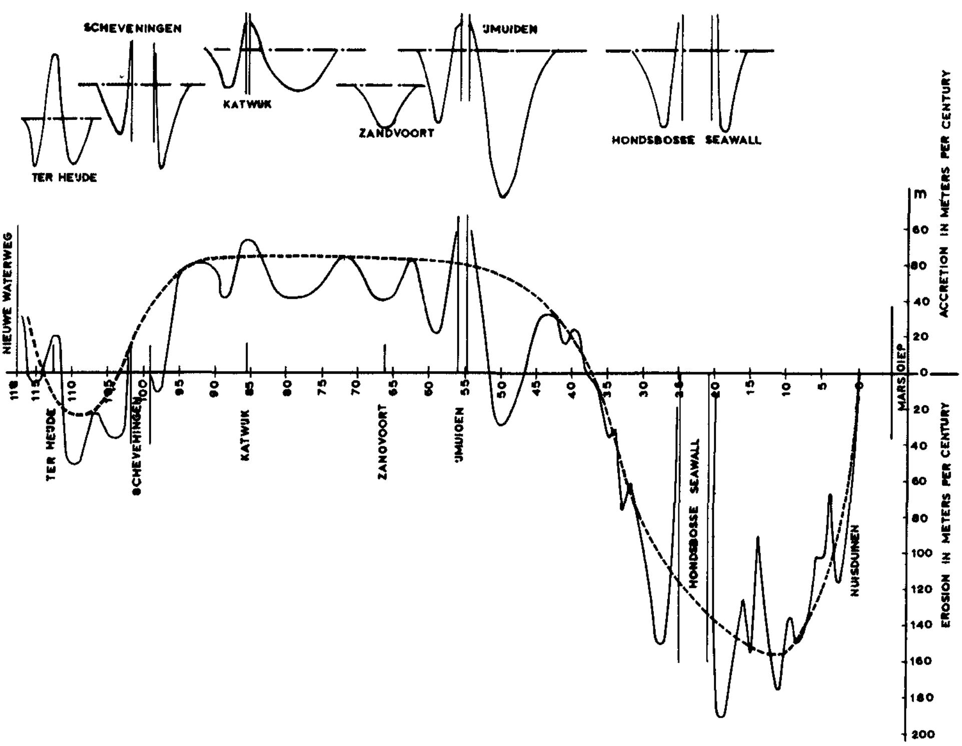

Fig. 5. Analysis of dune-foot movements between Hoek van Holland and Marsdiep.

10. EFFECTS TO BE EXPECTED

1. Belgian frontier - Hoek van Holland.
Accretion by tidal currents; equilibrium by waves (straight line); heavy disturbances by many large inlets, which probably will prevent a proper analysis.

2. Hoek van Holland - Marsdiep.
Accretion by tidal currents; accretion by wave action; disturbances by jetties and groins which will probably not prevent an analysis.

3. Marsdiep - Vlie.
Erosion by tidal currents; erosion by waves; heavy disturbances by inlets.

4. Vlie - Borndiep.
Erosion by tidal currents; erosion by waves from N.W., accretion by waves from W., perhaps a stretch where the influence of the inlets may be negligible.

5. Borndiep - Eems.
Erosion by tidal currents; light accretion by waves from N.W., light erosion by waves from W., heavy disturbances by large inlets, which probably will prevent a proper analysis.

This is, in a general way, what may be expected from theoretical considerations. We turn now to the facts and we will see in how far they affirm our expectations.

11. GEOLOGICAL DATA

In former times, probably, a sandy coastal barrier existed along the whole Dutch coast. This coastal barrier must have been interrupted by inlets, through which the rivers debouching into the lagune behind the barrier brought their water into the sea. This ancient barrier showed a weak surface relief, that may be described best as a series of low dune ridges, parallel to the coast-line, with oblong coastal plains between them. Afterwards (perhaps during the ninth century) this "ancient dune formation" has been partly covered by high dunes, the "young dune formation". These young dunes do not show a clear morphology; they have not been deposited in longitudinal ridges.

Between Hoek van Holland and the Marsdiep the ancient dune formation still exists. At the sea-side it is partly covered by the young dunes, but behind this region the uncovered ancient dune formation reaches landwards over one kilometre and more. Cities as The Hague, Haarlem and Alkmaar have been founded on the ancient dune ridges; the famous bulb-fields are situated nearly exclusively upon this ancient formation.

From figure IV it may be seen, that in the neighbourhood of the inlets (i.e. between The Hague and Hoek van Holland, and south of the Marsdiep) the uncovered ancient dune formation tends to disappear. The morphology of the coastal barrier as a whole suggests a coast, which is accruing since very remote times and which only at both its ends has been eroded under the influence of the bordering inlets. This is in accordance with the expectations, stated in paragraph 10.

Along the coast south of Hoek van Holland, only very few remains of the ancient dune formation are present. If extant (as for instance on the island of Schouwen) the ancient formation is always covered by young dunes. This gives the impression, that this coastal section, since centuries, is subject to erosion. Without any doubt, this erosion is caused by the large inlets.

It is a remarkable fact, that along the Belgian coast the uncovered ancient dune formation is still in existence, from which we may perhaps conclude, that the average dominant wave direction is more likely to be N.W. than W.

In sharp contrast with the above mentioned parts of the coast, there are no traces of an ancient dune formation along the Dutch coast North of the Marsdiep. Even on the island of Texel, the southern part of which consists of a very resistent boulder clay, an ancient dune formation does not exist. We are dealing here with an eroding coast, its coastal barrier must always have been whirled up and thrown back by waves and currents.

So far, geological and morphological data are in good accordance with our theoretical derivations.

12. COASTAL MEASUREMENTS

Since more than one hundred years the position of the L.W.-line, the H.W.-line and the dune foot, once a year, has been measured every one thousand metre along the Dutch coast. Especially between Hoek van Holland and the Marsdiep a beautiful series of data results, from which the movements of the coast-line during the last century can be studied in detail.

The data about the dune foot provide the most regular series. From this series, therefore, we derived figure V, in which the resulting movement of the dune foot from ± 1850 till ± 1950 is plotted. At first we obtained a rather irregular curve in which, however, the disturbances caused by the jetties of IJmuiden and Scheveningen, by the Hondsbosse Seawall and a few others, can be clearly distinguished. After subtraction of the disturbances and after some flattening, the dotted curve of figure V emerges. The outer parts of this curve represent the border-disturbances due to the southern system of inlets and to the northern inlet of the Marsdiep. The southern disturbance extends to about km 90; the northern one is longer and extends to about km 55 (IJmuiden). Between km 55 and km 90 there are no border- disturbances present; in this section the undisturbed coast-line proves to have migrated seawards over about 60 m (as an average) during the last one hundred years.

Thus, by studying the measured data, we have been able to estimate quantitatively an accretion, the existence of which we derived qualitatively from theoretical considerations.

Similar data of the Wadden-islands yield only a very confused picture. No clear evidence of a permanent tendency of a landward movement of the coast-line could be found. The measured data of the islands of Ameland and Schiermonnikoog rather seem to indicate an accretion of their northern coasts.

13. HISTORICAL DATA

Historical data throw some more light on the behaviour of the Wadden-islands. It is known, for instance, that formerly the western part of Vlieland was situated far more northwards than to-day. This part, with high dunes upon it, has been destroyed by the sea during the 17th and 18th centuries; from the remaining sand the sea built up a flat sand-bank, without any dunes: the present-day southwestern part of the island. Since that time, the eastern part of Vlieland was so heavily attacked by the sea, that the coast had to be protected by 54 groins in order to stop the ever increasing erosion.

During the last centuries the coast of Terschelling has not shown very great alterations. The island has been lengthened in easterly direction and the northwestern point has shown a slow accretion. A tendency of landward movements of the coast-line is not evident.

From ancient sea-charts it can be derived that the islands of Ameland and Schiermonnikoog move in eastward direction (erosion at the western end; accretion at the eastern end). Archaeological data point in the same direction. As an average over many centuries, the eastbound velocity may have been some hundred metres per century. Again, there is no evidence of a movement in a southerly direction.

The behaviour of the little island of Rottumeroog, especially during the last 150 years, is well-known. The island moves in easterly direction at a rate of 10 or 20 metres per year. Every 25 or 30 years the house of the guardian has to be rebuilt upon the eastern side; after due time it finds itself standing on the western shore, where it is attacked by the sea.

The available data suggest, that during the last centuries the Dutch coast between Vlie and Eems, in sharp contrast with the coast between Marsdiep and Vlie, has not endured an accretion or an erosion of any importance. After all, the coast-line in this part is nearly a straight line, so that the waves are hardly able to cause an important accretion or erosion. Material, however, is transported to a large amount along this section. So we tend once more to the conclusion, that the average dominant wave direction is more likely to be N.W. than W.

14. CONCLUSION

From the continuity-condition it follows, that the changes of the transport-capacity are responsible for erosion or accretion along a sandy coast.

The transport-capacity of tidal currents depends on the tidal range. The transport-capacity of waves changes with the direction in which the waves approach the coast. This means that, if a dominant wave-direction exists, the curvature of the coast must be responsible for erosion or accretion by wave action.

Since the pattern of the tidal range along the Dutch coast is well-known, as well as the curvature and the general shape of this coast, a general and qualitative prediction could be given about the behaviour of the coast-line.

Disturbances by inlets, groins, jetties, etc., however, spoil the picture and have even prevented in some cases a proper prediction.

However, investigation of available geological, morphological and historical data and an analysis of data from coastal measurements prove, that such data are in good accordance with predictions derived as mentioned above. Our simple theory, therefore, may perhaps be considered to give a rough explanation of the behaviour of the Dutch coast-line.