D. Rakhorst, D. de Wilde and C. Schot

Seaward Coastal Defence Scheme Eierland

Abstract

As early as the 12th and 13th centuries, the united sand barrier in the north of The Netherlands, divided into the separate islands such as Texel and Vlieland known as the Wadden Isles. The coast of Eierland in the NW corner of the Isle of Texel has been eroding for more than a century, and since 1979 this has been subject to sand replenishment.

The objective of the Netherlands Ministry of Transport, Public Works and Water Management (Rijkswaterstaat RWS) was to construct a coastal defence scheme as a means to prevent coastal erosion. After determining the cause of coastal erosion, three possible solutions were considered: breakwaters, beachheads and dams.

Considering morphological, ecological and economical effects, it was decided to construct a dam. Various alternatives for the dam were considered and a selection was made based on durability, cost and feasibility. Despite difficult weather conditions the construction is completed and appears to be meeting expectations to curtail erosion.

Introduction: Case History

The coast of Eierland in the NW corner of the Isle of Texel has been declining for more than a century (Figures 1 and 2). A yearly loss of a million cubic metres of sand is recorded. Since 1979 this has been compensated by sand replenishment to date, this ± 5 km region has received nearly 10 million cubic metres of sand. Politically seen, replenishment is in line with the present Dutch national policy regarding coastal protection (1990), which has opted to maintain the present coastline.
In taking this approach one has to conclude that in places with extremely heavy erosion, the option of a seaward approach might be more effective.
The Ministry of Transportation, Public Works and Water Management has therefore requested research into this matter; not only on the effects regarding the coast, but also as it effects landscape, ecology and tourism.

Mr Rakhorst is employed by the Ministry of Transport, Public Works and Water Management, Directorate General North Holland, as a senior policymaker for coastal zones. For the Eierland project he chaired the working group Morphology and had overall responsibility for the design of the works.

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Mr de Wilde is also employed by the Ministry of Transport, Public Works and Water Management, the Civil Engineering Division. He is a specialist in the field of project design, execution and process management, and initiated the quality management system as it was applied in the Eierland dam project.

D. de Wilde

Mr Schot graduated from the Zeeuws Technical Institute, The Netherlands and joined HAM in 1963 where he has fulfilled a variety of positions. He is presently Regional Manager for several coastal zones of The Netherlands, including the Isle of Texel.

C. Schot

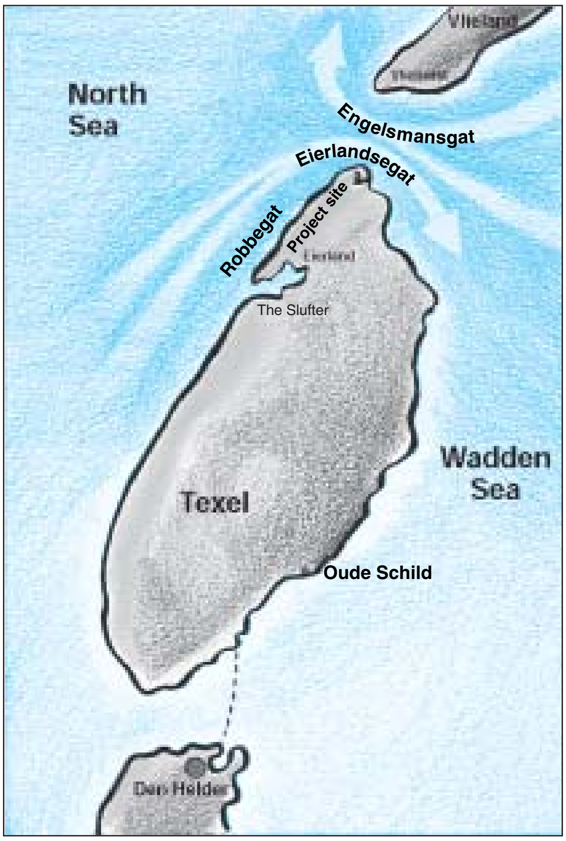


Figure 1. (Left) Lap of the Netherlands with the Isle of Texel.

Figure 2. (Above) Detail of the Isle of Texel with names of areas as they appear in the article.

The first designs of a seaward defence of Eierland date from 1975. Also the policy-analytical research of the coastal protection of Texel, the so-called SIBAS-study (1982), refers to the possibility of a dam at Eierland. This only appeared to be more advantageous at a sand price for beach replenishment of about NLG 7 per m^3.

Coastal Erosion

The Wadden Isles in the north of The Netherlands were originally a united sandy barrier. As a result of storms in the 12th and 13th century a channel originated between the islands Texel and Vlieland. Also Eierland became a separate island; the construction of a driftsand dam in 1630 reunited it with Texel again (Figure 3).
In time a sandy area formed in front of this dike which is presently known as the Slufter area. Because of this barrier, the flow rate in the Eierlandse Gat increased, the Head of Eierland eroded and the Vliehorst increased in strength. From 1700 to the beginning of the 20th century there was a balance in the situation around Eierland, even though there was an enormous coastal increase between 1850 and 1880.

Since 1880 the coast of Eierland has been eroding, presently at about 6 to 8 metres a year. The most important reason for the erosion is the tidal currents between Texel and Vlieland. At high tide the water flows in along the top of Texel and carries the sand away from the coast of Eierland. At low tide the water flows out through a channel, the Engelsmangat, centrally located between Texel and Vlieland, to an outer delta offshore the coast of Vlieland. Eventually waves carry this sand to the coast of Vlieland.

Figure 3. The coast of Eierland has been eroding for more than a century; shown here erosion between 1860 and 1990.

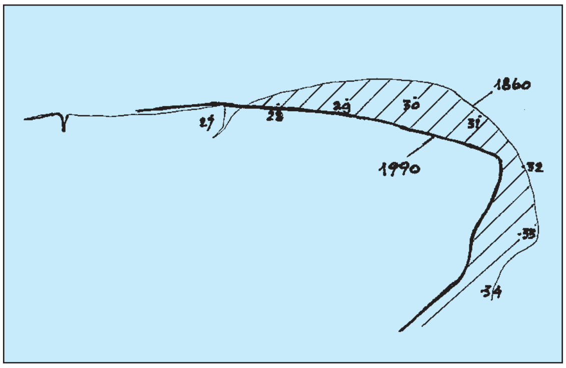


Figure 4. Combined dam solutions 2 and 4 at the head of Eierland, as explained in the text below.

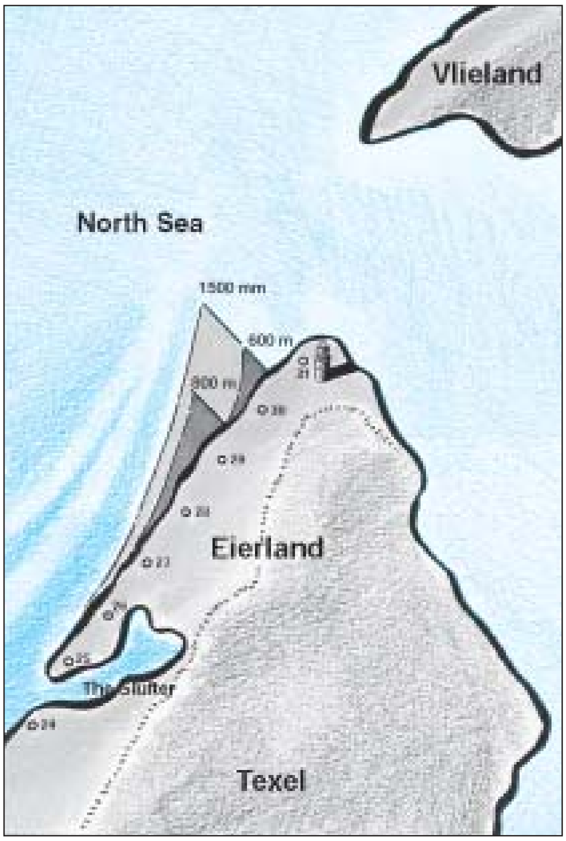


Figure 5. Combined dam solutions 1 and 3 at the head of Eierland, as explained in the text below.

Possible Measures

Having established the cause of the coastal erosion, the search for solutions began (Figures 4 and 5). After the first wide-range selection, the following options were selected:

– breakwaters (dams parallel to the coast),
– beachheads (short dams perpendicular to the coast), and
– dams.

These options were studied by the Delft Hydraulic Laboratory with 1- and 2-dimensional models (flow, wave and sand transportation models). With these models the shoreline's geographical position in time was determined as well as the areas which would be affected by sedimentation or erosion. Also determined was the amount of sand needed for replenishment measures. The studies showed that breakwaters did not outperform beachheads, and since they are more expensive, they were eliminated.

Further studies were done on beachheads and 1 or 2 long dams, whereby location and length were varied. Besides just sand replenishment four other "hard" solutions were considered. These four were:

1. 1500 m dam at km 30.5
2. 600 m dam at km 30.5
3. 600 m dam at km 30.5 and 800 m dam at km 29.5
4. Beachhead series consisting of:
   550 m dam at km 30.5
   300 m dam at km 29.5
   250 m dam at km 28.5
   200 m dam at km 27.5

All financially attractive solutions require the initial construction of the 550 or 600 m dam at km 30.5. From a financial viewpoint, all measures are equally expensive, only the 1500 m dam was considerably more costly. These four solutions as well as sand replenishment have been considered in the Environmental Impact Study [EIS].

EIS Results

Research was done on the effects:
- morphological,
- ecological, and
- economical.

Morphological effects
The current around the head of Eierland has a tidal influence. With a dam or beachhead, at windward side sedimentation will occur, while the lee side will erode. To what degree this will occur will be determined by the length and location of the dam. A dam at km 30.5 will have hardly any lee side erosion, compared to a

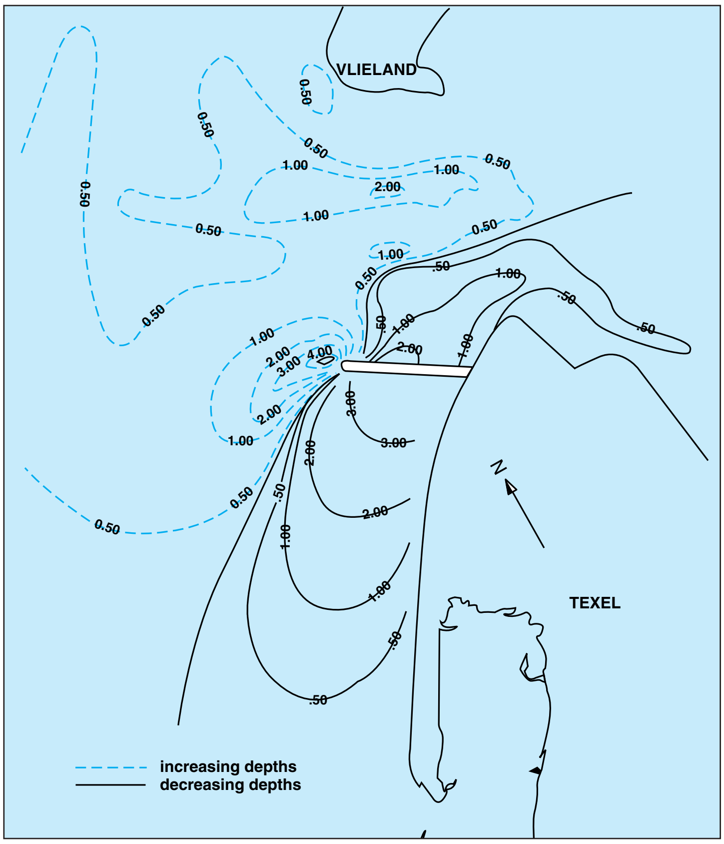


Figure 6. Sea bottom changes in metres as a result of a 1200-metre-long dam, according to a Delft Hydraulic Laboratory SCOUR model.

dam at km 29.5. The sedimentation at the windward side will be considerably less by a dam at km 30.5 than at km 29.5.
This is caused by the strong coastal curving at km 30.5. In all solutions the sedimentation is rather sluggish and will have to be (at least temporarily) supplemented. There need not be any concern about the sedimentation of the Slufter mouth. An erosion hole will appear in front of the dam. Since there will be hardly any change in the discharge of the Eierland sea outlet, the present balance of the inner delta will be maintained. However, several changes in the outer delta may occur, especially if the dam is longer and closer to the Head of Texel. Since the sand supply will be partially stopped, one can assume that the sedimentation of the NW sector of the inner delta will diminish or even stop (Figure 6).

Ecological effects
None of the measures will cause serious ecological changes in the inner or outer delta. The shoals and channel areas will remain the same. Also the Slufter area will barely be influenced. The main change will be the creation of a foreshore. A small dam will yield a small foreshore, a large (lengthy) dam will supply a large one. The existence of a foreshore will, however, raise the groundwater level in the nearby dunes.
The result being a wetter dune area and possibly dune lakes will appear (Figures 7 and 8).
However, judgements about this are debatable.
The study group "Ecology", which is involved in this matter, consider dune lakes to be a negative aspect, since they attract seagulls, whose droppings will create eutrophication. Except for the 1500 m long dam the solutions are acceptable. All solutions will change the landscape. Also in this respect, the larger the dam or foreshore, the more change in landscape.

Economical effects
None of the solutions will have a significant effect in regard to recreation or economy. It should be borne in mind that no recreational or agricultural activities should be developed on this newly formed foreshore.

The Solution

The 1500 metre dam was dismissed because of its high cost and possible negative morphological and hydrological effects. The choice fell ultimately on the 550 m dam with replenishing of 2.0*106 m^3 sand during the construction of the dam, 1.6*106 m^3 after 5 years, 1.1*106 m^3 after 10 years and afterwards 0.6*106 m^3 every 5 years. By constructing the 550 m dam with beach replenishment, one has chosen for one of the less expensive solutions and also one with the least amount of morphological and ecological changes. If, however, this proves unsatisfactory after all, a further seaward approach constructing a 800 m dam at km 29.5 or opting for series of beachheads is possible.

The Design

Morphological intervention
In the first instance the plan consisted of construction of the dam and the placing of 2*106 m^3 of sand, the latter replenishment borrowed further offshore at below the NAP (New Amsterdam Level) -20 m-line. However to spread the costs over a two-year period the replenishment was split up in 1.3*106 m^3 placed in 1994 and the remaining 0.7*106 m^3 in 1995 when the dam was built. Mid 1994 the idea of a morphological intervention arose (Figure 9). The intervention consisted of digging a flow channel between the erosion hole which would develop between the head of the dam and the Robbengat. This plan served three purposes:

1. The channel would cause sand to be deposited at ebb tide in the outer delta offshore Eierland. The waves then carry the sand to the shore of Eierland, therefore requiring less replenishment in the future. At ebb tide right now, most of the sand is deposited through the Engelsmangat and a lesser amount through several smaller ebb channels which developed a more westerly orientation in the outer delta. The new ebb-flood channel could take on the task of the existing smaller channels.

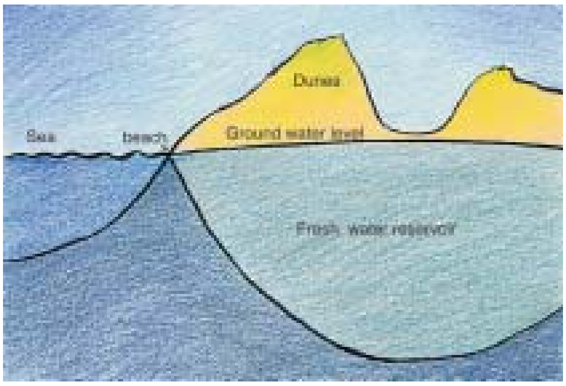


Figure 7. Groundwater level in the present situation.

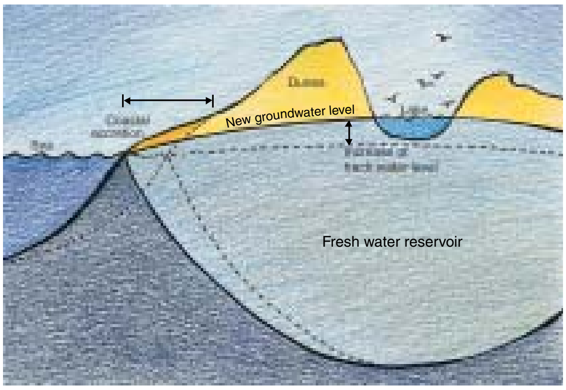


Figure 8. Groundwater level rise in a situation altered by coastal accretion.

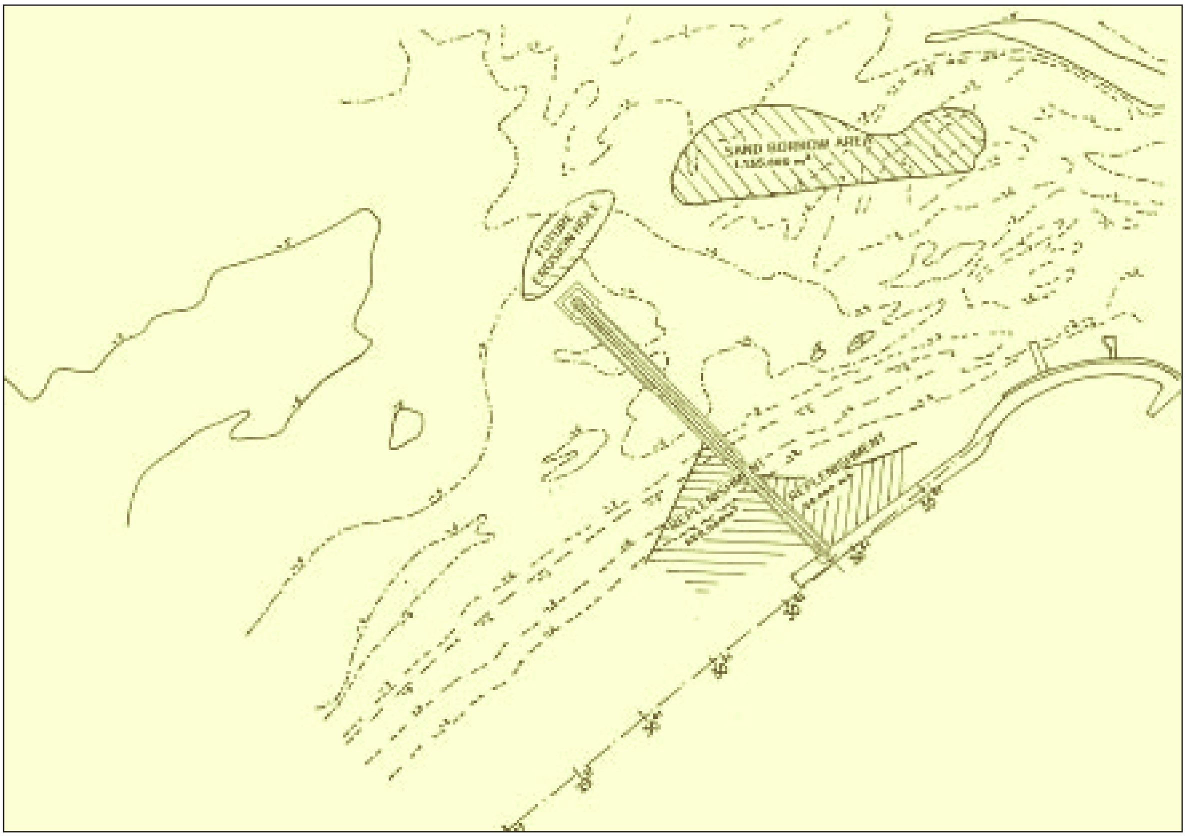
2. The sand released by the construction of the channel can then be used for the remaining replenishment of $0.7*106\ m^3$. Because of the shorter delivery distance, this sand will be cheaper than when having to be borrowed below the NAP -20-line.

3. Some experts are worried about channel-forming along the south side of the dam. This can possibly occur during a southwestern storm, during which the water will be driven along the south side of the dam. By depositing 300,000 m^3 of sand in the neck of the dam, the current will be brought offshore and the current gradations and therefore also the transport gradations will diminish. The chances of channel-forming will decrease. At the same time part of the dam can be made of a somewhat lighter construction, and the chances of damage will diminish. There is an analogy with the construction and extension of the harbour breakwater at Amsterdam's outer port IJmuiden. The largest sedimentation was there, where sand was placed in the neck.

Longitudinal profile of the dam

Starting point was a dam length of 550 m, from the most seaward MLW-line. Up to the foot of the dune the total length of the dam will then be 800 m.

Figure 9. Drawing with chosen solution and morphological intervention.



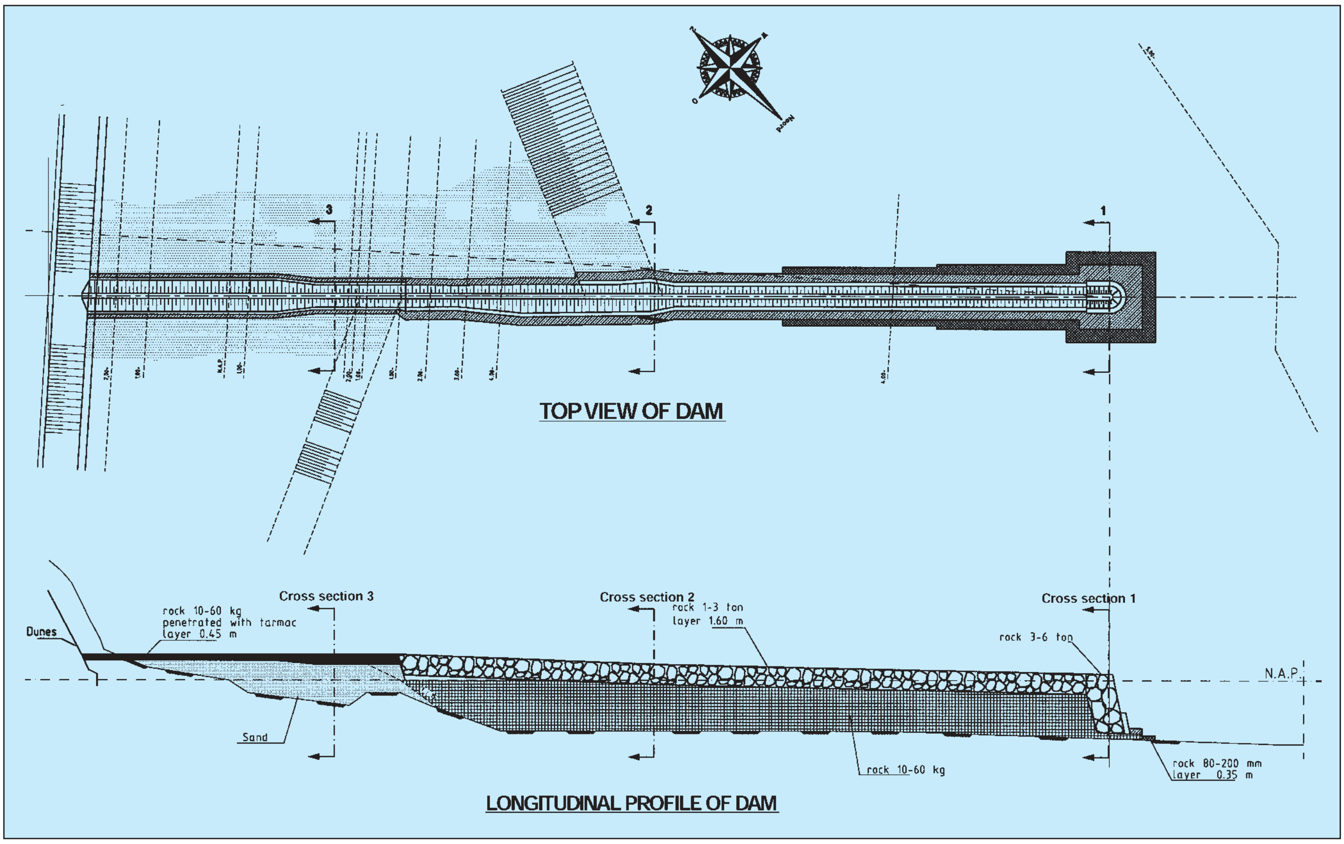


Figure 10. Top view and longitudinal profile of the dam.

Figure 11. Cross-sections indicated in Figure 10 are shown here: 1) at the head; 2) in the middle section; and 3) at the beach.

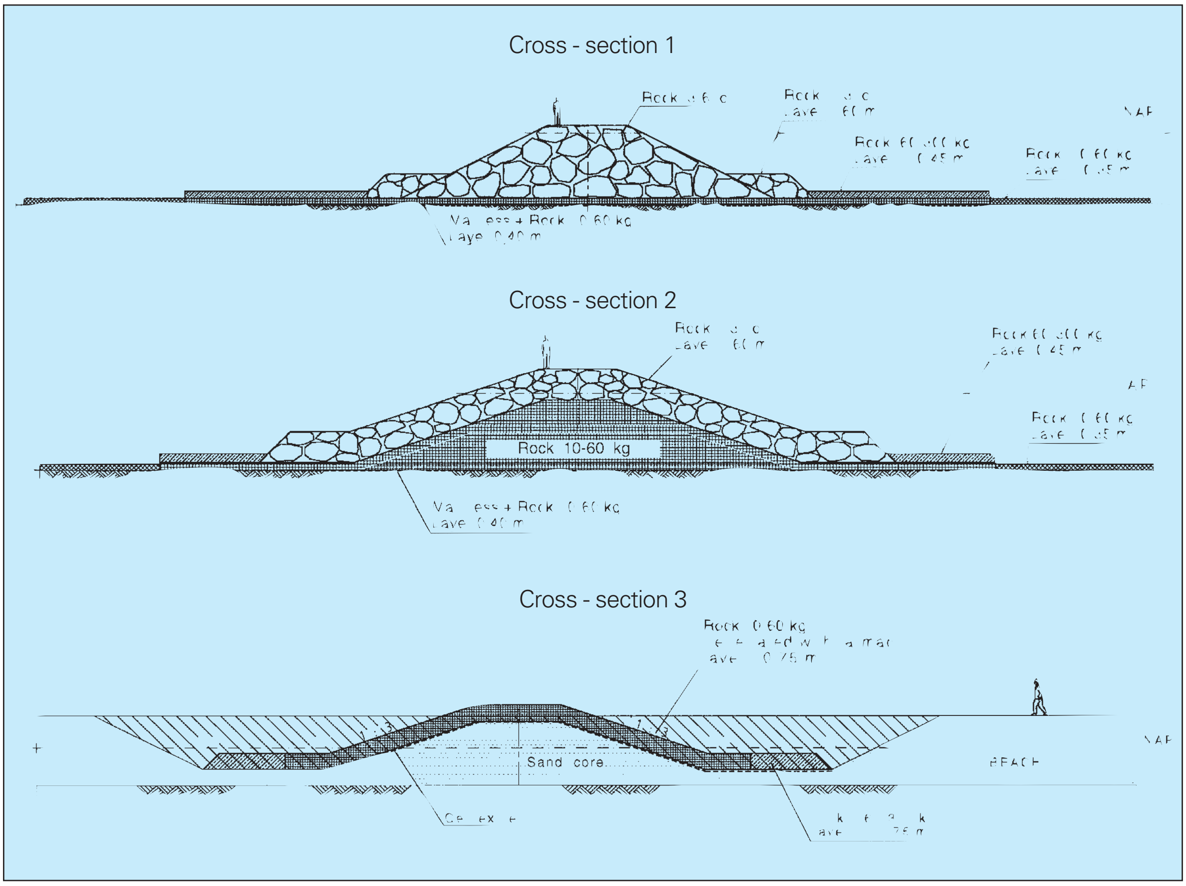


Figure 12. Work in progress at the Eierland dam as at May 1995.

An erosion hole at NAP -10 m will form at the head of the dam. This expectation is based on the flow rate pulling along the dam and on the analogy of the IJmuiden breakwaters.
However the same conclusion was reached in the model research.

Calculating the realistic slopes of the underwater sea-shore, an approximate 300 m seaward displacement of the MLW-line was found. Accordingly a shore inclination of 1:100 needs a foreshore of approx. 250 m at NAP +1.5 m. In this section the dam will be at a height of about 0.5 m above foreshore level, to assure that the sand will be retained. This height is further necessary to keep the water from flowing across the dam. (About once a year NAP +2 m will be surpassed.)
The head of the dam will be at NAP +0.5 m. This dam height was established mainly because of the demand to make the dam passable most of the time. At the same time eventual sand transport across the dam is negligible. The height incline of the dam is gradual, from NAP +2 m to NAP +0.5 m (see Figure 10).

Cross-section

Many alternatives were generated for the construction of the dam. These alternatives were:
- free dumped rockfill (4 varieties);
- penetrated rockfill (4 varieties);
- concrete elements (3 varieties);
- solid construction (3 varieties); and
- sand construction (4 varieties).

After a first selection, 6 varieties remained for further consideration:
- rockfill, homogenous;
- rockfill, with core;
- bitumen penetrated stone, saturated;
- bitumen penetrated stone, pattern penetrated;
- sand pancakes; and
- pile planking.

The last three were deleted because of, respectively, a lack of construction experience, cost, and uncertainty in regard to life expectancy.

The dam can be divided into three parts, based on design and construction aspects:
- beach: always dry construction;
- body: sandtrapping; and
- head: stability point in surf zone.

Therefore the following constructions have been chosen:
- beach: sand body covered by rock fill penetrated with asphalt, in order to obtain a strong and inexpensive cross-section;
- body: rockfill with core, because of tight and cheap construction; and
- head: one type of rock fill, because of solidity and the lesser importance of sand tightness.

Figure 11 shows three cross-sections: one is a cross-section at the head; two is a cross-section in the middle; and three is at the beach end.

Figure 13. Cutter suction dredger Sliedrecht 34 was used for beach replenishment at the start of the construction.

Figure 14. Close up of stone dumping on the dam.

The Construction

The beach replenishment in 1994 has been executed by a contractors joint venture, consisting of HAM-Van Oord Werkendam bv, Boskalis Oosterwijk bv and D. Blankevoort bv. The project of the dam was tendered on 16-12-1994 and awarded to the contractors joint venture; HAM-Van Oord Werkendam bv., P. Daalders Contracting Company bv and Van Oord-ACZ bv. The construction was completed on 01-10-1995 (Figure 12).

Special circumstances during execution of the works
The NW coast of the Isle of Texel is a difficult area to work in, mainly because of weather conditions:

- The navigation route from the Waddenzee changes constantly. Therefore it was necessary to make daily reconnaissance trips along the route due to wandering shallowness.
- The dam has been projected in an area with water depths varying from NAP -4.50 m to NAP +1.00 m. The average high water is at NAP +0.60 m, the average low water is at NAP -0.80 m.
- The toleration requirement of +/- 10 cm to ensure a level top layer with 1-3 tons stones is physically impossible.

Preparations
Before starting the actual construction, 3 stone deposits were established at the head of Eierland.
The rockfill, originating from Norway, was delivered by ship. About 90,000 tons were delivered in Oudeschild and stored in depots; 27,000 tons were deposited straight from the barges onto the site.
Simultaneously two mattresses were constructed on the parking lot next to the lighthouse, to enable continuous sinking operation. From there the mattresses were pulled to the shoreline by mechanical shovels and subsequently towed to the sinking site. At the start of the project sinking of the mattresses was much delayed by the constant swell. Later the delay was made up when it became possible to sink 3 mattresses per day.
The execution of the beach part of the dam could only be done after the beach was heightened by sand replenishment. At the start of the construction the beach had decreased to such extent that it was impossible to gain access with the construction equipment.

Beach replenishment
In 1994 already 1.3*106 m^3 of the replenishment of 2.0*106 m^3 had been placed. This sand was reclaimed by trailing suction hopper dredgers from a borrow area off the centre of Texel below the NAP -20 m line.
In 1995 the remaining 0.7*106 m^3 of the replenishment was placed and another 0.3 million cubic metres in the neck of the dam. The latter 1 million cubic metres has been placed in seven days and has also been used to make the beach passable for construction equipment. This was borrowed by the cutter suction dredger *Sliedrecht 34* from an area between the future scour hole at the head of the dam and the Robbengat. In reality 100,000 cubic metres of extra sand was placed free of charge, as a result of the less expensive way of execution (Figure 13).

Dam with sand core
Figures 14 and 15 show the site during the execution period. This part of the dam with a length of 275 m has been executed by excavating the (heightened) beach. On the excavated sand profile a polypropylene filter cloth with reed cover has been placed topped by a layer of stone 10-60 kg. An asphalt mixture has been poured over and in between the stones. The berms have been finished off with stone 60-300 kg.

Dam with core of rockfill
Originally the core would consist of phosphor slag's covered by stone 10-60 kg. At the request of the contractor this was changed to a core of only stone 10-60 kg. The core of the first 400 m of this part of the dam was delivered by driving over the dam. The crest of the core was temporarily filled with stone 60-300 kg, to create enough work space to be able to use a hydraulic excavator over the first 400 metres, to place the 1-3 tons stone cover layer in the crest.
The work was done seawards to land side and moving

Figure 15. Overview of the Eierland dam as it nears completion.

backward the 60-300 kg stone were picked up and placed onto the berm. The cover layer of the most seaward section, with a length of 150 m, was placed with the aid of a floating crane, seagoing barges and stone dumping vessel *HAM 602*.

Head of the dam

The body of the head of the dam is completely constructed from rock 3-6 tons. The berm has, as is the case along the total dam, a cover layer of rock 1-3 tons over a 3 m width. This construction was a marine operation insofar as the navigable depth allowed.
The section of bottom protection, outside the cover layer of stone 1-3 tons is covered with stone 60-300 kg. This stone was placed with a stone dumping vessel, at lower depths with seagoing barges and floating cranes, and, at depths of NAP -1.00 m. and higher, with hydraulic excavator and dumpers. The dam was finished before October 1st 1995. Until now the dam has held its profile very well.

Some conclusions about construction methods

- The weather influx was underestimated (wind force 4 nationally in The Netherlands is wind force 6 at the Isle of Texel).
- The supply capacity of the heavy rock and the progress of the bottom protection work define the progress of construction.
- The transportation of rock on stone pontoons, from Oudeschild across the North Sea is an unsafe working method, but can be done with the help of stone dumpers.
- Extra equipment is required because of the combined "dry " and "wet" working methods.
- The best working method is to extend as much as possible the "dry" construction from the beach. More security is given by constructing the dam in a completely "dry" way.
- When confronted by similar work at depths of less than 3 metres, the dry method should certainly be chosen to avoid the risks due to weather, waves, swell and so on.
- Driving across rockfill 1-3 tons is impossible without a fill-in layer.
- The location to assemble the mattresses was fixed in the specifications. At this location it proved difficult to couple the tow beam of the mattress at high tide.
- A floating crane with stone pontoon alongside is overly sensitive to swell.
- The specification quantities were calculated, by theoretical means, in cubic metres. By conversion of cubic metres to tonnes, one should not calculate by volume weight (mass 2800 kg/m^3 x 60% = 1680 kg/m^3). Practice has proven that, including deviations of mass, deviations in void percentages, losses and freeboard, a bulk specific gravity of about 2000 kg/m^3 should be calculated.

Quality Guarantee

The construction of the Eierland dam occurred under a quality guarantee. It was one of the first "marine" construction projects commissioned by the client The Netherlands Ministry of Transport, Public Works and Water Management (Rijkswaterstaat RWS) Directorate North Holland done under quality guarantee. The most important considerations in applying the quality guarantee were:

- Future RWS policy in relationship to contracting certified contractors.
- Gaining experience in this type of working method in order to learn and apply this to own organisation and future projects (Pilot Project).
- It was possible to appeal to the Bouwdienst RWS (Construction Service RWS), which had experience in working with quality guarantee, so that they could be counted on for support during the tender, award and construction phases.
- To put the responsibility during the construction where it belongs, namely, with the contractor.

The purpose of quality guarantee

Social relations have changed and equality between the parties entails working together, each in the realm of the specific tasks, although each party ultimately has its own interests.The modern working method entails, client and contractor, each with their own tasks, responsibilities and qualifications. In construction a tendency toward product liability continues, thereby requiring the producers to be more and more responsible to deliver quality goods.

Accepting product responsibility goes hand in hand with the competency to make one's own decisions. The traditional work method in which the supervisor determines the quality, does not fit into this philosophy. Quality guarantee means that the contractor must show the products made meet the requirements agreed upon in the tender specifications. In this way the party which can influence the processes most is in charge of the quality. The client's role shifts to one of auditing the work, through which he becomes responsible for eventually proven faults in construction.

Working method

In the preparatory phase much emphasis has been put into drawing up the product-oriented tender specifications, including quality assurance aspects, and into the education of the project employees.

Prior to the start of the project, the quality control system handed in by the contractor has, by means of NEN ISO 9002-norm, been commented on and eventually been accepted.

By means of the contractor's technical evaluation plan, based on the critical parts, properties of construction and processes, the execution and inspection plan presented by the contractors has been judged, discussed and accepted. Various construction processes and measuring methods were described in the execution plan, while executed measurements and controls, to be executed per subproduct were described in the inspection plan. Also the attendance, report and stop items, requested by the client were described.

These items were meant to give the client the opportunity to be present at the inspections and measurements or do them itself. In addition, the client made several system and product audits to ascertain that the contractors adhered to the procedures and working methods as described in the plans.

Findings about quality guarantee

The project's most important findings in regard to working under quality guarantee, as experienced by the client are:

- Communication between client and contractor is of utmost importance to guarantee a final quality plan.
- At the start of the project "double work" occurred during a certain period, because the client's side "held on" to the existing security. Only after the contractor proved to be able to hold his own security did more trust developed.
- Uncertainty existed on the part of the auditors as to when they could intervene in the contractor's process. The traditional type of supervision to which they were accustomed, and working with quality control demanded a subtle combination. Therefore, on the one hand all project employees need to have enough know-how about and ability to deal with quality control. On the other hand the client also needs to follow its own quality system in which the qualifications, procedures and working methods are determined.
- The project quality system was based on the certified system of one of the contractors and imposed, more or less via a "top down" system, on all project employees. This led to a bit of a problematic start.
- In case of increased pressure on cost and planning, quality control is easily dropped.
- Audits implemented by the client are an important means to measure the quality control. The audits had a positive influence on the quality awareness of the employees of both parties.

Costs

The total project exists of the construction of a ± 800 metres dam at km 30.5 and of a sand replenishment of 2.0*106 m^3. Included in the cost of the dam is the sand replenishment of 300,000 m3 in the neck of the dam. There is no cost involved for the excavation of the ebb channel of the cutter dredge at the head of the dam and the Robbengat since this was part of the sand borrow area.

Scope of the works

According to the tender documents the scope of the works was as follows:

- beach replenishment	300,000 m^3
- rock; all types	95,800 tonnes
- mattresses	24,000 m^2

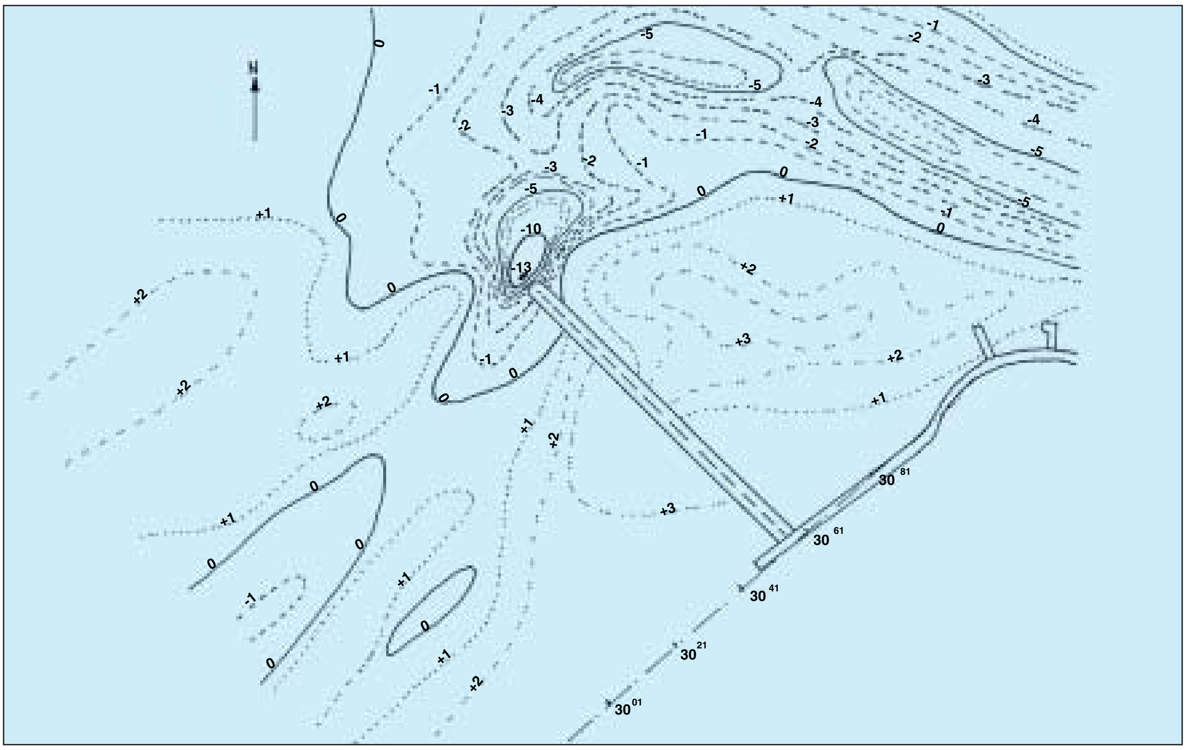


Figure 16. Sea bottom changes in metres as at December 1996.

In 1992 it was estimated that, if the work was done in 1994, the total cost of the project would be ± NLG. 30 million. Total project cost, including VAT were as follows:

– dam:	NLG 16.0 million
– beach replenishment:	NLG 21.0 million
– Total:	NLG 37.0 million

For this amount more than 100,000 m3 extra sand has been placed.

Conclusions

Regarding the morphological evaluation, the expected developments were:
- sedimentation on the south side of the dam;
- the forming of an erosion hole with a depth of ± NAP -10 m at the head of the dam;
- sedimentation offshore Eierland resulting from the digging of the ebb channel;
- light sedimentation of the Robbengat and erosion in the Engelsmangat caused by altered flow rates, but also lee side erosion in the Robbengat;
- displacement of the ebb channel in NW direction.

Actual morphological developments are (Figure 16):
- major, unexpected sedimentation on the north side of the dam. The total area between the dam and the head of Eierland is sedimented with nearly 1 million cubic metres of sand;
- major erosion in the Robbengat;
- a much deeper scour hole (up to NAP -18 m) than expected. This led to placement of an extra rubble layer, after the completion of the dam, and again at the end of 1996. Expectations were for a much wider and more shallow hole. Possibly because of the position in the outer delta which causes sand pressure, a smaller and deeper hole was formed;
- sedimentation on the south side of the dam. Close to the dam the MLG-line has moved more seaward than expected. As the coastal curve is too sharp, this led initially to a disappointing amount of sedimentation;
- the dredged ebb channel indeed did place a large quantity of sand at the coastline of Eierland. Until November 1996, this sand was not mobile because of the lack of storms. As expected, however, after the November/early December storms a fair part of the sand has moved to shore. Because of the storms, the shoal north of the dam has been reduced in height and the sand has moved to the edges of the shoal. After the storms the scour hole has been reduced with 1.5 m;
- the dredged ebb channel has not silted but unfortunately has moved in the same manner as the original small ebb channels. The expectation is that this displacement will continue and that the ebb channel will eventually be extinguished. Unfortunately this means that in time much less sand will be carried through the ebb channel to the NW part of the outer delta.

Up to now the main purpose of the dam has met the original objective, which was to limit the erosion of the coastal plain of Eierland. If, as expected, a replenishment of ± 1.5*106 m^3 is necessary in 1999 remains to be seen.