

CHAPTER 231

OFFSHORE BREAKWATERS VERSUS BEACH NOURISHMENTS A COMPARISON

M. Pluijm¹, J.C. van der Lem², A.W. Kraak³, J.H.W. de Ruig⁴

ABSTRACT

In the last decades two methods of coastal protection have become increasingly popular for the protection of sandy shores: beach nourishments and offshore breakwaters. In The Netherlands the first of both is well known and applied regularly. The second method has not been applied yet. With the increasing cost for beach nourishment and the apparent succes of offshore breakwater systems abroad, a study has been executed to the technical and economic feasibility of offshore breakwater systems in The Netherlands compared to the present strategy of beach nourishments. This paper highlights the results of this feasibility study.

INTRODUCTION

Protection of eroding sandy beaches can be done in many ways, each with its individual advantages and disadvantages. One of the things learned from the past is that dynamic coastal systems preferably should be kept dynamic. Including rigid structures in such environments often generate more problems than they solve. A demonstration of the new approach is the increase in application of beach nourishments as a shore erosion control measure.

¹ Head of Marine Department, Frederic R. Harris B.V., Badhuisweg 11, P.O. Box 87875, 2508 DG, The Hague, The Netherlands

² Senior Coastal Engineer, Frederic R. Harris B.V., Badhuisweg 11, P.O. Box 87875, 2508 DG, The Hague, The Netherlands

³ Project Engineer, Rijkswaterstaat, Road and Hydraulic Engineering Division, P.O. Box 5044, 2600 GA Delft, The Netherlands

⁴ Project Engineer, Rijkswaterstaat, National Institute for Coastal and Marine Management, P.O. Box 20907, 2500 EX The Hague, The Netherlands

A disadvantage of this method is the certainty that, at sites with structural erosion, the nourishment will be eroded in due course and will have to be repeated. Apart from expensive, to outsiders this gives the impression that money is thrown into the water. In order to reduce the number of maintenance nourishments (increase the timespan between two nourishments) one could therefore decide to protect the beaches with structures of some kind.

One of the successful methods, in certain cases, to achieve such protection is the application of offshore breakwaters. By interfering in the near shore sediment transport processes, offshore breakwaters influence the development of the coastline. It has been shown in numerous projects that offshore breakwaters have beneficial effects on beaches and can be used in combination with nourishments or even when nourishments are not applied.

For the Dutch coast where offshore breakwaters are not (yet) applied, but with a number of sites where beach nourishments are repetitively executed, it has been investigated whether application of offshore breakwaters will result in technically and economically feasible alternatives to singular beach nourishments.

THE DUTCH COAST

Although The Netherlands is well known to many people for its dikes and the Deltaworks, most people do not know that the majority of the Dutch coastline does not consist of dikes. Of the approximately 350 km of coastline (Figure 1), 254 km (72%) consists of dunes, 38 km (11%) of beach flats, 34 km (10%) of seadikes and 27 km (7%) of seawalls, boulevards and the like. This makes it clear that the major part of the Dutch coastal protection effort is put into the protection and maintenance of dunes and beaches.

Fortunately the shape of and the conditions along the Dutch coast are such that only at a limited number of sites structural erosion takes place. With the increase in pumping capacity of dredgers since the 1950's and the success of the strategy, beach nourishments have been applied in increasing numbers (Figure 1, Roelse 1990). The total volume of sand applied in nourishments has increased significantly over the years. Starting with some 1.5 million m³/year in the 1950's the volume increased to

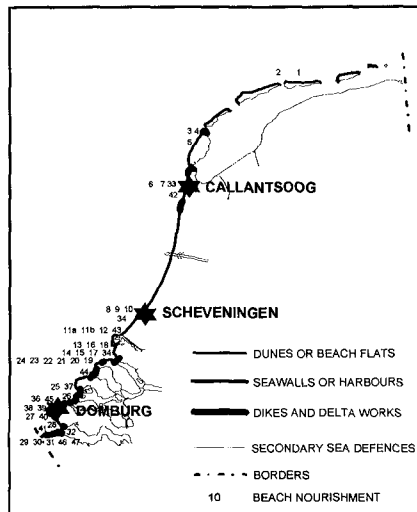


Figure 1 The Dutch coast

about 3 million m³/year in the 1970's and 1980's. Currently this figure has increased even further to about 5-7 million m³/year. The total budget currently made available by the Dutch government for beach nourishments is Dfl. 60 million per year (Hillen 1993).

In view of this budget it is not surprising that questions have been raised whether the applied beach nourishment strategy has not become too expensive and whether cheaper methods (or reduction methods) would not result in a reduction of total maintenance cost.

SHORE PROTECTION METHODS

With the majority of the Dutch coast consisting of sand, it is not surprising that beach erosion problems are not new to the Dutch coastalmanagement organizations. In fact, at most of the locations along the Dutch coast where structural beach erosion takes place, shore protection measures have already been taken. In most cases these consist of groynes and at some places also dunefoot protection is applied. Some of these groyne systems have been set-up more than a century ago (the construction of the oldest systems has been initiated more than 200 years ago) and because of this, a lot of applied experience has been gained. Experience has shown that the effects of groyne systems along the Dutch coast are small (Verhagen 1990). Only at sites where tidal gullies run near the coast or for sites where a strong predominant oblique wave direction is present, groyne systems have some effect. For sites with a large variation in wave direction and hence a small nett littoral drift, the groyne systems hardly show a beneficial effect.

In view of this, new groyne systems were not proposed to reduce erosion of executed beach nourishments. Instead, because of experience gained abroad, offshore breakwaters were proposed as a seemingly attractive alternative for coastal protection of the Dutch coast. Questions to be answered in order to decide whether offshore breakwaters would be technically and economically feasible are:

Technically: does an offshore breakwater system help to reduce repetitive nourishments and how much is the reduction?

Economically: Will the cost for shore protection (including construction and maintenance of the offshore breakwater, remaining beach nourishment cost etc.) be less than the current practice of beach nourishments only?

The answer to these questions depends on many things and not the least on site conditions. With the numerous locations in The Netherlands where nourishments have been and are executed, it was decided not to relate the research to one site, but to three sites, each of which with its own specific site conditions.

SITE SELECTION

After evaluation of potential sites, the three sites selected for further analyses were:

CALLANTSOOG: The beach and dunes near Callantsoog (Figure 1) are subject to structural erosion in the order of 1 to 2 m per year. The beach and dunes are relatively narrow and safety against flooding is the main argument for execution of regular beach nourishments (1976/ '77, '79/80, '86 and '91). The shore is protected with groynes, but is not intersected by breakwaters, rivers or others.

SCHEVENINGEN: The regularly (1969, '75, '85, '91) nourished beach at Scheveningen (Figure 1) is backed by a vertical seawall and is located just north of Scheveningen harbour. The shore is protected by groynes (constructed before construction of the harbour) and the coastline is intercepted by two short breakwaters (Figure 2). The vertical seawall prevents the construction of a mass sand storage in the form of dunes and consequently beach acts as the only sand buffer. Quick erosion of this beach during extreme events, the lee side effect of the harbour moles and the lack of natural regeneration are the major arguments why regularly beach nourishments have to be executed.

DOMBURG: The coastline at Domburg (Figure 1) is subject to structural erosion in the order of 4 m per year. Typical of the site is the presence of a vast system of sand banks in the nearshore area, albeit that a tidal channel runs between this sandbank system and the coast. A system of pile rows is aimed at keeping the tidal current away from the shore. For northwesterly storms the coastline is very sensitive to erosion. Any loss of sand in the tidal gully is a permanent loss. As a result the coast near Domburg has been nourished in 1986, '89, '90 and '92.

OFFSHORE BREAKWATERS IN DUTCH COASTAL WATERS

What distinguishes the site conditions in Dutch waters from many of the other locations in the world where offshore breakwaters are applied, are two main items. First the tidal motion. The tidal range for the three sites varies between approx. 3.90 m (Domburg) and 1.50 m (Callantsoog). Consequently under normal tidal conditions the influence of an offshore breakwater is influenced by the water level and tidal current. The second is the influence of storms. Because of the funnel shape of the North Sea, northwesterly storms can generate considerable increases in water level (storm surge). With the majority of the land area behind the dunes well below mean sea level (MSL), the design storm surge level (in combination with waves) for which the sea defences should maintain safety is in the order of +5.50 m above MSL (1 in 10,000 years risk of flooding).

In order to keep the offshore breakwater system economically feasible it is clear that the breakwaters should be kept small. Hence under extreme conditions as indicated

above, the breakwaters will be submerged and their influence consequently reduced. On the other hand, for low water level conditions it is likely that the offshore breakwater system will emerge above still water level. These conditions impose special requirements in the design of the offshore breakwater system. Combinations of different water levels and wave height and consequently different loading conditions (submerged, emerged yet overtopping) must be taken into account in the design of the breakwaters.

Although for the cross sectional design of an offshore breakwater system numerous alternatives can be thought off, the combination of conditions indicated above imposes the requirement that a proper breakwater system must be designed for a wide range of different conditions (water levels, waves, currents). In addition, it is required that the costs for breakwater construction and maintenance are kept small. This led to the conclusion that a rubble mound breakwater type was to be preferred. Design rules would be available for all different loading combinations, construction and maintenance cost assessment would be easy and general experience with this type of breakwater is good.

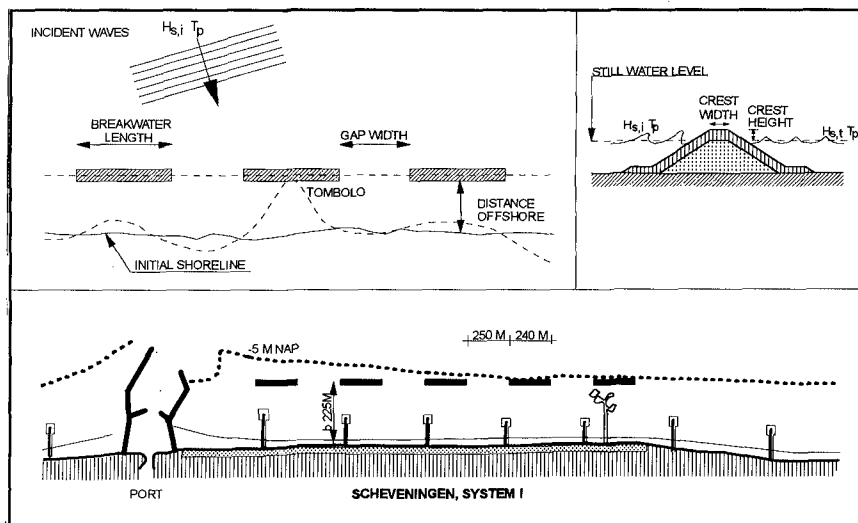


Figure 2 Offshore breakwaters at Scheveningen

PLAN VIEW AND CROSS SECTION OF OFFSHORE BREAKWATERS

Although a lot has been published on the application of offshore breakwaters (Dally and Pope 1986, Rosati 1990) and the physics by which offshore breakwaters function becomes more and more understood, accurate and straight forward design methodologies are not available.

The initial lay-out design of the offshore breakwater systems therefore has been based on rules from practice (Rosati 1990) relating dimensions as breakwater length, gap width, distance offshore etc. (figure 2). In this initial design stage it has been adopted as design requirement that tombolo formation (such large accretion of the beach that the accreted sand reaches the lee slope of the offshore breakwater - figure 2) should not develop. This requirement is invoked by the expectation that tombolo formation will result in blocking of longshore sediment transport and consequently causing large lee side erosion.

The combined effect of water level and wave height imposes special requirements on the cross sectional design of the rubble mound breakwaters. Especially the height of the crest relative to still water level and the width of the crest influence the overtopping (and thus the wave attack on beach and dune) as well as the wave loads on the breakwater itself.

Cross sectional design, offshore distance, breakwater length and gap width finally will determine the total volume of the breakwater construction materials. To keep the cost of the breakwater systems small, it was chosen to locate the breakwaters as near to the coast as possible (minimum depth) but far enough to prevent tombolo formation. For the Scheveningen site this resulted in the breakwater scheme of Figure 2. For the Domburg and Callantsoog site the proposed breakwater schemes were more or less similar.

The cross sectional design was chosen to be trapezoidal with side slopes of 1 in 1.5. This will result in a minimum rubble mound breakwater which will remain stable with a reasonable rock size as armouring. The height of the breakwater is dominant for the overtopping and the weight of the armour to be used. The higher the breakwater, the less the transmission and overtopping but the heavier the armour unit to be applied and visa versa. Eventually for Scheveningen it was decided to put the crest level of the offshore breakwater system at approximately +1.25 m MSL, just above mean high water of spring tides. Under these conditions the impact of the breakwaters on wave transmission is maximised, but this will reduce with increasing water levels. At extreme high water levels the breakwaters will be submerged and be subject to reduced wave forces despite the higher waves associated with the storm surges and deeper water. Finally under normal daily wind and wave conditions the breakwater system will be visible, not unimportant for the increasing pleasure craft navigation along the Dutch coast.

QUALITATIVE DESCRIPTION OF THE IMPACT OF OFFSHORE BREAKWATERS ON THE DUTCH COAST

Before trying to estimate the magnitude of the effects of offshore breakwaters on the Dutch coast, it is first of all important to identify the processes involved. By understanding the processes involved, mathematical approximation of these processes

may be used to indicate the magnitude of the impact of offshore breakwaters. As implicitly indicated in the previous, a differentiation should be made between normal conditions (without storm surges) and extreme events (including storm surges). The influence of offshore breakwaters under these two conditions will be quite different.

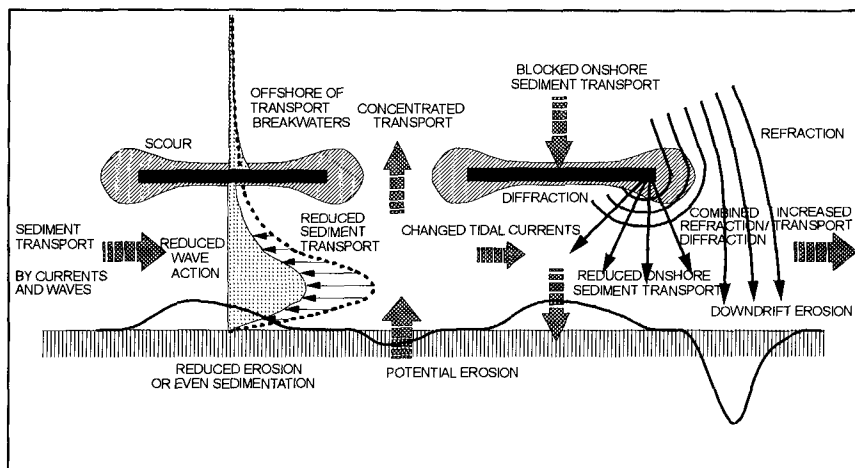


Figure 3 Offshore breakwaters: physical processes under normal conditions

Normal Conditions

Under normal conditions the morphological processes at the coast under influence of waves and tidal currents result in predominant longshore sediment transport. The application of offshore breakwaters is under these conditions aimed at reducing the longshore sediment transport behind the breakwaters, by shielding the coast from predominant wave attack. Assuming that this can be accomplished, the result will be a reduced erosion behind the breakwaters or even sedimentation (Figure 3).

The offshore breakwater system will have a limited length and consequently will end somewhere. In the Dutch case, with a net longshore sediment transport in northerly direction, a reduction in sediment transport behind the offshore breakwaters is likely to result in erosion on the northside of a breakwater system (lee side erosion). This lee side erosion is an important phenomena which counter effects the positive effect of beach accretion behind offshore breakwaters. In the overall (economic) evaluation this lee side erosion and consequent additional beach nourishments should be taken into account.

Although longshore sediment transport will be dominant under normal conditions, the cross shore transport will also be influenced by offshore breakwaters. An important aspect in this cross shore transport under normal and fair weather conditions is the

transport of sediment towards the coast. Being primarily a bedload transport offshore breakwaters will block the onshore transport and prevent the natural rehabilitation of eroded beaches.

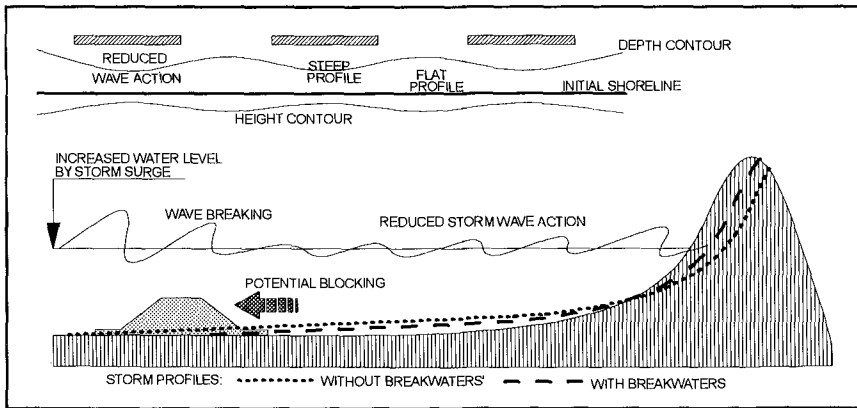


Figure 4 Offshore breakwaters: physical processes under extreme conditions

Extreme Conditions

Under extreme conditions, the breakwaters may be submerged and wave conditions will be severe (Figure 4). Without offshore breakwaters under such conditions erosion of beaches and dunes can be expected. However, even though the offshore breakwaters are submerged, the crest level is still so high that the breakwaters will influence the wave conditions. Reduced wave conditions will result in reduced erosion of beach and dunes. Depending on the distance of the offshore breakwaters relative to the coastline, the resulting cross sectional storm profile of dune and beach may reach as far as the breakwaters. The breakwaters then could perform a containment function.

As indicated previously, a disadvantage of offshore breakwaters is that they not only prevent natural rehabilitation of the beach (and the dunes) from the seaward side of the breakwaters towards the coast, but also due to the reduced wave conditions behind the breakwaters from the landward side.

QUANTITATIVE DESCRIPTION OF THE IMPACT OF OFFSHORE BREAKWATERS ON THE DUTCH COAST

A quantitative assessment of the influence of all these processes on the coastline clearly will be difficult let alone inaccurate. This difficulty finds its origin in the complexity of the hydraulics and the coastal morphology processes. The current and

wave field between the breakwaters will have a strong two-dimensional effect. Generated bed shear stresses, radiation stresses etc. also will vary significantly in a horizontal plane. Gradients will not only occur parallel to the coast, but also perpendicular to the coast. Currently available coastline models are often one line models in which the complex water/sediment/structure interaction has to be included in a simple way. Usually only the sheltering of wave action is included in the model (Delft Hydraulics 1992, Hanson 1989). Changes of tidal current conditions are usually not included. In view of this it was concluded that the available one-line models are still limited in predicting shoreline changes with sufficient detail and reliability to support the design of offshore breakwater systems. Especially in feasibility studies where eventually costs will have to be implemented, a proper assessment of remaining nourishments volumes may be the key element of the outcome of the study.

A quantitative assessment of the influence of offshore breakwaters under extreme conditions may be made, assuming that under extreme conditions primarily cross sectional profile changes occur. With the breakwaters under water, the wave height still will be reduced and a reduction in cross sectional erosion may be expected. The effects of offshore breakwater on erosion profile development has been studied using two cross sectional erosion models (RWS-DWW 1992). The results of this study indicated that by applying offshore breakwaters, under extreme conditions a reduction in cross sectional erosion is achieved up to a maximum of 30%.

In view of the previous it appears to be impossible to conclude whether offshore breakwaters in The Netherlands would be economically feasible, not knowing the beneficial and negative effects of these breakwaters on the protected and adjacent coastline. One way to overcome this is to make the economic evaluation based on an assumed beneficial effect.

CROSS SECTIONAL DESIGN OF OFFSHORE BREAKWATERS

As indicated previously, the offshore breakwaters have been designed as rubble mound breakwaters. The influence of water level and wave conditions have been taken into account in the design of the breakwaters, as well as the effect of wave breaking on the wave height and the wave height distribution.

A requirement in the breakwater design is the flexibility of the breakwaters. Further the breakwaters should not be sensitive to damage (maintenance) nor for excessive damage (collapse). To fulfil these requirements, the breakwaters have been designed out of one grade of (main) armour, without filter layers and core. Only a filterlayer/bottom protection is provided (Figure 5). The advantage of such design is that even with large damage, filterlayers and core can not be eroded since these are not applied. The porosity of the structure is high, which allows the application of relatively small main armour units. Major damage most likely will manifest itself in

the form of lowering of the crest. This will reduce the effect of the breakwaters on the wave conditions and thus on the coast. However, because of the single grade of main armour it would be relatively easy to increase the height again. Similarly because of the single grade main armour, extension or shortening the offshore breakwaters would be relatively simple.

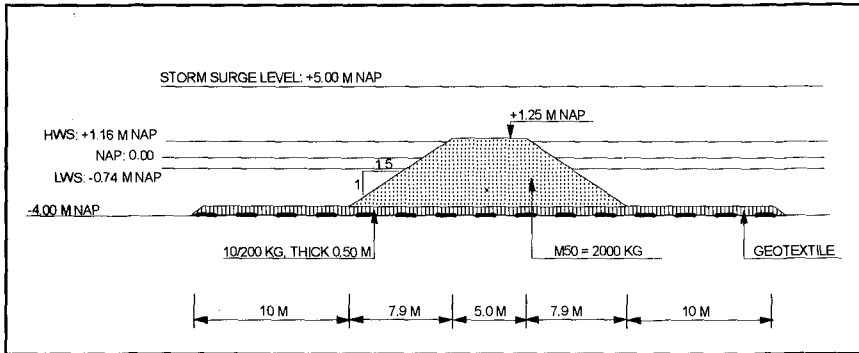


Figure 5 Scheveningen: typical offshore breakwater cross section

In the design of the breakwaters, the combination of design conditions required the breakwaters to be designed as overtopping breakwater and as submerged (reef) breakwaters. Applying appropriate design rules (CUR/CIRIA 1991) the cross sectional design for the Scheveningen site is presented in Figure 5. Similar designs were developed for the Domburg and Callantsoog site. Based on this type of cross section a cost estimate for the construction of the breakwater system was established.

ECONOMIC EVALUATION

In the economic evaluation of the feasibility of offshore breakwaters in The Netherlands three main items have to be taken into account:

1. What are the present costs for coastline maintenance, i.e. without offshore breakwaters?
2. What are the future costs for coastline maintenance, i.e. with offshore breakwaters?
3. What are the costs for the construction of the breakwaters?

The evaluation will be illustrated for the Scheveningen location. For the other locations a similar approach has been followed.

Present costs for coastline maintenance.

The size of maintenance beach nourishments as executed in the past years approximates 70,000 m³/yr. Adopting a unit rate of Dfl 10.00 per m³, the yearly cost for beach nourishments for the situation without offshore breakwaters would be Dfl 700,000. With the length of the nourished beach being in the order of 2000 m, the yearly costs amount Dfl. 350.00 per linear meter of coast. These costs refer to the nourishments only. (The total yearly maintenance costs of the coastline are much higher, taking into account the costs for maintenance of the groynes, the seawall, the dunes etc. For these costs a total of Dfl 150.00 per linear meter should be added.)

Future cost for coastline maintenance.

The future cost for coastline maintenance depends on the effectiveness of the offshore breakwaters to reduce the costs for beach nourishments. Most optimistically would be a situation that the offshore breakwaters just counter effect the erosion (no remaining nourishments). Most pessimistically would be a situation that still additional nourishments would be required, varying from 0% (no additional nourishments) to more then 100% (more than currently required). The latter situation would develop, if behind the breakwaters sedimentation would take place and in the lee side of the breakwater system the nett sediment transport is generated again. With the nourishment cost at Dfl 350.00 per linear meter of coast per year, the future cost for nourishment may range between Dfl 0.00 and more than Dfl 350.00 depending the effectiveness of the offshore breakwater system.

Cost for breakwater construction

The capital costs for the breakwater cross section presented in Figure 5 is estimated at Dfl 15,000.00 per linear meter of breakwater. The cost per linear meter of coast is a function of the breakwater length and the gap width between the breakwaters. For the Scheveningen site a gap width - breakwater length ratio of 250/240 (system I) and 60/120 (system II) has been used. In the first case the capital costs are approx. Dfl 7,350.00 per linear meter of coast and in the second case approx. Dfl. 10,000.00 per linear meter of coast.

Comparison

The final comparison is based on a nett present value calculation for the shore protection with and without offshore breakwaters. In this calculation, the effect of the offshore breakwater on the coast is expressed in percentage of remaining nourishment (0% = no more nourishments, 100% = unchanged nourishment volume). The interest rate has been taken at 5% and the calculation period at 30

years. At the end of the calculation period, the breakwater rest value is assessed at 40% of the initial construction cost. Maintenance for the breakwater is 2% per year. The results for Scheveningen are presented in Figure 6. This figure indicates that both offshore breakwaters schemes proposed for Scheveningen are more expensive than beach nourishments only, given the adopted unit rates for breakwater construction material, sand etc.

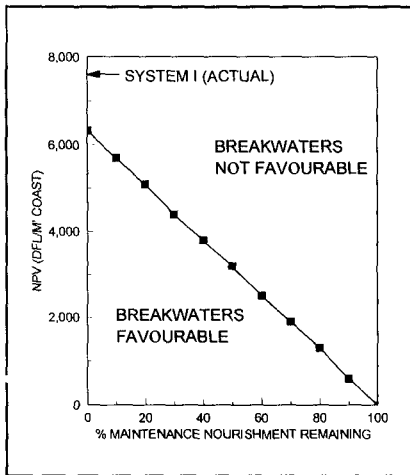


Figure 6 Scheveningen: NPV comparison for two systems

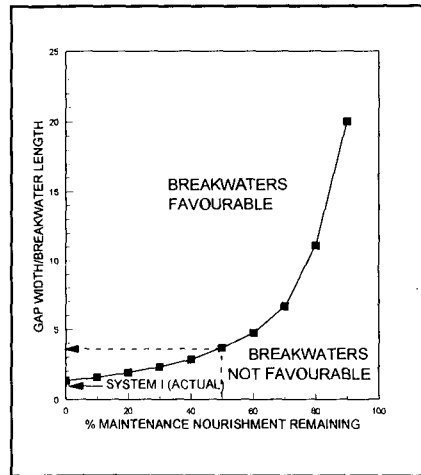


Figure 7 Scheveningen: break even NPV

Using the same nett present value approach, Figure 7 indicates what the cost for offshore breakwaters per linear meter of coast may be, assuming the magnitude of the remaining beach nourishments, to reach a break even point with beach nourishments only. The figure indicates that if the effect of the offshore breakwater scheme is small (large remaining nourishments) the breakwater construction cost should be small. If the effect is large (small remaining nourishments) the breakwater construction costs may be higher.

Given these break even construction cost and the construction cost per linear meter of breakwater (based on Figure 5), the gap width/breakwater length ratio can be determined to reach the break even point for an assumed effect of the offshore breakwaters on the nourishment (Figure 8). This figure indicates that a reduction of the maintenance nourishment to 50% of the present nourishments should be achieved with a gap width/breakwater length ratio of approximately 4. With the large gaps thus resulting between the breakwaters it is assessed that this can not be achieved.

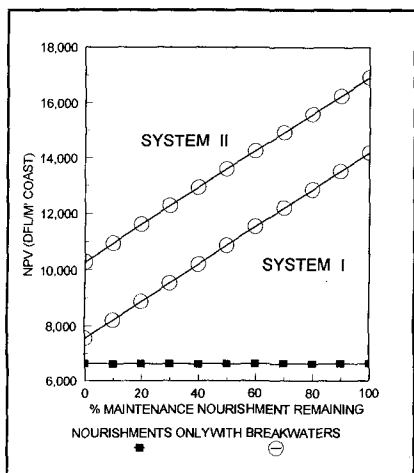


Figure 8 Scheveningen: break even gap width/breakwater length ratio

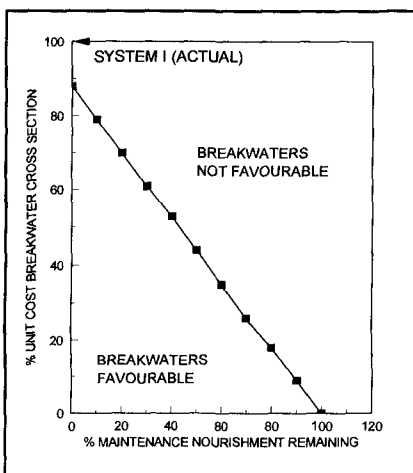


Figure 9 Scheveningen: break even relative cross sectional costs

Alternatively, knowing the break even costs for the offshore breakwater scheme, the average unit rate for the breakwater construction material has been determined. Using the cross sectional profile of Figure 5 and a gap width/breakwater length of 1 the average rates are indicated in Figure 9. It should be noted that the average cost for the breakwater according Figure 5 is approximately Dfl 187.00 per m^3 . The results indicate that if the effect of the offshore breakwater is large, the breakwaters can be constructed of a more expensive material (rock). When the assumed effect of the breakwaters is small, the breakwaters should be constructed of a cheap material (sand). However in the last situation, the offshore breakwaters are not breakwaters any more but offshore sandbanks. Under these situation the morphological processes will be quite different compared to statically stable offshore breakwaters.

EVALUATION

Often Coastal Zone Management organizations resent the application of repetitive beach nourishment as shore protection methodology. This aversion initially is generated by the idea that over the years, regular beach nourishments will cost a large amount of money. For this reason one tends to take protective measures to reduces the losses or even completely stop the erosion of the coast.

The qualitative evaluation of offshore breakwater schemes executed in this study indicates that for ongoing sandy coasts the erosion at the down drift side of the offshore breakwater scheme forms an important aspect and an argument to expect

that even after construction of offshore breakwaters, maintenance nourishments will still be required to counter measure this.

In cases where offshore breakwaters are applied and large storm set-up occur, erosion of beach and dunes still can be expected, although the magnitude of the erosion will be reduced. Hence in cases where single storms may have a large impact, offshore breakwaters will have a mitigating influence on the effect of each single event.

The quantitative assessment of the effect of offshore breakwater schemes on the coastline, especially for a hydro-morphological system including currents and waves, still appears to be complex. One-line coastline models available to the Consultant insufficiently represented this complex hydro-morphological system to supply reliable results to support the outcome of this study.

In that respect initial results of 2-dimensional modelling of offshore breakwater schemes show promising results. It is expected that in the future this will allow for more physically correct modelling and be the basis for a reliable assessment of the quantitative effect of breakwaters on the coast.

Because of the latter limitation, the economical feasibility study of the application of offshore breakwater in Dutch coastal waters has been based on an assumed beneficial effect. Rubble mound offshore breakwater do not show to be economically feasible with the unit rates for sand and breakwater construction materials as applicable in The Netherlands. Offshore breakwaters may become economically attractive when the construction cost is reduced. This may be achieved by alternative breakwater designs, but this has not been executed in this study.

Finally, one could argue whether other arguments can be raised to construct offshore breakwaters despite the higher cost. Assuming some beneficial effect of the offshore breakwater scheme, the average interval between consecutive maintenance nourishments will increase, giving to the public the impression that "less money is thrown into the water". Secondly, taking into account that the beneficial effect of on offshore breakwater scheme is partly counter affected by erosion at the down drift side of the breakwater scheme, offshore breakwater may be used to "shift" the problem. This can be applied to shift the nourishment activity to less frequently used beaches.

REFERENCES

- ROELSE, P. (1990) Beach and dune nourishment in The Netherlands. Proc. 22nd Int. Coastal Eng. Conference, Delft, The Netherlands
- HILLEN, R. and HAAN, Tj. de (1993) Coastlines of the southern North Sea, ASCE.

VERHAGEN, H.J. (1990) Coastal protection after 1990, Technical report 12: groynes and pile rows, Ministry of Transport and Public Works and Watermanagement (Rijkswaterstaat), Road and Hydraulic Engineering Division, The Netherlands (in Dutch)

DALLY, W.R. and POPE, J. (1986) Detached breakwaters for shore protection, WES, CERC, Vicksburg, USA

ROSATI, J.D. (1990) Functional design of breakwaters for shore protection: empirical methods, WES, CERC, Vicksburg, USA

HANSON, H (1989) Genesis: generalized model for simulating shoreline change, WES, CERC, USA.

DELFT HYDRAULICS (1992), Unibest-CL: a software suite for simulation of sediment transport processes and related morphodynamics of beach profiles and coastline evolution, Delft Hydraulics, The Netherlands

RWS-DWW (1992) Comparative calculations with DUROSTA and DUINAF to determine beach and dune erosion for situations with and without offshore breakwaters, Rijkswaterstaat, Road- and Hydraulic Engineering Department (DWW), The Netherlands (in Dutch).