Shore Parallel Breakwaters & Beach Nourishments

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Abstract

The application of shore parallel offshore breakwaters in coastal engineering is discussed. Four well-defined practical coastal engineering problems are the starting point of discussion. The possibilities of a new morphological model and a design support model are indicated.

1 Introduction

Within the CUR-framework (CUR: Centre for Civil Engineering Research, Codes and Specifications), many Dutch partners (Governmental institutes, Consulting firms, Contractors and Universities) recently participated in a joint Dutch research project concerning the application of shore parallel detached breakwaters in combination with beach nourishments.

Shore parallel detached breakwaters are increasingly used as a tool in coastal engineering practice. All over the world series of detached breakwaters have been constructed. In the Netherlands, however, shore parallel breakwaters have not yet been applied in the open sea. Whether this is wise or not is an almost ever lasting debate amongst experts in the Netherlands. The CUR project was partly initiated with the aim to provide the debaters with some joint background information. A second aim was of course to enhance the knowledge concerning this intriguing tool in coastal

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engineering practice.

Many series of shore parallel breakwaters have been built along many coasts all over the world. To build detached breakwaters calls generally for huge investment costs. Thus consequently serious problems had apparently to be resolved with the help of detached breakwaters. It is striking that in the overwhelming number of books, papers and reports which appeared concerning the detached breakwaters topic, often the very reason to apply this tool is hardly discussed. In literature often great successes of the application of series of offshore breakwaters are reported. But, what was the problem which had to be resolved with the help of offshore breakwaters? Often this very basic question is not dealt with in the papers.

In the study a slightly different approach was followed. First four well-defined practical coastal engineering problems were stated and next the possible application of shore parallel breakwaters to resolve these four problems was investigated. (Of course realizing that the use of shore parallel breakwaters is only one tool out of many other tools, and realizing that in more cases than the restricted number of four defined problems, shore parallel breakwaters can be used.) In the investigation it was analyzed how the use of breakwaters could resolve the problem. Special attention was paid to possible additional effects of the application of shore parallel structures. The study was restricted to the application of shore parallel (rock) structures, whether in combination with artificial nourishments or not.

2 Outline of study

The entire study was divided in three phases. In Phase I 'Introduction and inventory' amongst others four well-defined practical coastal engineering problems were outlined; one case was subdivided in two alternatives, viz.:

- A Erosion of a continuous coastline;
- B1 Coastline with interrupted sediment transport: near harbour breakwaters;
- B2 Coastline with interrupted sediment transport: near a tidal inlet;
- C Artificial beaches along coastlines with a lack of natural sediments (recreational beaches);
- D Seaward shifted coastline of a large-scale land reclamation project.

The several cases were defined and the possible use of shore parallel breakwaters was indicated. Typical design problems were pointed out concerning each of the cases. In the Phase I report (CUR, 1997a) also a brief summary was given of more than 100 papers related to the application of shore parallel breakwaters.

In Phase II 'Modelling of sand transport' of the study a method was developed to quantify the effect with time, of (series of) shore parallel breakwaters on coastal morphology in the vicinity of the breakwaters. An existing multi-layer computational model was adapted to a large extent. New formulations were derived. The effect of diffraction behind the breakwaters was taken into account.
One case of the four cases, Case A 'Erosion of a continuous coastline' was studied in detail.

The use of shore parallel breakwaters is often an alternative for the application of artificial (beach) nourishments. The application of breakwaters will often only reduce the erosion rate in the area under consideration; a real zero erosion rate, however, is difficult to achieve. It must be stressed that any reduction of the erosion rate in the area under consideration is often at the spent of the lee-side area. In that area increased erosion rates are to be expected.

The efficiency of an applied shore parallel system of breakwaters was defined in the model as the ratio between the savings in erosion rate and the original erosion rate **in the area to be protected**. The expected increased erosion rates in the lee-side area are not taken into account in the efficiency to be determined. An essential feature of the model is the easy way in which the efficiency of a given (arbitrary) series of breakwaters can be determined. The results of the study in Phase II are summarized in (CUR, 1997b).

With the help of the model developed in Phase III 'Evaluation by a design support model' (CUR, 1997c), the consequences of the application of shore parallel structures related to costs and several other aspects, can easily be evaluated. By filling out some Menu's, the user defines the problem to be studied and the characteristics of the solution with offshore breakwaters in mind. Alternative offshore structures schemes are easily to be generated by the user; the model next calculates the costs.

The basic comparison parameter to evaluate different alternatives is the net present value (NPV) of an alternative. Interest rate and assumed lifetime of a project are to be defined by the user. Also for the zero option (compensation of the observed erosion rate in the area to be protected by artificial nourishments) NPV calculations are made.

The models as developed in Phase II and III of the study are further discussed in Paragraph 4 and 5. In Paragraph 3 the four basic coastal engineering problems where shore parallel breakwaters might be used, are discussed in more detail.

3 Basic problems and the application of shore parallel breakwaters

General

Coastal erosion is in fact a tricky notion. Erosion of the part of the coast which is often considered to be the most valuable part, viz.: beach and dunes (or mainland), can be because of two fundamentally different processes:

i) erosion during a severe storm surge;

ii) structural erosion.

To a first approximation process i) can be considered as a typical (temporary) cross-shore redistribution phenomenon. Sand from the dunes and upper part of the beach is transported during the storm surge to deeper water and settles there. (Under common weather conditions the sand will return to its pre-storm position.) The total volume of sand between some fixed limits in a cross-shore profile [m^3/m] does not essentially change because of the storm surge.

Process ii), structural erosion, is quite different from erosion due to a storm surge. Because of the structural erosion process the volume of sand within a cross-shore profile reduces gradually with time. Sooner or later also the upper part of the profile (dune area) is lost permanently.

If erosion control is required, both types of erosion call for quite different solutions. In the present study structural erosion problems are mainly considered. If in the following **erosion** is mentioned, the erosion is meant to originate from structural erosion processes. When, however, an erosion control scheme to a structural erosion problem is designed, one always needs to take into account the consequences of the selected alternative for the erosion process during storm surges.

Case A: Erosion of a continuous coastline

The present, more or less autonomous, behaviour of many stretches of coast is often annoying the coastal zone managers involved. E.g. structural erosion of a part of the coast calls often for adequate countermeasures. Artificial nourishments have proven to be a good solution for this type of problems, despite the fact that this solution does not resolve the basic cause of the erosion problem. The gradual erosion still continues; only the detrimental effects of the erosion process (e.g. the final loss of beaches) is ultimately prevented. The occurring losses are replenished at a regular basis. (Say every 5 till 10 years.) Application of artificial nourishments in this case can be considered as a **curing-the-symptoms** approach.

With the application of structures (either groynes or shore parallel breakwaters) the coastal zone manager intends to interfere in such a manner in the present sediment transport processes in the erosion area, that the gradual erosion stops or at least is reduced. This approach may be characterized with a **curing-the-disease** approach.

Because many structural erosion problems are due to gradients in longshore sediment transport, it means in fact that often the longshore transports have to be reduced along some parts of the eroding coast. An effective application of structures to stop or to reduce the gradual erosion in the area under consideration, always results in a reduced input of sediments to the lee-side area. Often this reduced input leads to (increased) erosion in the lee-side area compared to the previous situation. Whether this is acceptable or not depends on the particular case. The lee-side consequences must always be taken into account properly in studying solutions for erosion problems.

The unavoidable lee-side consequences of a for the rest even perfect protection scheme, are a serious draw-back of this type of shore protection. Nevertheless in some cases the (extra) lee-side erosion might be acceptable. E.g. in cases where the lee-side area is considered to be less valuable than the protected area, or in cases where artificial nourishments can be better (cheaper) carried out in the lee-side area than in the area to be protected. If the erosion area concerns for instance an important recreation area, artificial nourishments on a regular basis may yield extra costs with respect to economic losses.

A structural erosion problem can be characterized with several parameters, e.g.:

i) length of area to be protected;
ii) rate of autonomous erosion in that area;
iii) longshore sediment transports passing the boundaries of the erosion area;
iv) boundary conditions with respect to wave climate and tide characteristics;
v) 'value' of the lee-side area with increased erosion.

With the actual values of these parameters as starting point, different schemes of shore parallel breakwaters provide an equal number of solutions, each with its own related costs. The main emphasis of the study was to acquire facts to judge the quality of different alternatives. That means that one should be able to quantify in sufficient detail the morphological impact of a chosen system of shore parallel breakwaters. Although some rules of thumb exist, it is generally felt that our knowledge of this topic is far from sufficient. A quote from the US Corps of Engineers Technical Report (Chasten *et al.*, 1993) may illustrate this:

> *'Although numerous references exist for functional design of U.S. detached breakwater projects, the predictive ability for much of this guidance is limited. Knowledge of coastal processes at the project site, experience from other prototype projects, and a significant amount of engineering judgement must be incorporated in the functional design of a breakwater project.'*

(Page 10 of Chasten *et al.*, 1993.)

Within the study in Phase II an important step forward has been made towards our ability to model (and thus to quantify) the effects of arbitrary breakwater schemes properly. (See Section 4.)

Case B: Coastline with interrupted sediment transport

The classical example of a port, built along a sandy coast with a significant longshore sediment transport, shows large morphological changes at both sides of that port. Because of the interruption of the sediment transport by the breakwaters, at the up-drift side of the port continuous accumulation of sediment is observed. Erosion occurs at the down-drift side. (Lee-side erosion.) Although eventually also the accumulation of sediments will yield serious problems for a smooth operation of the port (sediment transport along the up-drift breakwater and sedimentation in the approach channel to the port), in the first years after the construction of the port the gain of new areas is often considered as advantageous. The lee-side erosion, however, is in most cases a serious detrimental side effect of the new port. If this lee-side erosion is not accepted, series of offshore breakwaters might be helpful to mitigate the erosion problem. As long as the breakwaters entirely interrupt the longshore sediment transport, the sediment input into the erosion area remains zero. In order to avoid continuous erosion in the down-drift area the only and best solution with the use of structures is to achieve resulting zero longshore sediment transports in the down-drift area to be protected. At the very end of the protection scheme the lee-side erosion (again) will take place. Indeed only a shift of the local erosion problem can be achieved. Whether this is acceptable or not depends on the particular case. With a well-designed shore parallel offshore breakwater scheme this goal can be achieved in principle.

Although an artificial sand by-pass system with a capacity equal to the full interrupted transport would resolve most of the morphological problems, in practice often under-designed systems are applied (if a system is applied at all). If only a part of the required volume is by-passed (say 75 %), still some lee-side erosion can be expected. Mitigating the remaining erosion with the help of an offshore breakwater scheme to an area further down-drift, puts quite different requirements to the scheme than compared to the zero sediment transport option. Now the scheme should be designed allowing to pass continuously 75 % of the original sediment transport. Undoubtedly quite different design characteristics of the protection scheme are required than in the zero transport case.

The coastlines of the stretches of coast near tidal inlets often show continuous erosion. A tidal basin which is out of equilibrium (e.g. by land reclamation projects in the basin area) continuously 'calls' for sediment imports in order to reach a new equilibrium state. Often the required import of material is at the spent of the sediment volumes in the ebb tidal delta in the initial phase, but eventually also at the spent of the adjacent stretches of coast. This results in a gradual erosion of the coast for a rather long time. This erosion can be prevented by application of an offshore breakwater scheme; a proper design is, however, complicated because the erosion is often (partly) due to effects of tidal currents at deeper water.

If a proper design of the protection scheme is achieved, one has to take into account that less material will reach the tidal basin. The 'demand' of the tidal basin for sediments in order to reach a new equilibrium has then to be fulfilled by other sources.

Case C: Artificial beaches along coastlines with a lack of natural sediments (recreational beaches)

Coastal areas which rely heavily on recreational use of their beaches are often faced with a lack of natural sediments. Consequently small and poor beaches are only available. (E.g. many beaches along the Mediterranean.) Improving the beaches in a restricted area will have large economical benefits for these areas. Since often only in a small area improvements are required and to restrict the volume of sand, artificial nourishment schemes call for additional projects in order to keep the nourishments in place. Shore parallel breakwaters, probably in combination with end-groynes, serve this goal. Wide beaches and a rather long waterline can be achieved in this way. Behind the breakwater segments often tombolo's are designed and constructed.

In order to be able to make a proper design, one should know what is the equilibrium position of the bay-shape behind the gaps between the breakwater segments in relation to the breakwater lay-out and boundary conditions. Sometimes also the case of a non-equilibrium position of the bay-shape (seaward shifted bay-shape in comparison with the equilibrium shape), but with some yearly maintenance nourishments, might be a proper solution. In order to apply this possibility one should have a proper insight in the (yearly) losses as a function of the deviation from the equilibrium position of the bay-shape.

Because of variations (within a year) of the predominant wave direction in fact a real equilibrium position of a bay-shape does not exist. What are the expected variations in this position in a particular case? For a coastal zone manager and the users of the beaches a clear answer to this question is important.

An equilibrium position of a bay-shape under (yearly averaged) common conditions might be a proper notion. However, for a total judgement of an applied scheme, also the behaviour of the scheme under severe storm conditions should be known. Probably irreversible losses of sediments through the gaps will occur. Quantifying these losses as a function of the particular conditions is a difficult design task.

Case D: Seaward shifted coastline of a large-scale land reclamation project

A large land reclamation project in front of a (straight) coastline in open sea calls for huge volumes of sediment. Provided that the new situation calls again for a beach as sea front, a zero option would be to shift all depth contours with the required distance (say two kilometers) in seaward direction. In this case the shape of the cross-shore profile is after the reclamation project the same as before the project. To a first approximation the coastal processes (longshore and cross-shore sediment transports) are expected to change only slightly by the reclamation project.
Shifting all depth contours (say from Datum +5 m to Datum -17 m) means that for each m^2 of new land 22 m^3 of sand is required. Indeed a huge total volume of sand is thus needed for a large reclamation project. Much of the eventual required volume is stored in deeper water in the 'toe' of the cross-shore profile. If one would be able to avoid the fill of the toe, large savings can be achieved.

Shore parallel submerged breakwaters could be used to 'support' the upper part of the cross-shore profile, while the toe can be omitted (a 'perched beach'). In the present example (2000 m seaward shift and 22 m^3 sand for each m^2 new area) 44,000 m^3 sand is required per running meter alongshore. A submerged breakwater supporting the upper part of the profile above Datum -8 m which is situated in the original profile at Datum -13 m yields a reduction with approximately 13,000 m^3 sand per running meter (approximately 30 % reduction). In this application 1 m^3 of stone 'saves' approximately 130 m^3 of sand; in other cases slightly different values are found.

The savings figures as given seem promising. Before the application of submerged breakwaters will be considered as a real alternative, however, various problems have to be resolved (and quantified). What are the losses of sand from the upper part of the profile over and across the submerged breakwater? Is the equilibrium shape of the supported part of the profile still the same as in the shifted case? What are the details of the transition between submerged breakwater and supported profile? Is the transition at crest level of the breakwater or at some distance below the crest?

Comparable to the application as discussed under Case C also a series of emerged shore parallel breakwaters could be considered as a seaward boundary of a large land reclamation project. Instead of a straight new coastline, now a series of bay-shapes serves as sea front. Equilibrium shapes as well as non-equilibrium shapes (but then with some additional maintenance nourishments) are to be considered. Each alternative has advantages and disadvantages. Before real applications are considered, quantification of the morphological consequences is necessary.

Discussion of possible applications of shore parallel breakwaters in some coastal engineering problems

In the discussion of the possible application of shore parallel breakwaters for Cases A to D it became clear that these breakwaters have to be considered as promising alternatives for the problems as indicated. However, it also became clear that before application still some fundamental problems have to be resolved. One should e.g. be able to quantify, as reliable as possible the morphological impact of a proposed scheme. It is felt that no standard methods are yet available to do so. Different boundary conditions only already yield quite different morphological responses and hence quite different protection schemes are to be applied.

Taking some clearly defined real life coastal engineering problems as a guide, has turned out to be a good starting point in notifying the required complex design process of a shore parallel breakwater scheme. Sediment transports play a leading part in the morphological behaviour. Phase II of the study was meant to reveal some of the needed sediment transport quantification aspects of a possible application of shore parallel breakwater schemes. (See Section 4.)

4 Model of Phase II

In Phase II of the project an existing multi-layer computation model is adapted and extended in order to cope with the complicated processes occurring near (especially landward of) offshore breakwaters. In the multi-layer concept distinction is made between longshore transports and cross-shore transports.

In the multi-layer concept the cross-shore profile is schematized in a series of horizontal (rectangular) layers. (See Fig.1.) After schematization the cross-shore profile looks like a staircase. Cross-shore transport occurs from one layer to another; along each vertical part of the staircase a part of the total longshore transport takes place.

The present mutual distance between two adjoining layers $a_{pres.}$ (the present length of a step) is compared with the mutual distance of these layers under equilibrium conditions $a_{eq.}$ (equilibrium distance of a step). The rate of cross-shore transport S_y is assumed to be proportional to the difference between $a_{eq.}$ and $a_{pres.}$.

$$S_y = s_y (a_{eq.} - a_{pres.})$$

where s_y is the cross-shore transport constant. The values of s_y depend amongst others on the depth in the profile. In this approach a cross-shore profile which is out of equilibrium, 'returns' because of cross-shore profile adjustments to equilibrium again after some time. Based on many calculations with a detailed cross-shore morphological computation model (UNIBEST-TC developed by DELFT HYDRAULICS) a distribution over depth of s_y is determined.

Fig.2 shows the well-known distribution of the longshore sediment transport over a cross-shore profile because of an obliquely approaching wave field for a uniform coast in longshore direction. If this distribution is plotted as a function of depth, a (remarkable) triangular distribution is found (see also Fig.2). Such a triangular distribution was found for many different cases (different cross-shore profiles; different wave conditions; different particle sizes). The characteristic water depths d_{top} and d_{zero} (see Fig.2) appeared to be simple functions of the significant wave height H_s. ($d_{top} = \alpha H_s$; $\alpha \approx 1.4$; $d_{zero} = \beta H_s$; $\beta \approx 3.0$.)
Also in cases with a combination of waves and currents typical distributions of the longshore sediment transport over depth have been derived. (See CUR 1997b.)

Reliable distributions of the longshore sediment transport over the horizontal layers are required in the multi-layer model. In the model the orientation of a horizontal layer determines the rate of longshore transport in the part of the profile which is schematized by the layer.

With the existing multi-layer concept the morphological behaviour of large coastal stretches, however, without structures could be simulated with time. To be able to handle also offshore breakwaters in the model, did require serious adaptations of the model. A typical effect of shore parallel breakwaters (either submerged or emerged) is the reduction of the wave height in the 'shadow' zone of the breakwater. Since the wave height is an important determining parameter in the sediment transports, these wave height reductions have to be quantified as a function of breakwater layout (e.g. position with respect to waterline; gap width; length of breakwater segments; crest height) and boundary conditions (e.g. wave height; wave direction; tidal currents).

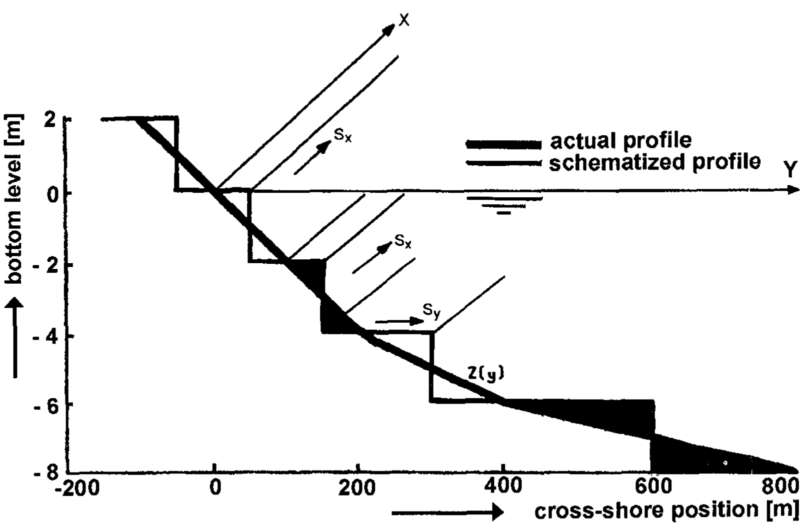

Fig.1 Schematized cross-shore profile.
(Cross-shore transport S_y occurs at different levels; longshore transport S_x is distributed over profile.)

Taking wave transmission and wave diffraction into account, the wave height adaptation has been quantified for some general cases.

The adapted model has been applied in a typical Case A problem with a series of different shore parallel breakwater schemes. The morphological development with time after inserting a breakwater scheme in the model, could be simulated. Some test cases showed reliable results; at least showed a behaviour as qualitatively expected.

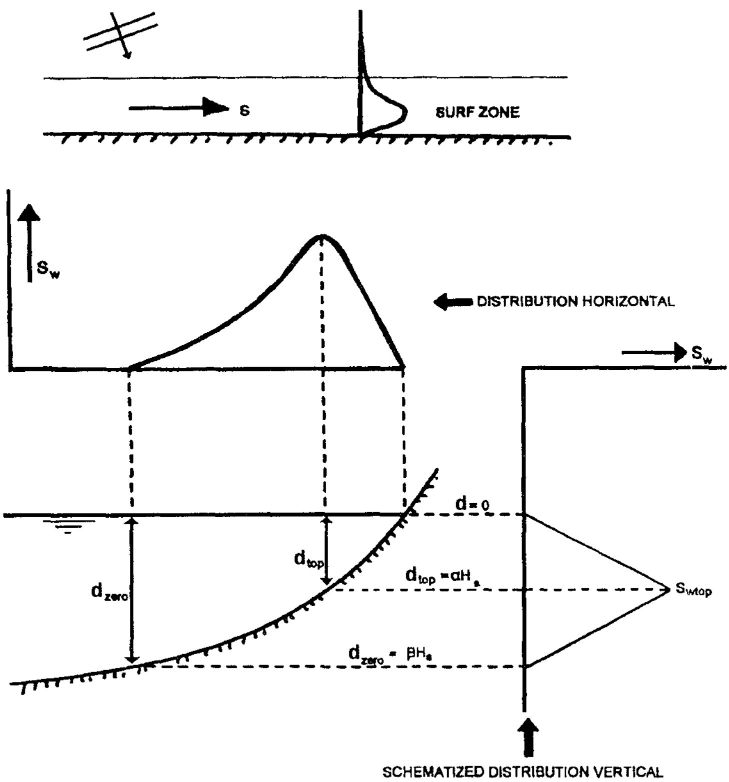

Fig.2 Longshore sediment transport distribution because of obliquely approaching waves.
(Upper panel: top view; lower panel: horizontal and vertical distribution of longshore transport.)

The efficiency of a given breakwater scheme is an important parameter in a design process. The efficiency of a scheme is defined as the ratio between the savings in erosion volume and the original erosion volumes **strictly in the area to be protected.** The model is provided with a very useful 'auto-nourishment' option. With that option the efficiency of a given scheme can be directly determined. Assume that the policy is to keep the waterline at least seaward of a limit position. If somewhere in the area to be protected at any time the waterline surpasses the limit position in landward direction, the computational model adds the required volume of sand in order to restore the position of the waterline to the limit position. Comparing the volumes still to be added in a case with a shore parallel protection scheme, with the volumes to be added in the unprotected case, yields the efficiency of that scheme. (See Figs.3 and 4 for examples.)

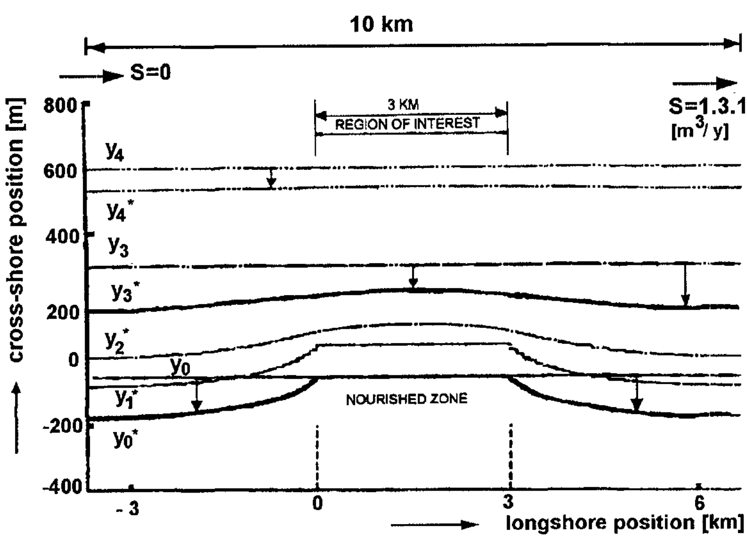

Fig.3 Development of eroding coast after 10 years with auto-nourishments.
(A stretch of coast of 10 km shows a large gradient in longshore sediment transport; dS_x/dx = 130 m^3/m per year. The waterline of the middle part is kept at position with the auto-nourishment option. The figure shows the development of 5 different layers.)

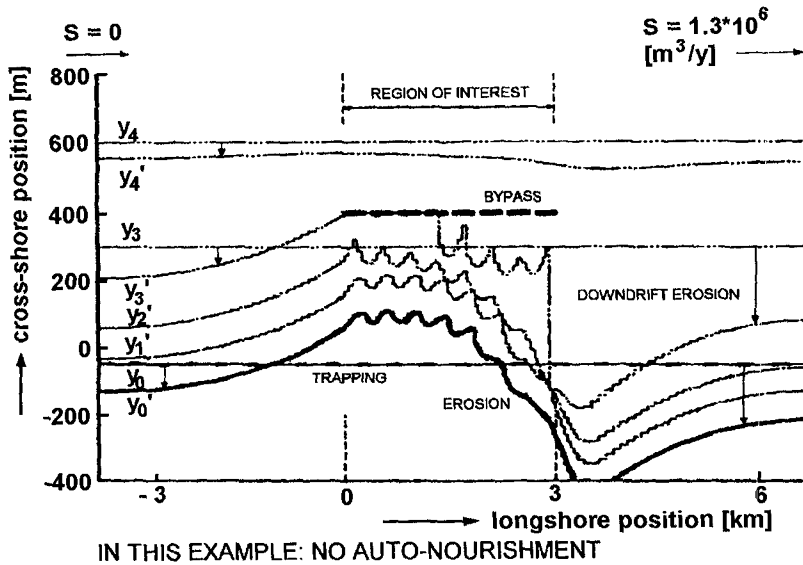

Fig.4 Development of eroding coast protected by a series of offshore breakwaters after 10 years.
(Same stretch of coast of Fig.3. In this case protected by a series of shore parallel offshore breakwaters. Notice the accumulation of sediments at the up-drift side behind the breakwaters and the lee-side erosion.)

The Phase II model has been applied in only a restricted number of cases. The model has shown its abilities. The model is still a research version; it will be upgraded in future to a general applicable model. (See Steetzel *et al.*, 1998.)

Applying a multi-layer model to simulate the very complex morphodynamical processes in the vicinity of offshore breakwaters is in fact a sign of weakness. Applying process-based morphological models would be strongly preferred. Although this type of models is improving very fast, the present versions are not yet able to simulate the development of the coast over a longer time for offshore breakwater cases satisfactorily. As a part of the studies in Phase II of the project some simulations of a few basic lay-outs of offshore breakwaters have been made with the Delft 2D morphological model of DELFT HYDRAULICS. The results are promising, but further research is necessary before this approach can be used in general applications. It is expected that as a result of the EU sponsored SASME project (SASME: Surf and Swash zone MEchanics), much progress will be made in the morphological modelling abilities.

5 Model of Phase III

A design support model was developed in Phase III of the project. It has proven to be a useful tool during the first phases of a design process. Different alternatives can be fast and easily evaluated. The model is Menu-oriented; the user has to fill out the basic characteristics of the design in mind. The model is available in a LOTUS 123 release 3.4, and in an Excel version.

The problem, indicated as Case A (erosion of a continuous coastline) has been studied in detail. The autonomous behaviour of the stretch of coast under consideration yields erosion. The detrimental effects because of the retreat of the coast can be mitigated by regular beach nourishments. This solution is considered as zero option. Also with different shore parallel breakwater schemes the erosion problem can be (partly) resolved. Often the problem is indeed only partly resolved, because the scheme does not prevent the erosion entirely. Some additional (but reduced) regular artificial nourishments are still required to keep the coastline at the prescribed position. Four sets of input data are required to run the design support model. These four sets of data can be generated with the Phase II model. Consequently a strong link exists between the Phase II and the Phase III model. Based on experience, rules of thumb or engineering judgement these four sets of data can of course be simply changed.

The model thus requires the input of a (restricted) number of efficiency values as a function of characteristic breakwater lay-out parameters like:
(i) the position of the offshore breakwaters from the coastline;
(ii) the relationship between offshore distance and length of the breakwater segments;
(iii) the ratio between gap width and length of the breakwater segments;
(iv) the crest height of the segments relative to the mean water level.

Within the program some basic dimensions of a breakwater scheme and some boundary conditions have to be specified by the user; next 'automatically' a simple static stable cross-section is calculated (Hudson formula). With (freely to select) fixed costs and unit prices for primary layers, secondary layers and core material, the construction costs of the breakwater scheme are determined.

The model is primarily developed for the use of rock structures as breakwaters. If for instance the use of geocontainers (large bags of geotextiles filled with sand) is considered as construction material for the offshore breakwaters, the user can 'simulate' this application by simply using appropriate unit prices.

The basic comparison parameter to evaluate different alternatives (including the zero option) is the net present value (NPV) of an alternative. Interest rate and assumed lifetime of a project are to be defined by the user.

If along a continuous eroding stretch of coast an offshore breakwater protection scheme is applied, the reduction in erosion in the protected area is always at the spent of the lee-side area. If at the end of the day also the (increased) erosion problem in the lee-side area has to be resolved, a shore parallel breakwater scheme ean never be an adequate solution. In some special cases, however, this firm statement might be relaxed. If, for example, regular nourishments in an area to be protected yield huge additional cost (e.g. economic losses in an important recreation area), concentrated nourishments in the lee-side area could be ultimately cheaper. The design support model has been provided with opportunities to take such cases into account.

6 Concluding remarks and recommendations

Concluding remarks

Although many day to day coastal engineering problems can be properly resolved with 'soft' methods (artificial nourishments), the application of shore parallel structures ('hard' method) could be a promising alternative in some cases. [Often a combination of 'hard' and (additional) 'soft' seems a good solution.]

Although the project has not resolved all problems, and not all aims have been achieved, the study has certainly increased the knowledge concerning the possible application of shore parallel structures. The project has served as a fruitful starting point for further studies. A promising approach to resolve the remaining problems has been found.

Recommendations

The Phase II part of the study has revealed that a promising modelling tool has been developed. It is recommended to extend and to generalize the use of this computation model. See e.g. Steetzel *et al.*, 1998.

Process-based morphodynamic modelling of complex cases (like offshore breakwaters applications) is developing very fast. It is recommended to spend additional efforts in attempts to model some typical cases with this type of morphodynamic models.

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