CHAPTER 155

SEAWALLS and SHORELINE PROTECTION

by:
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Abstract

All over the world shore-parallel constructions (seawalls; revetments; bulkheads) suffer from damage. It is argued that these constructions are in fact frequently built at places where they shouldn't.

1 Introduction

Coast managers are frequently faced with erosion of their sandy coasts. Valuable land is encroached by the sea. Owners of houses and hotels, bordering eroding coasts, often 'force' (sometimes by means of the politics) the coast manager 'to-do-something'. Not seldom it is then felt more important to do indeed 'something' than doing the right things.
Unfortunately, too often a seawall or a revetment is selected to overcome the direct erosion problems. However, just from the common coastal engineering practice it can be seen that seawalls or revetments do not solve the problems in the right way. Entirely destroyed seawalls can be observed along coasts all over the world. This destruction is by no means always due to the fact (that would be a legitimate reason) that the design conditions were surpassed during a single storm. No, the basic ideas behind the application of seawalls or revetments were in fact quite often wrong.
Demolished coastal constructions harm the prestige of 'coastal engineering' as a respectable profession and should be avoided as far as possible.

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In this paper mainly the rôles of seawalls and revetments in the game of coastline erosion are discussed. Possible alternatives come hardly up for discussion.

2 Definitions and limitations of present discussion

Seawalls and revetments are shore-parallel constructions and are meant to protect the hinterland against flooding and/or erosion. They are situated against features like scarps, embankments, cliffs, dunes and promenades. The distinction between seawalls, revetments and also bulkheads is generally not quite clear. Throughout the present paper the term 'seawalls' will be used to indicate the type of constructions under consideration. (Shore-parallel constructions.)

Sandy beaches are mainly considered in the paper. So at least under 'usual' conditions a sandy beach, for instance for recreation use, is assumed to exist in front of the seawall.

Fig. 1 shows three typical cross-sections with a shore-parallel construction. Cases like case a) and b) are considered in the present paper (sandy beaches in front of the construction under usual conditions). Cases like case c) are not considered (no beach in front of the construction).

Case a) is typical for well-developed seaside resorts. On the benefit of a prosperous development often a clear distinction between 'sea' and 'land' is desired. A seawall can provide that.

Case b) is typical for important investments which are apparently at stake. The encroaching sea obviously causes erosion of the beaches and the dunes. With the shore-parallel construction the attack of the sea is thought to be beaten off.

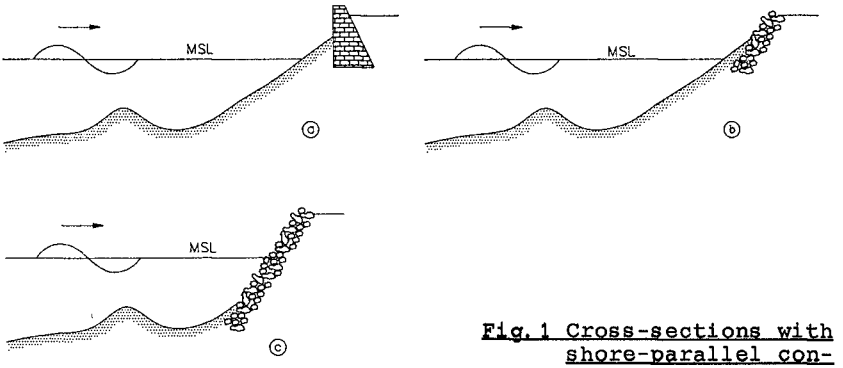

Fig. 1 Cross-sections with shore-parallel constructions

All over the world, however, damaged and even entirely demolished seawalls can be found. In many cases it is felt that in fact design errors are the main cause of the damage. Preventing of some of these errors in future is the main aim of the present paper.

3 Analysis of erosion problems

Seawalls are often built to overcome the felt 'problems' of our coasts. In principle two basic erosion problems with sandy coasts do exist, viz.:

a) erosion/recession during a storm (surge) event
b) gradual long term erosion

Fig. 2 shows in plan view a stretch of a coast at a certain moment in time (under 'usual' sea conditions). The 'problems' a) and b) can be clearly illustrated if the behaviour of cross-section A-A of Fig. 2 is considered as a function of a long time. For reasons of simplicity the behaviour of the position with respect to the reference line of the so-called dune-foot is considered to be representative for the behaviour of the entire cross-section (other characteristic profile features could also be selected). The dune-foot is the intersection point between the gentle beach slope and the steep slope of the dune front.

Fig. 3 shows three typical possibilities of the behaviour of a sandy coast.

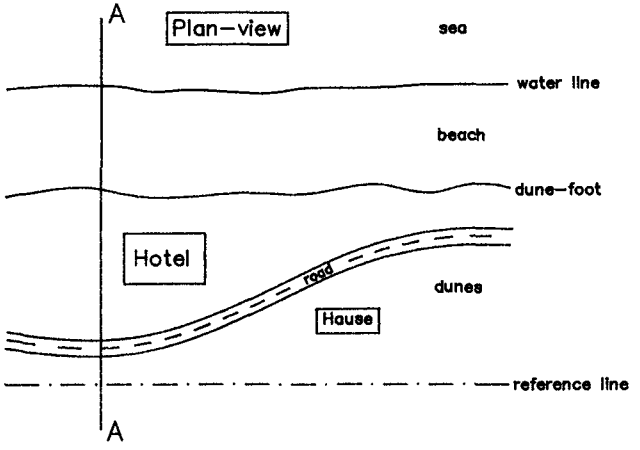

Fig. 2 Plan-view of coast

Fig. 3a represents an essentially stable coastline. However, storm (surge) events cause sudden recessions of the position of the dune-foot. Since the cross-section in consideration is, seen over a longer period, stable, a recovery of the dunes will take place in the years after the storm event. Depending on the seriousness of the storm event the magnitude of the recession can vary considerably. Fig. 3a represents in fact case a) indicated in this section.

Fig. 3b shows a gradually eroding coast (with surge events superimposed on that). The recovery after a surge is not entire. Fig. 3b represents case b).

[For the sake of completiness in Fig. 3c an accreting coast is shown (also with storm events). In the present discussions these cases are not considered since accreting coasts cause hardly 'problems' to the coast managers.]

4 Erosion/recession during a storm (surge) event

Erosion of the dunes and the upper part of the beaches can occur during a severe storm. The rate of recession during that event depends on the seriousness of the storm involved. During the storm not only the wave attack is greater than during usual conditions, but also the water level (surge level) increases to levels (far) higher than usual. Along coasts bordering oceans the increase in water level during the passage of a storm is often moderate; along coasts bordering funnel-shaped seas the increase of the water level may mount several meters.

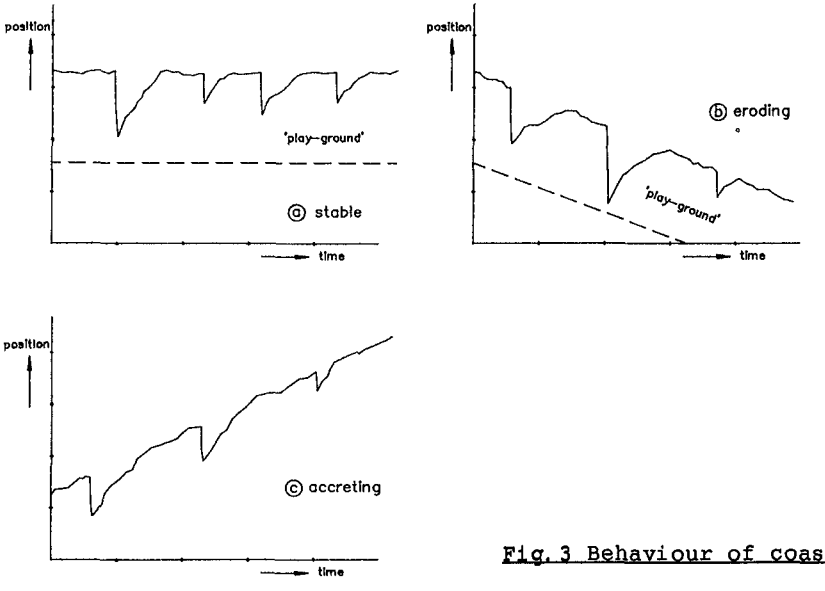

Fig. 3 Behaviour of coast

Fig. 4 shows schematically what happens during a severe surge. Material of the dunes is eroded and (mostly) settled again on the foreshore. Since the shape of the profile becomes less steep, the erosion process (the rate of erosion) slows down with time. After the surge a retreat distance RD can be observed.
Various methods are available at present to calculate the volume of dune erosion after the storm surge. [Kriebel and Dean (1985); Vellinga (1986).] These methods can be applied if the boundary conditions during the storm surge are known

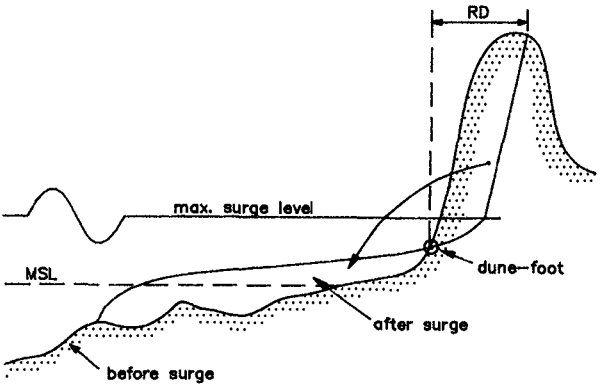

Fig. 4 Dune erosion process

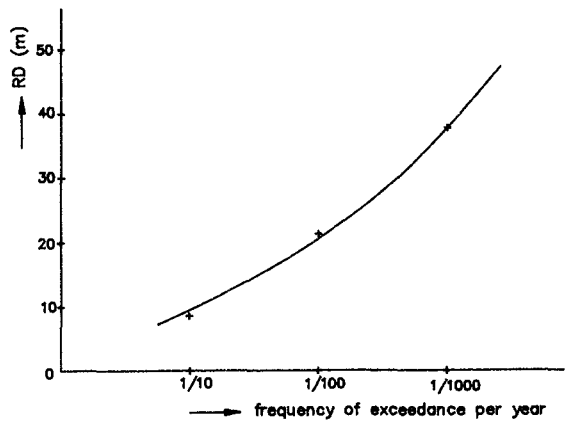

Fig. 5 RD as a function of frequency of exceedance

(wave height; wave period; maximum surge level; storm duration; particle size diameter; initial profile). Many of these boundary conditions have a highly stochastic nature. Nobody knows what the conditions will be next year. Based on long term observations and/or simulation calculations one is in fact only able to predict the probability of occurrence of a set of bad boundary conditions in a certain storm season or a certain year. With probabilistic methods [see e.g. Van de Graaff (1986)] one is eventually able to determine a figure like Fig. 5. Different retreat distances RD are expected depending on the frequency of exceedance.

In order to prevent superfluous damage the coast manager (or the 'society') has next to select an appropriate design frequency of exceedance (with a related design-RD distance). It should in fact be avoided that high investments in valuable goods like houses, hotels and roads are done in the selected design distance. From a coastal engineering point of view this seems quite logical. The sea needs a certain 'play-ground'. (In Figs. 3a and 3b arbitrary 'play-grounds' have been sketched.) Also from an economical point of view such a proceeding of a restriction policy can be simply justified. The everyday practice, however, is quite different. Partly due to a (sometimes pardonable) lack of insight in the 'tricks' of the sea, but also sometimes due to an almost blameworthy inability of the responsible authorities, too many valuable investments are done too close to the shoreline. A (apparently unexpected) rather severe storm surge may destroy consequently many buildings. After such an occasion the call for countermeasures will grow and it will be obvious that the construction of a seawall will come up as a possibility to avoid similar problems in future. It will be for sure that in this particular case a well-designed shore-parallel construction may indeed overcome the erosion problems due to a severe storm surge. A seawall can diminish the 'play-ground' of the sea. It should be stressed that a well-designed construction should be applied. E.g. Steetzel (1987) argues that if the erosion of the dunes is prevented due to the construction of a revetment against the dune front, severe erosion just in front of the revetment has to be expected. If the so-called 'denied' volume (= eroded volume from the dunes if the revetment was not there) is large, the depth increase in front of the construction may become quite considerable. Under Dutch design conditions, so far, erosion depths are expected of several meters below the initial beach profile. If the foundation depth of the construction is too small, stability problems for the entire construction may rise. In an essentially stable case, a recovery of the erosion pit will mostly follow soon after the storm [cf. Dean (1986)].

In conclusion it can be stated that in essential stable cases, where it is felt that the needed 'play-ground' of the sea should be restricted, a properly designed seawall might be applied.

5 Gradual long term erosion

Fig. 3b is characteristic in the case in consideration. The coast apparently recedes seen over a number of years. The yearly rate of recession depends of course on the particular situation, but is often up to some meters per year. [During real serious storm (surge) events the retreat might be up to some tens of meters per occasion (per day).]

A sneaking retreat of a built-up coastal area (with sometimes a storm surge event imposed on it), is extremely annoying to a coast manager. From time to time buildings have to be abandoned and often it can be almost precisely predicted when the next building is on its turn.

In cases like these too often the next (wrong) reasoning to build a seawall is followed:

- The coast (the built-up area) recedes.
- We have to stop this recession.
- Let us fix the dune front and the coast cannot recede further.
- Let us build a seawall to fix the dune front.

In the first years after the construction, unfortunately, all seems like a bed of roses. The erosion of the built-up area has been stopped indeed. The owners of the buildings are quite satisfied and the coast manager, happy with his great success, decides to build also a seawall along another eroding part of the coast which is under his control.

However, after the first happy years after the construction, a period with increasing problems starts. It will turn out that the erosion of the beaches in front of the seawall has continued or has even increased. The beaches in front of the seawall have lowered. The waves reach more easily and more frequently the seawall. The attack on the seawall increases. To prevent serious damage the seawall has to be reinforced or has to be 'protected'. In spite of these countermeasures the erosion of the beaches continues. After some time all the beaches have been disappeared. A situation like in Fig. 1c has been developed. There are, also under usual conditions, no beaches anymore for recreation purposes. The seawall has little by little changed in a seadike. In spite of these in fact dramatic developments, our coast manager remains often proud. The erosion by the sea has certainly been stopped. The encroachment of the sea of houses and roads has certainly ceased. That the beaches have been lost is a pitty; it is all in the game. The costs of the regular reinforcements of the seawall are paid by the tax payers, so that does harm 'nobody'. At the end, after a number of years, only a few old persons know that in past nice sandy beaches did exist in this area.

What went wrong in fact?

The basic point is that it is a gradual erosion problem (cf. Fig. 3b). To overcome this type of problems, two methods are available in principle:

1) Feed from time to time artificially the amount of material which has apparently lost along the coastline (beach nourishment).
2) Try to interfere in the sediment transport process which causes the erosion. This interference should be such that the erosion stops in the area you like to save.

Method 1) is almost trivial. However, this method is increasingly attractive and can be applied almost always. The dutch Manual on Artificial Beach Nourishment (1987) is recommended to consult if an actual beach nourishment scheme has to be designed.

Method 2) is more difficult to execute. First of all it should be established which sediment transports cause the erosion. If that has been established one has next to decide how to interfere actually.

Two main causes do exist for a gradual erosion of a part of a coast:

a) Continuous offshore sediment transport from the upper parts of the beach profile (beach and dunes) to the deeper parts of the profile.
b) Gradient in the longshore sediment transport.

Re a) Continuous offshore transport

Cross-shore directed sediment transports always take place in an actual cross-section of a beach profile. Depending on the wave conditions, water level and the shape of the initial profile, onshore or offshore transports take place through an arbitrary vertical cross-section. Seen over a relatively long period (from year to year for example) the shape of the beach profile often doesn't change so much (dynamic equilibrium). In a constant situation with respect to the boundary conditions (constant mean sea level and constant yearly wave climate), there is in usual cases no reason that a continuous offshore directed transport will be the reason for a gradual erosion of the coast. If a continuous offshore transport from the upper parts of the beach profile to the lower parts of the profile would occur, the beach profile would be flatter with time. Next it can be argued that the offshore transport rates will then slow down till an equilibrium has been reached. (The 'sea' had many centuries time to reach that!) Only if the supplied material to the deeper part of the profile is eroded again (e.g. by a gradient in the longshore transport in that region) a continuous cross-shore transport might be maintained. The real reason for the erosion of the coastline is then, however, not the offshore transport, but the mentioned gradient in the longshore transport on the deeper parts of the beach profile. The offshore sediment transport is only an intermediary mode of transport.

Only if the boundary conditions change with time, a more or less continuous offshore sediment transport might occur. This transport can be seen as 'necessary' in order to adjust

the shape of the beach profile so that is fits (again) with the 'new' boundary conditions. The global sea-level rise and an abrupt change in the wave climate are examples of changes in the boundary conditions. It will be clear that if these changes in the boundary conditions occur, a simple seawall cannot solve the induced erosion problem. Under usual conditions the seawall doesn't interfere in the underlying transport processes. (Only if the seawall is directly attacked, some interference might occur.) The erosion of the upper parts of the beach will continue. The seawall will be attacked more frequently and more intensively. If one likes to interfere actually in the (offshore) sediment transports one has to think of (submerged) detached offshore breakwaters. Such a construction might eventually effect (reduce) the wave action which approaches the coast and consequently might reduce the offshore sediment transports.

Re b) Gradient in the longshore sediment transport

In many cases a gradient in the longshore sediment transport is the main reason of the erosion problems of sandy coasts. Examples are the lee-side erosion near breakwaters or jetties and the erosion of convex coastlines.

Fig. 6 shows schematically the magnitude of the longshore sediment transport (e.g. in m3/year) as a function of the position along an eroding coast. The increasing sediment transport with x is the reason of the erosion problems. The magnitude of the gradient dS/dx is a measure of the actual erosion problem. If one wants to stop the recession of the coast in stretch A-B in Fig. 6, one has to nourish volume V (see Fig. 6) along section A-B on a yearly basis or one has to 'change' in one way or another the sediment transports

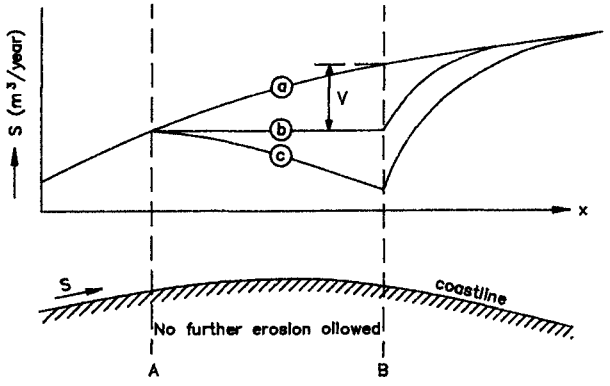

Fig. 6 Sediment transports along coast

along stretch A-B. Instead of a distribution of the sediment transports according to line a) in Fig. 6, a distribution according to line b) would in principle fulfil our requirements. The erosion in section A-B has stopped indeed ($dS/dx = 0$), but down stream of stretch A-B an increased erosion can be expected. (Increased dS/dx values in comparison with the initial situation.) To sketch a line like line b) is of course quite simple and is one thing, but how to acquire such a line in an actual case is another. It is for sure, however, that with a seawall by no means a situation like line b) can be reached. The basic problem was a gradient in the total longshore sediment transport and the longshore sediment transports take place (at least under usual conditions) on the foreshore and the shoreface. Since a seawall doesn't interfere in this type of sediment transport, no direct reducing effect can be expected. Only under storm conditions, when waves hit the shore-parallel construction directly, probably some reduction of the longshore sediment transports might be expected. In that case, however, it is also conceivable that, due to wave reflection, an increase of the longshore sediment transport will take place.

Since a shore-parallel construction near the dunes doesn't interfere generally in the sediment transports, the erosion continues; the shoreface, the foreshore and the beaches become deeper and at the end the attack of the sea on the seawall will intensify. Damage occurs; reinforcements of the seawall will be necessary. Nearly all seawalls built to restrict the further erosion at the lee-side of harbour breakwaters or jetties suffer from the stated problems.

As it has been indicated it is impossible to 'change' the sediment transport line a) in Fig. 6 to line b) with the help of a seawall. With the construction of groins or rows of (wooden) piles [perpendicular to the coast], or the construction of a (submerged) detached breakwater [parallel to the coast], the desired change from line a) to line b) is possible indeed. How to design these countermeasures actually, is a difficult coastal engineering problem, but from the 'physics' it can be understood at least that these constructions might help to overcome the erosion problem. (They interfere in the original sediment transports.) That a proper design of these countermeasures is indeed a difficult task can be illustrated with the help of Fig. 7. Case I line a) shows the same coastal erosion as Case II line c). The same gradients dS/dx occur, however, the magnitudes of the longshore sediment transport differ considerably. The lines b) and d) represent the ultimately desired sediment transport lines for Case I and Case II respectively. It is beyond doubt that the operation to achieve line b) from line a) calls for quite different countermeasures than to achieve line d) from line c). One has consequently to know quite precisely what the actual magnitudes of the sediment transports are, before a proper design of countermeasures can be made.

Changing the sediment transports along stretch A-B in fig. 6 from line a) to line b) is just necessary and sufficient to stop the erosion in that section. If line a) is changed in

line c) accreting of the section A-B can be expected. (That is in fact an 'over-kill' operation.) Accreting might be favourable to people living along section A-B. The erosion problems at the lee-side of section A-B will, however, consequently increase.

Since so many examples of the bad behaviour of seawalls are available, one might ask oneself whether seawalls will even worsen the erosion problems of the coasts they intend to protect. From the physics no sound support can be found for this idea. Seawalls do not interfere in the sediment transports, so consequently they will not increase the erosion problems. This hold at least till the time that some beaches are still present in front of the seawall under usual conditions. When all the beaches have disappeared (a case like Fig. 1c has been reached then), a quite different situation is reached. Increased as well as decreased sediment transports are conceivable depending on the actual conditions.

6 Conclusions

- Demolished seawalls harm the prestige of 'coastal engineering' as a respectable profession.
- The application of seawalls as a means to combat erosion of coasts should be restricted to a very limited number of cases.
- Only in essential stable cases where some reduction of the so-called 'play-ground' of the sea is required, a seawall would be an appropriate solution to achieve that goal.
- Along gradually eroding coasts, seawalls shouldn't be used to prevent further erosion. A seawall doesn't 'work' in these cases since a seawall doesn't interfere in the sediment transport processes.
- Generally seawalls don't 'destroy' beaches.

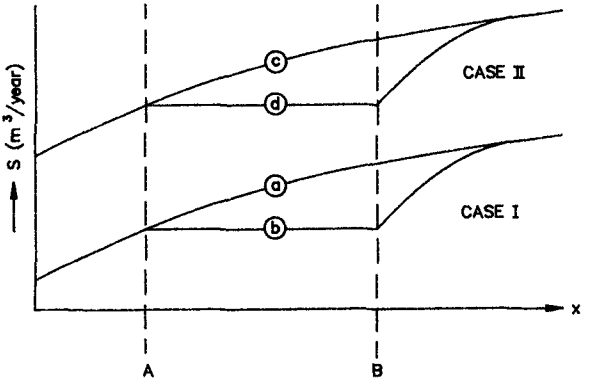

Fig. 7 Effect of magnitude of sediment transport

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