

Erosion Control with Breakwaters and Beach Nourishment

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ABSTRACT

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On some parts of the Danish North Sea coast the erosion average is 3-4 m per year. The peak average erosion is 11 m per year. On those eroding locations the dune system is weakened or has disappeared leaving low areas behind the dune system open to flooding. The measures against erosion are a combination of beach nourishment and low breakwaters close to the shoreline. The flood protection is re-established by building artificial dunes that are protected by a revetment.

INTRODUCTION

During the last 100 years, structures have been built at several locations along the Danish North Sea coast. Some of those structures, harbours and major groin systems, have caused

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severe leaside erosion. The subject of this paper is to describe how the erosion is stopped and how the damages are repaired.

THE EROSION PROBLEM

Figure 1 shows the Danish North Sea coast and Figure 2 shows the average shoreline

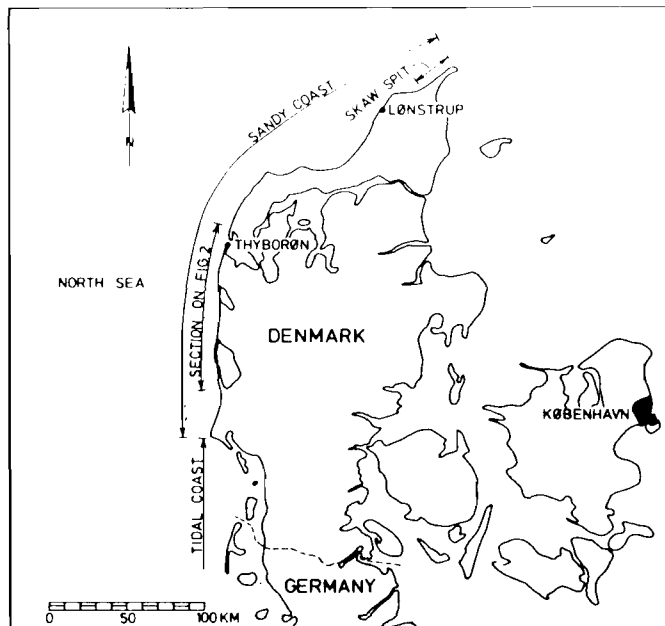


Figure 1. Map of Denmark.

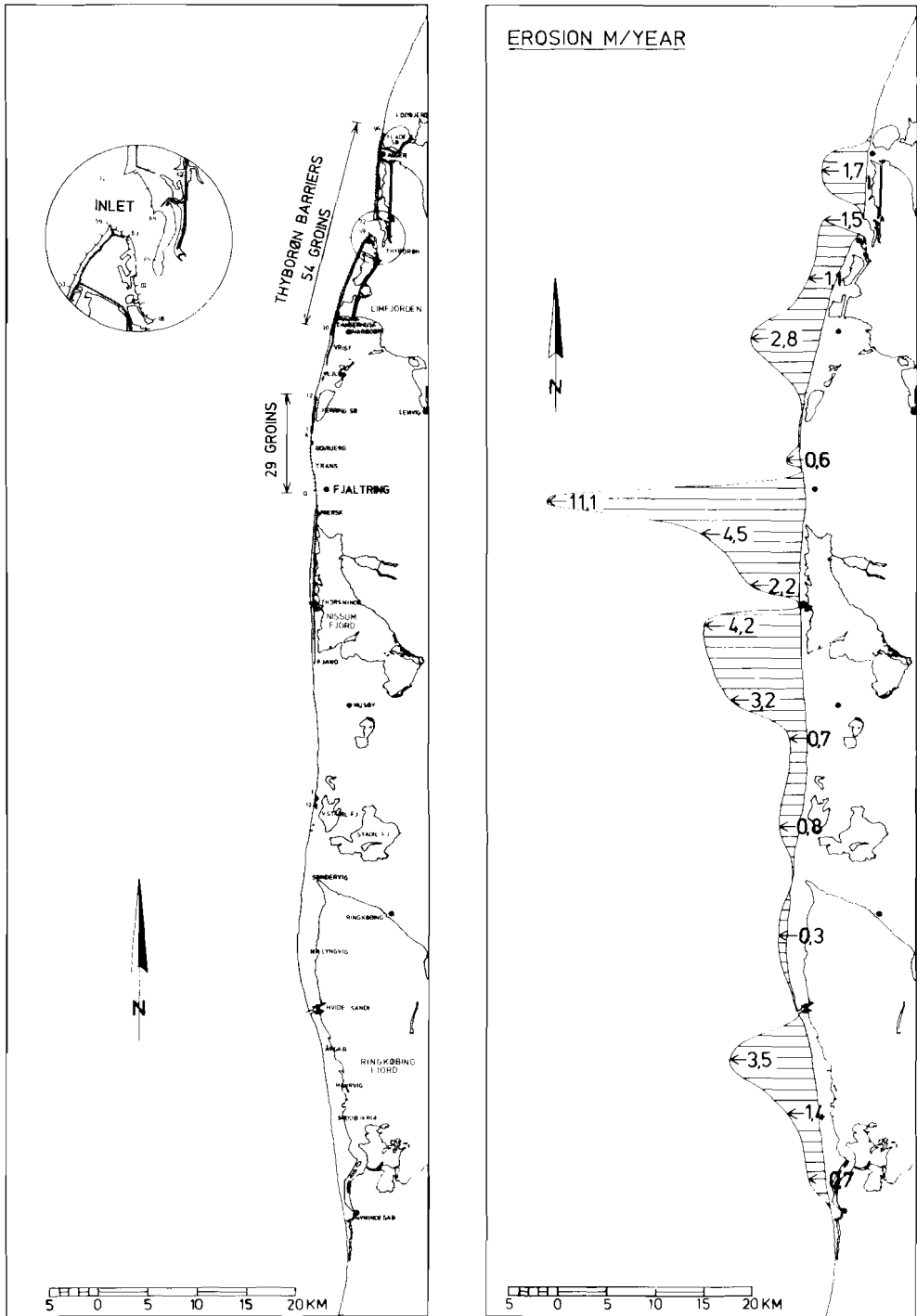


Figure 2. Average erosion, m per year.

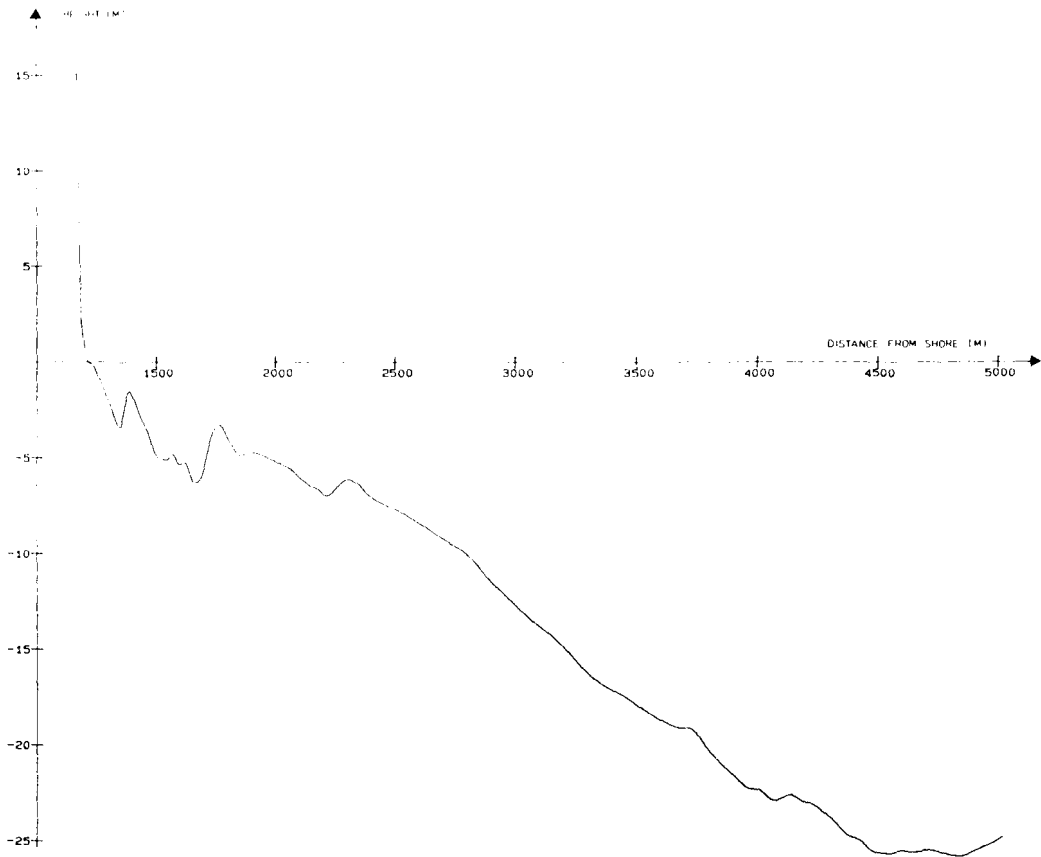


Figure 3. Example of coast profile.

Table 1. Statistics of water level and waves in the area with most severe erosion.

Return Period (years)	10	30	50	100	200
Waterlevels (m)	2.7	2.9	3.1	3.3	3.5
H_{0s} (m)	6.2	6.9	7.2	7.5	7.9
T_{02} (sec)	9.3	10.2	10.4	10.7	11.1

retreat in metres per year over a period of years on a part of this coast. The peak erosion of about 11 m per year has taken place on the leaside of a major groin group built in the first part of the century. On the parts with large erosion, the dune system has disappeared or is very weak which means that low areas behind the dunes are open to flooding. It is therefore necessary to re-establish the dune protection in order to stop erosion.

Erosion control is primarily achieved by sup-

plying sand to the beach and coast. This is, in many cases, combined with construction of low breakwaters close to the shoreline. The re-establishing of highwater protection is achieved by construction of an artificial dune protected by a revetment.

WATERLEVEL, WAVES AND COAST PROFILES

Waterlevel and wave statistics in the area with the most severe erosion are shown in Table 1. A typical shore profile is shown in Figure 3.

DESIGN OF BREAKWATERS

The reasons to use breakwaters in combination with nourishment are (a) to minimize the total cost of nourishment and breakwaters and

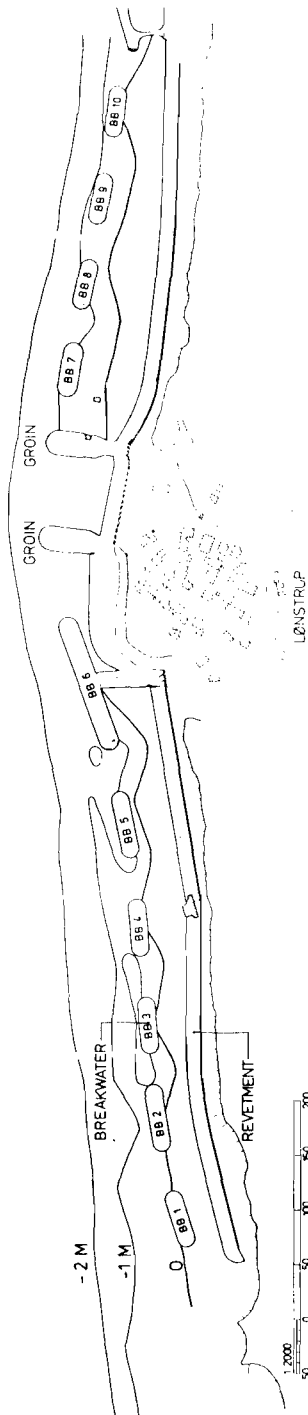


Figure 4. Group of breakwaters built in 1983 at Lonstrup.

(b) to also maintain a high level beach during rough weather.

Some economic design considerations concerning breakwaters are summarized in what follows. The most landward position in which a breakwater should be built is the shoreline in its most retreated position during the year. The seaward extension is determined by considering how far out in the profile it is possible to work with land-based equipment. The greatest depth we have been working in is 3 m and the farthest distance from the shoreline is about 50 m. Besides that, the positions of longshore bars set a limit for reasons of minimizing leaside erosion caused by the breakwaters, *i.e.* they should not effect more than the sediment transport on and close to the beach. Figure 4 shows the layout of a group of breakwaters built in 1983. Between the landward and seaward limits it is possible to optimize the position of the breakwaters. It is likely, that if the dunes are high and the costs of sand supply are high it will lead to higher and more seaward breakwaters, and vice versa. The concept is that the position and design height of the breakwaters represented by the level of the seabed and top level of the breakwaters can theoretically be estimated when certain presumptions are made, so that the total costs of shore protection are minimal. Total costs include building costs, capitalized maintenance, and nourishment costs.

The optimal design and position of the breakwaters are determined as follows:

(1) A frequency table of $H_{r,ms}$ at the position of the wave recorder is calculated. The waves are transferred to deep water where the direction is set equal to the direction of the wind.

(2) A frequency table of waves just in front of the breakwater is calculated. The calculation is carried out by refraction and shoaling of each wave component from deep water to breaking. After breaking the waveheight is calculated according to (GODA, 1985).

(3) When reaching the breakwater, wave energy is transmitted through and over the breakwater. Calculations of the transmitted wave height are made according to (SPM, 1984). Only the wave component perpendicular to the beach is considered. Waves passing through the gaps are considered not to be reduced.

(4) It is assumed that the percentage of total reduction of wave energy flux per m of beach

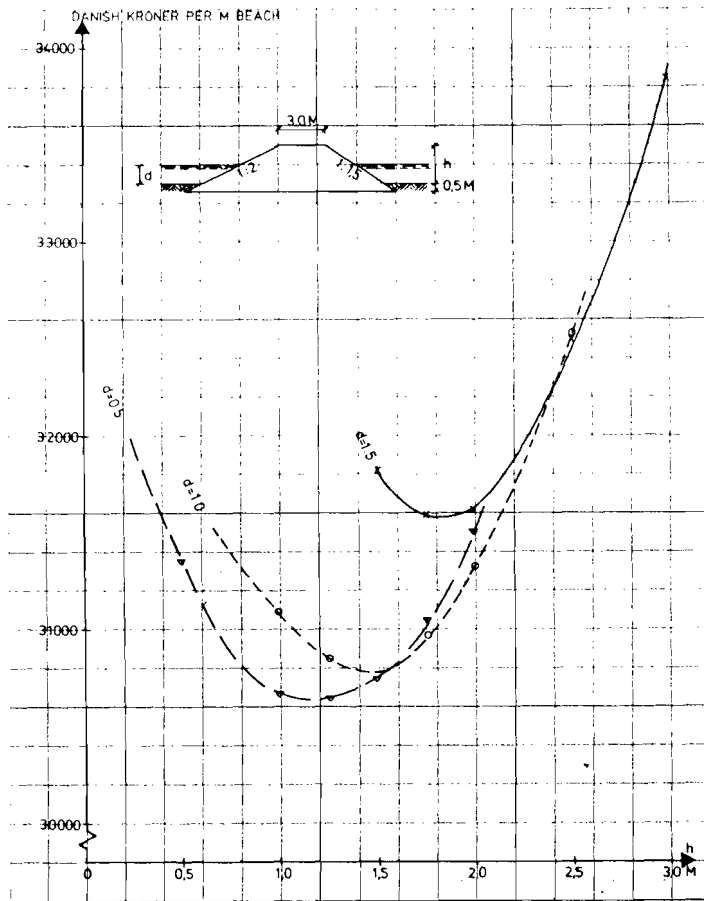


Figure 5. Design curves for breakwaters, example.

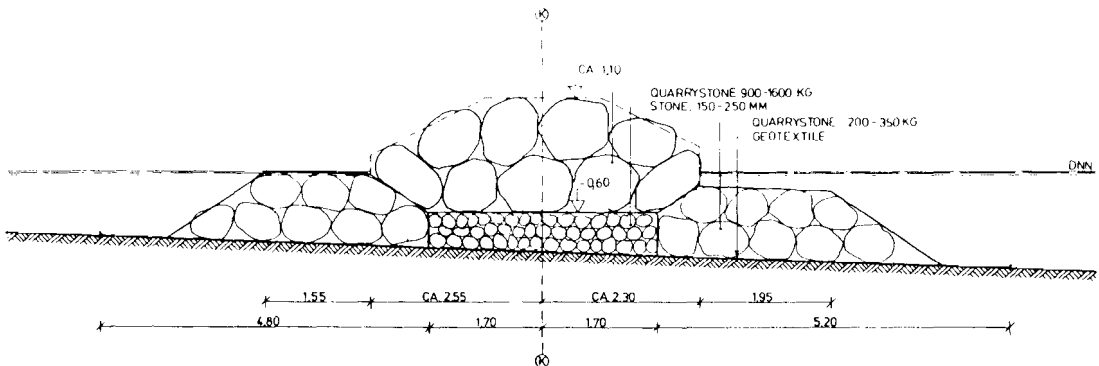


Figure 6. Breakwater cross section.

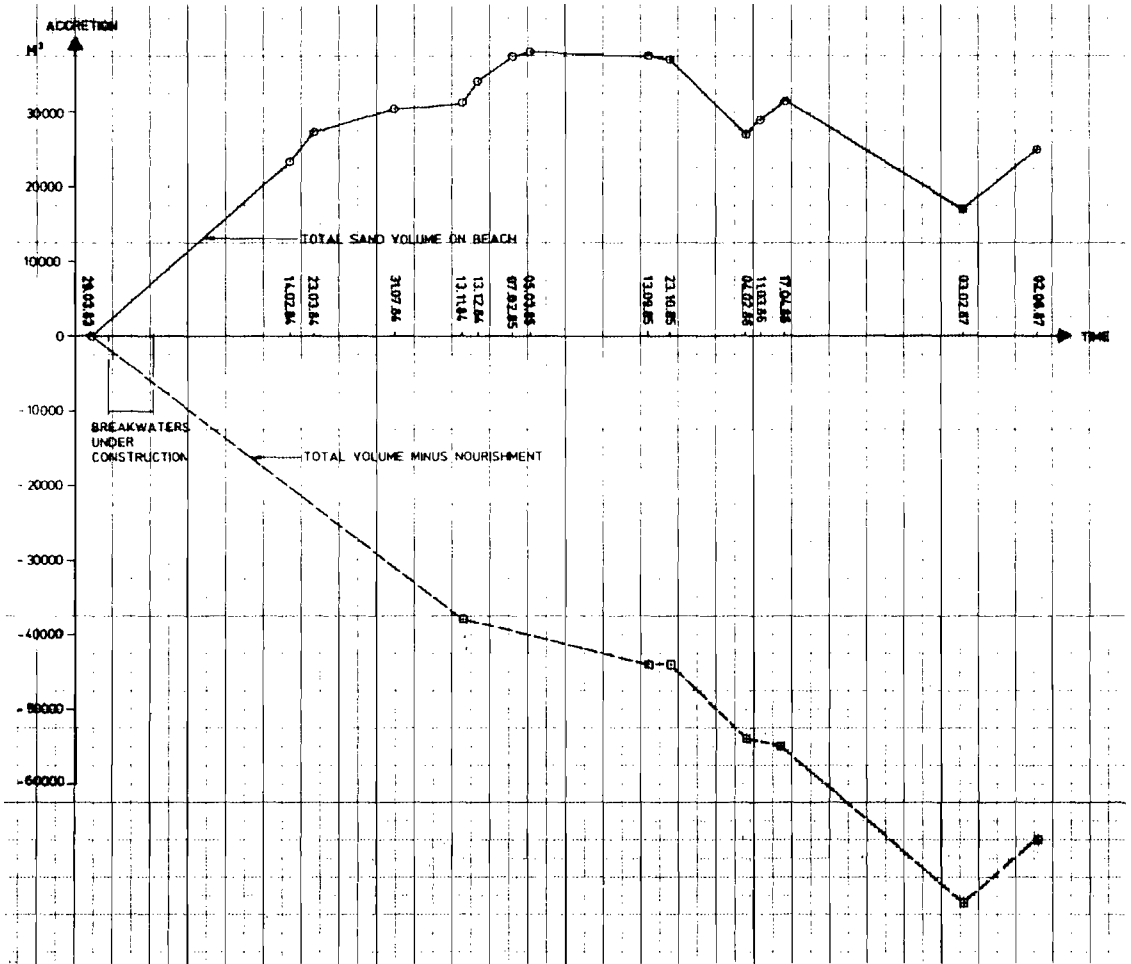


Figure 7. Effect of breakwaters on erosion.

perpendicular to the beach equals the percentage of total reduction of the erosion behind the breakwater.

(5) With that assumption, the total costs of building and nourishing the breakwaters can be calculated for different combinations of distance from the beach and height of the breakwaters. In figure 5, costs are calculated for a 20 year period.

When considering the actual positioning and heights of the breakwaters, the following considerations also have to be made: (1) recreational use of the beach, (2) profile shape and

position of the bars, and (3) streamlined layout along the coast.

EXPERIENCE WITH BREAKWATERS

The first group consisting of 9 breakwaters with a length of 50 m each and a gap of 50 m was built in 1983. The cross section is shown on Figure 6. The coast where it was built was not subject to very strong erosion, only 1.3 m per year. The effect of the group has been carefully surveyed since March 1983 to verify the theoretical design procedure. The result is shown on

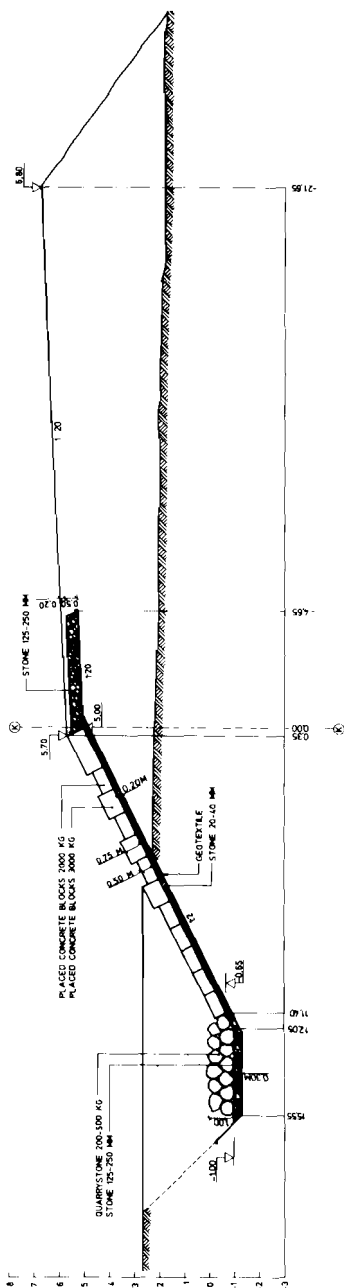


Figure 8. Revetment and artificial dune.

Figure 7. The upper curve shows the actual development of sand volume behind the breakwaters, including the nourishment. The lower

curve shows the sand volume when the nourishment has been subtracted.

During the surveyed period the total erosion was 16,200 m³ per year, on average. Before the construction of the breakwaters this erosion was 28,700 m³ which means that erosion has been reduced to 56%. According to the theoretical design calculations above, the reduction should be to 50%. Water level statistics show that the weather in the period has been close to normal.

DESIGN OF DUNE AND REVETMENT

Dune and revetment are constructed as shown on Figure 8. Design principles are listed below.

(1) The top of the revetment is designed so that wave impact occurs on the revetment.

(2) The dune is built so wide that theoretical wave overtopping is 2%. Model tests (see below) and experience indicate that the dune width is designed too small by this method. This is partly compensated by the development of windblown dunes on top of the constructed dune.

(3) The design of the different layers in the revetment has been tested with numerical models developed by Delft Geotechnics. Some of the concrete blocks are higher than normal to reduce overtopping.

(4) The foot of the revetment is constructed on a level which is safe for undercutting.

NOURISHMENT

Nourishment is placed partly on the beach and partly seawards of the breakwater. The reasons are (a) sand stays longer in the nourished profile if nourishment is placed where it is needed (BRUUN, 1985) and (b) erosion is not the same all over the profile—peaks occur at the revetment foot and at the seaward foot of the breakwater.

The minimum nourishment at the revetment foot is calculated as shown in Figure 9. In practice, the beach nourishment is placed on the upper part of the beach because that is the best way to maintain a stock of sand for the winter storms.

The sand for beach nourishment is normally unloaded at the harbours. In Fjaltring (Figure

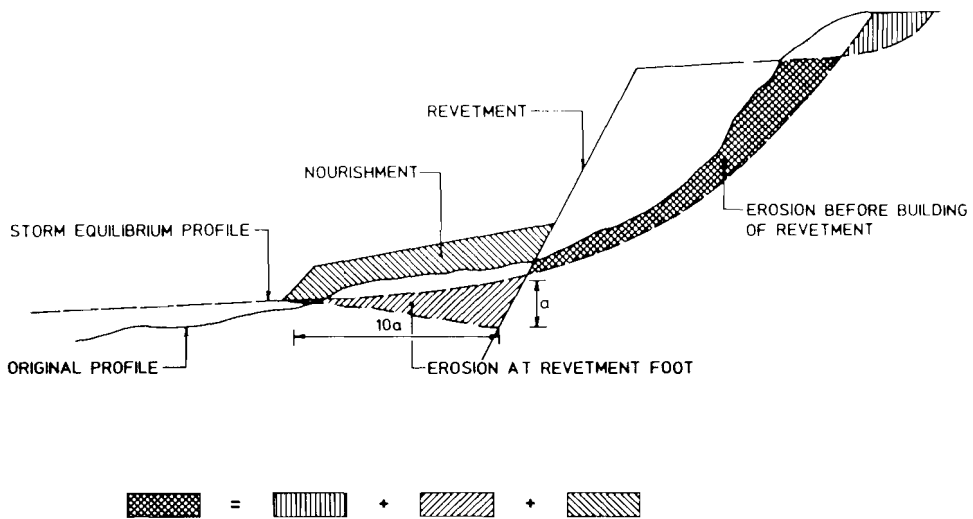


Figure 9. Erosion at revetment foot.

2) where the average shoreline retreat has been 11 m per year, the need for sand has been so high and the distance to a harbour so long that a 20" pipeline of 700 m length has been buried in the seabed permanently. Thus, each year sand can be supplied to the beach through the pipe. In 1987, 200,000 m³ were pumped and in 1988, 400,000 m³ will be pumped through the pipeline.

The sand is transported along the beach in lorries or dumpers. At present, we are developing a system of pipes and booster pumps which can easily be moved between the locations along the coast where sand is supplied. The idea is to use this system for transport along the beach instead of lorries and dumpers.

The nourishment needed on the seaside of breakwaters is placed as close to them as possible. Nourishment on the coast is performed either by splitbarges or by hoppers. In the case of hoppers, the sand is pumped over the bow. In some cases there are no longshore bars and the vessels can go close to the beach. In most cases, however, there is a bar just outside the breakwater and one or two more bars further out. Vessels can only move shoreward as far as the second bar.

In an attempt to find out how much of the sand dumped on the second bar is carried

onshore by waves and currents to the inner bar we dumped 240,000 m³ on the second bar in spring 1983. 80,000 m³ were dumped on each of 3 positions along the coast. One position was just in the leaside of the groin system which had caused the strong erosion and the two other positions were 1 km and 3 km further down line. The main result was that the amount dumped just in the lea of the groin group was carried onshore to the inner bar. The sand dumped at the two other positions remained on the second bar. These results can be used to plan the nourishment from the sea side of both the inner and the second and third longshore bars.

SUMMARY

By the end of 1987 about 8,700 m of revetment and 80 breakwaters (of length 50 m) had been built to stop erosion and re-establish flood protection along strongly eroding beaches. In 1987 the total yearly nourishment of the Danish North Sea coast will be about 620,000 m³. A method for designing the breakwaters and calculating the necessary beach nourishment, based on reduction of the wave energy by the breakwaters, is presented. Survey results show good agreement with theory.

LITERATURE CITED

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- Shore Protection Manual. US Army Corps of Engineers, Coastal Engineering Research Center, Vicksburg, MS, pp. 7.61-7.89.

□ DANISH SUMMARY □

På nogle strækninger af den jyske vestkyst er den gennemsnitlige årlige erosion 3-4 m. Den største gennemsnitlige erosion er 11 m pr. år. På disse strækninger er klitsystemet svækket eller helt forsvundet, så de lavestliggende arealer nær kysten er åbne for oversvømmelse. Foranstaltningerne mod erosionen består af en kombination af strandfodring og bygning af lave bølgebrydere tæt ved kystlinien. Beskyttelsen mod oversvømmelse genskabes ved opbygning af klitter med skråningsssikring.

□ RESUMEN □

En algunas zonas de la costa danesa del Mar del Norte, el promedio de erosión es de 3 a 4 m/año. El pico de la erosión promedio máxima es 11 m/año. En esas áreas el sistema dunar se ha debilitado o ha desaparecido, dejando las áreas bajas situadas detrás del sistema de dunas expuestas a la acción directa del mar. Las medidas contra la erosión son una combinación de realimentación de las playas y rompeolas exentos de baja altura cercanos a la línea de costa. La protección contra el mar se completa mediante la construcción de dunas artificiales protegidas con revestimientos.—*Department of Water Sciences, University of Cantabria, Santander, Spain.*

□ RÉSUMÉ □

Sur les côtes danoises de la Mer du Nord, la moyenne des érosions maximales est de 11m/an. Elle affecte des points où le système dunaire est affaibli ou a disparu, laissant ouvertes à l'inondation les terres basses situées en arrière du système dunaire érodé. Les mesures proposées pour combattre cette érosion combinent un apport sédimentaire et des brise-lames à proximité de la côte. La protection contre l'inondation est assurée par la construction de dunes artificielles maintenues par un revêtement.—*Catherine Bressolier, U.A. 910 du CNRS, EPHE, Montrouge, France.*

□ ZUSAMMENFASSUNG □

An einigen Stellen der dänischen Nordseeküste erreicht die Erosion Durchschnittswerte von 3-4 m/Jahr. Gemittelte Maximalwerte liegen sogar bei 11 m/Jahr. An solchen Stellen ist das Dünenystem geschwächt oder ganz verschwunden, so daß die dahinterliegenden Bereiche der Überflutung ausgesetzt sind. Maßnahmen gegen die Küstenerosion sind eine Kombination aus Strandergänzung und niedrigen Wellenbrechern nahe der Wasserlinie. Ein Flutschutz wird wieder hergestellt durch den Aufbau künstlicher Dünen, die durch ein Pflaster geschützt sind.—*Dieter Kelletat, Essen, FRG.*