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PERMEABEL GROYNES: EXPERIMENTS AND PRACTICE IN THE NETHERLANDS.

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PERMEABLE GROYNES: EXPERIMENTS AND PRACTICE IN THE NETHERLANDS

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ABSTRACT

This paper reports on model experiments and up to 20 years of practice in nature with a permeable groyne system, consisting of single or double permeable rows of wooden piles perpendicular to the beach, without bottom protection. This system costs only 10 to 25% of the impermeable stone groynes which have for centuries been used in the Netherlands.

Model experiments confirm that wave-induced currents in the protected areas are reduced to 65%, and tidal currents even to 50%, depending on the pile screen configuration. Prototype measurements could not lead to straightforward conclusions with statistical significance: the effect of the pile screens on beach evolution is partly merged into natural fluctuations and trends. Wooden pile screens do not prevent the shoreward motion of tidal channels, which can cause washing out of piles. Furthermore, *constructional failures*, which in the future can be avoided, at some places resulted in negative experience. It is concluded that permeable pile screens deserve serious consideration as a first flexible and cheap phase in combating coastal erosion. Its application however should be based on a thorough analysis of the local coastal current climate.

1 INTRODUCTION

Holland has to defend its low-lying land against the wind-swept waters of the North Sea. Large portions of its natural defence line, the coastal dune ridge, are subject to erosion [Bakker and Joustra, 1970], as a result of long-term or cyclic beach recession and short-term storm-surge dune erosion.
In the past centuries many different structures have been applied in order to contribute to the coastal defence system, among which about 500 stone groynes. Traditionally, these structures are founded on willow matting and consist of rubble stone covered by hand-set stones. Especially in the SW province of Zeeland, where the tidal range reaches 4 m, the groynes were heightened by constructing single or double wooden pile rows on their crests. There is good reason to state

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that the recession of the coastline is indeed retarded by these massive groynes; their effectiveness has been studied in practice [Bakker and Joustra, 1970], theoretically [Bakker, 1968] and experimentally [Hulsbergen, Bakker, and van Bochove, 1976].

However, four main disadvantages of massive groynes are obvious, viz.:

- They are very expensive.
- They tend to induce deep erosion pits seaward of the groyne-head because of locally increased currents.
- They may stimulate rip-currents and seaward loss of sand.
- Extensive lee-side erosion may occur on the adjacent unprotected coastline.

Since 1965 a new type of groyne has been applied in the Netherlands in order to cope with these problems: it merely consists of wooden piles driven into the beach with mutual distances of about one pile diameter, so that permeable pile screens are formed, aligned perpendicularly to the beach, without bottom protection. These "permeable groynes" will further be referred to as "pile screens" or simply "screens", whereas traditional massive structures will be indicated as "groynes". The purpose of the pile screens is discussed in chapter 2.

The pile screens were initially constructed as an experiment, and different geometrical variations (length, height, distance, single or double rows, etc.) have been applied. In 1972 analytical and laboratory studies were performed in order to gain a better understanding of their effect in various hydraulic and geometrical settings; the results are outlined in chapter 3. Design and cost aspects are discussed in chapter 4.
Some of the pile screen projects, which were implemented since 1965, have been a success; others failed. This is discussed in chapter 5. In some cases it is difficult to distinguish the proper screen effect from the large-scale background morphologic development. Chapters 6 and 7 aim to analyze and summarize the experience gained so far.

2 PURPOSE OF PERMEABLE PILE SCREENS

In contrast to massive groynes, which seek to form a complete obstruction to the longshore current and to the longshore sediment transport, permeable pile screens are meant as an artificial hydraulic resistance in order to reduce the longshore current velocity and thus reduce the rate of longshore sediment transport. This may be explained as follows.
The longshore sediment transport concept [Bijker, 1971] is based on the notion that sediment is stirred up from the bottom by a shear stress which is produced by the combined action of waves and currents; the currents may be a combination of wave-induced and tidal currents. Once stirred up, the sediment is transported by the currents while being kept in suspension by waves and currents for some time. Hence, by reducing the current velocity (by means of the screens), both the stirring-up and the transporting phases of the sediment transport mechanism will be reduced, virtually without directly reducing the primary wave action.
With respect to the disadvantages of massive groynes as mentioned in chapter 1, the purpose and the expectation of permeable pile screens

can be summarized as follows:

- low cost structures
- less pronounced current concentration seaward of the head, provided that the permeability is adapted along the screen length
- reduced tendency to form rip-currents, for the same reason
- the ability to reduce the longshore sediment transport in a gradual way is an important asset in order to reduce the lee-side erosion behind massive structures: by an adequate screen field lay-out the total sediment deficit of the lee-side area will be distributed over a larger distance, thus decreasing the rate of recession.

3 LABORATORY EXPERIMENTS

Preliminary calculations, taking into account the bed shear stress and the estimated hydraulic resistance of the pile screens, showed that velocity reductions of 30% would result for 50 to 75% open screens, 200 m long and 400 m apart; a further reduction would require progressively more piles per unit beach length [Hulsbergen and ter Horst, 1973]. In view of the uncertainty involved in the underlying assumptions, and because of the lack of detail in terms of the resulting current pattern, in 1972 fixed-bed laboratory tests were deemed necessary in order to find out to what extent pile screens of various geometrical forms reduce the coastal currents under different hydraulic boundary conditions.

The model set-up is shown in Figs. 1 and 2. Horizontal and vertical scales are both 40, and the velocity scale is 6.32 according to Froude. The coastal profile is typical for Zeeland, where tidal currents of 1 m/s occur in a water depth of 10 m close to the beach, and where the tidal range is appr. 4 m. The model bed consists of smooth concrete and has straight parallel depth contours. A variety of prefab model pile screen configurations (Fig. 3) have been installed in grooves which are 1.25 m apart. (All units in this chapter are in model measures unless otherwise indicated).

The model piles are 6 mm in diameter and their mutual clearance varies from 6 mm at the landward end to 19 mm near the seaward tip. The piles may be combined to short screens (3.5 m long) or long screens (5 m long), either as a single row, or in double rows 8.75 cm apart. The mutual screen distance varies from 3.75 m to 10 m.

Several hydraulic conditions have been installed, of which the most important are:

- H.W. and current only (most of the tests)
- H.W., a current, and a wave generated current in the same direction as the tidal current; regular wave period $T = 1.04$ sec, wave height at (spilling) breaking $H_{br} = 3.0$ cm, angle of incidence at breaking $\alpha_{br} = 8°$).

For a variety of special velocity measurements with screen configurations and hydraulic conditions different from those mentioned above, reference is made to [Hulsbergen and ter Horst, 1973].

The main test results for the present purpose are expressed in terms of the relative velocity V_{rel}, i.e. the ratio of the longshore current velocity with screens over the longshore current velocity without screens, measured on the same spot and with the same hydraulic condition. Combining some of these results, the following conclusions are drawn.

For current only:

a. In general the investigated screens cause an appreciable reduction of the longshore current velocity; near the beach V_{rel} is only 50%, but further seaward V_{rel} increases, and even grows up to 115% just seaward of the tip.
b. V_{rel} diminishes, but not proportionally, as the number of screens per unit length of beach is increased (Fig. 4, short screens).
c. V_{rel} diminishes as the screens are concentrated (e.g. double rows at 10 m intervals instead of single rows at 5 m intervals), without increasing the amount of material per unit length of beach (Fig. 5, long screens).
d. Lengthening of screens causes a reduction in current velocity at that depth, but this is partly at the expense of the reduction as it existed in the short screen range (Fig. 6, average V_{rel} values for short and long screens).
e. The aforementioned screen effects cause an increase of the perpendicular gradient in the longshore current profile which may lead to an increasing offshore sediment transport. Especially short screens have this disadvantage.

For a current and a wave-generated current in the same direction:

f. As compared to current only there are important differences; one must discriminate between the areas inside and outside the surf zone (the waves start breaking at approximately 2 m from HW mark).
g. Outside the surf zone, concentration of screens without increasing the amount of material per unit length of beach causes V_{rel} to decrease, just as for current only. Inside the surf zone, however, concentration of screens causes V_{rel} to increase (for explanation see point i).
h. Outside the surf zone, the value of V_{rel} is lower than for current only (Fig. 7, screen type C). This can be explained by noting that orbital motion in the plane of the pile screens effectively hinders the tidal current to flow through the openings between the piles.
i. Inside the surf zone, the value of V_{rel} is larger than for current only (Fig. 7). This can be explained by the different mechanism of generation of a tidal current and a wave-generated current:
   - a tidal current, once hindered by a screen, restarts slowly by the gradual diffusion of mass and momentum from the outside main stream towards the retarded water near the coast;
   - a wave-generated current on the other hand, once slowed down by a screen, is fed immediately with momentum and mass by the breaking waves themselves which travel right into the retarded zone.

One overall conclusion is that it makes a great deal of difference to the efficacy of permeable pile screens whether there are waves, and if so, from what direction. Perpendicularly incident waves increase the velocity reduction of the screens; obliquely incident waves, however, generate a longshore current to which the screens form only a limited hindrance. For the test conditions it seems that screens of type C show an overall good performance.
With an adequate formula, e.g.[Bijker and Svasek, 1969] or [Bijker,

1971], the above hydraulic results may be transferred to longshore sediment transport quantities, and thence into predictions for coastal development without and with screens.

4 DESIGN, CONSTRUCTION AND COSTS

The functional design of pile screens should be based on the required reduction of the longshore sediment transport, and thus on the required reduction of the current velocity parallel to the coast. So, one should start with a careful analysis of the natural coastal current climate, and one should well discriminate between tidal and wave generated currents (see chapter 3). Starting from such analysis, and taking into account the computational and experimental results as outlined in chapter 3, for a particular location an optimum is found for the screen geometry in terms of pile screen length, mutual distance of screens and piles, and height of piles.

Obviously, aspects of local materials, construction operations and costs may interfere with the ideal functional design. In the Netherlands only wooden piles (oak or tropical) with round or square cross-section (0.25 - 0.30 m) have been used. Piles of square cross-section may be placed in a diamond pattern rather than orthogonally in order to save material for the same hydraulic resistance. These piles may be subject to borers and/or marine growth; concrete may be an alternative.

The toplevel of the piles is partly determined by the workability conditions (waves and tides). The total length of the piles must allow for natural variations in local bed elevation; as a rule 60% of the total length is in the bed. A typical screen is shown in Fig. 8. When a double screen is applied (which is cheaper than 2 single rows), their mutual distance is 3 m. In order to allow traffic on the beach an oblique opening is provided. The piles may be jetted or rammed with a conventional rig on the dry beach. Beyond the low water line there are several options, viz. working from a floating barge, from a mobile platform (Fig. 8), from a temporary jetty, or working over the top of the finished part (double screens only).
The costs of screens increase rather fast if they extend seaward of the low water line. A rough idea is given in Fig. 9, where three screen configurations are shown with their cost per 1000 m^1 of beach length as compared to typical traditional massive groynes.

5 APPLICATIONS OF PILE SCREENS IN NATURE

Since 1965 permeable pile screens have been applied on ten locations in the Netherlands (Fig. 10).

- On the SW coast of Walcheren, the recreational beach of Flushing (Fig. 10, ①) is situated at the leeside of a protruding remnant of an old dike, and is since long subject to leeside scour. Additional to periodical sand supply (1952, 1966 and 1975), in 1975 the old deteriorated groyne system was replaced by three double pile screens. It is hard to specify their effect because of the many artificial changes of this beach. There are slight indications that the rate of sand loss is decreasing.
- On the SW coast of Walcheren near the village of Zoutelande (Fig.

10,②), in 1968 the existing coastal protection (consisting of heavy massive groynes with piles on top) was extended in SE direction by means of three long double screens and two short single screens (Fig. 11, and lower photo on Fig. 8). Since then the discontinuity in the coastline, caused by the leeside scour resulting from the original system, was evened out. Even some accretion occurred directly southward of the former end of the groyne system. The leeside scour shifted to the end of the new screen system. This project indicates that these pile screens do have the expected effect.

- The NW coast of Walcheren borders the estuary of the Eastern Scheldt (Fig. 10,③,④, and Fig. 12), and reacts intensely upon the dynamic behaviour of its tidal channels.
  Although generally eroding, accretion may also occur during long-term fluctuations. In 1968 the deteriorated groynes near the village of Domburg (Fig. 12,③ and Fig. 13a) were replaced by pile screens. Originally the landward part of the screens consisted of a single row of piles (Fig. 13b), whereas the seaward part was double. As mussel growth on the seaward piles increased the flow resistance even more (Fig. 14), unfavourable current concentrations resulted both seaward and landward of the dense sections (Fig. 15). The resulting current velocity during H.W. on the beach was even higher than before the screens were there. Therefore, in 1977-1978 all screens were doubled, and at the SW end some extra screens were placed. At the SW end the beach accreted, but in the NE part the beach receded. An explanation has not been found. An overall picture of beachline behaviour since 1920 in this area is given in the lower part of Fig. 13. For a number of ranges perpendicular to the coast, the position of the point half way between the H.W. line and the L.W. line is indicated as a function of time. Further, in Fig. 13 is indicated: the moment of the landward extension of the old groyne stone heads with pile screens, the moment of construction of new screens, and the moment of doubling these screens. From Fig. 13 a diminution of the erosion in the last decade can be observed; however, long-term fluctuations may have played a role.
- The first application of pile screens in the Netherlands dates from 1965, near the village of Oostkapelle on the NW coast of Walcheren (Fig. 10,④ and Fig. 12,④). The existing row of stone groynes with horizontal crowns had caused leeside erosion in northward direction; therefore a row of short screens was built in 1965 (Fig. 16).
  These screens and their effects were drastically affected by large scale autonomous morphological developments in this area (Fig. 16). Between the main tidal channel "the Roompot" of the Eastern Scheldt estuary and the local near-shore flood channel "the Urk", a shoal developed right in front of the beach with screens. This shoal urged the "Urk" channel closer inshore, and seaward extension of the screens could not prevent this development. Later on, the shoal even merged with the beach (Fig. 16, 1981), and some more additional screens were built. This could not prevent that during the last phase of the shoreward moving "Urk" channel heavy damage occurred to the screens, and even some 12 m long piles were washed out.
- The development of the west coast of the island of Schouwen is de-

termined by the secondary tidal channel "the Krabbengat" (Figs. 12 and 17), which moves landward during the last centuries. Periods of erosion and accretion alternate, under the influence of changes in the tidal estuaries of the Eastern Scheldt to the South of Schouwen, and the Brouwershavense Gat to the North. In 1968 long screens were erected along the northern part of the beach (Fig. 10 ⑤, Fig. 12 ⑤, and Fig. 17), and soon a spectacular accretion occurred, even with new dune formation on the beach. The landward piles were consequently pulled somewhat (Fig. 18) because they tended to disappear under the sand. It is not clear, however, to what extent this accretion is due to the pile screens alone. The original recession of the beach stopped about 5 years before the screens were placed: probably the areas of accretion and erosion tended to shift under the influence of "the Krabbengat". Furthermore, the estuary of the Brouwershavense Gat was closed in 1972, of which the effects cannot accurately be assessed.

- In 1975 the above mentioned row of screens was extended southward with short double screens (Fig. 10 ⑥, Fig. 12 ⑥ and Fig. 17). The long-term trend of erosion however did not change. Also outflanking behind the landward end of the screens near the dunes occurred (Fig. 19). Another negative aspect was observed in that rip-currents tended to concentrate along the screens (Fig. 20).
- Just south of the new entrance to Europort (Fig. 10, ⑦) a new coastal defence system was necessary in order to protect the reclaimed harbour area [Svasek and de Nekker, 1977]. Instead of the original design, which consisted of a section of 4000 m of rubble mound breakwater, an artificial beach and dune combination was proposed, saving about 80 million dollars on construction costs. In order to maintain the artificial beach, an artificial sand supply of 400,000 m^3/yr would be required [Svasek and Versteegh, 1977]. Further optimization calculations resulted in a project with seven pile screens (Fig. 21) plus a limited sand supply of 200,000 m^3/yr [Bijker et al., 1981]. Four double pile screens extended to the depth contour of MSL -3 m, and three short single screens down to MSL - 0.5 m were placed in between. The 0.3 m diameter piles were spaced 0.3 m apart. To determine the pile length, a seasonal depth variation of 1 m was assumed.

As the planned sand supply of 200,000 m^3/yr was not effectuated, a local erosion of about this same rate should be expected. Based on frequent detailed soundings and beach levelings in the area concerned, a comparison was possible (Fig. 22) between the calculated erosion (with pile screens but without sand supply), and the observed erosion which amounted to 220,000 m^3/yr. This is in good agreement, taking into account the feasible accuracy of the levelings and soundings. As the area concerned is approximately 600,000 m^2 large, the average erosion in 2 years was about 0.6 m with local scour of more than 1 m.

About 2½ years after construction, the most southern two long screens lost about 30% of their piles (mainly in the deepest section) during a severe storm.

The main causes for this failure are:

- Artificial feeding was omitted, causing the bed to be eroded locally below the storm season profile, for which an overdepth of 1 m was designed.
- The tidal channel "Gat van Hawk", which was shoaling and stable

in position at the time of design, moved unexpectedly in shoreward direction.
- Some of the washed-out piles did not meet the design length requirements.

Later on, this pile screen project was abandoned.

- In 1974 near Bergen (Fig. 10, ⑧) five single short screens were erected with mutual distances of 150 to 200 m (Fig. 23). These screens, only covering the beach width of 120 m, were designed to mitigate the leeside scour just south of a long row of stone groynes. Afterwards the general beach elevation increased with 0.5 to 1.0 m. The proper screen effect is hard to tell, because in the same time windscreens of reed were placed and reshoveling of the beach occurred.
  From regular levelings it appeared that just seaward and landward of the screens erosion occurred, the latter caused by outflanking.
- The island of Texel suffers from severe erosion, and has been extensively defended with stone groynes. The area under consideration (Fig. 10, ⑨) is subject to heavy erosion, the dune foot receding at a rate of 15 m/yr. The classical groynes, with a flat crown at about MSL, are extended in landward direction if the coast keeps eroding; furthermore in that case the system is extended with more groynes (short ones in first design) along the beach.
  In 1973, some of the relatively recent stone groynes were extended in landward direction (following further dune foot recession) with pile screens instead of stone groynes; furthermore some intermediate pile screens were constructed (Fig. 24a). Rather strong outflanking occurred near the dune foot, probably boosting the dune foot erosion rather than stopping it (Fig. 24b). For this reason the pile screens were removed in 1980.
- Also in 1973, on the island of Ameland (Fig. 10, ⑩) four single pile screens were constructed. These screens - in combination with other coastal defence systems - link the continuous bottom protection along the main tidal channel "the Borndiep" with the beach (Fig. 25a). The coastal erosion in the area covered by the screens stopped indeed, whereas in the vicinity erosion proceeded. Just as on Texel however outflanking occurred near the dune foot (Fig. 25b).

6 EVALUATION OF THE EFFECT OF PILE SCREENS IN NATURE

With respect to reporting on experience with coastal defence systems the general difficulty remains how to tell the proper effect from the background noise.
With respect to impermeable groynes some proof is available of its potential to combat erosion [Bakker and Joustra, 1970]. However, the system presently under investigation is a "softer" system and its effect may easily merge into the effect of nature. This so much the more as essentially where groynes are applied, nature shows either heavy fluctuations or heavy erosion. In the case of heavy erosion the present system failed in the sense that without these screens the same or maybe a more favourable effect could have been achieved (Oostkapelle; Texel). Therefore only the cases with heavy natural fluctuations remain to be analyzed, yielding the results mentioned in chapter 5.

Besides it is a fascinating thought that the use of impermeable groynes near Oostkapelle probably would have given worse results: the contraction and the turbulence near the head of the groyne could have prevented the favourable incorporation of the migrating shoal with the beach.

Having no statistically significant evidence regarding the screen effect, the question still remains: should the use of pile screens be advised for coastal defence?
In the first place, as long as no really predictive mathematical (large-scale) coastal models are available, the words of Schijf regarding coastal protection plans still apply: "Postpone till tomorrow what not necessarily has to be done today".
However, given the fact that something should be done at a certain site applying the best available knowledge, pile screens might come in the picture. First checkpoint should be an evaluation of the risk of washing out of piles by shoreward motion of tidal channels. One might face situations that even the maximum practical pile length will not be enough to guarantee constructional stability.
It should be kept in mind, that pile screens cannot prevent this channel motion.
If this risk is acceptable, or if it can be eliminated (for instance by periodical sand supply), the authors feel, that the use of pile screens deserves serious consideration.

- Based on theoretical and experimental evidence (chapter 3) positive effects can be expected; especially in areas with a large tidal range, piles have effect during a longer part of the tidal cycle than stone groynes with flat berms.
- Most of the negative experience can be attributed to constructional failures, which in the future can be avoided. For instance, in Oostkapelle and Europort the piles were too short at the site where the washing-out occurred, because at these locations no heavy erosion had been foreseen.
  It seems to be of much importance that the screens are well incorporated in the dunes, implying some temporary removal of sand.
  At present, mussels are regularly removed from the screens.
- Although an objective financial balance of the use of pile screens is hard to make (as the effects are not clear and a financial value can hardly be assigned), the feeling exists, that this balance is positive and that, for instance, it has been a wise decision to protect the Schouwen area with pile screens instead of impermeable groynes.
- Pile screens form a much more flexible construction than stone groynes: piles can be added, lifted or removed, and in the case of very heavy erosion one can make - if absolutely necessary - stone berms in a later stage, thus postponing the expense. Furthermore a combination of pile screens and sand supply is feasible.

7 CONCLUSIONS

I Advantages of permeable pile screens are:

a. Low cost (Fig. 9).
b. Reduced longshore current velocity, as demonstrated by model tests (Figs. 4, 5, 6, 7).
c. Flexible construction, which may easily be adapted to changing

beach elevation (Fig. 18).

d. A more continuous beach line (as compared to the saw-tooth beach line with impermeable groynes). This is an advantage, in the sense that the point of most erosion determines the safety of the coastal protection.

e. A more gradual velocity gradient and less turbulence near the seaward end (as compared to impermeable groynes).

II Problems encountered are:

a. Failure on the seaward side: washing-out of piles.

b. Failure on the landward side: outflanking near the dune foot. (Fig. 19).

c. Mussels, often causing a diminution of the permeability of the outer region of the screens. Where the inner region consists of a single screen this may lead to higher local current velocities than before the screens were constructed (Figs. 14, 15).

d. Attraction of rip-channels, with consequent seaward sand loss (Fig. 20).

III Proposed remedies against the problems are:

a. Careful analysis with respect to morphological changes in the coastal area (are tidal channels moving to the coast? Does lee-side erosion occur?). Piles should be embedded for 60 percent of the total length below the lowest beach level to be expected.

b. Pile screens should be sufficiently extended landward of the existing dune foot, even if this includes a temporary removal of much sand

c. Regular removal of mussels.

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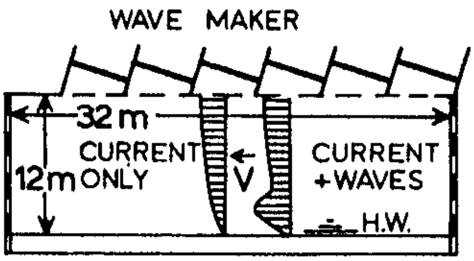


FIG.1 Model basin

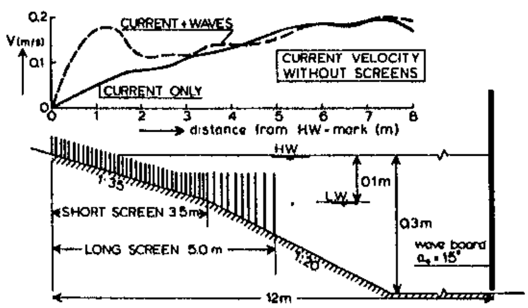


FIG.2 Cross-section of model

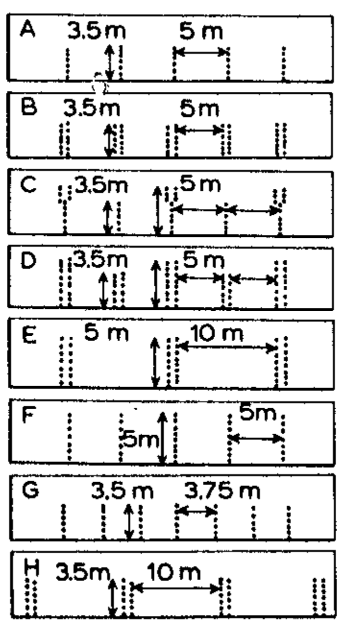


FIG.3 Screen configurations

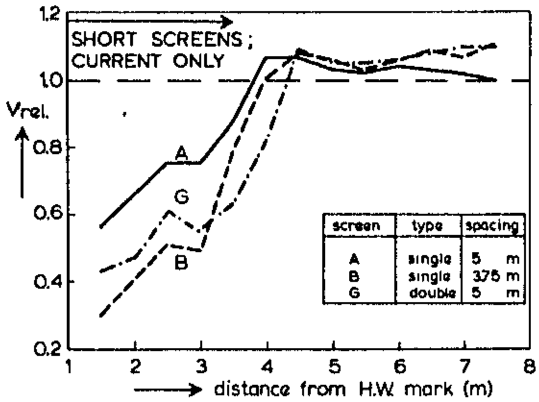


FIG.4 Effect of more screens

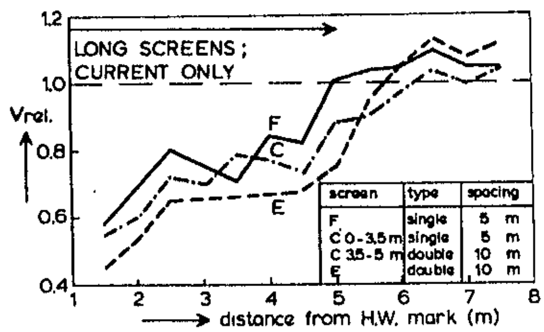


FIG.5 Effect of screen concentration

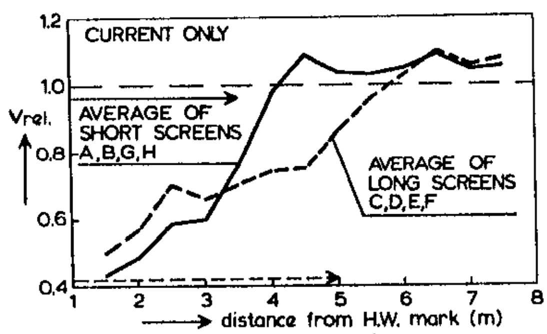


FIG.6 Effect of screen length

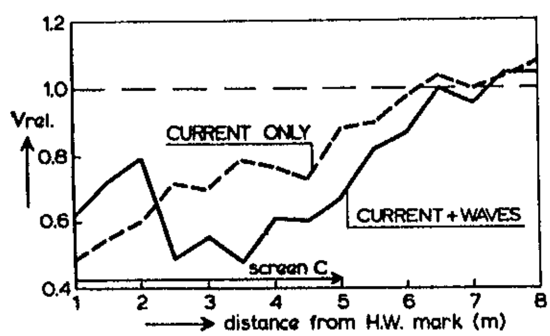


FIG.7 Effect of waves

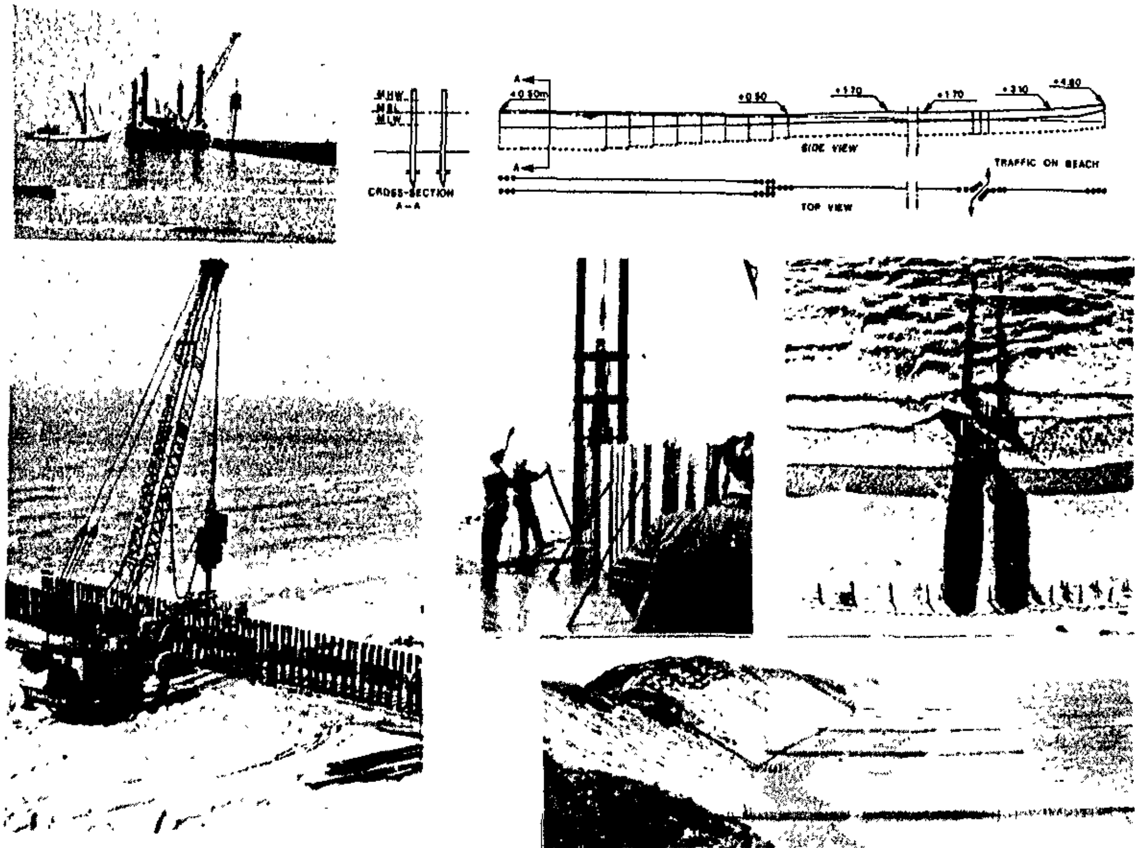


FIG.8 Construction of screens

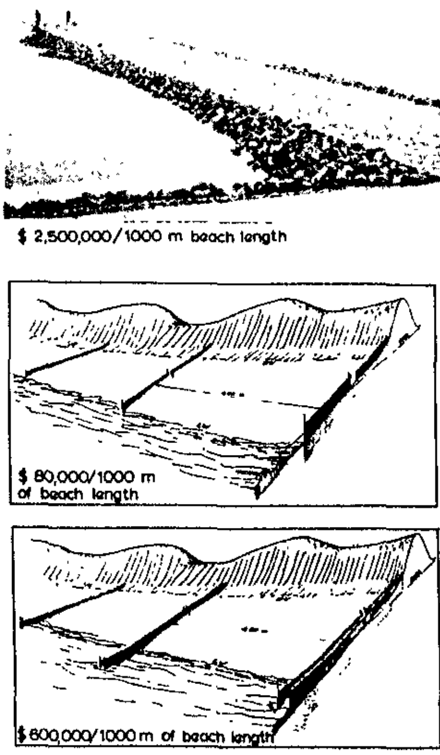


FIG.9 Costs of groynes and screens

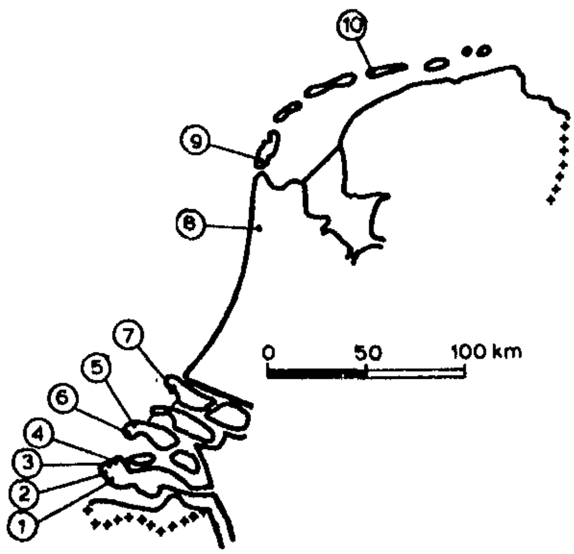


FIG.10 Locations of screens

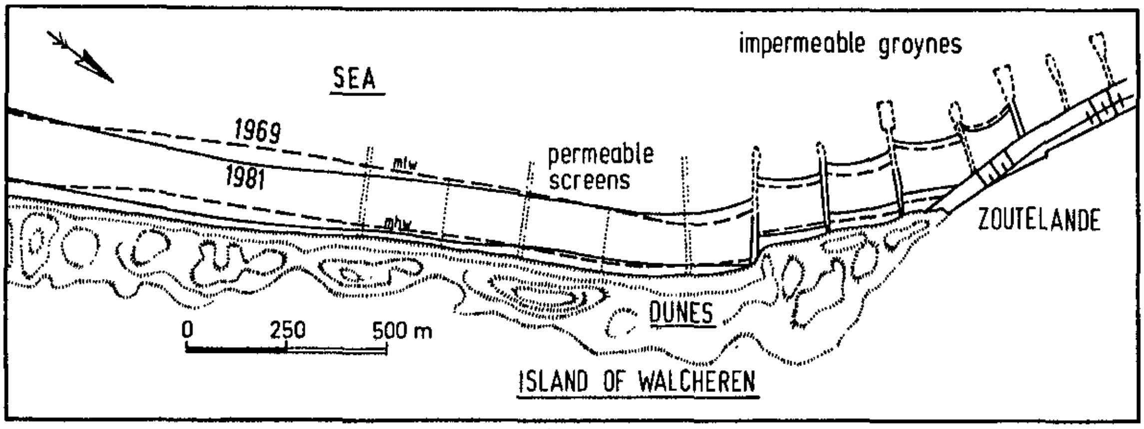


FIG.11 Screens near Zoutelande ②

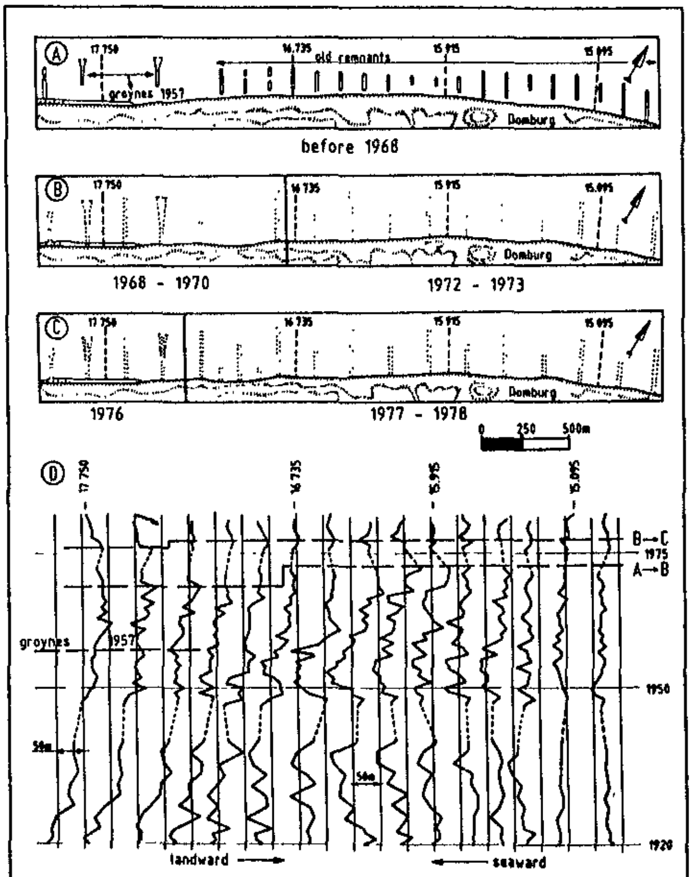


FIG.13 Screens near Domburg ③

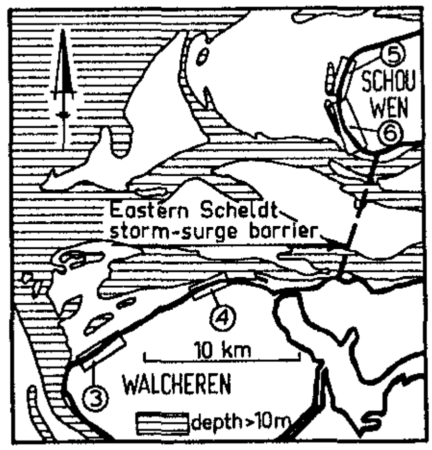


FIG.12 Screens near Eastern Scheldt estuary

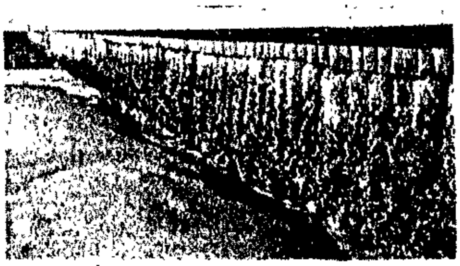


FIG.14 Mussel growth

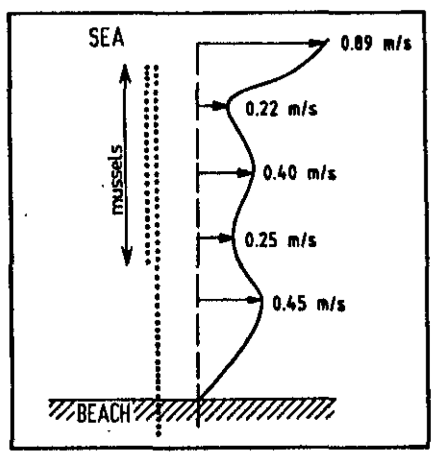


FIG.15 Effect of mussels

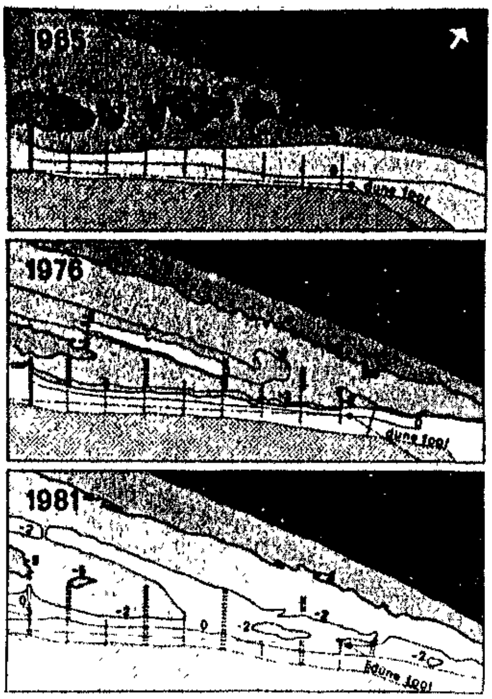


FIG.16 Screens near Oostkapelle ④

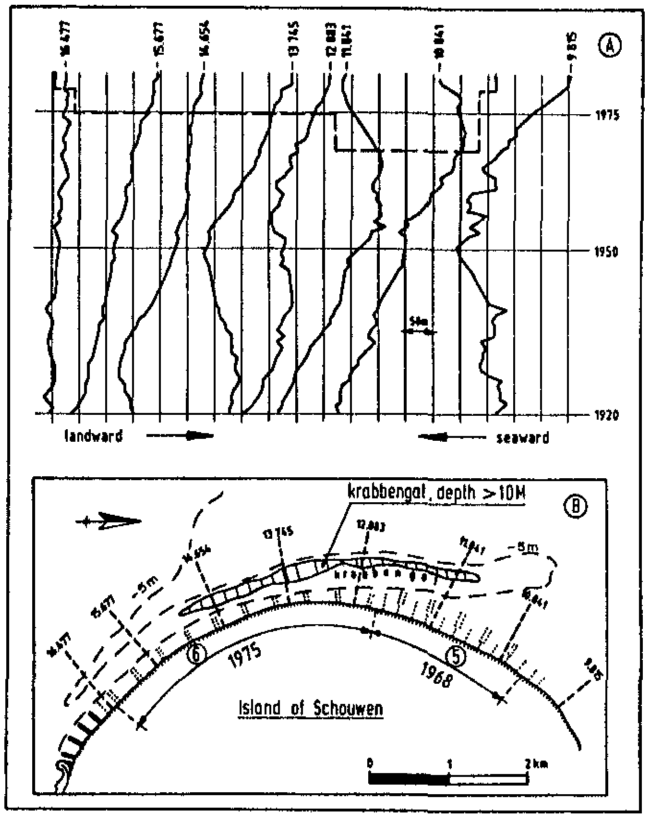


FIG.17 Screens on Schouwen ⑤, ⑥

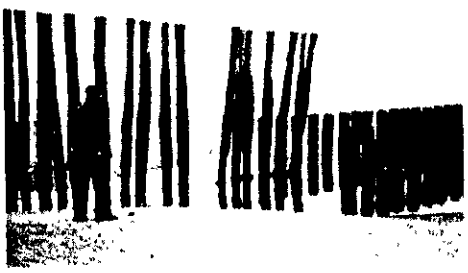


FIG.18 Pulled piles

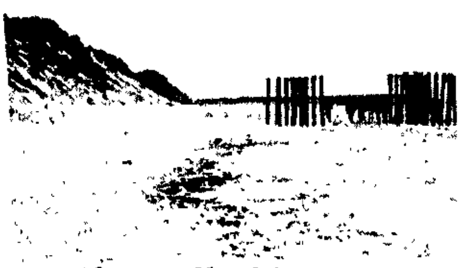


FIG.19 Outflanking

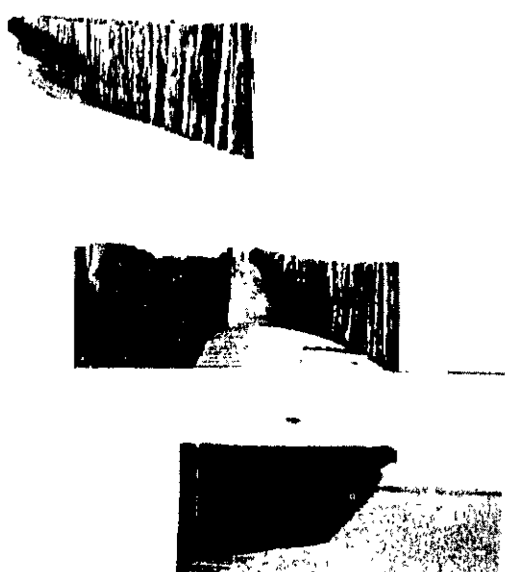


FIG.20 Rip channel near screen

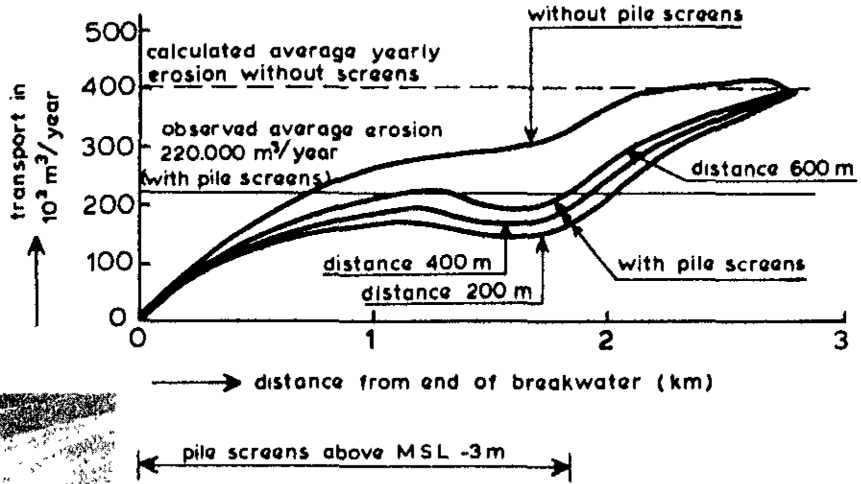
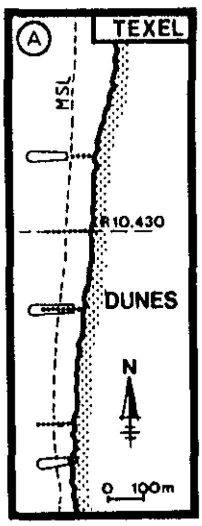


FIG.22 Calculated screen effect near Europort ⑦

FIG.21 Screens near Europort ⑦



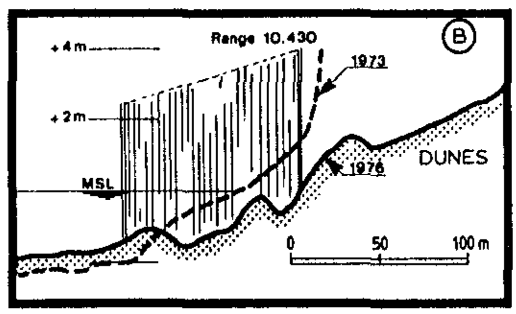


FIG.24 Screens on Texel ⑨

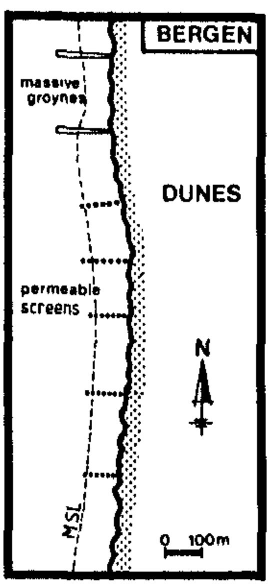


FIG.23 Screens near Bergen ⑧

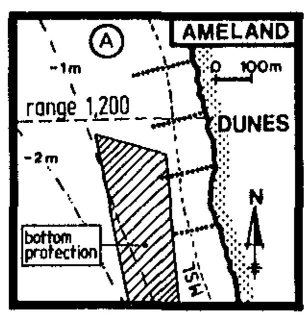


FIG.25 Screens on Ameland ⑩