PREVENTING NATURAL BREACHING OF THE MAJOR SAND SPIT PROTECTING THE PORT OF WALVIS BAY

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Abstract

During seasonal storms, waves wash over the major peninsular sand spit protecting the Port of Walvis Bay. The possibility of breaching of the spit was assessed and conceptual measures were proposed to prevent breaching. Aeolian, longshore and cross-shore sand transport rates were computed. Modelling was done of beach profile changes during storms. It was found that the spit would probably not be breached during a single storm. Sand nourishment, methods to prevent erosion, and methods to induce accretion in vulnerable areas were considered to prevent breaching. A contingency plan was recommended involving the use of low-cost shore protection.

1. Introduction

Major coastal sand spits are common features along the Namibian and Angolan coasts of Africa. Examples of these can be found at Walvis Bay (central Namibia; Figure 1), Sandwich harbour (50 km south of Walvis Bay), Baia dos Tigres (southern Angola, about 70 km north of the mouth of the Kunene River) and Lobito (central Angola).

Walvis Bay, which is the biggest deep-water port in Namibia (Figure 1), is protected against wave action by the Walvis Peninsula. This long (about 10 km) but low-lying (about +1 m to mean sea level, MSL) sand spit is growing northwards because of the net northbound longshore transport. However, during storms at high tide, the waves wash over a section of the sand spit (at Donkie Bay; Figure 1), causing concern that natural breaching may occur. This can be a real threat. At

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Baia dos Tigres natural breaching of the 41 km long spit occurred, leaving an 11 km wide gap in the spit and destroying safe anchorage. At Sandwich harbour extremely dynamic sand banks and channels occur. If breaching does occur at Walvis Bay, the port would have to contend with significant wave action hindering navigation and quay operations. Furthermore, shifting sand banks which are hazardous to shipping, may form in the shipping channel and result in increased maintenance dredging. Because of the seriousness of the consequences and the cost of closing a gap in the spit, a study was undertaken to assess the possibility of breaching of the Walvis Peninsula and propose conceptual measures to prevent it (CSIR, 1996).

The aims of the study were: an initial assessment of the possibility of breaching, the gathering of essential data required for this task, and the proposal of conceptual measures (e.g. shore protection) to prevent breaching. For the study, beach and hydrographic surveys were conducted of the low-lying area (Donkie Bay) and of Pelican Point (the tip of the Walvis Peninsula). It was essential to obtain accurate information on sand spit levels in order to determine the extent of the problem and the most suitable solution. A survey of the Pelican Point area was conducted to assist in estimating the longshore sand transport rate along the Walvis Peninsula.

2. Environmental data

2.1 Historical data

Although charts of the study area date back to 1796, the first reliable map was compiled in 1885 by the British Navy. Subsequently a number of charts and aerial photographs became available which illustrate the development of the spit over the past 100 years. From these data an average annual growth rate could be determined, which has a direct bearing on the longshore sediment transport rate in the area - an aspect which will be discussed in more detail in Section 3.2 below.

2.2 Bathymetry and topography

To assess the present configuration of the Walvis Peninsula, detailed bathymetric and topographical surveys of Pelican Point and its surrounds as well as the area around Donkie Bay were conducted. Echo-sounding and conventional land surveying techniques were used to obtain detailed elevation contours at 1 m intervals. The data show that the Walvis Peninsula is a low-lying spit with an average height of about +1.0 m to MSL, sloping steeply towards deeper water, especially at Pelican Point.

A cross-section at Donkie Bay (Profile 2) is shown in Figure 2. The profiles at Donkie Bay are very similar; however, the crest of the dune is the lowest in Profile 2.

2.3 Waves

The dominant deep-sea waves, obtained from voluntary observing ships

(VOS), originate from the southerly, south-south-westerly and south-westerly sector. Due to the orientation of the peninsula, the Port of Walvis Bay is protected from these dominant waves. The median significant wave height is 1.1 m and the median peak wave period is 11.6 s as obtained from accurate Waverider data measured in 50 m water depth (Figure 1).

2.4 Sediment grain size

Sand samples taken from the wetted beach and the sea bottom at Donkie Bay and Pelican Point show that the average median grain size (D_{50}) is about 0.35 mm, that is, medium sand.

3. Sediment transport analysis

3.1 Aeolian transport

About 6 years of wind data collected near the Walvis Lagoon (Figure 1) were used to compute seasonal and annual wind-blown sand transport rates on the Walvis Peninsula, using the method proposed by Swart (1986). The average of the median grain sizes (0.33 mm) of the samples taken on land across the Walvis Peninsula was applied.

It was found that the dominant transport is towards the north-eastern and north-western sectors with distinct seasonal variations. The net northward movement of sand is equal to the difference between the northbound and southbound transports, which is about 38 m^3/year per m. By using the average width of the Walvis Peninsula (605 m), it was calculated that the potential net northbound aeolian transport is approximately 23 000 m^3/year.

3.2 Longshore transport

Longshore sediment transport usually takes place from south to north along the western shore of the Walvis Peninsula. The tip of the Walvis Peninsula acts as a total trap for sand moving alongshore with the result that the spit is growing over time. By determining the volume of sand deposited over a period of time, the net longshore transport rate can be calculated. An analysis of the historic data (old maps and aerial photographs) showed that Pelican Point grew at an average rate of about 17.4 m/year between 1885 and 1980. Between 1980 and 1996 Pelican Point has prograded over a total distance of 340 m (determined accurately from the surveys), that is 22.6 m/year on average. In contrast to growth at the tip the eastern coastline configuration of the spit did not change between 1980 and 1996. Along the western flank, however, a significant shift took place around Donkie Bay, resulting in a decreased width in this area, which gave rise to the present concerns regarding breaching.

Based on all the available statistical information, a prediction was made with respect to the expected location of Pelican Point in the year 2006, that is, in 10 years' time. Using geographical information system (GIS) techniques, it was found that a total of 8.83 million m^3 of sediment will be required to enable the growth of

Pelican Point to achieve its predicted shape in 2006. This implies an average annual addition of 883 000 m^3 of sediment. If the Walvis Peninsula is considered a total sediment trap, the figure of 883 000 m^3/year represents the net northward sediment transport rate along this coastline.

One should subtract the net northbound aeolian transport (23 000 m^3/year) from the calculated volumetric rate of 883 000 m^3/year. Thus the net northbound longshore transport rate along the western shore of the Walvis Peninsula is considered to be 860 000 m^3/year.

3.3 Cross-shore transport

Erosion by offshore sand transport (during storms) can potentially cause breaching of the Walvis Peninsula. Modelling of cross-shore transport and the associated beach profile changes was therefore carried out.

The Sbeach cross-shore transport/morphological model (Larson and Kraus, 1989) was chosen for predicting beach profile variations due to storms. In a comprehensive review, Schoonees and Theron (1995) found that this is one of the best models currently available. The theoretical basis is acceptable and the model has been extensively verified (Schoonees and Theron, 1995). In addition, it can simulate dune overwash which can be important in the Donkie Bay case. No calibration data are available for the Donkie Bay case and the results should therefore be regarded as first estimates only. However, since Sbeach is a well-verified model against prototype data, the results are considered to be realistic.

Profile 2 was selected because the crest of the dune is the lowest in this profile (Figure 2), thus representing the most critical scenario. A median grain size of 0.35 mm was used for the profile. Two storms were modelled, namely, storms having significant wave heights (H_s) of 3 m and 4 m respectively. These wave heights correspond roughly to the 1-in-1 year (3.6 m) and the 1-in-10 year (4.4 m) conditions. More extreme wave heights were not chosen because it has previously been found that medium-sized waves occurring over longer periods cause more erosion than short-lived, high-wave events. The peak wave periods (T_p) associated with these wave heights are 11.7 s and 12.5 s respectively. The durations of these two storms were 68 h and 41 h respectively. The water-level variation was obtained from the most extreme tides predicted for 1996: from -0.94 m to +0.89 m to MSL (the latter value approaches the highest astronomical tide of +1.02 m to MSL).

Figure 2 shows the progressive erosion of the beach profile for the 3 m storm. An offshore bar formed at a depth of about -5 m to MSL. The predicted maximum horizontal erosion of 23.5 m (and 18.8 m for the 4 m storm) occurred at 0 m to MSL. Because of its longer duration, the 3 m storm caused slightly more erosion than the 4 m storm. Based on experience, these values appear realistic. As indicated by Figure 2, it is unlikely that the dune crest will be flattened, although the model does predict overwash as has been observed on site. Smaller waves will therefore not be able to erode the beach continually. However, it should be borne in mind that the model could not be calibrated for Walvis Bay due to a lack of data.

The results are therefore preliminary only. In addition, only two storms were modelled.

4. Possible breaching of the Walvis Peninsula

The possible breaching of the Walvis Peninsula was approached in two ways: firstly, by analysing measured beach profile variations (in a horizontal plane) from other sites and secondly, by modelling storm erosion as explained above.

Beach profile variations have been recorded on exposed beaches along the Southern African coastline. Typically the maximum, natural, horizontal storm erosion for exposed beaches is between 30 m and 95 m over the long term.

The predicted maximum horizontal erosion of 23.5 m compares well with the range of measured erosion. The beach profile modelling showed that overwash will most probably not flatten the dune (Figure 2). However, caution is necessary because it was not possible to calibrate the model (Sbeach) for Walvis Bay.

When considering the width of the Walvis Peninsula, which is at least 500 m wide, it is clear that it is highly unlikely that the peninsula could be breached by a single storm. Erosion of no more than 50 m can be expected during one storm. However, a potential danger exists for wave action to flatten the frontal dune (although this was not predicted in the beach profile modelling). This could possibly cause smaller, more commonly occurring waves to flatten the peninsula with breaching occurring eventually.

It is therefore recommended that the Donkie Bay area be inspected weekly and also immediately after heavy seas to ensure that flattening of the dune is noticed timeously. In the event of flattening, emergency protection can be installed (see Chapter 5) to prevent breaching. It is further recommended that bi-monthly beach surveys be conducted of the Donkie Bay area.

5. Conceptual measures to prevent breaching

5.1 General

A number of generic measures can be employed to prevent breaching of the Walvis Peninsula. These measures are: sand nourishment, methods to prevent erosion, and methods that induced accretion in the vulnerable areas.

A number of factors should be considered when evaluating the suitability of these measures. These factors include availability of construction materials and equipment, cost of construction, accessibility of the construction site and whether a temporary or permanent solution is required.

5.2 Sand nourishment

Sand can be brought in artificially to widen the vulnerable section of the peninsula (Donkie Bay). Possible methods for bringing in sand from nearby areas where there is abundant sand are: by means of trucks, pumping, or bulldozing sand into the sea just south of the Donkie Bay area. Especially in the case of bulldozing, the sea can be used to transport the sand towards the Donkie Bay area.

The extra sand can serve as an emergency measure by filling up or feeding an eroded section, or by acting as a buffer against future erosion. It is most likely that sand nourishment will be only a temporary solution. If applied correctly, it can, however, be an effective and low-cost solution.

5.3 Methods to prevent erosion

There are a number of different methods for preventing erosion. These include low-cost shore protection, a rock berm (armour), a gabion structure, and a sheetpile wall.

The CSIR has done extensive research into *low-cost shore protection.* Initially, a literature survey was done and new concepts were developed which were tested in the laboratory. Thereafter, a one-day field exercise was conducted. This was followed by a full-scale test at Hermanus (an exposed site) in November 1992. A 3 m high dune (sand wall) of 110 m length was constructed, which was protected by four different configurations of low-cost protection structures. The detailed results of this test are discussed in Theron *et al.* (1994). Based on these results, the three most promising protection methods were found to be sandbags, sand sausages (Figure 3) or a combination of both. In two subsequent cases sandbag groynes were also used successfully in False Bay near Cape Town.

Low-cost protection and breakwaters are in use around the world. In Mexico several major coastal structures have been built (Porraz, 1976, 1987) which have withstood a number of hurricanes. Dette and Raudkivi (1994) devised a shore protection system (Figure 4) very similar to the CSIR design shown in Figure 3. They tested it in the Large Wave Flume in Hannover, Germany before a successful prototype application on the island of Sylt in the North Sea. The defence has withstood storms from 1991 up to at least the date of the publication (1994). Dette and Raudkivi (1994) also mentioned a similar successful deployment in Fidji for hurricane protection.

The main advantages of low-cost shore protection are that it is relatively easy and fast to build and remove and that the building material (usually sand) is locally available. The disadvantages are that the protection is mostly temporary (that is, withstanding a 2 to 6 month period of wave attack) and that degradation of the geotextile material will eventually occur due to ultra-violet radiation from the sun.

Profile 2 (Figure 2) is the most vulnerable section of the Walvis Peninsula. If the top of the dune is flattened during a storm, it is possible to protect the peninsula with a double row of tightly stacked (1 m^3) sandbags placed as shown in Figures 5 and 6 around the eroded area. These emergency measures are, however, only essential if significant erosion has already occurred.

For protecting the Walvis Peninsula permanently, a dynamically stable *rock berm,* consisting of smaller rock, will most probably be cheaper (also in the long term) than a statically stable rock protection. Allowance will have to be made for scour in front of the structure. By placing enough rock, a sacrificial toe can be

constructed which will partially fall into the expected scour hole in front of the rock protection. Figure 7 shows a conceptual rock berm (median rock mass (w_{50}) = 1 150 kg) for protecting the vulnerable Donkie Bay area. This type of design has proved its adequacy in prototype in a similar situation at Saldanha near Cape Town (CSIR, 1994). Such a rock berm can be placed in the same position as the low-cost shore protection (Figure 5). Three-dimensional effects need to be considered. For example, wave overtopping can cause the formation of pools of water behind the rock berm which will rush back to sea at the lowest point of the berm, causing a dangerous and erosive return current.

Other possible methods of preventing erosion at the Walvis Peninsula are *gabions* and a *sheetpile wall*. Gabions are susceptible to failure if they are continually exposed to wave action. This is mainly due to abrasion and corrosion of the wire of the gabions. A sheetpile wall will probably be very expensive. Allowance also has to be made for the extra scour in front of such a wall because of wave reflection. Therefore, these two methods do not appear to be appropriate for the Walvis Peninsula.

5.4 Methods that induce accretion

There are different methods that can be employed to induce accretion of sand in the Donkie Bay area. These include: one or more groynes to trap the longshore transport of sediment, the construction of a headland to trigger the formation of a half-heart bay, and the trapping of wind-blown sand.

One-line theory (Larson *et al.*, 1987) was chosen to predict the shoreline evolution caused by the construction of different *groynes*. The theory predicts the position of a single contour line over time (taken to be the shoreline or 0 m to MSL contour). Despite simplifying assumptions such as the theory being only applicable for small wave approach angles and that no net cross-shore sediment transport takes place, one-line theory has been proved to give good results in Japan (Hanson and Kraus, 1986), the United Kingdom (Brampton and Goldberg, 1991), the USA (Hanson *et al.*, 1989) and Southern Africa (Coppoolse *et al.*, 1994).

Three different groynes extending to -1.5 m, -3 m and -5 m to MSL were simulated in the model. These groynes are 61 m, 86 m and 116 m long if measured from the +2 m to MSL contour. The simulation runs were for a groyne just north of the vulnerable Donkie Bay section at alongshore distance (or Chainage) 4 000 m (Figure 5). At Chainage 3 800 m (the corner of Donkie Bay), the shoreline turns sharply westwards forming Donkie Bay. In addition, two groynes of 61 m length each, one at the above-mentioned position at Chainage 4 000 m and one at 350 m further northward along the Walvis Peninsula at Chainage 4 350 m, were also simulated. This was done because it is considerably cheaper to build two 61 m groynes than one long groyne. In addition, the 61 m groynes will only extend to -1.5 m to MSL, which means that they can be constructed from land using sandbags (Theron, *et al.*, 1994).

As input parameters, the net longshore transport obtained in Section 3.2, a

representative wave incidence angle at the breaker line (4°), a total height (above and below the water) over which nearshore profile changes take place (12 m), and beach slopes and water depths at the groynes obtained from the surveys were used.

Figure 8 represents the shoreline evolution caused by the 116 m groyne. Note that the original coastline is at a cross-shore distance of 200 m. Accretion of about 69 m takes place reasonably rapidly next to the groyne. Equilibrium is reached after about two years with little significant accretion occurring after a year. This means that significant bypassing will take place almost immediately after the groyne has been constructed, thus limiting downdrift erosion. At 200 m south of the groyne (in the corner of Donkie Bay) eventual accretion of approximately 63 m (12 m after 1 month) can be expected. The sand will form an appreciable extra buffer against storm erosion.

Two 61 m groynes were also modelled to evaluate the effects on the beach (Figure 9). It can be seen from this figure that, initially, some erosion is evident north (to the right) of the first groyne (at Chainage 4 000 m), after which significant bypassing takes place and accretion occurs (in the order of 19 m). Because of the relatively high longshore transport rate and the short groynes, the coast will be close to equilibrium after about 6 months.

Downdrift erosion of about the same magnitude as the accretion can be expected to the north of the groyne (or the northernmost groyne in the case of two groynes). However, if erosion occurs when the peninsula is wide (more than 500 m) and not vulnerable, it is considered acceptable.

Half-heart bays can be used to stabilise a coast. However, in the case of the Walvis Peninsula, this will mean that at least one major headland will have to be constructed because the peninsula is an exposed coastline with high longshore transport. Because of the high cost, this option is not considered viable.

Aeolian sand can be *trapped* by erecting geotextile fences across the Walvis Peninsula. Because of the low aeolian transport rate of about 23 000 m^3/year, it will take a long time to achieve appreciable accretion at Donkie Bay. To be conservative, only the width of dry sand on the peninsula should be considered and not the total width of the peninsula at Donkie Bay because moisture limits sand transport by wind. If this is done, the net northbound aeolian transport is only about 3 040 m^3/year. The accretion against the fences will therefore be small and it will take a long time to achieve significant results. The additional protection offered against storm erosion will therefore be small in the short to medium term, which is the required time span.

Although the solution is initially cheap, considerable maintenance is envisaged. Access to Pelican Point for lighthouse personnel, anglers, etc. will be hindered because of the fences. The fences are also prone to damage by vandalism. Trapping wind-blown sand is therefore not regarded as a suitable option.

6. Conclusions and recommendations

It is highly unlikely that the Walvis Peninsula would be breached during a

single storm. There is, however, the potential danger that wave action could flatten the frontal dune (although this is not predicted in the beach profile modelling). Flattening of the frontal dune could possibly cause smaller more commonly occurring waves to flatten the peninsula with breaching occurring eventually. It is therefore recommended that the Donkie Bay area be inspected weekly and also immediately after heavy seas to ensure that flattening of the dune is noticed timeously. In the event of flattening, emergency protection can be installed to prevent breaching. Bi-annual beach surveys of the area are recommended.

Because it is unlikely that the peninsula would be breached during a single storm, it is not deemed necessary to opt for the best permanent solution, namely a rock berm. Such a permanent solution will obviously be more expensive than a temporary solution. However, it is strongly recommended that a contingency plan be drawn up in order to facilitate a timeous response in case of an emergency. It is recommended that 1 m^3 bulk bags be bought and kept in storage at Walvis Bay for such an emergency. These can be used either as low-cost shore protection (Figures 5 and 6) or to construct one or two short groynes (Figure 9). Arrangements should also be made for obtaining a large excavator (on metal tracks; 20 tonnes) at short notice to fill and transport the bulk bags. The low-cost shore protection and groyne(s) should be designed in detail because experience has shown that the method of construction and deployment can have a profound effect on the overall success of the protection (Theron *et al.*, 1994).

It is also advisable to a have a bulldozer available at short notice. Bulldozing sand into the surf zone upstream of the damaged (eroded) area can help to delay erosion, thus buying time for placing the bulk sandbags. It is also advisable, though not essential, to build one short (61 m) groyne. The advantages are that an additional buffer of sand will be formed thereby reducing the possibility of a breach and that the construction will serve as a training exercise for deployment of low-cost protection during an emergency. In addition, by monitoring the beach accretion, calibration data for modelling shoreline evolution resulting from the groyne will be obtained to confirm the predictions presented above. The disadvantage of the construction of the groyne is that unnecessary cost will be incurred. On the other hand, such a groyne will most probably cost less than the more extensive remedial protection required in an emergency.

Acknowledgement

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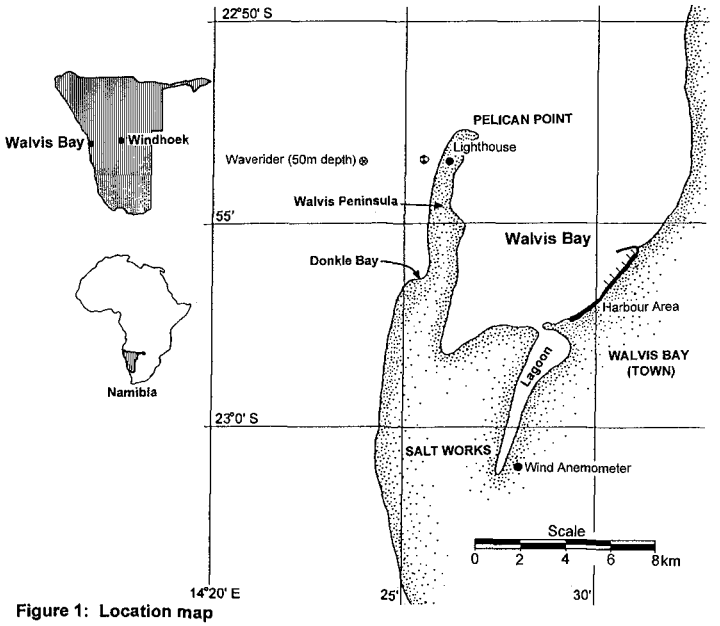


Figure 1: Location map

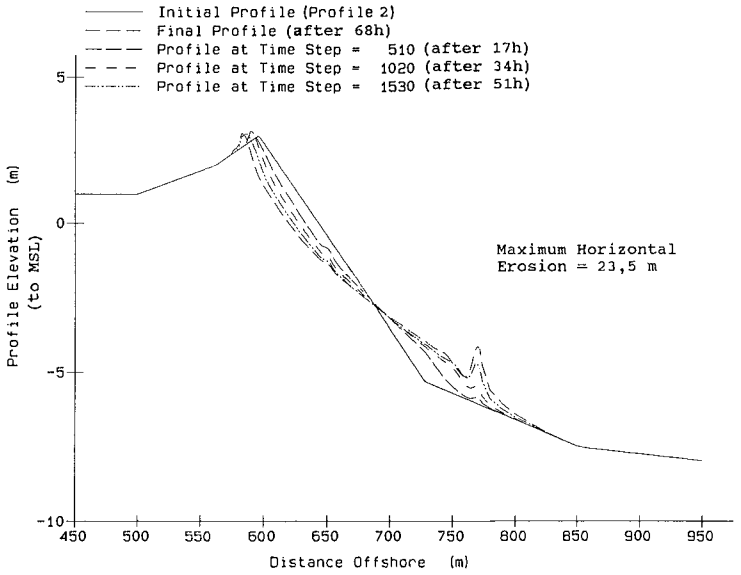


Figure 2: Profile evolution during the 3 m storm

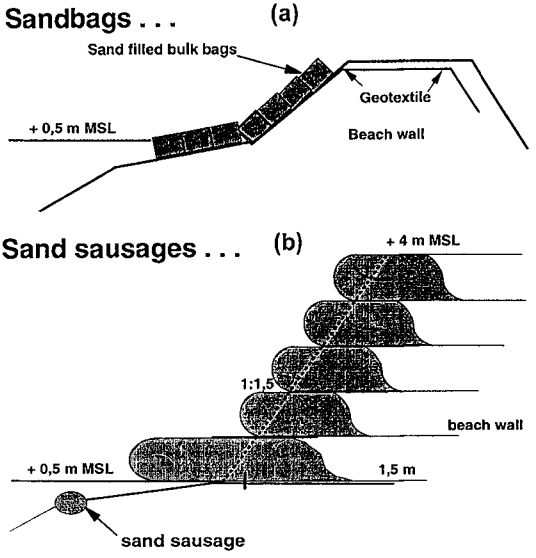
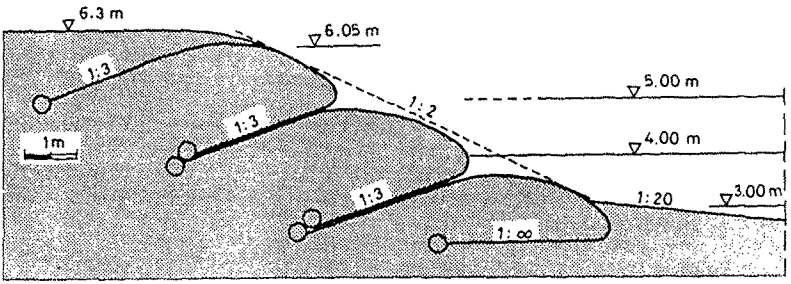


Figure 3: Low-cost shore protection using sandbags and sand sausages



(FROM DETTE AND RAUDKIVI, 1994)

Figure 4: Geotextile membrane tested in the large wave flume

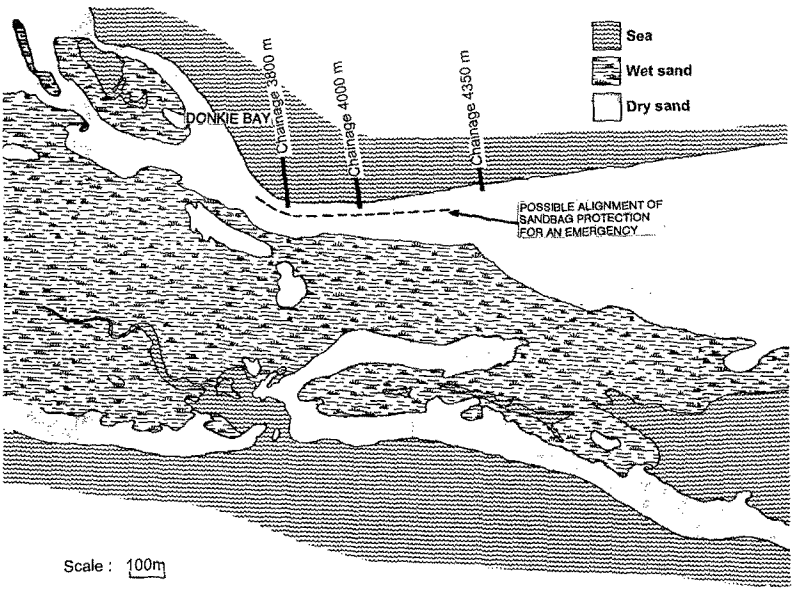


Figure 5: Possible position of the sandbag protection

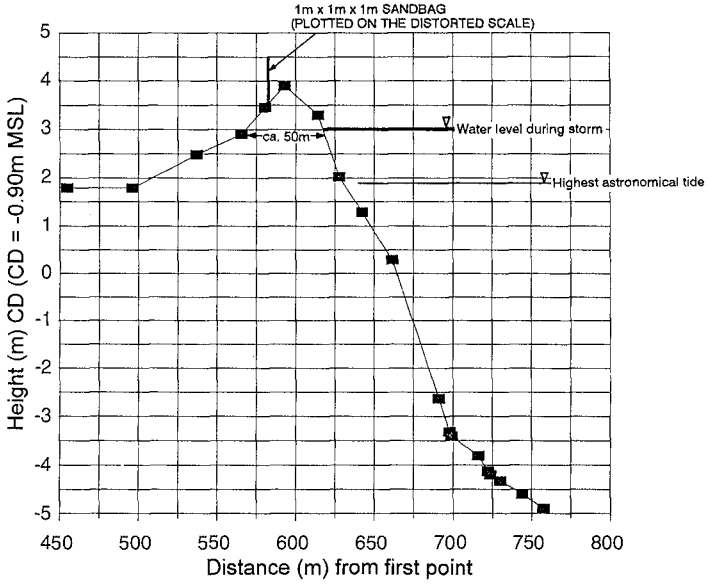


Figure 6: Position of the sandbag protection on the profile

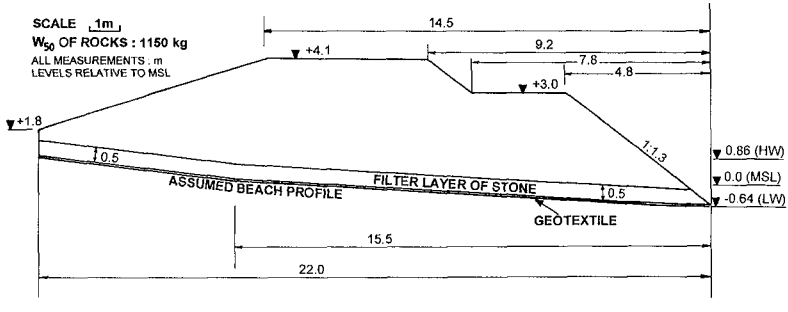


Figure 7: Cross-section of rock berm

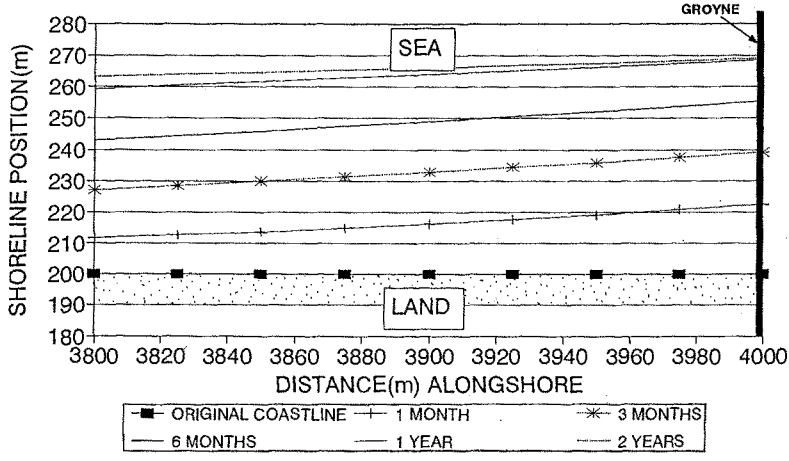


Figure 8: Shoreline evolution caused by the 116 m long groyne

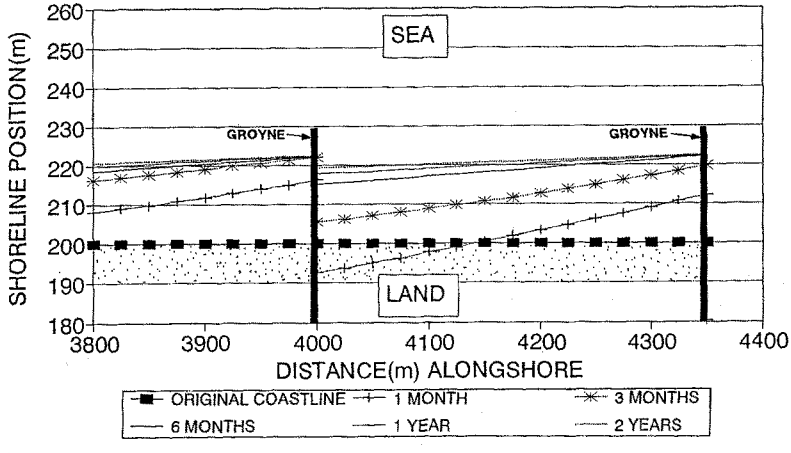


Figure 9: Shoreline evolution caused by two 61 m long groynes