CHAPTER 183

Causes of Damage to Saldanha Sand Breakwater

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1. Abstract

The Port of Saldanha, situated 120 km north-west of Cape Town, South Africa, is protected from the dominant south-south-westerly swell conditions by a sand breakwater which is presently eroding. This paper summarises the results of the monitoring of the breakwater, which consisted of aerial and beach photographs as well as hydrographic surveys. Another part of the investigation was to examine the reasons for the erosion (found by the monitoring to be increasing) on the basis of the prevailing environmental conditions such as wind, waves and currents. To do this the wind and nearshore wave climates were determined. Subsequently, the optimum alignment of the sand breakwater was calculated by three different methods. The equilibrium slope of the breakwater, which was also determined, indicated that the design slope was too steep. Of the remedial measures considered, namely, the use of sand or rock, the latter was chosen.

2. Introduction

The Port of Saldanha, situated some 120 km north-west of Cape Town on the South African west coast was constructed mainly for the export of iron ore. Shelter from the swell conditions that occur there was obtained by building a sand (or spending beach) breakwater between Hoedjiespunt on the mainland and Marcus Island (Figure 1). Zwemmer and Van't Hoff (1982) describe the design and construction of the breakwater in detail.

About 20 million m^3 of sand was used for the construction of the 1,9 km long breakwater. Some difficulty was encountered in obtaining this quantity. It was also found that rock protection (as a spur before placing sand) was necessary in order to build the breakwater. This resulted in a sand breakwater with some rock protection, mainly above the low-water mark. See Zwemmer and Van't Hoff (1982) for details.

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** J W J Kluger passed away in 1988. His contribution is gratefully acknowledged.

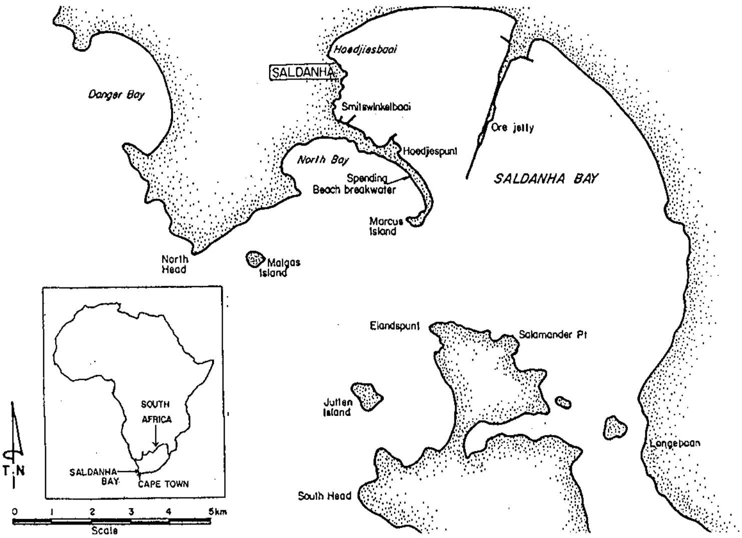


FIGURE 1 : LOCALITY MAP

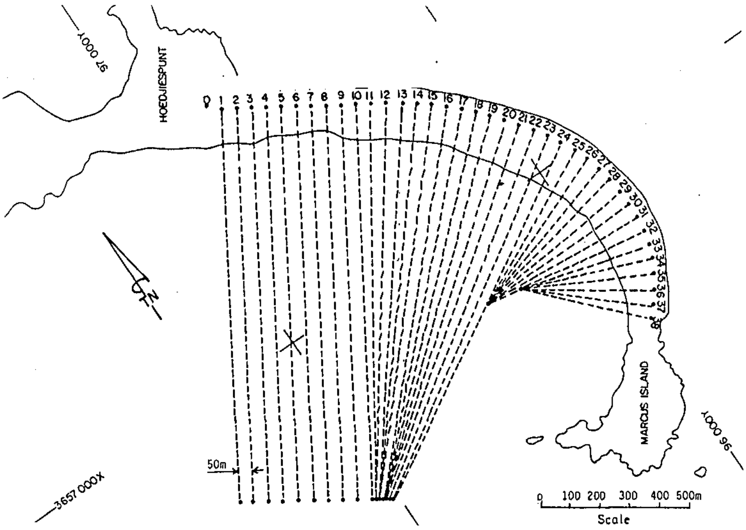


FIGURE 4 : POSITION OF THE SURVEY LINES

A preliminary study of the stability of the sand breakwater (CSIR, 1985) was commissioned by the then South African Transport Services (now Portnet). This study, by using the then available hydrographic and beach survey data, concluded that sand is eroded steadily from the breakwater at a rate of approximately 50 000 m^3/year. Based on a recommendation of this study, a detailed investigation (CSIR, 1988) was undertaken to establish the reason(s) for this erosion on the basis of the prevailing environmental conditions such as wind, waves and currents. It was further recommended that the breakwater be monitored on a regular basis.

CSIR (1988), of which this paper is basically a summary, deals with the photographic and hydrographic monitoring of the breakwater, the effect of wind, the wave climate, the optimum alignment of the breakwater and the equilibrium slope of the breakwater as well as possible remedial measures.

3. Monitoring of the Breakwater

3.1 General

The monitoring consisted of low-altitude aerial photography, beach photography and beach and hydrographic surveys.

3.2 Aerial Photography

The aim of the aerial photography, conducted at roughly three-monthly intervals and taken at low water, was to establish whether overall changes of the breakwater, and especially the erosion areas detected previously in the rock protection placed during construction, had taken place.

Figure 2 is an example of a photomozaic compiled from such photographs.

The aerial photography showed that no drastic change of the erosion areas occurred and that the overall appearance of the breakwater has virtually stayed the same during the period August 1985 to November 1986.

3.3 Beach Photography

The main purpose of the close-up beach photographs was to provide an indication of the movement of stone and of possible degradation of the stone of the rock protection itself.

An aluminium tripod, giving a camera elevation of 3 m above ground level, was used to photograph the beach. One leg of the tripod consisted of a ladder which provided access for the photographer to the top of the tripod (Figure 3). At each position of the tripod, a horizontal area of 4,2 m × 4,2 m was photographed. Thus, by moving the tripod 4 m along a selected line after taking each photograph, a continuous strip of the beach 4,2 m wide and as long as required, could be photographed.

Seven beach photography areas were chosen, namely, survey lines 2, 4, 9, 15, 21, 27 and 37. See Figure 4 for the positions of these survey lines and Figure 5 for an example of such photographs.

FIGURE 2 : AERIAL PHOTOMOZAIC TAKEN ON 26 JUNE 1986

FIGURE 3 : TRIPOD USED FOR THE BEACH PHOTOGRAPHY

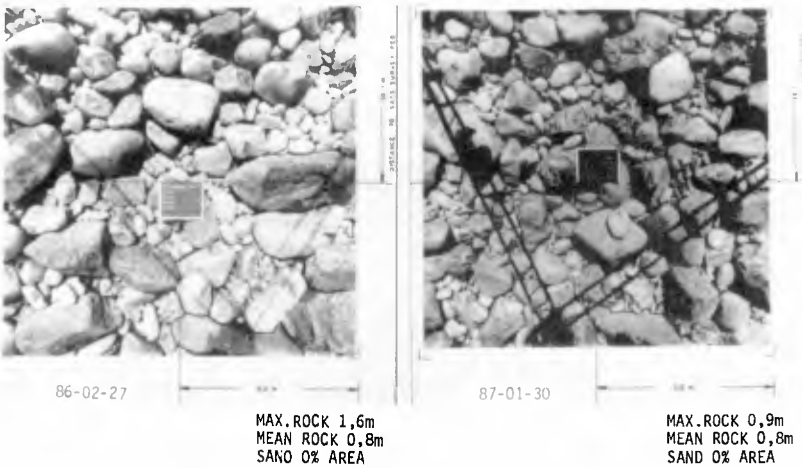


FIGURE 5 : AN EXAMPLE OF THE BEACH PHOTOGRAPHY ON SURVEY LINE 15

No measurable stone degradation could be detected on the beach photographs taken during the 11-month recording period. These photographs, however, indicated that stones up to 1,5 m in size (approximately 3 t) moved on the beach slope below +4 m CD (CD = chart datum which is 0,90 m below mean sea level (MSL)). The most severe movement took place between survey stations 3 and 9 and stations 27 to 37.

3.4 Beach and Hydrographic Surveys

Hydrographic surveys were done by measuring nearshore profiles along survey lines (Figure 4) with an echosounder mounted on a boat. Depths up to about -20 m CD were recorded. The beach profiles were surveyed on the beach along the same survey lines by using a theodolite and a staff.

Figure 6 shows a fair chart of one of the surveys. Note that there is a gap between the beach and hydrographic surveys. This, is unfortunately, in the area where most of the seabed changes occur. This is due to the restriction imposed by the draught of the available survey vessel as well as by the rough wave conditions normally encountered at the breakwater.

Volume differences between surveys were calculated (in the gap between beach and hydrographic surveys, linear interpolation was used). The following table summarises these volume changes:

Date	Volume difference[1] (m^3)	Period (months)	Calculated rate (m^3/year)
27-06-78			
	-43 500	3,75	-139 300
20-10-78			
	-93 400	6,25	-179 400
26-04-79			
	+168 800	7,00	+289 400
28-11-79			
	-271 700	35,00	- 93 200
29-10-82			
14-11-84			
	-362 600	17,75	-245 100
07-05-86			

[1] + means accretion
- means erosion

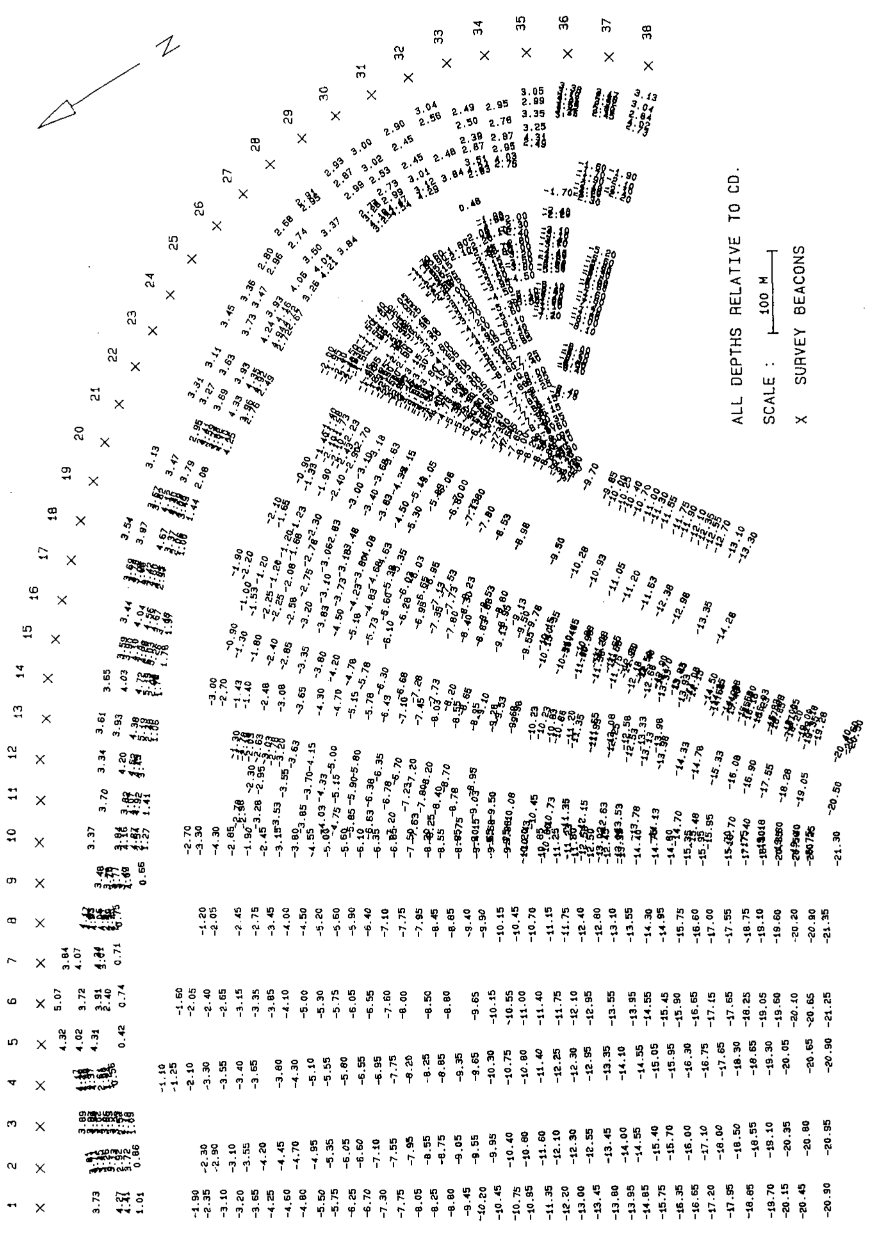


FIGURE 6 : HYDROGRAPHIC SURVEY OF 86-05-07

From this table it is clear that considerable volume changes (erosion and accretion) occurred. Statistical comparison of the last erosion rate, of -245 100 m^3/year, with the previous rates indicates (at a 90 % confidence level) that the erosion rate increased significantly during the period November 1984 to May 1986. Although this rate is small in comparison with the total volume of sand placed to form the breakwater, this loss of sand may endanger the breakwater. It is, therefore, important to monitor the breakwater in future to establish whether this tendency continues. If so, it is important that remedial measures be undertaken.

Every effort should be made to minimise the gap between the future hydrographic and beach surveys because some of the large variation in the volume differences between surveys and possibly the accretion, can be attributed to this.

The beach profiles showed either erosion or remained basically stable. The most severe beach erosion occurred at profiles 2 and 36.

4. Wind

Based on hourly wind recordings over a 3-year period at nearby Elandspunt (see Figure 1 for the position of Elandspunt), the dominant wind directions were found to be SSW, SW, S and NNE. Calms occur on average 6,9 % of the time.

It was found that, because of the very limited availability of sand on the breakwater owing to stone and vegetation cover and because of short wind fetch lengths for the major wind directions, the effect of wind on the breakwater is negligible.

5. Wave Climate

For sediment transport computations, simultaneous recordings of wave height, wave period and wave direction are necessary. The only wave data sources that met this requirement, namely, clinometer (graded telescope) and VOS data (estimates from voluntary observing ships), were compared with other available measurements of wave characteristics (Waverider records). The clinometer data were found to be the hetter data source. Deep-sea clinometer wave directions were accepted unaltered while clinometer wave period and deep-sea wave heights were adjusted by means of exceedance curves to give 'equivalent' Waverider periods and deep-sea wave heights.

Figure 7 gives the details of the deep-sea wave climate. Combinations of deep-sea wave directions from SSE, S, SSW...NW and peak wave periods between 6,2 s and 23,8 s were compiled to serve as input for a wave refraction study.

This study was to transfer the deep-sea wave climate to shallow water at the spending beach breakwater. For this purpose extensive coverage of the irregular bathymetry of the area at and surrounding the spending beach breakwater was obtained from hydrographic maps. The hathymetry was then

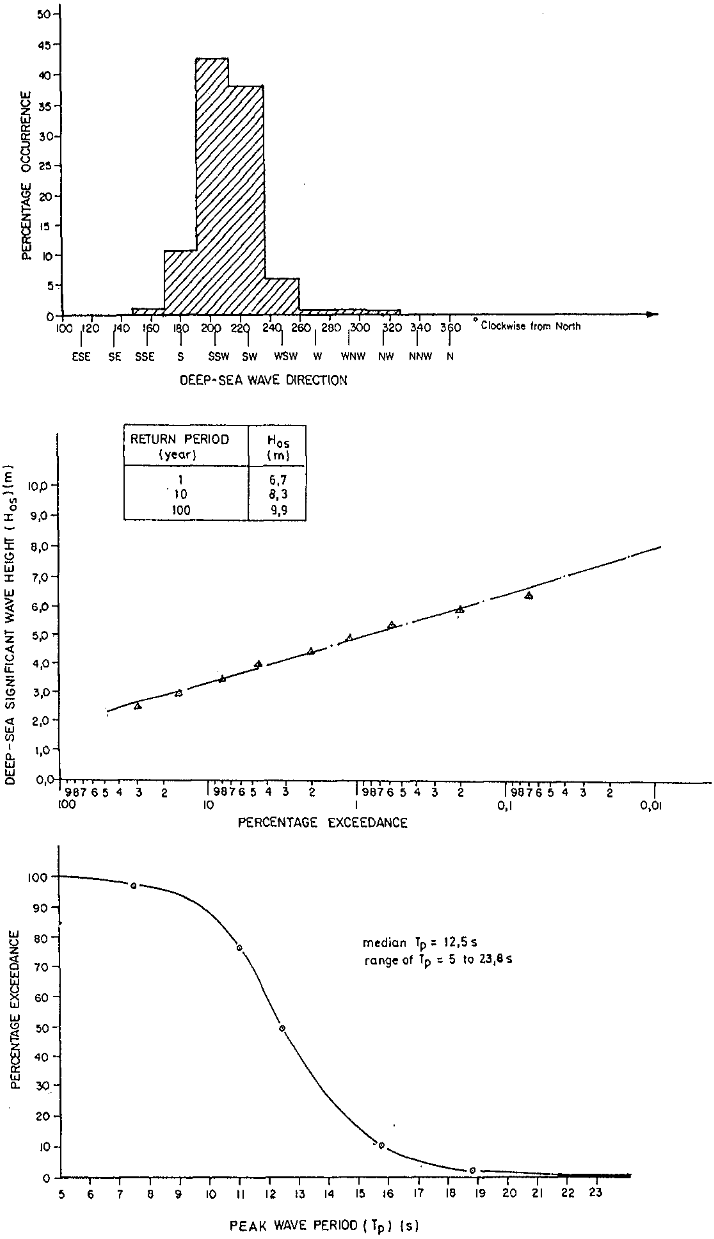


FIGURE 7 : DEEP-SEA WAVE CHARACTERISTICS

represented in eighteen model grids in which the grid squares became progressively smaller from deep to shallow water.

Refraction and shoaling of each of 37 recorded deep-sea wave conditions were done. Figure 8 shows a refraction diagram. For each deep-sea wave direction/wave period combination, the nearshore wave characteristics at the 3 m (to MSL) contour were compiled every 200 m along the breakwater.

6. Optimum Alignment of the Breakwater

6.1 General

The optimum alignment of the breakwater was calculated in two ways (Methods 1 and 2). A third and empirical method (Method 3) was used to check the results of Methods 1 and 2.

6.2 Method 1

The optimum alignment of the breakwater was calculated by determining at different points along the breakwater, what the alignment of the breakwater should be for each wave condition in order to make the longshore sediment transport potential due to obliquely incident waves zero. A weighted mean alignment of the breakwater at the different points was then computed. This is similar to the way in which the alignment of the breakwater was initially determined (Zwemmer and Van't Hoff, 1982).

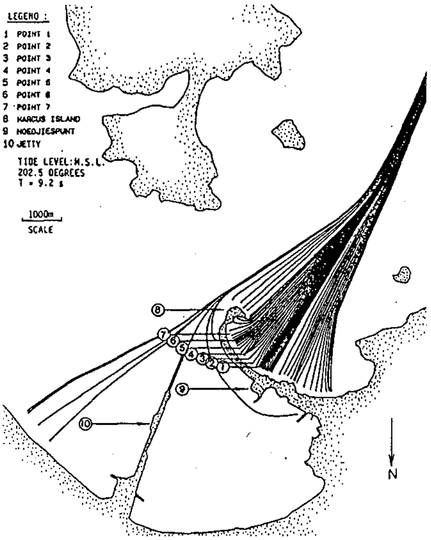
The approach of Shore Protection Manual formula for longshore sediment transport given in US Army Corps of Engineers (1984) was applied. This formula is valid for non-cohesive sediment of grain sizes between 160 μm and 1 mm. Although it does not contain sediment grain size, it has been shown by Swart (1976) and Bruno *et al.* (1981) that the 'constant' in the formula is actually a function of the grain size. Therefore, although the breakwater consists predominantly of sand (but covered by a stone capping at and above the water line), the form of the formula can be regarded as being the same for coarser material even though the 'constant' will change. Therefore, if the wave incidence angle is zero, no longshore transport will occur, irrespective of the grain size.

The weighted mean values were used to plot, in Figure 9, the general alignment of the breakwater if it is to be left alone as well as the realignment needed for reconstruction.

The alignment calculated by Method 1 neglects the effects of secondary flows due to diffraction-type currents. This shortcoming is eliminated in Method 2.

6.3 Method 2

The basic procedure followed was the same as in the first method, except that the longshore current velocity in the middle of the surf zone, due to obliquely incident waves and a longshore variation in breaker wave height was set to zero and the corresponding orientation of the breakwater calculated. Because the longshore sediment transport is a function of the longshore current



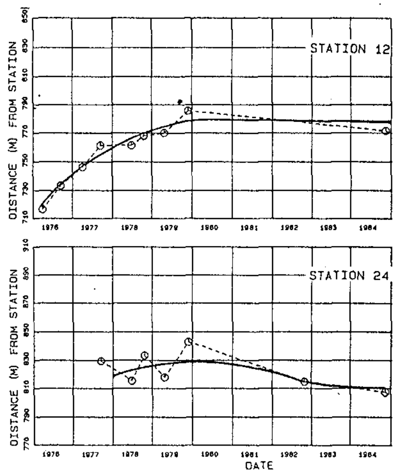


FIGURE 10 : EQUILIBRIUM TREND IN THE MOVEMENT OF THE -14m CD CONTOUR

FIGURE 8 : WAVE REFRACTION DIAGRAM

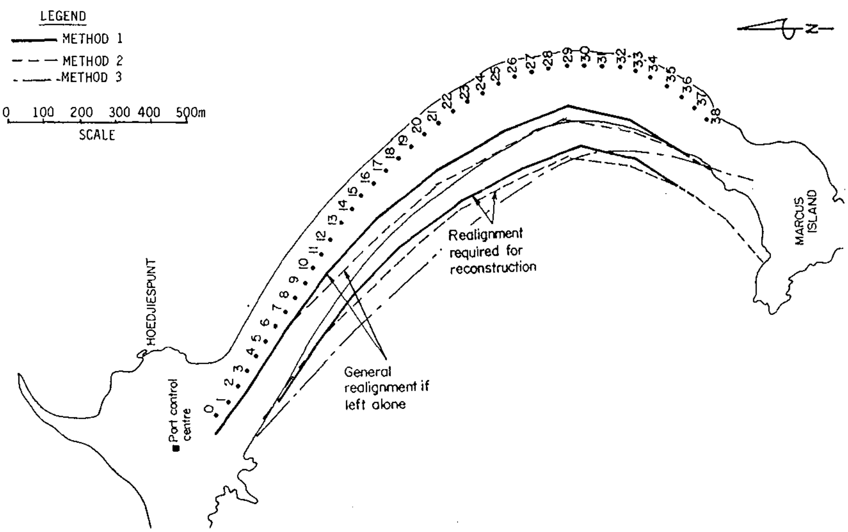


FIGURE 9 : OPTIMUM ALIGNMENT OF THE BREAKWATER

velocity, this means that the longshore transport will be zero if no longshore current is generated. Again, a weighted mean alignment was computed along the breakwater (at 21 points, 100 m apart).

A formula by Komar (1975) for the determination of the longshore current velocity (v) distribution across the surf zone due to obliquely incident waves and a longshore variation in breaker heights, was applied in the same way as in Schoonees (1986) to calculate the wave incidence angle at which v = 0 in the middle of the surf zone.

The results of this method are also illustrated in Figure 9.

6.4 Method 3

Building on the earlier work of amongst others, Yasso (1965), Silvester (1970) and Silvester and Ho (1972), Hsu *et al.* (1989) proposed new relationships to determine the equilibrium planform of bays.

The weighted mean wave approach angle at Marcus Island was calculated in order to apply the method. Figure 9 shows the predicted planform of the breakwater according to Method 3.

6.5 Discussion

Although the results of the first two methods differ somewhat, as can be expected, the same conclusions can be drawn from them. These are:

(i) It is not feasible to realign the breakwater considering the volume of material (approximately 500 000 m^3) that will be required. Furthermore, no suitable (medium to coarse) sand is available.

(ii) If the breakwater is left indefinitely to realign itself, it may be in danger of eventually being breached.

The equilibrium planform of the breakwater according to Method 3 agrees reasonably well with the planform of the breakwater needed for reconstruction obtained from the other two methods.

7. Equilibrium Slope of the Breakwater

7.1 Method

The equilibrium beach and nearshore profile at a specific position along the breakwater was determined in the following way from the surveys available at the time of the analysis:

A series of plots of distance of the contour from the survey station versus time for different depths (+4 m, +2 m, 0 m,... -20 m CD) were drawn. An example of such a plot is included as Figure 10.

These plots were used to deduce the long-term (equilibrium) trend in the movement of the specific contour (Figure 10). In other words, the equilibrium distance of the specific contour from the station was obtained. By plotting the depths of the contours versus these equilibrium distances, an equilibrium beach and nearshore profile was acquired.

Equilibrium profiles were determined opposite survey stations 2, 12 and 24 (see Figure 4 for the positions of these stations). These positions were chosen to be representative of the breakwater. The profiles are plotted in Figure 11.

7.2 Results

The predicted equilibrium slope at the three stations is virtually identical (1/45) and considerably flatter than the design slope of 1/35. This explains why erosion occurs above approximately -4 m CD and accretion below this level.

Therefore, while the breakwater is realigning itself alongshore, sediment is being steadily moved in an offshore direction from the breakwater. Thus when the breakwater has reached its optimum alignment, it will recede slowly as a whole and may in time be in danger of being breached.

8. Remedial Measures

Using sand as a solution was not considered feasible for the following reasons:

(i) A large volume (approximately 500 000 m^3) of sand would be needed for realignment. In addition, regular maintenance of the breakwater requiring about 50 000 m^3/year of suitable sand (medium to coarse) would be needed.

(ii) Suitable sand is not readily available. All available sources were utilised during the construction of the breakwater.

(iii) Some sort of expensive toe protection at about -14 m CD is most probably necessary to prevent excessive sand losses to deep water.

It was therefore recommended that a suitable rock protection be provided along the spending beach breakwater.

Before rock can be placed as protection, the erosion areas (Figure 2) should be filled up with sand. This should be followed by a geo-textile on the sandy areas and a layer of 0,5 m of well-graded filter stone (2 kg to 5 kg) over the whole area to be treated. Rock protection using stone between 1 t and 6 t should be placed as conceptually shown in Figure 12. The foundation of geo-textile and filter stone should extend beyond the toe of the rock armouring to provide scour protection. About 50 000 m^3 of rock will be needed for the erosion areas and approximately 150 000 m^3 for the entire sand breakwater.

It was recommended to check and optimise the design of the rock armouring in a model study using random waves. Flume tests to this effect were subsequently carried out (CSIR, 1989). The results of this investigation, however, fall outside the scope of this paper.

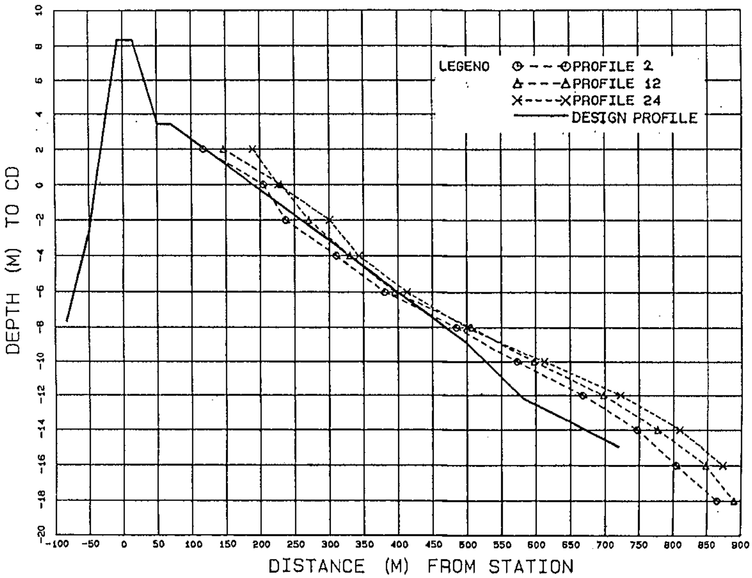


FIGURE 11 : EQUILIBRIUM PROFILES

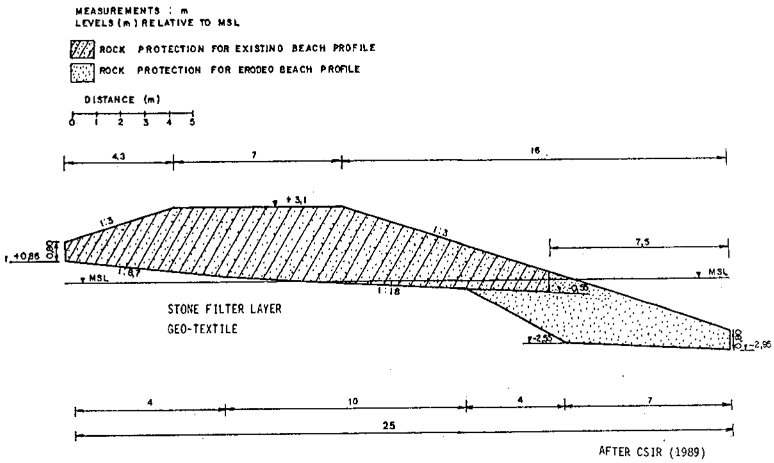


FIGURE 12 : CONCEPTUAL LAYOUT OF ROCK PROTECTION

It was also recommended that a hydrographic survey together with aerial photography be conducted annually and that beach profiles and beach photography be done more often to monitor the breakwater and the erosion areas. Particular attention should be given to obtain nearshore profile data in the surf zone.

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Acknowledgement

The permission granted by Portnet to publish this paper is gratefully acknowledged.