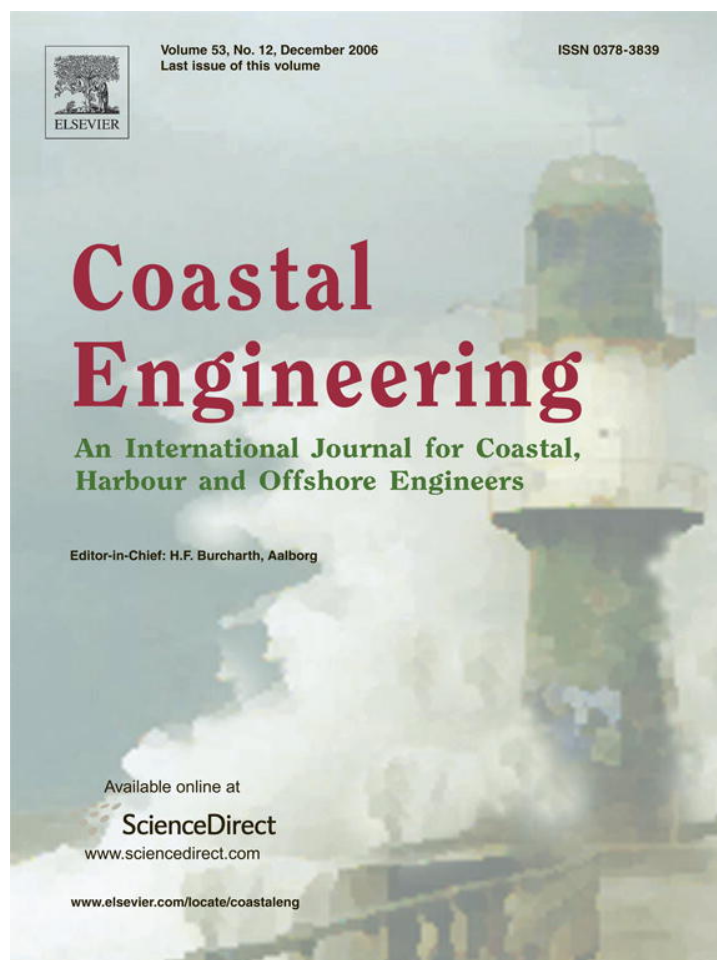


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## Shoreline accretion and sand transport at groynes inside the Port of Richards Bay

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### Abstract

The south-western shoreline along the entrance channel inside the Port of Richards Bay has experienced continued erosion. Four groynes were constructed to stabilise the shoreline. Monitoring of shoreline evolution provided valuable data on the accretion adjacent to two of the groynes and on the sediment transport rates at these groynes. Tides, beach slopes, winds, wave climate, current regime, and sand grain sizes were documented. The one site is “moderately protected” from wave action while the other is “protected” according to the Wiegel [Wiegel, R. L. (1964). Oceanographical engineering. Prentice Hall, Inc., Englewood Cliffs, NJ.] classification. The shoreline accreted progressively at the two groynes at 0.065 m/day and 0.021 m/day respectively. The shorelines accreted right up to the most seaward extremity of the groynes. Equilibrium shorelines were reached within about 3.5 years to 4 years, which compare well with other sites around the world. The mean wave incidence angle is large and was found to be about 22°. The median sand grain sizes were 0.33 mm and 0.37 mm. The groynes acted as total traps, the beach surveys were extended to an adequate depth, and cross-shore sediment transport did not cause appreciable net sand losses into the entrance channel. The net longshore transport rate along the study area, which is north-westbound, is only slightly lower than the gross longshore transport. The actual net longshore transport rates are 18 000 m<sup>3</sup>/year and 4 600 m<sup>3</sup>/year respectively at the two groynes. A rocky area limits the availability of sand at one groyne. There is fair agreement between the predicted and measured longshore transport rates at the other groyne.

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**Keywords:** Shoreline evolution; Accretion; Longshore sand transport; Groynes; Richards Bay

### 1. Introduction

The Port of Richards Bay (Fig. 1), situated on the east coast of South Africa, was constructed mainly as a coal export harbour and was opened for shipping in 1978 by the National Ports Authority of South Africa (NPA). The south-western shoreline along the navigation (or entrance) channel inside the Port of Richards Bay (Fig. 1) has experienced continued erosion. This erosion endangered the road leading to the south breakwater, as well as Building 4043 (Fig. 1). Coastal processes were studied to determine the causes of the erosion and different solutions were investigated to protect this shoreline against the erosion (CSIR, 1997; Schoonees et al., 1999).

Four groynes (Fig. 1) were constructed to stabilise the shoreline along the navigation channel (Schoonees et al., 1999). These groynes successfully withstood a major storm without suffering significant damage. Sand trapped by the groynes provided sufficient protection and has continued to halt localised erosion. The shoreline evolution in the vicinity of the groynes has been monitored on an ongoing basis, providing valuable data on the accretion adjacent to the groynes, the orientation of the shoreline, and the rate of accretion. At the same time, the environmental conditions at the site are well-known. This case study therefore provides valuable information on the shoreline accretion and longshore sediment transport at both a “protected” and a “moderately protected” site.

The purpose of this paper is to document the shoreline evolution and to provide estimates of the longshore sediment transport rate along the study site. Dong (2004) stressed the importance of assessing the actual performance of groynes; this

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is addressed within the constraints of the monitoring data. In addition, other aspects, like the construction of the groynes, are briefly discussed. The study area (or site) is the south-western shoreline along the entrance channel (Fig. 1). The focus is on the shoreline updrift of the L groyne (Groyne A) and at Building 4043 (Groyne C) because most of the shoreline evolution has occurred there. The study site is subjected to both swell and locally generated waves having large incidence angles.

Section 2 of this paper deals with the environmental conditions at the site. Section 3 summarizes the construction of the groynes while Section 4 treats the measured shoreline changes adjacent to these two groynes. Section 5 discusses the longshore sediment transport in the study area. Conclusions to the study are provided (Section 6).

## 2. Environmental conditions at the site

### 2.1. Tides

Tides are semi-diurnal at Richards Bay. The average neap tidal range is 0.52 m while the mean spring tidal range is 1.80 m. The mean high-water spring tide level is approximately +2.0 m to chart datum of the port ( $CD_{\text{port}}$ ) or +1.1 m to mean sea level (MSL). ( $CD_{\text{port}}$  is 0.90 m below MSL.)

### 2.2. Beach slopes

A bathymetric survey of the nearshore zone of the study area and the adjacent entrance channel was conducted on 30 November 1995 before construction of the groynes. This survey (Figs. 2 and 3) shows that the beach and nearshore profiles are characterised by a flat upper beach, a steep channel side slope and an almost horizontal channel bottom at approximately  $-21$  m to  $CD_{\text{port}}$  (CSIR, 1997; Schoonees et al., 1999). The upper beach slope (slope from the shoreline to the deepest point of the upper beach) is approximately 1/74. (The beach surveys also shown in Figs. 2 and 3 are discussed in Section 4.2.)

### 2.3. Winds

Wind data collected near the entrance of the port indicate that the dominant winds are north-north-east, north-east, south-west and south-south-west. These dominant winds all blow essentially in onshore and offshore directions along the site; that is, approximately normal to the entrance channel. The wind data were used to compute locally generated wind waves.

### 2.4. Wave climate

Wave recordings are presently conducted by means of a directional wave buoy, which is situated just outside the entrance to the port. A brief assessment of the wave climate on the exposed coastline of Richards Bay (based on earlier measurements) can be found in Laubscher et al. (1991) and Coppoolse et al. (1994). However, the study area is located inside the Port of Richards Bay and, as such, the focus is on the wave climate there.

Both wind waves and swell penetrating the port were considered in determining the wave climate (CSIR, 1997; Schoonees et al., 1999).

The ACES model, as described by Leenknecht et al. (1992), was used to compute the wind wave characteristics, based on the wind velocities and persistences combined with fetch lengths. The wind waves have low significant wave heights (mean about 0.10 m and a maximum height of only 0.29 m) and short periods (typically between 1.0 s to 1.5 s with a maximum period of almost 2.1 s). The directions of the wind waves correspond to the wind directions, being usually north-north-east, north-east (which are onshore along the site), south-west and south-south-west (which are offshore).

Swell heights and periods were derived at two positions (Points Y and Z; Fig. 1) along the centreline of the navigation channel. Results from previous physical model studies (CSIR, 1990) were used. Exceedance curves were plotted for Points Y and Z. These curves were then used to predict the swell wave heights in the study area (Table 1).

The wave heights contained in Table 1 show that there is only a gradual increase in wave height from low return periods to high return periods. Wave penetration studies (CSIR, 1990) showed a linear decrease in wave height between Point Y (which is very calm) and Point Z (which is partially protected). This means that the site at Groyne A can be classified as “moderately protected” according to the Wiegel (1964) system, in which a site is either “exposed”, “moderately protected” or “protected”. The site at Groyne C is “protected”.

Typically, the peak swell wave periods vary between 8 s and 16 s, with a median peak period of 12 s. A comparison of wind waves and swell shows that swell is the dominant source of wave energy in the study area.

A few vertical aerial photographs taken between 1975 and 1995 (CSIR, 1997) were used in the design of the groynes to measure wave incidence angles near the location of Groyne A. A mean wave incidence angle of  $43^\circ$  clockwise from north was found. That is, the crests of the waves are orientated  $133^\circ$  clockwise from north. By using the average orientation of the shoreline before Groyne A was constructed, it means that the wave incidence angle relative to the shoreline is about  $9^\circ$ .

### 2.5. Current regime

Currents usually transport the sediment mobilised by wave action. Knowledge of the current regime is therefore necessary to understand the occurrence of erosion and accretion in the study area. Currents are normally generated by tide, wave, and wind action. Although the tidal flow through the navigation channel is considerable, the cross-sectional area of the channel is also large. Tidal currents are therefore weak, ranging from a peak, depth-averaged current of 0.03 m/s at neap tide to 0.17 m/s at spring tide along the centre of the entrance channel as found by means of hydrodynamic modelling (CSIR, 1998, 2000). The profile of the channel is such that the tidal flow is concentrated in the deeper part of the channel with small tidal flow on the upper slope close to the shoreline along the study area.

Wind-driven surface currents normally flow at about 2% to 3% of the wind velocity. This means that by taking typical wind velocities into account (CSIR, 1997), wind-driven surface currents will normally be of the order of 0.10 m/s to 0.15 m/s during these conditions.

Longshore currents are generated by waves approaching the coast obliquely and by a gradient in wave height along the coastline. It is estimated that the wave-driven current velocities at the site will mostly be between 0.10 m/s and 0.20 m/s moving towards the west–north–west (into the harbour).

Floods in the Mzingazi Canal (Fig. 1) can also induce currents along the study site. These currents are estimated to be weak, based on the bathymetry of the area. The occurrence of these events is

very limited and usually of short duration. Therefore the currents induced by floods were not taken into account in this study.

Because the current velocities based on the combined effect of waves, tides, winds and floods are usually small, the sediment processes of accretion and erosion will occur relatively slowly in the study area, especially when compared with the rate of these processes along an exposed shoreline.

### 2.6. Sand grain sizes before construction of the groyne

Sediment samples were collected before construction of the groyne on 14 March 1996 (CSIR, 1997) along the shoreline at three positions on the beach: at the high-water mark, at the low-



Fig. 1. Locality map.

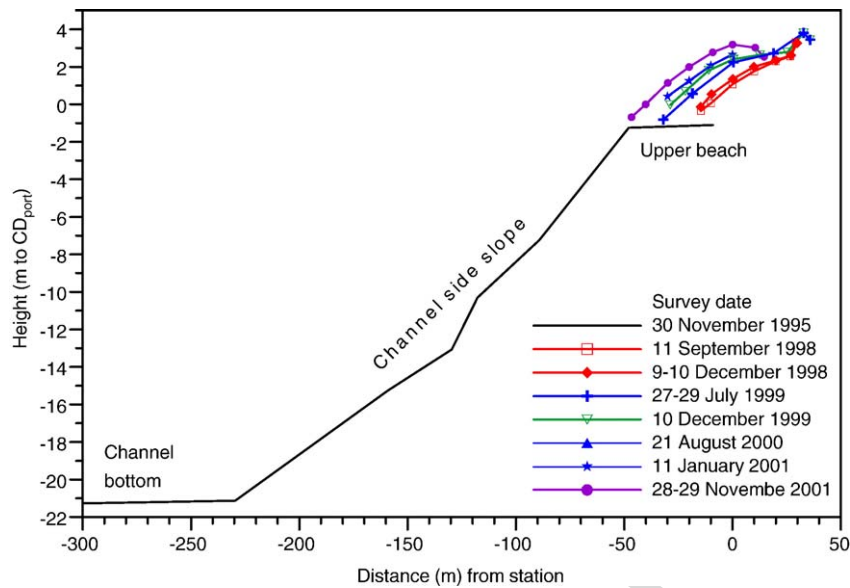


Fig. 2. Profile EC15 at Groyne C.

water mark and below the low-water mark (at about  $-0.5$  m to  $CD_{port}$ ). The median sand grain sizes along the shoreline of the site (average of the three samples taken on each beach profile) are illustrated in Fig. 4. The average median sand grain sizes were respectively  $0.26$  mm and  $0.28$  mm updrift of Groynes A and C (both are medium sands).

These sand grain sizes will be compared with the sand sizes found after accretion occurred updrift of the groynes.

### 3. Construction of the groynes

Fig. 1 shows the locations of the four existing groynes, namely: Groyne A (the L groyne), Groyne C (near Building 4043), Groyne D at Spinach Point and Groyne E between Groynes C and D. (Groyne B, planned to be between Groynes A

and C (CSIR, 1997), was never constructed.) More recently, two more groynes were built between Groynes A and C.

The groynes, which were designed according to the Van der Meer (1990) method, were constructed by end tipping (Schoonees et al., 1999). Two layers, namely, the core and armour layers, were built with steep side slopes of 1: 1.5 to minimise the required volume of rock. The rock of the armour layers was, respectively, 2 tonne and 200 kg for Groynes A and C (CSIR, 1997; Schoonees et al., 1999). The crest height of both these structures is quite high in view of the relatively calm environment, namely,  $+2.5$  m to MSL for Groyne C and  $+3.6$  m to MSL for Groyne A (CSIR, 1997; Schoonees et al., 1999). The high crest height was chosen for ease of construction.

Table 2 lists the periods during which the core and armour layers of each of the groynes were built, as well as the total

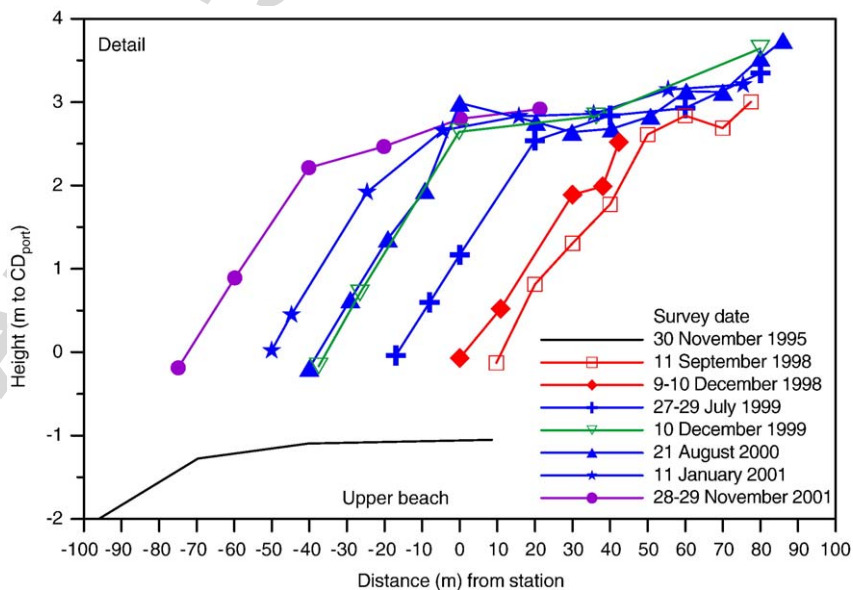


Fig. 3. Profile EC42 at Groyne A.

Table 1  
Significant swell wave heights at Points Y and Z

Return period (year)	Point Y	Point Z
	$H_{os}$ (m)	$H_{os}$ (m)
1	0.7	1.7
10	0.9	2.1
50	1.0	2.4
100	1.1	2.5

$H_{os}$ =significant wave height in the centre of the navigation channel.

amounts of rock used and the cost of the rock. These four groynes were built within about a year, namely, between November 1997 and October 1998. An interesting fact is that the smaller rock was more expensive than the larger rock (about USA \$ 5.6/tonne for 10 kg to 50 kg rock versus approximately \$ 4.7/tonne for 1 tonne to 4 tonne rock; Table 2).

The date on which the structures started trapping sediment is important in the study of the accretion of sand next to the groynes. Because the crest height of the core layer of each of the groynes is at +1.5 m to MSL (which is above the spring high tide level of +1.1 m to MSL), the structures began trapping sediment as soon as the core layer had been placed. Table 2 therefore also contains the dates on which the core layers were constructed.

#### 4. Shoreline changes

##### 4.1. General

Different aspects of the monitoring of the shoreline changes adjacent to the existing groynes are summarised in this section:

- sand grain sizes along the shoreline after the construction of the groynes;
- beach surveys, volume changes and the general shoreline orientations of the accretion updrift of the groynes.

The emphasis of the analysis is on the accretion updrift of Groyne A (the L groyne) and Groyne C (at Building 4043), at both of which most of the shoreline evolution occurred.

##### 4.2. Beach surveys

Seven beach surveys have been conducted along the south-western shoreline of the entrance channel. Table 3 lists the dates of the surveys and the number of days since the first beach survey was done on 11 September 1998.

Note that the core layer of Groyne A was completed (and started to trap sediment) on 6 April 1998, while the first survey was carried out on 11 September 1998, which is about 5 months later (Table 2). The core layer of Groyne C was, however, completed earlier, namely on 19 December 1997, or approximately 9 months before the first survey (Table 2).

The locations of the surveyed profiles are shown in Figs. 5 and 6. Profiles EC15 to EC18 are located just updrift of Groyne C near Building 4043, and Profiles EC41 to EC46 just updrift of Groyne A. The profiles at Stations EC15 and EC42, which represent respectively the areas just updrift of Groynes C and A, are presented in Figs. 2 and 3. These profiles (Figs. 2 and 3) show progressive accretion. In contrast, erosion of the shoreline occurred downdrift of Groyne A (Fig. 6). The shoreline between Groynes C and E was required to be stable in order to protect a mangrove area (Schoonees et al., 1999) from erosion. (The inlets to the mangrove area are located to the south–west of Groyne D (to the left of Groyne D in Fig. 1) and as such, are not significantly influenced by shoreline evolution along the study site.) Fig. 5 confirms that the requirement of a stable shoreline between Groynes C and E was indeed met.

The progressive accretion of the shoreline updrift of Groynes A and C is also illustrated in Figs. 7 and 8. In these figures the horizontal distances from the survey station have been plotted as a function of time. Note that positive distances are measured from the survey stations towards the shoreline (that is, roughly in a

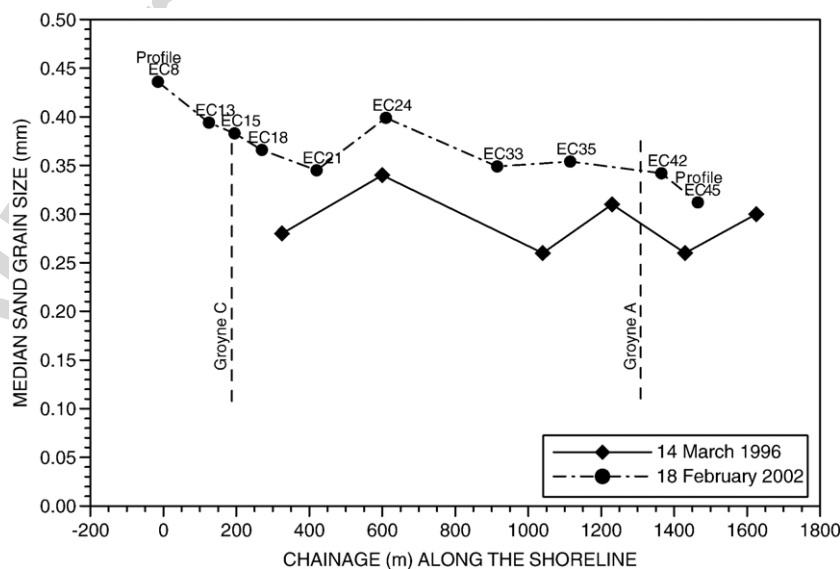


Fig. 4. Median sand grain sizes along the south-western shoreline of the entrance channel.

Table 2  
Construction of the groyne

Structure <sup>a</sup>	Length (m)	Armour											
		Size range (kg)	Total amount of rock used (tonne)	Start of construction	End of construction	Order of construction	Cost of rock <sup>b</sup> 1997/98 (R/tonne)	Size range (tonne or kg)	Total amount of rock used (tonne)	Start of construction	End of construction	Order of construction	Cost of rock <sup>b</sup> 1997/98 (R/tonne)
Groyne A	220	100–500	15 668	1998-01-19	1998-04-06	3	51.75	1–4 tonne	5 291	1998-04-08	1998-05-11	4	47.37
Groyne C	110	10–50	5 760	1997-11-06	1997-12-19	1	56.14	100–500 kg	2 280	1998-01-05	1998-01-14	2	51.75
Groyne D	45	10–50	2 350	1998-06-17	1998-06-30	5	56.14	100–500 kg	1 492	1998-10-12	1998-10-22	8	51.75
Groyne E	65	10–50	3 809	1998-08-21	1998-09-10	6	56.14	100–500 kg	1 902	1998-09-11	1998-09-23	7	51.75

<sup>a</sup> Fig. 1 shows the locations of the groyne.

<sup>b</sup> USA \$ 1 was approximately South African R 10 during 1997 to 1998.

south-south-westerly direction) while negative distances are measured from the survey station towards the entrance channel. Figs. 7 and 8 show that the accretion (as a horizontal distance) is on average about 0.021 m/day and 0.065 m/day (average slopes of these curves) respectively for the accretion areas updrift of Groyne C and A. This means that the shoreline accreted considerably faster (about three times faster) at Groyne A compared with Groyne C. This is to be expected because the shoreline at Groyne A is significantly more exposed to wave action (with the associated larger sand transport rates) than the shoreline at Groyne C (which is located deeper inside the port; CSIR, 1997).

The most seaward extremity of a groyne (usually the tip of the structure) plays an important role in the maximum accretion that is possible updrift of the groyne. Figs. 5 and 6 show that the shorelines updrift of Groyne A and C had reached the most seaward extremity of the groyne by the time of the last survey (28–29 November 2001). This means that it took respectively 3 years and 11 months and 3 years and 7 months for Groyne C and A to reach equilibrium after their core layers were completed. Figs. 9 and 10, which are photographs taken on 14 March 2002, confirm that both groyne have been filled to capacity. It can be concluded that the equilibrium shorelines were reached within 3.5 years to 4 years. Since March 2002, aeolian sand transport and sand bypassing Groyne A caused local accretion at and west of the tip of this groyne. At that stage, it had not yet reached the downdrift shoreline.

In physical model tests of beach improvement schemes in False Bay near Cape Town (Swart and Schoonees, 1994), it was found that most shoreline changes occurred within 2 or 3 years after construction of the groyne. Equilibrium was reached after 4 years. This is in accordance with what has been found in the field in Israel (Nir, 1982), Japan (Toyoshima, 1976) and Britain (Barber and Davies, 1985). It is interesting to note that the conditions and the degree of wave exposure vary considerably at these sites around the world, yet the time required to attain equilibrium, is similar.

#### 4.3. Shoreline orientations

Curved beaches are normally found along bays between headlands. These beaches have been called crenulate-shaped beaches, half-heart beaches or headland-bay beaches (Hsu et al., 1989). Theory exists which can be used to predict the planform of these beaches. Hsu and Evans (1989) derived a so-called parabolic bay shape equation for this purpose (see also CEM, 2005). Further developments include: (1) the use of MEPBAY software (Klein et al., 2003) to visually evaluate the existing

Table 3  
Dates of the beach surveys

Number	Date of beach survey	Number of days after the first survey of 11 September 1998
1	11 September 1998	0
2	9–10 December 1998	90
3	27–29 July 1999	320
4	10 December 1999	456
5	21 August 2000	711
6	11 January 2001	854
7	28–29 November 2001	1175

shoreline in relation to the static equilibrium planform of the beach; and (2) a modification of the Hsu and Evans (1989) method by Gonzalez and Medina (2001), which has been applied with success to natural and man-made Spanish beaches.

Parabolic bay shape theory (Hsu and Evans, 1989; Hsu et al., 1989) was used to determine the layout of the Richards Bay groynes (CSIR, 1997; Schoonees et al., 1999). According to Hsu et al. (1989), the shoreline orientation at the downdrift side of a half-heart bay in equilibrium is parallel to the wave crests (that is, the wave incidence angle). The wave incidence angle is an important parameter when predicting the equilibrium form of a half-heart bay; therefore this parameter was measured immediately updrift of Groynes A and C.

Two sources of information were used to measure the wave incidence angles:

- The beach surveys (Section 4.2) of the south-western shoreline along the entrance channel. The shoreline (0.0 m to MSL) was interpolated from the survey data by NPA and plotted in Figs. 5 and 6.
- Vertical aerial photographs taken on 27 September 1998, 20 July 1999, and 16 June 2000 after Groynes A and C were completed. These photographs were taken between the first and the fifth surveys (Table 3).

The measured wave incidence angles varied by up to  $9^\circ$ . The mean angles of the wave crests updrift of Groynes A and C are respectively  $146^\circ$  and  $138^\circ$  clockwise from north. Before the construction of the groynes, the mean wave incidence angle was estimated to be  $133^\circ$  (Section 2.4), which is  $13^\circ$  less than the  $146^\circ$  found after construction of the groynes. This means that the wave incidence angle relative to the original shoreline updrift of Groyne A is approximately  $22^\circ$  instead of  $9^\circ$  as originally estimated (Section 2.4). Because the wave incidence angle is an important parameter in parabolic bay shape theory, this difference ( $13^\circ$ ) emphasises the need for accurate input data for design. For example, the maximum indentation of a half-heart bay can typically increase by between 6% and 26% if the

wave incidence angle increases by  $13^\circ$ , according to the theory of Hsu et al. (1989).

Unfortunately, it is not possible to compare directly the predicted shorelines at Groynes A and C (CSIR, 1997) with the measured shorelines (Figs. 5 and 6) because Groyne B, which affects the predicted shorelines, was never built. Furthermore, two other factors also affected shoreline evolution, namely: (1) two additional groynes were constructed between Groynes A and C; and (2) the occurrence of a rocky area along the shoreline of the channel.

#### 4.4. Sand grain sizes after construction of the groynes

Sand samples were also collected on 18 February 2002 (almost 3.5 years after completion of the groynes) on both the wetted beach and in the surf zone (at about  $-2$  m to MSL or waist deep at spring low tide) along the south-western shoreline of the entrance channel. The samples were taken at 10 different cross-sections. The grain size distributions of these samples were determined by sieving.

The median grain sizes are shown in Fig. 4. The median sand grain size ( $D_{50}$ ) does not vary much along the shoreline (Fig. 4). Except for Profiles EC42 and EC45 (their locations are given in Fig. 6), there are only small differences in  $D_{50}$  of typically 0.04 mm along each profile (that is, in a cross-shore direction). The average median sand grain sizes were respectively 0.33 mm and 0.37 mm updrift of Groynes A and C (both are medium sands).

Comparing the average median sand grain sizes updrift of Groynes A and C from before construction of the groynes (March 1996) with the sand that had accreted after the groynes were built (February 2002), it is clear that the sand is only slightly coarser than before (0.33 mm and 0.37 mm versus 0.26 mm and 0.28 mm (Section 2.6)). Not enough data are available to determine whether the coarser sand is the result of natural variations from year to year, or perhaps due to seasonal changes (the earlier sand samples were collected in autumn whilst the later samples were taken in summer).

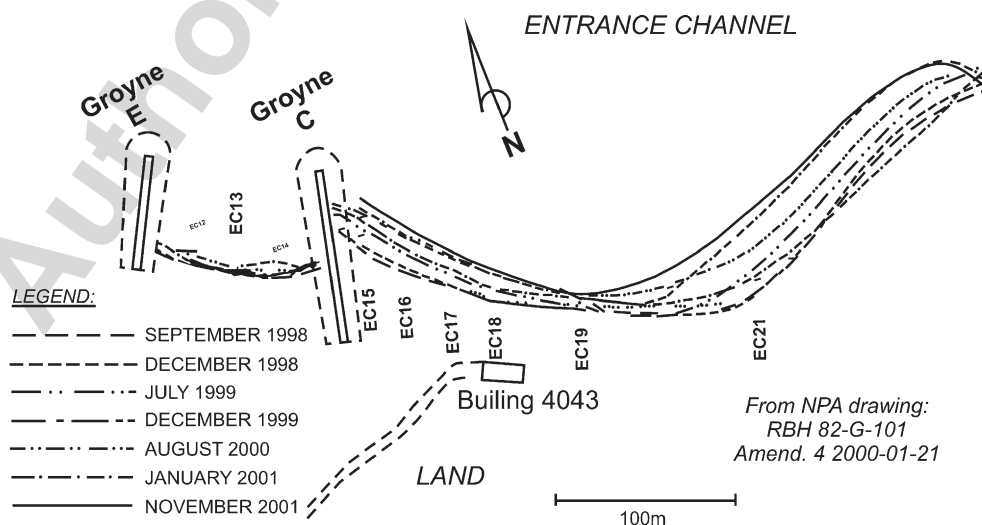


Fig. 5. Shoreline evolution at Groyne C.



#### 4.5. Sand volume changes

Loss/gain maps of the areas updrift of the groyne were produced showing changes in vertical elevation between consecutive surveys, as well as sand volume changes per unit area. The volume changes are in  $\text{m}^3$  in 10 m by 10 m squares. Positive values of elevation change indicate sediment accretion or deposition, while negative values depict erosion. Similarly, positive volume changes indicate the amount of sediment deposited in the area while negative values depict the amount of erosion over that period.

Fig. 11 shows the accretion updrift of Groyne A. This figure illustrates the total elevation and volume changes that occurred over the whole survey period of 1 175 days, or about 3 years and 2 months; that is, from 11 September 1998 to 28–29 November 2001. A similar loss/gain map for the accretion updrift of Groyne C was prepared (not shown). Volume changes were calculated down to levels of  $-1.7$  m to MSL for Groyne C and down to  $-1.1$  m to MSL for Groyne A (Fig. 11). These levels represent the lowest elevations reached by the beach surveys (Figs. 2 and 3).

In Fig. 12 the volume changes between consecutive surveys from the loss/gain maps have been plotted as a function of time. Also shown on this figure are the cumulative volume changes from the first survey.

In Figs. 12 it can be seen that for the accretion updrift of Groyne C, the rate of accretion (that is, the cumulative volume change) is virtually constant up to the survey of 21 August 2000, or almost 2 years after the first survey. Note that the total period from the completion of construction of the core layer of Groyne C to 21 August 2000 is about 2 years and 9 months. The rate of accretion at Groyne C is  $11.2 \text{ m}^3/\text{day}$  (above an elevation of  $-1.7$  m to MSL). Thereafter the curve has a different and flatter slope and will eventually tend asymptotically to a

maximum volume, indicating that a significant amount of sand is bypassing the groyne.

The rate of accretion at Groyne A, which is almost constant over the whole survey period of approximately 3 years and 2 months (Fig. 12), is  $36.8 \text{ m}^3/\text{day}$  (above an elevation of  $-1.1$  m to MSL). However, accretion occurred over about 3 years and 7 months, which is the period since the construction of the core layer of Groyne A had been completed. By November 2001, the curve for this groyne had not yet reached the stage where it tended asymptotically to a maximum volume. Similar to the rate of shoreline accretion as a horizontal distance, the rate of accretion as a volume is considerably higher at Groyne A than at Groyne C.

## 5. Longshore sediment transport

### 5.1. Direction of transport

Swell waves entering the Port of Richards Bay cause longshore sediment transport towards the north-west; that is, into the harbour. The dominant wind directions are north-north-east (NNE), north-east (NE), south-west (SW) and south-south-west (SSW) (Section 2.3). The NNE and NE winds generate wind waves that (on their own) cause (low) longshore transport towards the south-east (towards the south breakwater). The wind waves generated by the SWly and SSWly winds travel away from the study area and, as such, do not influence significantly the longshore transport budget of the study area. From the accretion updrift of Groynes A and C (Figs. 1, 5 and 6), it can be seen that the net longshore sediment transport is north-westbound (into the port).

Because the wind waves are so small, the south-eastbound longshore transport is very small and, therefore, it is expected that the net longshore transport rate along the study area is very similar and only slightly smaller than the gross longshore transport.

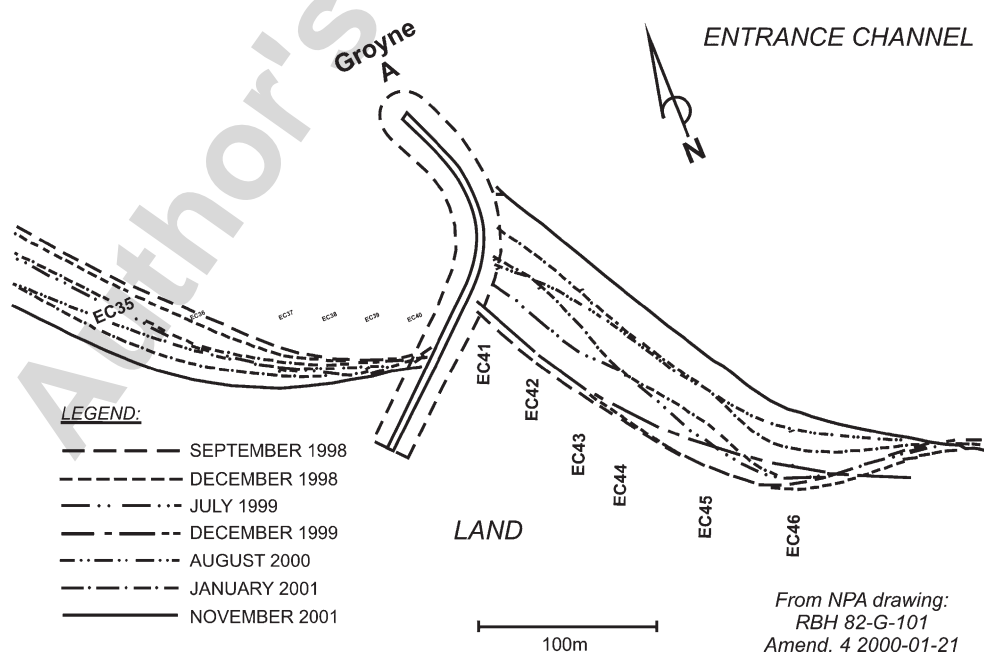


Fig. 6. Shoreline evolution at Groyne A.

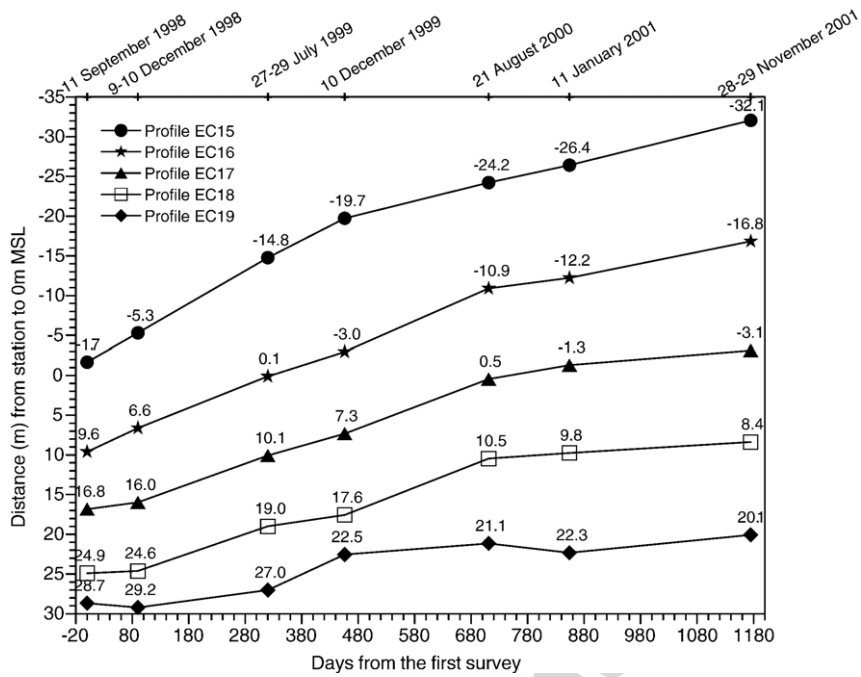


Fig. 7. Accretion (as a horizontal distance) updrift of Groyne C.

### 5.2. Net longshore transport rates

Three criteria should be adhered to before the volume changes over time adjacent to Groynes A and C can be equated to the net longshore transport rates at those two locations. These criteria are:

The groynes must be total traps of the longshore transport, meaning that virtually no sediment should bypass or be transported through or over the groynes.

The volume changes calculated from the survey data should be the total volume changes that have occurred. In other words, the surveys should extend far enough seawards to capture the total profile changes and, therefore, the total volume changes.

Sand should not be lost in a cross-shore direction into the entrance channel of the port, thus reducing the volume of sand that would otherwise have accreted at the groynes.

Analysis of aerial photographs has indicated that the width of the surf zone at Groynes A and C is exceptionally narrow. The

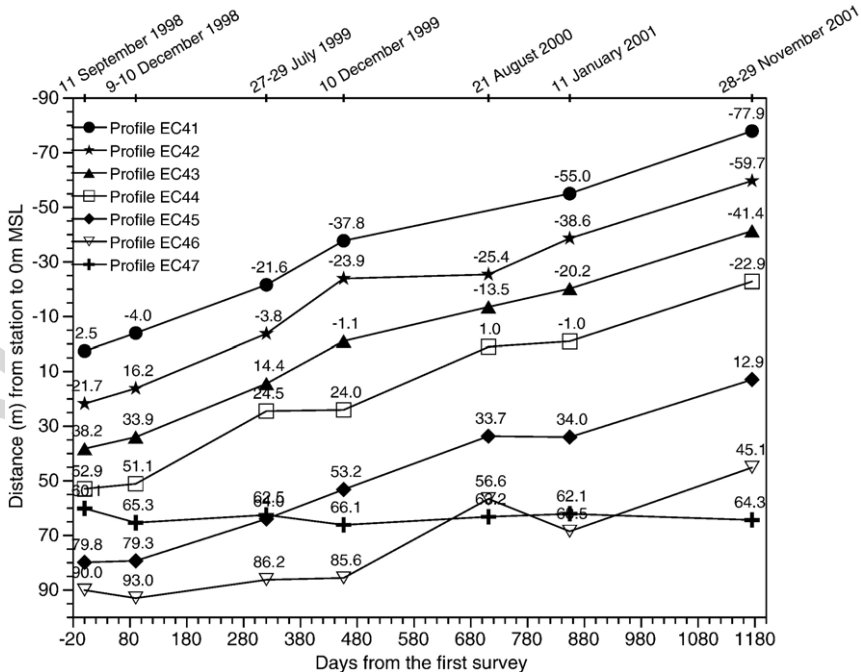


Fig. 8. Accretion (as a horizontal distance) updrift of Groyne A.



Fig. 9. Equilibrium shoreline at Groyne C.

surf zone width is typically less than 5 m because of the small waves (for example, see Figs. 9 and 10). Observations during site visits confirmed this result. In Fig. 1, the surf zone is very

narrow near Groyne A and not visible at Groyne C, although there is a wide surf zone outside the port next to the south breakwater. This means that Groynes A and C, which are



Fig. 10. Equilibrium shoreline at Groyne A.

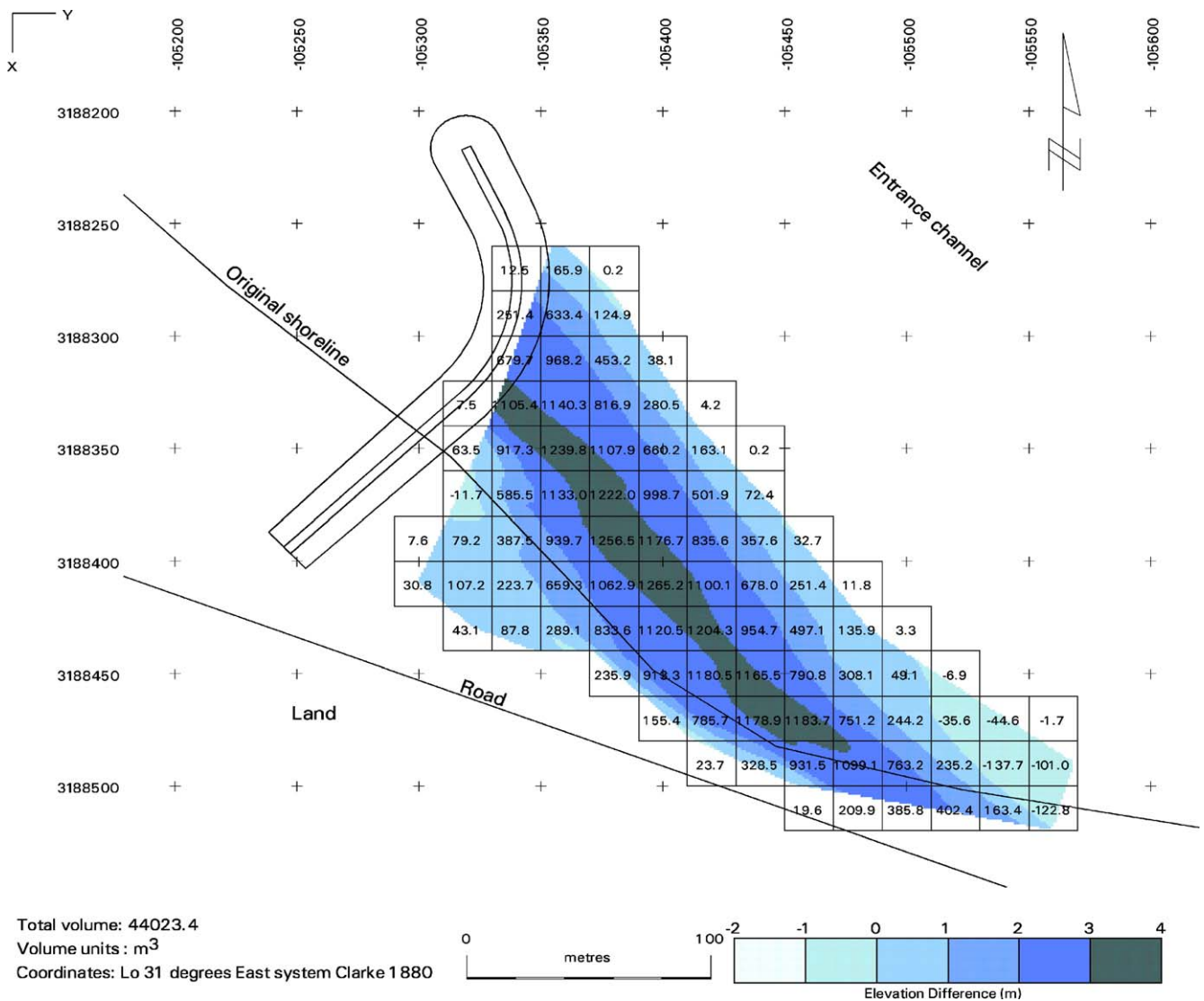


Fig. 11. Loss/gain map for Profiles EC41–47, 11 September 1998 to 28–29 November 2001.

respectively 220 m and 110 m long (Table 2), were indeed initially total traps of the longshore transport. It is only when the shoreline had accreted close to the tip of Groyne C that significant bypassing of sand occurred. By being constructed of two layers, the groynes are effectively impermeable. In addition, the relatively high crest heights of the groynes (+3.6 m and +2.5 m; Section 3) prevent virtually all overtopping of sand over the groynes. The currents in the study area are also weak and no significant bypassing of sand is expected to have occurred through current action alone. The results indicated in Fig. 12 show that the groynes were indeed total traps, at least initially, because of the even rates of accretion (even slopes of the cumulative volume change) found in these figures.

The rate of accretion determined from Fig. 12 was computed over the full period under consideration (that is, 11 September 1998 to 28–29 November 2001, or about 3 years 2 months) for Groyne A. For Groyne C, only the period between 11 September 1998 and 21 August 2002 (the initial period of almost 2 years) was considered. During these periods the groynes acted as total traps of the longshore sediment transport.

The beach surveys reached a depth of only about –0.2 m to –1 m to CD<sub>port</sub>, or approximately –1 m to –2 m to MSL (Figs. 2 and 3). However, it should be recalled from Section 2.2 that the upper beach slope in the nearshore zone is quite flat (on average 1/74). The beach surveys show that the wetted beach accreted at almost a constant slope of about 1/8.8 near Groyne C and almost 1/14.0 near Groyne A. Fig. 2, which reflects not only the beach surveys, but also a bathymetric survey, indicates that the beach surveys at Groyne C extended almost far enough seawards to capture the total profile changes. Fig. 3 shows that the beach surveys at Groyne A did not extend deep enough. The beach surveys at both groynes were extrapolated a short distance by maintaining the same beach slope until the profiles reached the upper beach slope of the channel. In this way, corrections were made to ensure that the total volume changes were computed; that is, allowances were made to account for the volume differences between –0.8 m to CD<sub>port</sub> (–1.7 m to MSL) and the upper beach slope of the channel (for Groyne C) and between –0.2 m to CD<sub>port</sub> (–1.1 m to MSL) and the upper beach slope (for Groyne A).

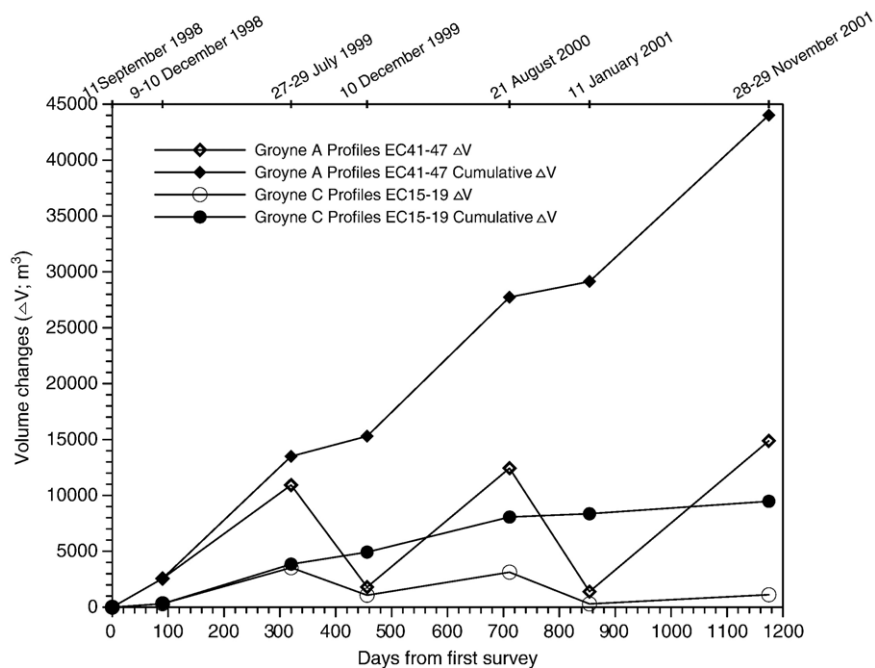


Fig. 12. Volumetric accretion updrift of Groynes A and C.

In determining the causes of the erosion along the south-western shoreline of the entrance channel (CSIR, 1997; Schoonees et al., 1999), cross-shore sediment transport was also assessed. Beach profile variations caused by cross-shore sediment transport were evaluated in terms of erosion/accretion predictors, equilibrium beach slopes and close-out (or closure) depths (the maximum depth at which significant changes in the profile are encountered, is called the close-out depth). If most of the close-out depths exceed the deepest point on the upper beach (Figs. 2 and 3), then it is reasonable to assume that sand will be deposited in the navigation channel. Sand is regularly dredged from the channel and therefore constitutes a loss of sand from the beaches along the site. However, if most of the close-out depths are less than the deepest point of the upper beach, it means that the sand is retained in the nearshore zone and will eventually be transported shoreward again. In this case there is no net cross-shore loss of sand from the beach.

For virtually all the wind wave and swell conditions considered (CSIR, 1997; Schoonees et al., 1999), accretion was predicted at the shoreline. The mean close-out depths calculated for wind waves and swell were found to be  $-0.2$  m and  $-2.5$  m to MSL respectively (CSIR, 1997). The maximum close-out depth was computed to be  $-3.6$  m to MSL. These values are less than the lower end of the upper beach, which is generally at  $-3.9$  m to  $-4.9$  m to MSL (CSIR, 1997). This implies that virtually no sand is transported offshore into the navigation channel from where it could be dredged. It is concluded that cross-shore sediment transport did not cause appreciable net sand losses (Schoonees et al., 1999).

If all the criteria for accurately determining the longshore transport were met, the net longshore transport can be equated to the total volume change over time. The accretion rates of respectively  $11.2$  m<sup>3</sup>/day (above  $-0.8$  m to  $CD_{port}$ ) and  $36.8$  m<sup>3</sup>/

day (above  $-0.2$  m to  $CD_{port}$ ) can be scaled up and corrected to capture the total volume changes in order to yield the associated net longshore transport rates of about  $4\,600$  m<sup>3</sup>/year (at Groyne C) and approximately  $18\,000$  m<sup>3</sup>/year at Groyne A.

The question then remains whether the availability of sand restricted the transport rate updrift of the two groynes. From site inspections and from aerial photographs, it is clear that the shoreline is partially rocky south-eastwards of Groyne A (Fig. 1). The accretion of sand was therefore limited at Groyne A so that the real (or actual) longshore transport rate was less than the potential transport rate by wave and current action. On the other hand, there is abundant sand updrift (south-eastwards) of Groyne C. The real and potential transport rates are therefore the same at Groyne C.

### 5.3. Comparison of predicted and measured longshore transport rates

The predicted longshore transport rate can only be compared with the measured rate at Groyne C because a rocky area limits the availability of sand at Groyne A.

In a comprehensive assessment of 52 longshore sediment transport formulae, Schoonees and Theron (1996) and Schoonees (2001) found that the Kamphuis formula (Kamphuis, 1991) is the most accurate. This formula, which performed well over the full range of the field data in the assessment, was recalibrated and slightly improved by Schoonees (2001). Kamphuis (2002) also showed that his formula fits other field data well. The Schoonees (2001) calibration was applied.

Extrapolation of wave data from physical model tests (CSIR, 1990) from Point Z through Point Y to opposite Groyne C along the centreline of the channel, did not yield realistic values. The average significant wave height, wave period and direction at the directional wave buoy just outside the port entrance in 20 m to

MSL of water was computed. Limited refraction undertaken with the Swan model (CSIR, 1994) was applied to obtain the mean breaker wave height at Groyne C. However, no accurate wave directions could be found at Groyne C from the refraction modelling because the model was set up to yield wave conditions outside the port and because of the effect of wind waves in the model results. Based on the measured shoreline orientation and simple refraction calculations, the mean wave condition along the breaker line at Groyne C was found. This mean condition, assumed to occur throughout the year, is: a significant wave height of 0.05 m; peak wave period of 10.6 s; and a breaker angle (relative to the local shoreline) of 2.9°. To improve this estimate of the mean wave condition or to determine the full wave climate at the Groyne C, a comprehensive investigation is required. The beach slope is 1/8.8 and the median sand grain size is 0.37 mm (Sections 5.2 and 4.4).

With these input data, the predicted longshore transport rate is 2 200 m<sup>3</sup>/year while the measured rate is 4 600 m<sup>3</sup>/year. A small increase in the wave height of about 0.02 m yields the right longshore transport rate. The agreement with the measured transport rate of 4 600 m<sup>3</sup>/year is therefore fair given the uncertainty in the wave characteristics.

## 6. Conclusions

Groynes were constructed to stabilise the previously eroding shoreline along the navigation channel of the Port of Richards Bay. Monitoring of shoreline evolution provided valuable data on the accretion adjacent to two of the groynes and on the sediment transport rates at these groynes.

The high crest height of the core of the groynes resulted in easier construction. The project also showed that using larger rock for armouring of groynes is not always more expensive.

The environmental conditions at the study area, such as tides, beach slopes, winds, wave climate, current regime, and sand grain sizes, were documented. The site at Groyne A is “moderately protected” from wave action while the site at Groyne C (near Building 4043) is “protected” according to the Wiegand (1964) classification.

The beach surveys showed progressive accretion of the shoreline updrift of Groynes A and C. The average rates of accretion (as a horizontal distance) were respectively about 0.065 m/day and 0.021 m/day for the accretion areas at Groynes A and C. Erosion of the shoreline occurred downdrift of Groyne A. The shoreline between Groynes C and E was required to be stable in order to protect a mangrove area from erosion. Fig. 5 confirms that the requirement of a stable shoreline between Groynes C and E was indeed met.

The shorelines at Groynes A and C accreted right up to the most seaward extremity of the groynes. Equilibrium shorelines updrift of Groynes A and C were reached within about 3.5 years to 4 years. The time taken in reaching equilibrium compares well with sites from around the world, although conditions vary considerably amongst these sites.

The mean angles of the wave crests updrift of Groynes A and C are respectively 146° and 138° clockwise from north. A significantly different incidence angle of 133° was estimated

before construction of the groynes. The wave incidence angle relative to the original shoreline updrift of Groyne A is approximately 22° instead of 9° as originally estimated. Because the wave incidence angle is an important parameter in parabolic bay shape theory, this difference emphasises the need for accurate input data for design. For example, the maximum indentation of a half-heart bay can significantly increase if the wave incidence angle increases by 13° (from 133° to 146°).

Sand samples taken after construction of the groynes show that the average median sand grain sizes were respectively 0.33 mm and 0.37 mm updrift of Groynes A and C. The accreted sand was found to be only slightly coarser than that before the groynes were constructed.

The initial rate of accretion updrift of Groynes A and C was almost constant, being respectively 36.8 m<sup>3</sup>/day (above −1.1 m to MSL) and 11.2 m<sup>3</sup>/day (above −1.7 m to MSL). Similar to the rate of accretion as a horizontal distance, the rate of accretion as a volume is considerably higher at Groyne A than at Groyne C because the shoreline at Groyne A is significantly more exposed to wave action than the shoreline at Groyne C.

The net longshore transport rate along the study area, which is north-westbound, is very similar and only slightly lower than the gross longshore transport.

It was found that the groynes were indeed total traps, at least initially. The beach surveys were conducted and extended to reach an adequate depth (the upper beach slope of the entrance channel) in order for the calculated and corrected volume changes to be equal to the transport rates. Cross-shore sediment transport did not cause appreciable net sand losses into the entrance channel. The best estimates of the actual net longshore transport rates are 18 000 m<sup>3</sup>/year at Groyne A and 4 600 m<sup>3</sup>/year at Groyne C.

At Groyne A the real longshore transport rate was less than the potential transport rate because the shoreline is partially rocky south-eastwards of Groyne A. In contrast, there is abundant sand updrift (south-eastwards) of Groyne C. The actual and potential transport rates are therefore the same at Groyne C.

Estimation of the mean breaker wave condition at Groyne C enabled comparison of the measured transport rate of transport rate predicted with the Kamphuis formula. The agreement of the predicted with the measured transport rate is fair given the uncertainty in the wave characteristics.

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