CHAPTER 85

GRAVITY DRAINAGE: A NEW METHOD OF BEACH STABILISATION THROUGH DRAINAGE OF THE WATERTABLE

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ABSTRACT

Beach nourishment to provide an erosion buffer and increase amenity is a well established coastal management option and is favoured because it is a relatively "soft" option with few aesthetic drawbacks. This paper describes how enhancement and stabilisation of the natural accretion processes may be achieved by a low-cost beach drainage system. The project described here shows that the watertable and shoreline can be lowered by a drainage system installed in the beachface. A prototype system was installed on Dee Why Beach, New South Wales, Australia in February–March 1991 and has been continuously discharging water until the present (November 1992). A number of minor storms have exposed and caused some damage to drainage material but the system continues to work.

Survey data are being collected at regular intervals to show the effects of the drainage system on the watertable and the morphology of the beach. Analysis of changes in morphology in both drained and undrained segments of the beach shows a significantly more stable beachface in the area of the drained beachface.

INTRODUCTION

Protection of coastal assets may be provided by seawalls while on coastlines with longshore littoral drift, groynes may provide both protection and a beach amenity. However, these hard structures may be aesthetically displeasing and may have adverse effects on adjacent areas of the coastline. Beach nourishment is not perceived to have these drawbacks. However,

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beach nourishment projects may have a limited life and therefore require further nourishment in the future. Recently a new technique of beach stabilisation through watertable drainage has been reported in the literature (eg, Parks 1989; Terchunion 1989; Bruun 1989; Ogden and Weisman 1991). This technique may extend the life of beach nourishment works thereby reducing the on-going costs.

Beach watertable drainage is thought to enhance sand deposition on wave uprush while diminishing erosion on wave backwash. The net result is an increase in subaerial beach volume in the area of the drain. Previous experimental work by Chappell et al. (1978) on a natural beach involving localised watertable drainage concluded that ". . . the evidence from these experiments very strongly supports the idea that beach aggradation can be induced by maintaining the beach watertable at a low level". The larger prototype drainage/pumping installations used by Terchunion (1989) in Florida; and Hansen (1986), Vesterby and Parks (1988) in Denmark also strongly suggest that beach aggradation may be artificially induced by beach watertable drainage. These installations have all employed systems of buried pipes and electrically powered pumps. The current paper describes an alternative to this technology. The idea is to achieve lowering of the watertable without pumps by enhancing the beach's own drainage capacity or hydraulic conductivity through the use of strip drains **(Figure 1)**.

Duncan (1964) and Grant (1946, 1948) observed that beaches tend to erode as the tide falls and accrete as the tide rises. This is attributed to the effect of the watertable and its position relative to the offshore mean water level. As an incoming tide rises above the beach watertable, a proportion of the wave run-up infiltrates the beachface. This results in a reduction in the backwash volume and net beach accretion, particularly in the upper swash zone. As the tide falls, the beach watertable lags behind the offshore mean water level and thus contributes outflow to the swash zone. This contribution aids the backwash and causes net seaward movement of sediment. If this argument is correct, then it is the local watertable exit point

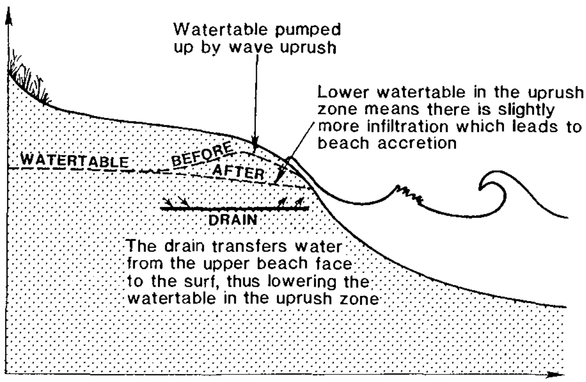

Figure 1 — Effect of the strip drain on the watertable

and its movement over a tidal cycle which is important for beach accretion and erosion and not the overall back beach watertable. Increasing the drainage capacity of the beach could be expected to decrease the time lag between oscillations of the beach watertable and the offshore mean water level and lower the watertable exit point within the wave run-up distribution of the beach.

This paper presents data relating to the effect of the drainage system on the beach watertable characteristics and some preliminary observations of the beach morphodynamics.

STUDY AREA

The beach drainage system was installed in the central part of Dee Why Beach, which is an open coastal embayment approximately 14km north of Sydney's Central Business District (Figure 2). The beach faces the South East which is the dominant direction of large swell waves from the Tasman Sea. The wave climate is highly variable and only weakly seasonal (Trenaman and Short, 1987). The tidal regime of the New South Wales coast is described by Easton (1970) as microtidal semidiurnal with a diurnal inequality, with a range up to 2m. Dee Why Beach occupies a drowned embayment and is flanked by rock headlands. The beach/barrier system encloses a small lagoon which is only occasionally open to the ocean. The beach has undergone recession over recent geological time and this recession is thought to be continuing (Chapman et al. 1982).

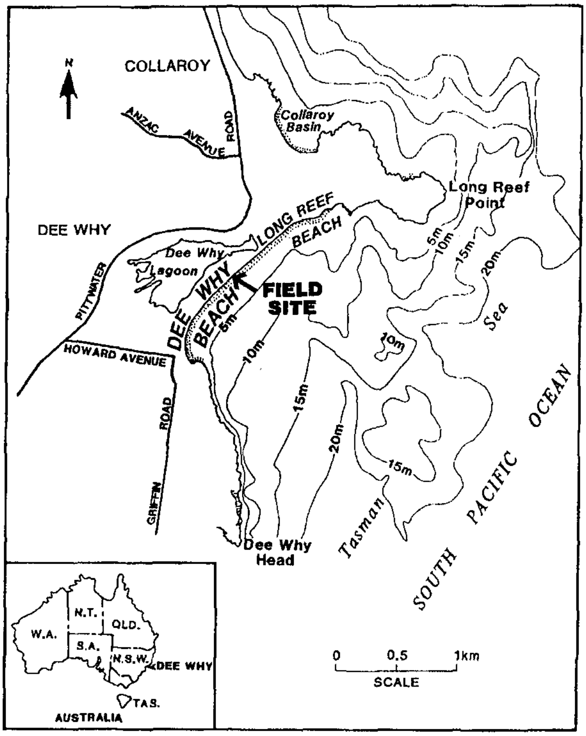

Figure 2 — Location diagram

Mean swash zone grain size is of the order of 0.5mm. The surf zone is generally characterised by rhythmic topography with crescentic or transverse bars and regular rip channels. The beach may range between a reflective state with cusps after calm periods and a more dissipative bar/trough system after storms (Nielsen & Hanslow, 1991).

MATERIALS AND INSTALLATION

The beach drainage system used in this installation incorporated an array of shore normal strip drains made of geotextile fabric enclosing a plastic core in an "egg-carton" configuration. The ends of the drains are covered with geotextile to prevent ingress of sand.

This type of drain is commonly used to drain ground-water from roads, parks and playing fields, etc. In these applications the drains are laid vertically. For the beach drainage system the drains were laid horizontally below the sand surface so as to minimise the risk of exposure during storms or rip formation. They were spaced from 5 to 15m apart and occupy 160m of the central part of Dee Why beach. A total of 18 drains were installed by 28 March, 1991. Drain installation was conducted during a period of spring low tides and small waves. A 27 tonne excavator was used to dig a series of 4 or 5 parallel trenches in the beach, finishing the job just before low tide. The drainage material was then laid and the trenches filled before the tide rose significantly. By this method, the seaward ends of the drains were buried to a level varying from –0.4m to –0.7m with respect to mean sea level (MSL).

The strip drain array was installed with the drains being parallel to one another and shore normal. This means that the landward ends of the drains have the greatest head due to elevated watertable and the seaward ends have the lesser head of the swash zone mean water level. Therefore, there is always a seaward flow potential. The location of the drains is indicated in **Figure 3**.

WATERTABLE CHARACTERISTICS

DATA COLLECTION

The impact of the drainage system on the beach watertable was assessed using the following techniques. All levels are to Australian Height Datum (AHD) which is approximately MSL.

Long-term watertable data were collected from a permanent beach well which housed a pressure transducer and data logging equipment. This well is in the drained area of the beach and located such that the sand elevation was approximately 3m AHD under normal conditions.

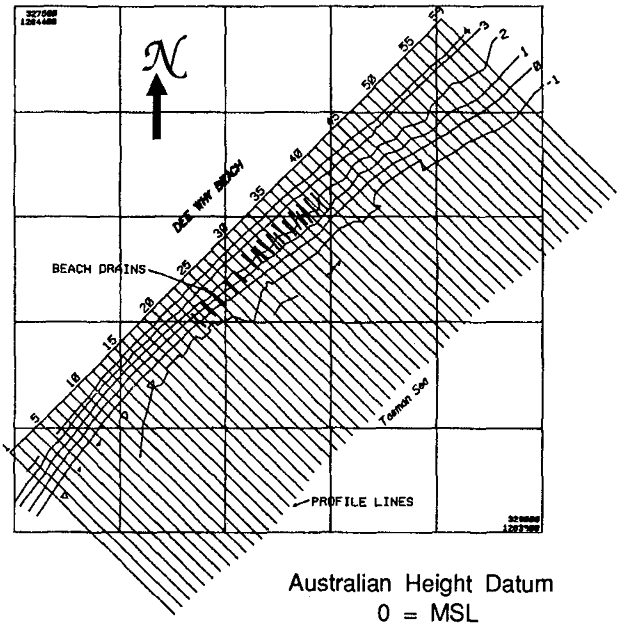

Figure 3 — Survey date 5–9–91. Location of beach drains and profiles for contour analysis

Short term observations of mean level were obtained using arrays of up to 95 stilling wells deployed in the beach. Water level inside the wells correspond to the local watertable. Levels were determined by surveying the well tops and then measuring the depth to the watertable. Wells were also used to determine the location of the shoreline in the drained and undrained sections of the beach. Wells were placed along a shore-normal transect with a spacing of between 2 to 5m. This spacing gives an accurate definition of the exit point of the watertable onto the beachface, and the intersection of mean water surface and the beachface, or shoreline.

The relative position of the shoreline or watertable exit point with respect to the run-up was determined by counting the number of waves running up past each of a number of beach wells or stakes marking points of known beach elevation. This was done over 20 minutes along drained and undrained transects, enabling calculation of the percentage of waves passing the watertable exit points on different sections of beach.

RESULTS

General

The drainage system has been deployed continuously in an open coastal beach for approximately 18 months. Observation of the treated intertidal beach shows, particularly at low tide, the marked seepage zones caused by outflow from the buried drains. Outflow from the drains has been observed to result in minor scour on very low tides. This scour appears to be limited by 'armouring' or increased coarseness of sediment around the drain ends. During periods when the beach has been relatively wide, these effects have become less apparent. On the rising tide, the seepage zones apparent at low tide give way to infiltration zones as local infiltration directly over the drains is evidenced by marked narrowing of the zone of watertable outflow in those areas, extending over a width of 3 or 4m. The drains experienced some damage from rip-cell formations resulting in up to 4m of the drains having to be cut off in the swash zone. However, subsequent accretion has since covered the damaged drains and all have since continued to discharge water.

Watertable Data

Figure 4 shows the response of the watertable at the permanent beach well before and after installation of the drains. The deep water wave height and tide record are also presented. This figure clearly shows that the placement of the drains immediately lowered the watertable and reduced the asymmetry of the tidal response. **Table 1** shows comparison of lag times and rates of change of water levels deduced from analysis of months of watertable and tide records.

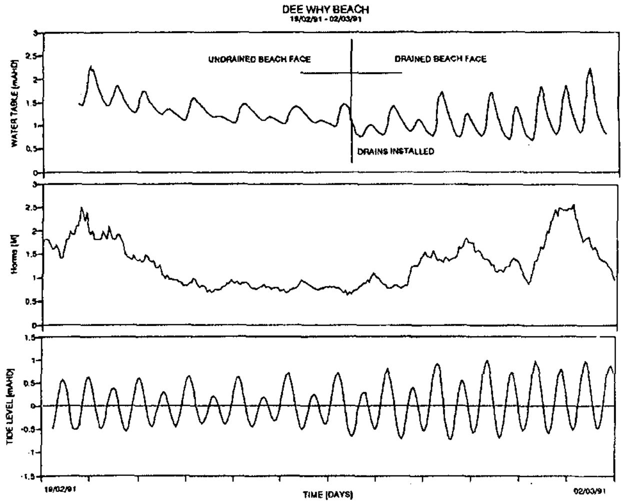

FIGURE 4 — Watertable record at permanent beach well and the deepwater wave height (H_{orms}) and tide levels (between 20–2–91 and 2–3–91)

Figure 5 shows a shore-parallel section of the beach in which the effect of a single drain in the inter-tidal zone of the beachface was monitored over a half tide cycle. The watertable is lowered by about 0.3m at the location of the drain and the effect is seen to diminish with increasing distance from the drain. **Figure 6** compares watertable profiles in two morphologically similar shore-normal transects, one in the drained section

Table 1 — Relative lag time and rate of change in water level before and after installation of drains.

	Before Installation of Drains		After Installation of Drains	
Lag Time (hrs)	Low Tide	High Tide	Low Tide	High Tide
	4.10	1.50	3.30	1.10
Average Rate of Change in Water level (cm/hr)	Falling Tide	Rising Tide	Falling Tide	Rising Tide
	4	8	8	15

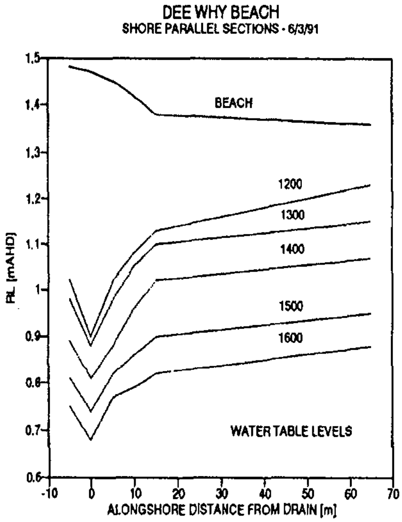

Figure 5 — Effects of a single drain on the watertable at various times (EST)

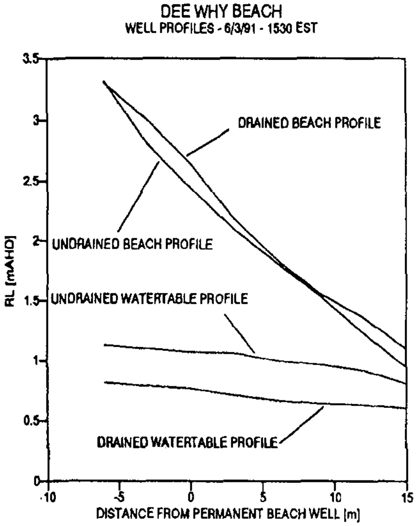

Figure 6 — Watertable for a typical drained transect and a similar undrained transect

and another in the undrained section of the beach. Again, at the drain the watertable was lowered approximately 0.3m along the transect.

Beachface Watertable Exit Point

The point of emergence of the watertable onto the beachface is important because it influences the swash zone dynamic sediment budget which is the key to the success of the beach drainage technique. The comparison of the watertable exit point at high tide on 24 April, 1991 for the drained and undrained beach transects in relation to the wave run-up at the time is presented in **Figure** 7. On the drained transect 44% of waves transgressed the watertable exit point while 29% did so in the undrained section. This means that at high tide the

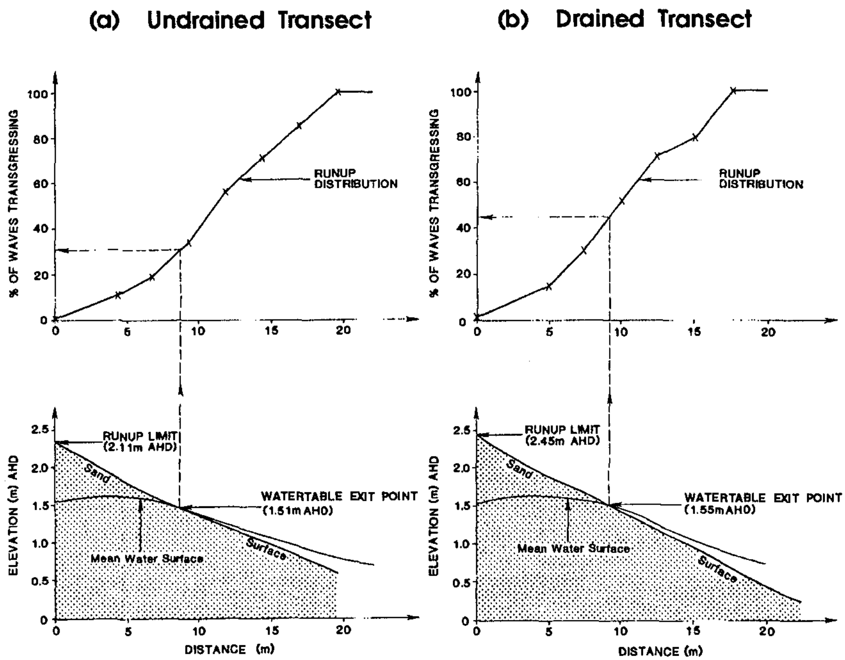

Figure 7 — Percentage of waves transgressing the watertable exit point on (a) Undrained and (b) Drained transects

watertable occurs lower within the run-up distribution on the drained section of the beach.

BEACH MORPHOLOGY

DATA COLLECTION

Variability of the location of the beach contours was used to assess the effects of the drainage system on beach morphology by comparing results for the drained and undrained section of the beach.

Pre-drainage beach morphology was determined using photogrammetric analysis of historical aerial photography. Fifteen dates of photography between 1961 and 1991 were analysed. Beach topography was contoured down to the water line using a Wild AC1 Stereo Restitution Instrument which plotted the position of the contours in plan view. A beach length of approximately 600m of the beach was contoured for each date of photography.

Post drainage beach surveys have been carried out every 10–15 days since drain installation. Again, the survey area comprised about 600m of beach centred about the drained section. Surveys were generally extended from the fence line (4.5m MSL) to approximately –1.5m MSL.

DATA ANALYSIS

Contour location data were determined for a series of parallel transects as shown in **Figure 3**. Distances from a base line to the 4m, 3m, 2m, 1m and 0m contours were measured along 60 transects for each beach survey taken since drain installation and for photogrammetric surveys prior to drain installation. These transects were spaced 10m apart and cover the drained section of the beach as well as equal portions of the undrained beach to the north and south. Measurements of contour location for each contour were compiled into data matrices consisting of distances at each profile and survey date.

BEACH STABILITY

Variation in contour position over time was assessed by determining the mean and standard deviation of the contour location at each profile.

An indication of the relative stability of different portions of the beach both before and after drain installation is presented in **Figure 8**. Here the standard deviation of the 1m and 2m contours are presented for the photogrammetric (i.e. undrained) data, together with the standard deviation of the 0m, 1m and 2m contours for the survey data collected since drain installation. The standard deviations from the photogrammetric data set are generally higher. This is because a number of the photography sets used were taken specifically to record eroded post-storm beach (profiles 22–38) morphology. This figure also shows that the variance in contour position is lower in the drained section of the beach than the areas either side. This contrasts with the photogrammetric data which shows increasing variance in the 2m contour towards the north and rhythmic variation of the 1m contour.

PRINCIPAL COMPONENTS

Beach morphology in the survey area since the installation of the drains has displayed considerable variability associated with both storm activity and rip current migration. For much of the time since the installation of the drains the beach has been characterised by rhythmic topography associated with rip cell formation and migration, this situation only changing during storms when the whole beach was cut back and assumed a more uniform shape.

The results of the principal components analysis reflect this variation in beach morphology, showing several important components. Results are presented in Figure 9 and Figure 10 for the 2m contour. The first

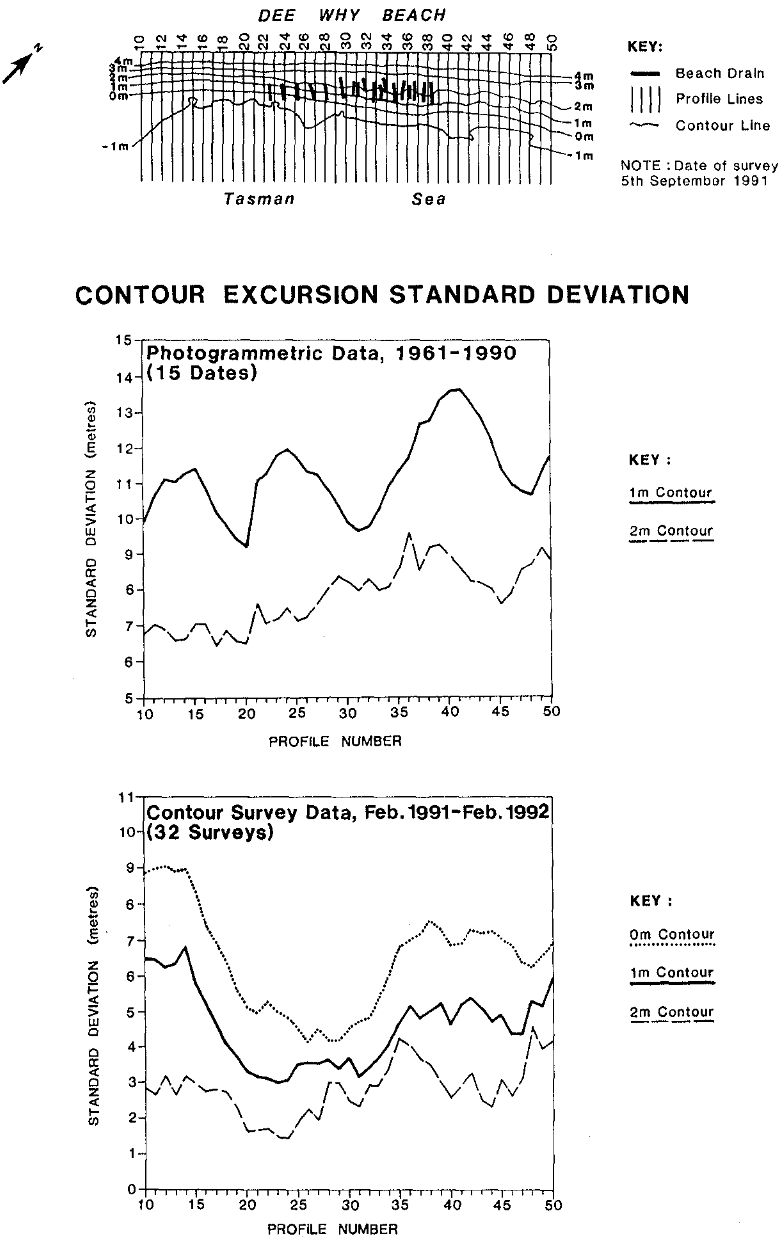

Figure 8 — Contour excursion standard deviation for photogrammetric data and survey data

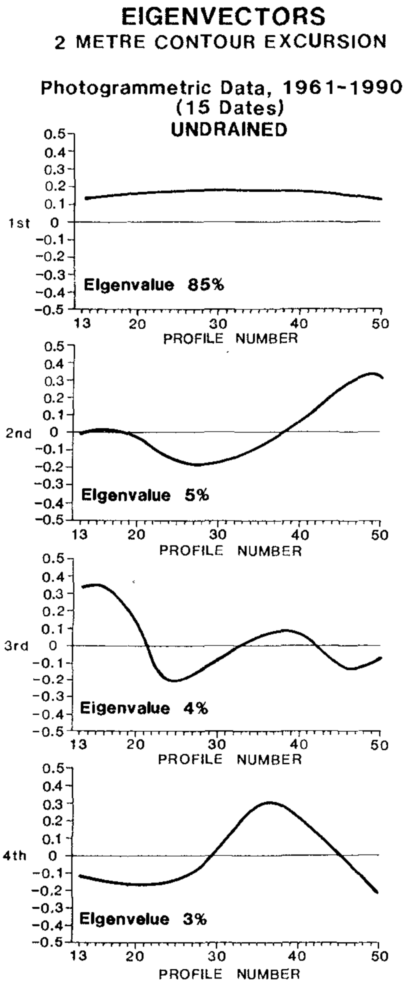

Figure 9 — Principal Components of the photogrammetric data

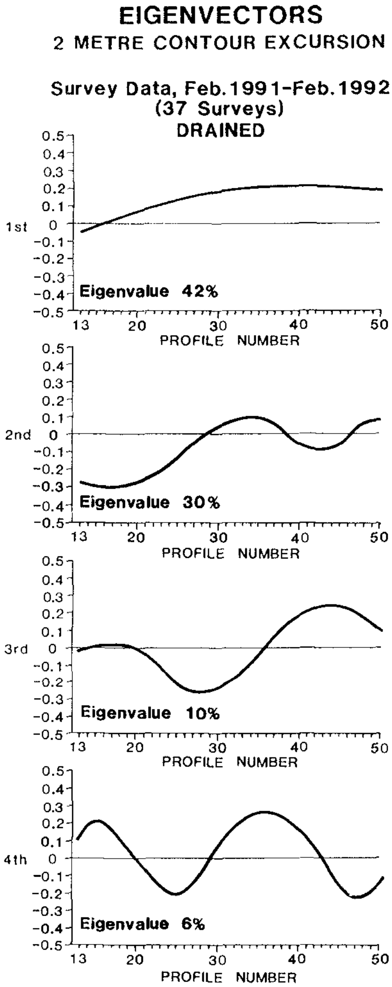

Figure 10 — Principal Components of the survey data

component in each case reflects the onshore offshore sediment exchange associated with beach erosion/accretion. Subsequent components reflect the rhythmic topography produced by rips and seasonal longshore sediment exchange together with the effect of the drains.

Examination of the second component of survey data shows general stability (neither erosion nor accretion) in the region of the drains. This function is not found in the principal components of the photogrammetric survey data which appear similar to the subsequent components of the survey data. This component supports the contour variation analysis provided earlier which showed greater stability in the region of the drains and shows that the drains have added a significant morphological pattern to the beach behaviour. Principal Components 3 and 4 in the survey data and 2, 3, 4 in the photogrammetry reflect various rip conditions which are probably related to different incident wave conditions.

CONCLUSIONS

The drainage material has been in place for approximately 18 months and is still performing well. There have been no operating or maintenance costs. Storm damage to the seaward ends of individual drains has reduced the efficiency of these drains but has not stopped the system from working. Although a general reduction in the watertable and shoreline levels sufficient to increase the stability of the beachface was achieved, a more closely spaced array of drains would be expected to increase these effects. In addition, a placement procedure providing a lower drainage system would reduce the potential for storm and rip damage without greatly reducing the draining capacity of the system.

It has been demonstrated that it is possible to alter the beach watertable by gravity drainage. Further, lowering the watertable by the method described has resulted in a stabilising of the beachface morphology in the local area.

If the nexus between watertable lowering and beach aggradation suggested by earlier researchers exists, then gravity drainage of the beachface watertable will prove to be a highly cost-effective means of beach stabilisation. It has the potential for significantly extending the life of beach nourishment programs.

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