Characteristics and Longevity of Beach Nourishment at Praia da Rocha, Portugal

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ABSTRACT


Beach fill instances on the Atlantic coast of the U.S.A. generally have a life expectancy of less than five years. Although beach nourishment is viewed as viable and is often preferred to hard structures, the geomorphologic life of the fill is an important variable in evaluating the success of the venture. Two adjacent, nourished beaches on the Algarve south coast of Portugal are examined to determine their morphologies following the fill and the variables that condition their temporal and spatial responses. The differential exposure to the ambient wave conditions and the nearshore circulation system differences caused by stacks and a very long jetty help to explain the contrasting history of beach fill in the two areas. Shoreline changes, surface morphologies, and sediment redistributions are traced through aerial photos, ground surveys, and a large collection of postcard views of the growing tourist area. The interpretation of this heterogeneous data set is that Praia da Rocha is regarded to be losing sediment very slowly, 2-5 cm per year, whereas the adjacent Praia dos Três Castelos is losing its emplaced sediment at a rate of about 15-20 cm per year. Within a distance of a few hundred meters, one nourishment episode is an unqualified success because much of the beach remains after two separate periods of filling (1970 and 1983), whereas the other beach has returned to its pre-fill (1983) narrow condition within 5 years.

ADDITIONAL INDEX WORDS: Beach nourishment, coastal erosion, archival techniques, sedimentation, Portugal.

INTRODUCTION

There is widespread interest in beach nourishment as a form of shoreline management for purposes of property protection, recreational beach development, and hazard mitigation (PILKEY and CLAYTON, 1989; U.S. ARMY CORPS OF ENGINEERS, 1984). Engineering practices are turning away from the ubiquitous use of hard structures to the employment of sediment recycling to maintain a beach in a desired location. Examples from Miami Beach (Florida) and Sandy Hook (New Jersey) point to the benefits of beach nourishment in providing recreational and tourist opportunity while protecting existing infrastructure (FROHLING, 1986; SLEZAK et al., 1984). Yet, beach nourishment is not a panacea and the basic causes of erosion and a negative sediment budget continue to exist. Beach nourishment extends the life of the beach by infusing a sediment supply that becomes subsequently reduced through time. The temporal viability of the fill and the morphological dynamics are important considerations in evaluating the effectiveness of the beach nourishment episode and in the justification of additional inputs of sediment to the system.

LEONARD et al. (1990) report that most of the beach fill projects along the East Coast of the U.S.A. have an average life expectancy of less than five years. That is, the fill has bought up to five years of reprieve from the effects of erosion as the shoreline is initially displaced seaward and then returns to its pre-fill position. During that period, the fill is being modified and entrained by the ambient processes. The morphological expression of the fill through time and the longevity of the fill are key factors in characterizing the fill and evaluating its performance.

This paper analyzes the geomorphological char-
The western half of the south coast of Portugal is composed largely of cliffs with small pocket beaches or short bay-mouth barriers (Morais, 1985). These morphological units are exposed to storm wave conditions emanating primarily from the southwest and secondarily from the southeast. Spring tides reach 4.0 m, thus providing considerable vertical exposure to the pocket beaches and cliffed coasts of southern Portugal. Common to most of the Portuguese southwestern coast, the cliffed coastline and small pocket beaches are fronted by an array of stacks and remnants of the dissected sedimentary formations (Figure 1). It is the presence of stacks that gives Praia da Rocha its name, a prominent stack referred to as “the rock”, and its ambiance (Figure 2). Within this setting, there have been two episodes of beach nourishment at Praia da Rocha and one at Praia dos Três Castelos, near the port of Portimão. There are a few reports that chronicle the events of the beach fill at Praia da Rocha and at the neighboring Praia dos Três Castelos and that describe some of the changes to the shoreline (Weinholtz, 1982, 1985; Psuty and Moreira, 1990). This report will focus on the different characteristics of two beach compartments, the morphology and the sediments, and the temporal interaction of the fill with ambient dynamics in each of the compartments.

GENERAL SETTING

The western half of the south coast of Portugal is composed largely of cliffs with small pocket beaches or short bay-mouth barriers (Morais, 1985). These morphological units are exposed to storm wave conditions emanating primarily from the southwest and secondarily from the southeast. Spring tides reach 4.0 m, thus providing considerable vertical exposure to the pocket beaches and cliffed coasts of southern Portugal. Common to most of the Portuguese southwestern coast, the cliffed coastline and small pocket beaches are fronted by an array of stacks and remnants of the dissected sedimentary formations (Figure 1). It is the presence of stacks that gives Praia da Rocha its name, a prominent stack referred to as “the rock”, and its ambiance (Figure 2). Within this setting, there have been two episodes of beach nourishment at Praia da Rocha and one at Praia dos Três Castelos, near the port of Portimão. There are a few reports that chronicle the events of the beach fill at Praia da Rocha and at the neighboring Praia dos Três Castelos and that describe some of the changes to the shoreline (Weinholtz, 1982, 1985; Psuty and Moreira, 1990). This report will focus on the different characteristics of two beach compartments, the morphology and the sediments, and the temporal interaction of the fill with ambient dynamics in each of the compartments.

DATA SOURCES

A study of shoreline changes requires a data set derived from aerial photos, ground photos, profile lines, and other similar views or measurements that can be compared through time. Whereas there is a good collection of aerial photos for this area for most purposes, they provide only the minimum coverage to evaluate the beach nourishment episodes. The aerial photo sets are from 1958, 1967, 1978, and 1987. The fill was accomplished in 1970 and in 1983. Thus, although the photos do provide before and after coverage, they lack the multiplicity of “looks” at the sites to establish rates of change or changes under differing dynamic conditions. Additional valuable information is contributed by beach profiles at the Praia da Rocha site before and after nourishment (Weinholtz, 1982) and augmented by our nine profiles of the two beaches measured in the fall of 1988 (see location of the profiles on Figure 2). Another source of documented characteristics is recovered from the many postcard views of the beaches which date from before the initial nourishment to the period after the second nourishment. Although the exact dates of the postcard views are generally unknown, it is possible to place them in a relative chronology and interpret the information that is portrayed on them. The presence of a few specific scenic overlooks has also created “photo points” from which similar postcard views were recorded and comparisons can be made. Thus, the postcards are used to add more points to the temporal variations established on the aerial photos and to contribute knowledge of the morphological variations at intervening times.

PRE-FILL CHARACTERISTICS

OF THE SITES

The development of stacks is most advanced in the vicinity of the western margin of Praia da

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1 Letters were written to each of the companies that produced the nearly 40 postcards that were used in this analysis requesting information as to the date of the particular postcard. Not one answer was received. The specific postcards used in this paper are cited along with the names of their companies in the references section.
Rocha, or both to the east and west of the rocky promontory (Ponta dos Castelos) between Rocha and Três Castelos (Figure 2). In this area, the sandy formation is underlain by a carbonate layer and this unit offers more resistance to the erosional processes. The result is that the carbonate layer forms a basal unit to the stacks, and the sandstone formation contributes a residual erosional remnant perched atop the carbonate base. The resistant carbonate layer forms a step in the profile of the stacks near the low tide level. In the absence of the overlying sandstone, the basal unit forms small isolated platforms which are at or near low tide. An example of a dissected platform is visible at low tide on the Três Castelos beach (Figure 3). Numerous rocky platform units are identifiable on the pre-fill aerial photos and postcards. The 1967 aerial photos show that there are portions of a submerged platform extending about 200 meters east from the central promontory of Ponta dos Castelos and that a platform exists westward along the complete face of the Três Castelos beach. Thus, the available photos and postcards provide evidence for the existence of a platform along Praia dos Três Castelos with a narrow wedge of sand against the cliff base. Conversely, although there is some evidence of a platform underlying Praia da Rocha, it is visible only at the western margin. Most of Praia da Rocha has a sandy beach that masks whatever platform may exist in front of the cliff face.

An early view available on the postcards provides some information about the conditions at Praia da Rocha (Figure 4). The temporal period represented is definitely prior to the first fill episode in 1970 but after the construction of the long jetties at the mouth of the River Arade during 1951–1957, probably taken in the mid 1960’s. The view on Figure 4 is from the eastern overlook at Forte de Santa Catarina and is a portrayal of the beach width associated with a low tide. The area of dry sand available for beach chairs with canvas covers (cabinas) is either one tier wide or restricted to small embayments in front of the cliff. The gray tone on the beach face suggests that the high tide reaches a position a short distance in front of the cabinas, at the site of the boat. The beach is very narrow in the middle ground and stacks are in the water at high tide in the background. The western portion of Praia da Rocha shows no visible high tide beach.

The exposed low tide beach on Figure 4 shows an emerged swash bar that is slightly inclined to the general shoreline. It is slightly farther offshore in the foreground and is attached to the beach in the middle distance. In addition, it is separated from the near foreshore by what appears to be a shallow trough. This morphology suggests that there is some alongshore transport from west to east in the form of this bar and that the bar is probably more orthogonal to the direction of the oncoming ambient wave conditions than the existing high tide beach. It is possible that a reorientation of the shoreline is occurring as a product of the river-mouth jetty that is trapping the alongshore migrating sediment and is causing buildout
Figure 3. Limestone platform near low tide level, Praia dos Três Castelos, 1983, prior to fill.

Figure 4. Narrow beach at base of cliff, looking west from Forte de Santa Catarina. (Postcard #755/122, Portugal Turístico)
of the shore zone. However, another postcard (Figure 5) which appears to be of similar vintage to Figure 4, judging by the coloration in the print, the character of the scene, and the identification number, shows the jetty as completely without any subaerial accumulation. The cliff face at the eastern margin extends into the water and the wave crests do not appear to be refracted and re-oriented by a submarine shoal. Thus, after a post-construction period of 10–15 years, there is no evidence of sediment accumulation on the updrift side of the jetty. This situation is verified on the 1967 aerial photos and on pre-fill ground photos incorporated in the report on the beach fill by Weinholtz (1982).

The situation at Praia dos Três Castelos in its pre-fill period is represented by a postcard view (Figure 3) that portrays the extreme narrowness of the beach zone. The subtidal portion of the beach contains many units of the calcareous platform that are at or below low tide. Numerous stacks dot the shoreline and offer some shelter to the beaches to their lee. Some of the beach irregularities are due to the protection from direct wave attack provided by the stacks. With the exception of a few high pocket accumulations of sand, most of the beach area is inundated at spring high tide. Although Praia da Rocha was nourished initially in 1970, Praia dos Três Castelos did not receive any fill until 1983 when a second period of inlet dredging resulted in emplacement of the dredged sediments on the western portion of Praia da Rocha and along Praia dos Três Castelos.

Thus, prior to the first episode of beach nourishment, the evidence from the aerial photos and postcards portrays the beaches as narrow accumulations within the crenelated planform of the cliffs. That there is a paucity of sediment available within the nearshore circulation system is demonstrated by the river mouth jetties begun in 1951 which show no evidence of accumulated sediment brought by alongshore transport. The lack of a nearshore sediment supply is probably the result of a combination of circumstances; especially at Praia da Rocha it incorporates (1) the absence of a source of sediment to the beach face following the creation of the long jetties which have encapsulated the subaqueous deltaic shoal and prevented its sediment from being transported westward, (2) the narrow window for wave entry which restricts the alongshore flux and is more favorable for cross-shore flux, and (3) the general lack of...
sediment availability from cliff erosion or from updrift.

**BEACH NOURISHMENT**

**Praia da Rocha**

According to Gomes and Weinholdt (1971), about 900,000 m$^3$ of sediment were emplaced at Praia da Rocha in 1970 (Table 1) creating a surface 4–6 meters above mean low water level (or up to 2 meters above high tide). The general width of the accumulation was on the order of 140 meters according to their measurements. Postcard information from the summer of 1970 is shown in Figure 6. This photo was taken during the period of dredging and pumping. A close inspection of the photo reveals that the beach at the far eastern side is offset seaward, indicating accumulation, and there are dark features which must be sections of the pipeline lying on the beach. Thus, this postcard records the position of the shoreline at Praia da Rocha in mid-1970 just as the filling was initiated. It is clear that the wetted beach is at

?Figure 6. Stacks in the beach, high tide against cliff base; fill has begun adjacent to jetty in background. (Postcard #148, J. Valle, Lisbon)

<table>
<thead>
<tr>
<th>Year</th>
<th>Area (m$^3$)</th>
<th>Area (m$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1967</td>
<td>17,050</td>
<td>44,500</td>
</tr>
<tr>
<td>1970</td>
<td>No fill added directly</td>
<td>880,000–1,100,000 m$^3$ of fill added</td>
</tr>
<tr>
<td>Dec. 1970</td>
<td>13,530 m$^3$</td>
<td>154,500 m$^2$</td>
</tr>
<tr>
<td>1978</td>
<td>28,390 m$^3$</td>
<td>156,000 m$^2$</td>
</tr>
<tr>
<td>1983</td>
<td>ca. 200,000 m$^3$ of fill added</td>
<td>ca. 150,000 m$^3$ of fill added</td>
</tr>
<tr>
<td>1983</td>
<td>88,950 m$^2$</td>
<td>214,500 m$^2$</td>
</tr>
<tr>
<td>1988</td>
<td>17,165 m$^2$</td>
<td>212,275 m$^2$</td>
</tr>
</tbody>
</table>

*Table 1. Beach areas and fill episodes at various times. Calculations derived from aerial photographs, profiles, postcards, and literature (Gomes and Weinholdt, 1971; Weinholdt, 1982, 1985; Pais and Moreira, 1990). Areas calculated to high tide line as best as possible.*

the cliff base at this time and the stacks are located in the water at high tide, essentially documenting a general absence of a subaerial beach accumulation.
It is likely that the dredge spoil was pumped onto the beach and was pushed out into the water by earth-moving machinery as the sediment accumulated, causing an oversteepening of the fore­shore. Once the fill had been emplaced, it is likely that the seaward margin of the fill was scarped and altered by the ambient waves and currents. The effect would be to cause an initial cutback and scarping of the fill surface as offshore and shoreface equilibrium slopes were reestablished as described by Dean (1983). It is likely that the entire frontal margin of the beach fill underwent a retreat and gentling of the shoreface slope. Gomes and Weinholdt (1971) comment on the modifications to the slope of the beach caused by the fill and indicate that the pre-fill beach slope of 2.5° was succeeded by a shoreface slope of 4° on the fill which later lessened to 3°. They are probably describing the changes that were occurring as the equilibrium was being reestablished. Following cutback of the slope, some alongshore transport shifted sediment from the west to east along Praia da Rocha. A scarp continued to mark the inner margin of the beach foreshore slope at the western portion, but the eastern area was receiving more sediment than it was losing and progradation ensued. The eastern buildout was in front of the post-fill scarp and this contrast can be seen in the creation of at least two levels in the eastern portion of Praia da Rocha and the development of accretionary ridges in the topography. Thus, the beach passed through a sequence of cut and fill in its developmental history that is recorded in the topography and in the sediments. It is in the topography in the form of the higher fill surface, the scarp at its seaward margin, and the lower accretionary ridge forms. It is in the sediment record in the coarser upper surface of the fill and the contrasting well-sorted, fine-grained, wave-worked sediments making up the lower level of the beach profile.

**Praia dos Três Castelos**

As seen on the aerial photos and the early postcards, the beach was very narrow with many stacks present in the water. The area is a promontory and sticks out unlike the embayment which incorporates the Rocha beach. The 1957 aerial photo gives an exceptional view of the bedrock platform through the water and shows it lining the entire frontal margin of the Três Castelos shoreline. There are sandstone stacks atop the basal carbonate layer and there are also several flat-topped platforms. In 1983, approximately 200,000 m³ of sediment were pumped from the Arade estuary onto the Três Castelos beach (Table 1), producing a buildout of about 50 m over a length of 1,000 m (Figure 7).
Figure 8. Beach profiles extending across the fill zone on Praia da Rocha and on Praia dos Três Castelos, October, 1988; location of profile lines depicted on Figure 2.

BEACH PROFILES

Praia da Rocha

The profile lines across the beach depict the high fill surface (or the remnants of it), the erosional margin of the surface, and they record stages in the development of the topography (Figure 8, Profiles 1–7). The characteristics of the profiles and their causative factors are as follows:

1. Initially, the seaward margin of the fill was scarped as the beach face adjusted from an oversteepened condition to what was equilibrium for the ambient waves and currents and the sediment. The GOMES and WEINHOLTZ (1971) notation of steeper beach slopes gradually returning to gentler slopes is an indication of this modification. Each profile incorporates a scarp within its topography (Figure 8, Profiles 1–7), either indicating continuing erosion if the scarp is active, or erosion succeeded by deposition if the scarp is located inland of the modern beach foreshore.

2. As the beach slopes were being adjusted by the reworking of the fill sediments, there was an abundance of sediment in the nearshore zone for alongshore and offshore transport. The long-term buildout of the eastern profiles shows that the net transfer was from west to east as the accretionary ridges created a low level that extended seaward in the middle and eastern portion of Praia da Rocha (Figure 8, Profiles 1–7). A short term tracer study conducted prior to the filling showed the same west to east net transport direction (LABORATORIO NACIONAL DE ENGENHARIA CIVIL, 1970). The tracer study also suggested that there was a limited circulation cell that did not cause sediment to travel eastward beyond the jetty margin of Praia da Rocha. Instead, the proposed circulation followed a west to east alongshore transport in the shallow water zone up to the vicinity of the jetty. From that location the transport was offshore but once in deeper water, shallower than the seaward limit of the jetty, there was a counter
flow that caused the sediment to be moved from east to west. The cycle was closed as the sediment moved onshore to nourish the western margin of Praia da Rocha. If the circulation were a closed system, there would appear to be little loss of sediment from the cell and the beach could exist in equilibrium. If the circulation cell were leaky and some sediment were lost to the offshore, or inland, or to the east of the jetty, then this amount would constitute a loss from the beach sand reservoir and would be manifested in net shoreline erosion. A similar pattern would develop if the predominant exchange were in the cross-shore direction and interspersed with southwesterly storms generating west to east transport and alongshore transport reversals associated with Levant conditions (a storm situation associated with winds and waves from the southeast, see PSUTY and MOREIRA, 1990). Although the causative processes are of interest and are of importance in the understanding of the mechanisms responsible for the sediment transfers, it is clear that the rate of loss from Praia da Rocha is occurring at a slow rate and that sediment is being re-circulated within the system. The tracer study is instructive in demonstrating that a circulation cell exists and that the leakage to the east of the jetty or to deeper water is of a limited amount.

(3) The fill surface offers evidence of some eolian transport. The high surface tends to be veneered by a lag deposit that is the product of deflation of the upper surface. It is difficult to suggest the amount of deflation that has occurred but it may not be very much because of the substantial proportion of shell hash and pebbles in the fill. In general, there is an absence of fine, wind-transported sediment on the high surface. There are no large dune zones at the cliff base nor are there significant ridges of eolian sediments or vegetated ridges on the high surface (Figure 8, Profiles 2–7). There are a few vegetation lines. They are narrow and low, only about 10–15 cm high. They tend to be located at an inland position, away from beach users, or at the seaward crest of the fill surface.

(4) The eastern profiles show the existence of
accretionary ridges low on the profile (Figure 8, Profiles 1-2). The far eastern profile also shows two ridge-like accumulations on the high surface. These appear to be eolian features. The largest ridge is located at the inland margin of the profile, against the cliff. At this location, there is an accumulation that has built to the level of the top of the 1.0 meter high wall which extends along the western side of the jetty. The wall may have been built in response to the drifting of sand across the beach and across the jetty. There is an eolian accumulation form extending about 60-70 meters from the cliff face and about 1.0-1.5 meters high. There is a second eolian ridge which is at the seaward margin of the high fill surface (Figure 9). In this case, the ridge coincides with the limit of retreat of the fill surface as the beach face was adjusting to a gentler slope. It is also coincident with the seaward limit of the 1.0 meter wall along the margin of the jetty. The location of an eolian cap on the eastern margin of the fill surface is reasonable because it lies at the position of greatest fetch across the fill surface. It is logical that the inland margin, against the cliff, is a favored location for the eolian accumulation. It is also logical that some eolian accumulation occurs at the crest of the fill because it is a location of wind acceleration up the face and deceleration beyond the crest. If sediment were to be transported by wind across the accretionary zone, accumulation would be favored at the base of the scarp until a ramp were created and then accumulations would occur at a position just beyond the crest due to flow separation. The wall along the jetty would be a physical barrier to eolian transport until a ramp were formed to reach the crest. Once that happened, sediment transport and loss to the system would occur as sand would be blown across the jetty into the river channel. The two sites where eolian accumulations have built up to overtop the 1.0 m wall occur at likely locations at the eastern border where the southwest winds could transport sediment out of the beach-fill system.

(5) There are several vegetation lines on the eastern portion of the beach fill zone. They seem to be associated with minor eolian accumulations, either in ridge form or in sand sheets (Figure 9). The vegetation cover could document small lines.
or areas of accumulation or could be temporary features caused by the absence of use of this section of the beach. The old postcards do not show any great accumulations of wind-blown sands being stabilized by vegetation.

(6) The higher surface is a residual transport surface for most of its extent (Figure 8, Profiles 1–7). The western portion of the high surface is composed of two episodes of fill, the latter accumulating to a higher elevation, covering the older fill and encroaching farther up the sides of the stacks while extending the shoreline seaward (Figure 8, Profiles 6–7). The 1983 fill is very noticeable on the postcards because of a darker coloration (Figure 10), a characteristic that remains observable today. The surface is planar in form and is composed of a coarse lag concentration.

(7) There is a loss of fine-grained sediments which are blown across the jetty and enter the channel, but that is a finite amount of material and it may have reached its maximum because the deflation surface is well armored at this time. A second source of eolian loss is from the newly-accumulating lower surface. It is capable of supplying a rather large quantity of fine to medium sand, as is the entire beach face of Praia da Rocha. The slight eolian cap at the seaward margin of the high fill surface (Figure 8, Profile 1) shows that there is some potential to send eolian-transported sediment inland from the beach. However, it is limited and slow. There may be opportunities for additional eolian transport if the lag deposit is disturbed by surface grooming for the tourist trade. If that is so, it is anticipated that pulses of fresh eolian-blown sand would be available to feed the ridge forms on Profile 1. Additional eolian supply would accompany storm events which would rework the low accretionary level and possibly scarp the high fill surface. The rebuilding of the beach face and berm would provide a source of sediment for inland transfer.

Praia dos Três Castelos

The Três Castelos area is unlike Rocha because it is situated on a promontory rather than in a cove. It had a narrower, higher beach fill episode. The fill was probably thinner in relation to Rocha because the accumulation was placed on top of
the bedrock platform. That translates into a lesser quantity of sediment being exposed to the mobilization processes of waves and currents per unit beach length. The general refraction of orthogonals did not cause the continuous alongshore transport and accumulation as at Rocha. Rather, the only areas of accumulation were tombolo-like features formed to the lee of the stacks caused by convergence of wave orthogonals.

Following the 1983 beach fill (Figures 2 and 7), this area experienced rapid scarping and cutting back (Figure 8, Profiles 8 and 9). The 1987 aerial photos show a surface area which was only about 20 per cent of the 1983 beach fill surface. In 1988, the remnants of the high surface, capped by highly-oxidized colluvial deposits, existed only in the small pocket embayments created in the irregular cliff face (Figure 2). The colluvial wash has produced conical accumulations building up on the surface where slope drainage leads down the cliff face onto the beach fill. There is a lower accretionary surface that is built of re-worked fill sediment in front of the scarp face. This lower surface, in turn, is scarped (see Figure 8, Profiles 8 and 9). There is very little sediment remaining from the initial fill (Figure 11). A general equilibrium may have been reached along this shoreline in which most of the exposed fill has been mobilized. The remaining emplaced dredge spoil is tucked into the high embayments and may not be easily dislodged except under extreme events (Figure 12).

**SEDIMENT TYPES**

The emplacement of dredged sediment onto the two beaches establishes an accumulation that is subsequently re-worked by the ambient processes to re-form and re-distribute the sediments. Given some general characteristics of the beach fill, the process of re-working may selectively shift and accumulate portions of the total grain-size distribution. Plots of the grain-size curves representing specific morpho-sedimentary assemblages provide yet another insight to the process-response modes of change in the beach fill system (Figure 13, A–J).
The Fill

These are estuarine sediments that show large size variation. There is a mixture of shell fragments, fine sand that may be marine deposits, coarse fluvial material derived from the terrestrial environment, and cultural materials such as pieces of brick, and perhaps exotic stones which were once ballast on some ship unloaded in the harbor near Portimão (Figure 14). The surface of the fill, except for the extreme eastern margin, consists of a lag deposit which results from the deflation of the finer sediments, causing a bimodal distribution of the residual materials. The surface has a high concentration of shell fragments which effectively shield the underlying sediments from mobilization by the ambient winds. There are fine-grained sediments beneath the shell lag which could be moved if exposed.

The Beach Face

These sediments have been re-worked by the ambient waves and currents (Figure 13A, C, F, and J). They were originally part of the beach fill. The coarser sediments have been sorted out and transported to some unknown location in the offshore zone. The fine and medium sands have returned to form the shoreface and nearshore zone characterized by a unimodal distribution of the finer portion. On the western margin of Praia da Rocha, the zone of well-sorted sediments is limited in extent. It is only in front of the scarp. On the eastern margin, the well-sorted zone is the area of the accretionary ridges. In both areas, the beach face is an accumulation of re-worked and well-sorted sediments.

The Scarp

The scarp is intermediate in sediment type because it contains the fill material without the concentration by deflation and it contains the finer sediments that have been sorted and returned to form the beach surface. It has a broader or a bimodal distribution (Figure 13D, G, H, and J). The scarp is somewhat limited in surface expression at the eastern margin because of the lower elevation and the masking by eolian accumulations. The scarp is probably coincident with the location of the seaward end of the 1.0 meter wall along the jetty. A 1988 photo shows the existence of the scarp and the two surfaces (Figure 14).
The scarp in the central portion of the Rocha beach (Profiles 3–5) is located some 50–60 m inland, indicating a general accretionary history following the period of slope readjustment. Some postcards show the existence of a scarp in this middle section, these postcards represent the pre-1983 period, prior to the second phase of fill. Thus the accretion in the central zone may be post-1983.

In the west, there is some variety in the character of the scarp. In the early fill episode, the western surface was low and the scarp was correspondingly of lesser magnitude. Some postcards show more of the stacks exposed and a low scarp in the beach (Figure 15). The second beach nourishment in 1983 placed about 150,000 m$^3$ primarily in the western portion of Praia da Rocha (Table 1). The fill raised the surface as well as displaced the shoreline seaward. Postcards taken after the 1983 fill show high sand levels around the stacks and also depict the new fill with a darker coloration. After the high fill of 1983, the stacks are under greater accumulation and are less exposed. Whereas there was an initial displacement of the shoreline associated with the second fill, the area from Profile 6 to Ponta dos Castelos has been reduced by 50% from 1983 to 1988. This is a product of wave diffraction around the point combined with a general west to east littoral transport that is creating a net negative budget. Further, there appears to be sediment being transferred from Praia dos Três Castelos into the Profile 6–7 area. A view of the area in 1989 (Figure 16) shows the further dissection and inland displacement along Profiles 6–7.

Eolian Forms

Portions of Profile 1 are zones of eolian accumulation, either on the high surface or even on the lower surface. The grain size distribution (Figure 15B) shows a unimodal peak that is finer than any of the other samples. This is probably the result of the eolian transfer from west to east and the accumulation that is occurring at the base of the jetty as well as the wall along its western side.
CONCLUSION

The measurement of success of the two beach fill episodes at Praia da Rocha and Praia dos Três Castelos offers considerably different outcomes. At Praia dos Três Castelos, the areal extent of the beach is much as it was prior to the nourishment, indicating that approximately 200,000 m$^3$ of the emplaced sediment was removed in about 5 years. Many factors combine to explain the conditions that mobilized and removed this accumulation. Perhaps of foremost importance is the highly exposed location of this section of the coast. This is a promontory that lies open to the storm waves coming from both the southwest as well as the southeast. In the pre-fill period, the beaches were poorly-developed, occupying small coves or lying to the lee of the sheltering offshore stacks. The offshore zone was a rocky platform that severely limited the quantity of sand that could be stored in the beach. Thus, the beach fill was a thin veneer of sediment situated atop a bedrock surface that was exposed to high wave energy events from nearly all directions. In essence, the fill contributed very little mass of sediment per unit length of beach to absorb the ambient waves and currents and thus the shoreline retreated very quickly at this exposed point. The result is a kind of scalloped shoreline whose seaward projections are in the shadows of the stacks and whose bays are in the openings between the stacks. The cre­nelated shoreline has an orientation that indicates the major formational energies are out of the southwest.

Praia da Rocha, on the other hand, occupied a relatively sheltered condition. It is bounded by Ponta dos Castelos toward the southwest and is sheltered by the west jetty of the Arade River from southeast waves. There is a window for waves to arrive from the south, but this direction is less common and has lower wave dimensions. This beach, therefore, occupies a cove that is protected from the direct approach of many of the storm waves. Refraction and diffraction serve to reduce the wave dimensions that do arrive to mold the Rocha beach. The orientation of the shoreline to the southwest approach offers testimony as to the predominant conditions shaping this area. The
transfer of sediment out of the western sector and toward the eastern margin will probably continue but the eastern area will not likely continue to buildout. Whereas the areal measures in Table 1 tend to portray Rocha as essentially balanced, this is a two-dimensional measure and is misleading. The profiles show that the losses are occurring in the high fill surface whereas the gains are topographically low and thus the third-dimensional information shows a loss of volume when the two areas are compared. Nevertheless, the circulation cell that keeps much of the sediment transport within the Praia do Rocha system works to restrict the rate of loss and prolong the effectiveness of the beach nourishment project. It is likely that the western end of Rocha will experience continuing erosion because of the absence of any new sediment entering this portion of the beach. The erosion will then extend eastward through the successive profile areas until even the beach adjacent to the jetty will retreat. Of course, this process will occur slowly, perhaps causing losses of about 2–5% of the volume per year. There is no new sediment entering into the system and thus the fate of the beach will be determined by the leakage into deeper water, some transfer around the west jetty in the subaqueous zone, and some wind-blown transport across the jetty directly into the river channel. These transfers will likely occur in stepwise fashion, i.e., large transfers associated with some major storm event that is well-positioned to approach Rocha directly. Major shifts will occur at these times with minor modifications during the intervening periods, marked by an expansion of the erosional scarp from west to east and a gradual return to pocket beaches at Praia da Rocha. Yet, the beach could last another 20 years and, similar to Miami Beach, boost the tourist economy and provide ample recreational activity for much more than the 5-year average life of East Coast U.S.A. beaches. Sheltered situations such as Praia da Rocha are prime sites for success stories associated with beach nourishment.

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LITERATURE CITED


LITERÁRIO NACIONAL DE ENGENHARIA CIVIL, 1970.

Psuty and Moreira


RESUMO

Os episódios de enchimento artificial das praias da costa Atlântica dos Estados Unidos da América têm uma vida útil inferior a cinco anos. No entanto, a alimentação artificial das praias é encarada como uma solução eficaz, e tem sido muitas vezes preferida ao uso de estruturas ditas pesadas. O sucesso desta técnica depende da estabilidade dos materiais de enchimento que, por sua vez, é função das características geomorfológicas da praia. Na costa do Algarve foram alimentadas artificialmente duas praias contíguas (Praia da Rocha e Praia dos Três Castelos), adjacentes a uma arriba arenítica em recuo. Neste trabalho analisam-se a evolução temporal e espacial da morfologia destas praias após o seu enchimento. Verifica-se que a Praia da Rocha, abrigada pelos molhe ocidental do porto de Portimão e pelos ilhotes do seu extremo ocidental, perde anualmente 2 a 5% de seu material, enquanto a Praia dos Três Castelos, mais exposta à ondulação, perde de 15 a 20% de seu material.

RESUME

Le nourrissement artificiel des plages de la côte atlantique des États Unis a une vie utile très courte; les sédiments fournis aux plages ne se conservent sur place que pendant 5 ans. Malgré ce fait, l'alimentation artificielle des plages est considérée comme la solution la plus efficace, et est préférable aux techniques de protection avec des structures dites lourdes. La stabilité des matériaux fournis à la plage dépend des caractéristiques géomorphologiques de la plage. Sur la côte de l'Algarve cette technique a été utilisée pour la récupération des plages de Três Castelos et Rocha, qui s'appuient à une falaise gréseuse en recul. Ce travail traite de l'évolution spatiale et temporelle de la morphologie de ces plages, après les deux épisodes de nourrissement, en 1970 et en 1985. On a vérifié que la plage de Rocha, abritée du SE par l'épisode ocidental du port de Portimão et des vagues de SW peur des îlots rocheux de son extrémité occidentale, perd 2 à 5% de ses sables par an. La plage de Três Castelos, plus exposée au déferlement de SW, perd chaque année 15 à 20% de son matériel.