TOWARDS THE ADOPTION OF ADEQUATE COASTAL PROTECTION STRATEGIES IN PORTUGAL

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ABSTRACT

Most of the portuguese littoral is under erosion, with rates exceeding 8-10 my⁻¹ in many cases. Shoreline retreat in sandy coastal stretches is induced by several factors, the most important being the deficiency in sediment supply to the shore. The strategy that has traditionally been used to face coastal erosion is the building of hard engineering structures, although beach nourishment has been already attempted and proven successful. In this paper, two case studies are used to compare the local and global cost-effectiveness of a "hard" and a "soft" approach. The chosen sites are characterized by differences in energy levels and magnitudes of littoral drift processes. In the higher-energy littoral (Costa Nova, in the west coast), groins seem to be cost-effective only when small coastal stretches are considered; in all other cases, beach nourishment is the best option. On the contrary, in the lower-energy littoral (Quarteira, in the south coast), artificial nourishment becomes a solution that is relatively cost-effective, regardless of the length of the coastal stretch.

INTRODUCTION

The Portuguese littoral stretches along 840 km and is quite diverse in morphology and vulnerability, dominated by beaches (ca 43%) and cliffs (ca 57%). Different morphological features can be identified, including sandy shores backed by dunes or cliffs, rocky coasts with low to high and plunging cliffs, shore platforms, pocket beaches, bays/headlands, estuaries and lagoons and associated tidal flats and salt marshes, tombolos, sand spits and barrier islands. The capes advancing into the sea correspond to high cliffs (Roca, Espichel and S. Vicente capes), low cliffs (Carvoeiro, Raso and Sines capes) or even sandy spits (Sta. Maria cape). Two of the most important coastal lagoons are the improperly named Aveiro and Formosa Rias, located, respectively, near the locality with the same name and in the area extending from Quarteira to Cacela (fig. 1).
The coast is high-mesotidal and wave-dominated, energy decreasing in sheltered W-E trending sections, including the south-facing littoral of the Algarve. The western coast is fully exposed to far-generated WNW-NNW waves in the Atlantic and is a high energy, swell-dominated coast. In this coast, calm sea is exceptional and storms are frequent between October and March. The southern Algarve is sheltered regarding waves approaching from the N-NW and the resultant regime is milder. Calm sea occurs during 30% of the year and storms never reach the intensity observed along the western coast. The prevailing wind and wave climate conditions induce longshore drift, which is generally southward and stronger in the western coast (in the order of 10^6 m^3y^{-1}, according to Oliveira et al., 1982) and eastward in the southern coast (in the order of 10^5 m^3y^{-1}, according to Granja et al., 1984).

Most of the littoral is under erosion, with rates exceeding 8-10 m.y^{-1} in many cases (Andrade and Freitas, 2001). Shoreline retreat in sandy coastal stretches is induced by several factors, one of (or perhaps the most important of) which is the deficiency in sediment supply to the shore. Sea level rise accounts for only ca. 10% of this retreat (e.g., Ferreira et al., 1990).

Two major sediment sources nourish the Portuguese coast: stream sources and coastal erosion. With respect to the former, the sediment yield to the coast has been dramatically reduced in relation to dam construction, changes in land use and mining of significant volumes of sand and shingle. This, in turn, led to the undersaturation of the potential longshore drift and starvation of the coast. As a consequence, coastal erosion is the present-day main sediment source. According to Oliveira (1997), coastal erosion accounts for a yearly loss of littoral territory in the order of 6 ha for the 120 km-long stretch immediately south of Porto.

Coastal erosion has been occasionally reported as hazardous or identified as a risk in the late 1800s and the turn of the century marks a significant threshold in the widespread and increasing intensity of this process, the reasons for this being still under discussion (Andrade and Freitas, 2001). Regardless the nature of causes, the setting up of erosion triggered a strong demand for coastal protection.

The strategy that is traditionally used to face coastal erosion is the building of hard engineering structures, although beach nourishment has been attempted and proven successful in Praia da Rocha (Gomes and Weinholdt, 1971) and in the Cacela Peninsula, in the Algarve (Ángelo, 2001). Dias (1990) and Oliveira (1997), among other authors, have recommended this latter strategy, as long as its economic feasibility is proved.

Whichever the strategy adopted to cope with the coastal erosion problem, it must clearly be cost-effective, both locally and globally, and be based on a detailed cost / benefit analysis and the knowledge of coastal dynamics. Such analysis should consider both direct costs (those related with a particular strategy) and indirect costs (those related with environment and tourism, for instance). However, only the former will
be considered in the present study, given the lack of suitable data.

Two case studies will be used to compare the local and global cost-effectiveness of a "hard" and a "soft" approach in order to provide decision-makers with a useful tool for the adoption of a rational strategy to deal with erosion problems and coastal protection. This problem must be addressed iteratively. The first iteration was presented in the 4th Symposium on the Atlantic continental margin. The present paper corresponds to a further development.

DIFFERENT APPROACHES TO FACE COASTAL EROSION

Hard engineering structures can be shore-normal (e.g., groins) or shore-parallel (e.g., seawalls or detached breakwaters). They are used to intercept and dissipate wave energy, and to protect the shore against erosion and sliding. However, some unwanted side effects have been observed, a minor part of which have been attributed to constructional failures.

Groins interrupt littoral drift. Sands accumulate updrift and there is downdrift erosion induced by that blocking, which is sometimes felt several km from the groin, leading, in some cases, to the construction of groin fields. The effectiveness of groins is most strongly related to the length of these structures with respect to the width of the surf zone. Feenstra et al. (1998) have shown that it will be most economical to build relatively short groins focusing on the reduction of the littoral drift in the inner surf zone during moderate wave conditions. They also discuss the situations in which groins may be applied and are cost-effective. According to these authors, these structures are not effective along, namely, steep reflective high-energy sand coasts and macro-tidal sand coasts. Nersesian et al. (1992) have concluded that groin fields can be used to reinforce or to hold protective beach fills and that bypassing of longshore sediment should be ensured.

One fundamental aspect of the functional design of groins is related to the ratio between groin spacing sg and groin length lg. According to US Army Corps of Engineers (2002), a ratio of 2 - 3 is required for the proper functioning of shore-normal groins.

Seawalls are vertical (or almost) retaining walls with the purpose of protection of the land against heavy wave-induced scour; they are not built to protect or stabilize the beach or shoreface in front of or adjacent to the structure. Thus, chronic erosion due to gradients of longshore transport will not be reduced. Furthermore, beach and shoreface erosion will ultimately lead to an increased wave attack intensifying the transport capacity. The hydraulic and morphodynamic effects of these structures concerning their contribution to erosion and scour are described in Kraus (1988) and in Van Rijn (1998).

Detached breakwaters can be emerged or submerged and are built as offshore barriers parallel to the shore protecting a portion of the shoreline by forming a shield to the waves (blocking of incident wave energy). Some of the effects induced by these structures are the reduction of wave energy at the shoreline, the local deposition of littoral sands within the protected lee of the breakwater and the reduction of onshore sediment transport. They often require beach fills in the lee zone and beach nourishment on the downdrift side (Van Rijn, 1998); furthermore, their maintenance is relatively high, because of settlement of the structure and the need of floating equipment for repair. Depending on geometrical scale, wave climate and sand availability, the shoreline may show a bulge-like pattern (salient) or may advance to the breakwater position (tombolo).

Beach nourishment is a soft protective and remedial measure that leaves a beach in a more natural state than hard structures and preserves its recreational value. It is a popular option in highly developed areas with heavily used beaches and valuable beachfront real estate, especially during the early onset of erosion. This option has been the worldwide selected alternative for shore protection since the 1960s. A good example is Miami Beach, Florida, US, which was renourished in 1979 at a cost of around 52×10^6 €. Attendance at the beach increased from 8 million in 1978 to 21 million in 1983. Globally, there was a 700 € return for every 1 € invested in beach nourishment (Houston, 1996).

Regular maintenance is required and can be reduced by using relatively coarse sand as fill material. Although sometimes quite expensive, is sometimes
less costly than hard structures, is clearly less aggressive to the littoral and much more adequate from an aesthetic point of view. The offshore sand borrow site is one of the main concerns when considering the viability of beach nourishment. Several works carried out in the Portuguese mainland coast (e.g. Dias et al., 1980; Magalhães, 2001, 2003) have identified large amounts of sand and gravel deposits in the continental shelf, whose characteristics and depth of occurrence make them favorable borrow areas for such operations.

CASE STUDIES

Two areas, which suffer from chronic coastal erosion problems, will be considered for the comparison of the local and global cost-effectiveness of the previous strategies: Costa Nova, south of Aveiro, in the west coast (fig. 2) and Quarteira, in the south coast (fig. 3).

1. COSTA NOVA

The erosion problems in the Costa Nova area are connected with the Aveiro harbour jetties. As a matter of fact, when these were built, shoreline retreat rates increased southward of these structures. Mean rates attained 8 my⁻¹, but local values of 10 my⁻¹ were detected. This situation has led to the construction of the Costa Nova groin field, which induced retreat values as high as 50 m in the two-year period after their construction (Dias, 1990).

A total of eleven groins were built in the period 1972/73 to protect this coastal stretch. However, the present-day situation, as evident from the analysis of aerial photographs, is somewhat different. The characteristics of the identifiable defence structures are given in Hidrotécnica Portuguesa (1997) and in Veloso-Gomes et al. (2002).

Figure 2. Costa Nova.
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Two 220 m - length groins were recently built south of Cost Nova, as proposed in the the Portuguese Water Institute (INAG)'s Coastal Zone Management Plan, each groin costing around 2,000,000 €. This means that the cost of each meter structures was around 9,000 €, clearly above Van Rijn (1998)'s estimate (2,500-5,000 €/m groin). Assuming that the maintenance of these structures increases their cost by a factor of 3 over 50 years (Van Rijn, 1998), an estimated cost of 27,000 €/m groin is obtained. Using a value of 3 for the ratio gs/gl, meaning that each meter of groin should protect 3 meters of shoreline (the maximum value suggested by US Army Corps of Engineers, 2002), an estimated cost over 50 years of 9,000 €/m shoreline or 180 €/m/y is obtained. As might be expected, this value is also above Van Rijn (1998)'s estimate (75-150 €/m/y). On the other hand, the maintenance costs for the period 1975-1997 (Hidrotécnica Portuguesa, 1997) suggest that Van Rijn (1998)'s estimates are underestimated in the case of Costa Nova.

For this sector, each seawall meter is assumed to cost around 5,000 €. Over 50 years, each seawall meter will cost 15,000 € and each shoreline meter the same. Thus, an estimate of 300 €/m/y is obtained if this coast is to be protected by seawalls, agreeing with Van Rijn (1998)'s (240-480 €/m/y).

Two detached breakwaters were recently built in Aguda and Castelo do Neiva, each meter costing around 12,000 €. Assuming a gap between breakwaters of twice their length and using the previous maintenance assumptions, a mean cost of around 360 €/m/y is expected.

Data from several beach nourishment operations indicates that their average cost is around 3 €/m³. For an overall volume in the order of 10⁶ m³/y (littoral drift), which is required for the system to become saturated, a global cost of 3×10⁶ €/m³/y is expected. When the littoral drift becomes saturated at a given local (i.e., the effective longshore drift equals the potential one), the same holds true for the entire downcurrent coastal stretch. This means that the protection cost per unit length of sandy shores decreases as larger coastal stretches are taken into account. Considering littoral stretches of 5 km, 20 km and 50 km, the corresponding costs are about 600 €/m/y, 150 €/m/y and 60 €/m/y, respectively.
The previous figures seem to indicate that, in this high-energy littoral, groins are only cost-effective when small coastal stretches are considered, emergencies being the most noticeable case. In all other cases, artificial nourishment is the best option.

However, for this particular area, some other strategies for coastal protection have been proposed. Ferreira et al. (1994) have proposed the nourishment of nearshore bars, since wave energy dissipation due to wave breaking over offshore bars is responsible for a strong decrease in the amount of wave energy that reaches the beachface.

2. QUARTEIRA

The Algarve coast is an area of intense anthropogenic changes due to tourism and urban development. The impact of these activities in the shoreline is clearly visible all along this coast and namely consists of local increases in coastal erosion. The cliffed coastal stretch eastward of Quarteira is one of the most affected areas.

Mean retreat rates for these cliffs were 0.2 to 0.8 mm/y in the period 1947-1974 (Marques, 1997). In order to attenuate coastal erosion, several groins were built in the decade of 1970, inducing, along with the Vilamoura marina, the interruption of the eastward littoral transport. As a consequence, there was a net increase in cliff retreat rates, which attained, during the period of 1974/80, a mean rate of 7.5 m/y downcoast of the groin field, at Forte Novo (Correia et al. 1994; Marques, 1997). Presently, the Quarteira groin field is composed by 7 groins 100 m to 140 m long, spaced from 280m.

From data on structures recently built in the Algarve coast, a mean building cost of 4,000 €/m groin may be assumed (which agrees with Van Rijn (1998)'s estimate). This points to an estimated cost of 12,000 €/meter groin over 50 years. Using a value of 3 for the ratio gs/gl, as in the previous sector, this suggests an estimated cost of 80 €/m/y. As expected, this estimate is smaller than the one obtained for the Costa Nova sector.

For this sector, each seawall meter is assumed to cost around 2,000 €. Over 50 years, each seawall meter will cost 6,000 € and each shoreline meter the same. Thus, an estimate of 120 €/m/y is obtained for the protection of this coast with seawalls.

As for detached breakwaters, each meter is assumed to cost around 5,000 €. Assuming a gap between breakwaters of twice their length and using the previous maintenance assumptions, a mean cost of around 150 €/m/y is expected.

The average cost of beach nourishment operations is around 2.5 €/m³. Thus, a cost of 2.5× 10⁴ € m³/y is expected for the system to become saturated by littoral drift (in the order of 10⁴ m³/y). Considering littoral stretches of 5 km, 20 km and 50 km, the corresponding costs are about 50 €/m/y, 13 €/m/y and 5 €/m/y, respectively. That is, artificial nourishment becomes a solution that is fairly cost-effective even for small coastal stretches. In this area, this is certainly the most advantageous solution, even because it results in substantial recreation and tourism benefits.

Table 1 summarizes the estimates that were obtained in the present work.

<table>
<thead>
<tr>
<th>Strategy</th>
<th>West coast</th>
<th>Southern coast</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Cost / meter</td>
<td>Cost / meter</td>
</tr>
<tr>
<td></td>
<td>structure</td>
<td>shoreline / year</td>
</tr>
<tr>
<td>Groin</td>
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<td>180</td>
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<tr>
<td>Seawall</td>
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<td>300</td>
</tr>
<tr>
<td>Breakwater</td>
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<td>Beach fill</td>
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<tr>
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<tr>
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<tr>
<td>50 km</td>
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</table>
CONCLUSION

Benefits and effectiveness of a given solution for coastal erosion problems are site specific. The two case studies considered in this work are characterised by differences in energy levels and magnitudes of littoral drift processes. The figures presented are based on available data; as more data will become available, cost estimates will be refined. Nevertheless, despite present uncertainties, some general conclusions on cost-effectiveness of different approaches to coastal erosion at studied sites can be drawn. In the higher-energy littoral (Costa Nova), groins appear to be cost-effective only when a small coastal stretch is considered; in all other cases, artificial nourishment is the best option. On the contrary, in the lower-energy littoral (Quarteira), artificial nourishment becomes a solution that is very cost-effective, regardless of the length of the coastal stretch. It must be further emphasised that the estimates presented herein only take into account direct protection costs. If indirect costs, such as those related with environment and tourism, were also incorporated in those estimates, artificial nourishment would become even more attractive.

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REFERENCES


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