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Large Scale Morphodynamics Characterisation of Exposed Sandy Beaches by DGPS

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ABSTRACT

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During the last decades important stretches of the coastal foredunes in the Aveiro Lagoon exposed sandy beaches (Portuguese west coast) were destroyed by wave action, with strong impact on the local social activities. As the foredune erosion and degree of destruction by overwashes are related with the foreshore and backshore morphology, the study of the morphological evolution of these areas of the beach is of special interest. In the present work, time scale of volumetric changes and recovery periods are analysed. A sector located south of an groin field with two contrasting stretches was selected. In one of those stretches, with about 3 km extension, artificial sand remobilization from the foreshore was operated to build a sand dike. The second one with 4 km extension has evolved without any direct human intervention. In order to determine the morphological evolution of these two stretches, a regular monitoring program was performed by accurate DGPS measurements provided by a multi-antenna system adapted on a four wheel motor quad.
Cross correlation analysis between morphological data obtained from DGPS measurements of the exposed beach and wave parameters was done. The wave breaking parameters were computed with the use of a wave model which includes shoaling and refraction. The average beach volume and the average beach face slope were correlated with the average wave height in the breaking zone for several different periods, since the day before to each survey until three months prior to each survey. From the results obtained we conclude that, the recovery period of the sedimentary volumes in the stretch where sand was artificially removed is lower than in the stretch without any human intervention, although this conclusion does not apply for beach face slope recovery.

ADDITIONAL INDEX WORDS: *Foreshore, cross correlation,.*

INTRODUCTION

The Aveiro lagoon coastal region, located in the Northwest coast of Portugal, is characterised by the presence of an almost continuos 50 km alongshore open sandy beach. This coastal region is only interrupted by hard engineering structures like groins, seawalls and the jetties of the Aveiro harbour (Figure 1).

The evolution of this region shows a strong regressive trend till the turn of the 19th century (FERREIRA *et al.*, 1992). However, by that time the coastal trend started to be transgressive probably due both to natural and human factors, being this transgressive behaviour intensified during the 20th century. At the end of 20th century the coastal erosion in this region shows a scenario in which most of the foredunes have almost disappeared. The coastal erosion, usually associated with the action of storm events, has strong impacts in the anthropic activities creating some difficulties in coastal management.

This region belongs to the Northwest coast of Portugal in which a mixed energy regime (wave dominated) occur according to the HAYES (1979) classification. The maximum tidal range is about 3.5 m and the mean annual significant offshore wave height is about 2.2 meters, with an average peak period of 11.3 seconds. Main wave direction is from NW inducing a southward net littoral drift of approximately $2x10^6$ m^3/year (OLIVEIRA, *et al.*, 1982). The mean number of storms, with significant wave height higher than 5 meters in the Portuguese west coast between 1956 and 1988, was about 3 storms/year (FERREIRA *et al.*, 1994).

The main purpose of the present work is to analyse the relations between the morphological characteristics of the foreshore and backshore in one sector of exposed sand beach, with about 7 km, and the incident wave energy. The average beach volume and the average beach face slope were correlated with the average significative wave height for several different periods including the day before each survey and seven, fifteen, thirty as well as to the most energetic five days of the month prior to each survey. It was also tested the average significative wave height for thirty day of three months prior to each survey. The goal is to evaluate the volumetric and slope changes of the beach and the recovery periods under normal and storm conditions.

STUDY REGION

Since 1999 several human interventions were carried out in some places of the Aveiro coastal region, namely southward of some groin fields which are more sensitive to overwashes. An artificial structure (sand dike) was built with sand from the foreshore to prevent overwashes in the places with more social impacts. The study area was chosen taken into account that human intervention. A sector with about 7 km extension situated between Vagueira and Poço da Cruz villages was selected in which two distinct stretches were considered (Figure 1b). In the first one with about 3 km extension intense sand remobilization from the foreshore had been carried out. By this way an artificial beach profile was produced in this place. Another aspect that characterises this 3 km stretch is the short wide of the beach profile, probably due to the downdrift effect of the Vagueira groin field. The second stretch, with 4 km extension, did not suffered any direct human intervention, and the non-disturbed coastal foredunes are still present (Figure 1).

METHODS

A monitoring program, including several campaigns has been accomplished, in the region under study, from November 2001 on for the present work one year of regular observations from November 2001 until November 2002, was selected.

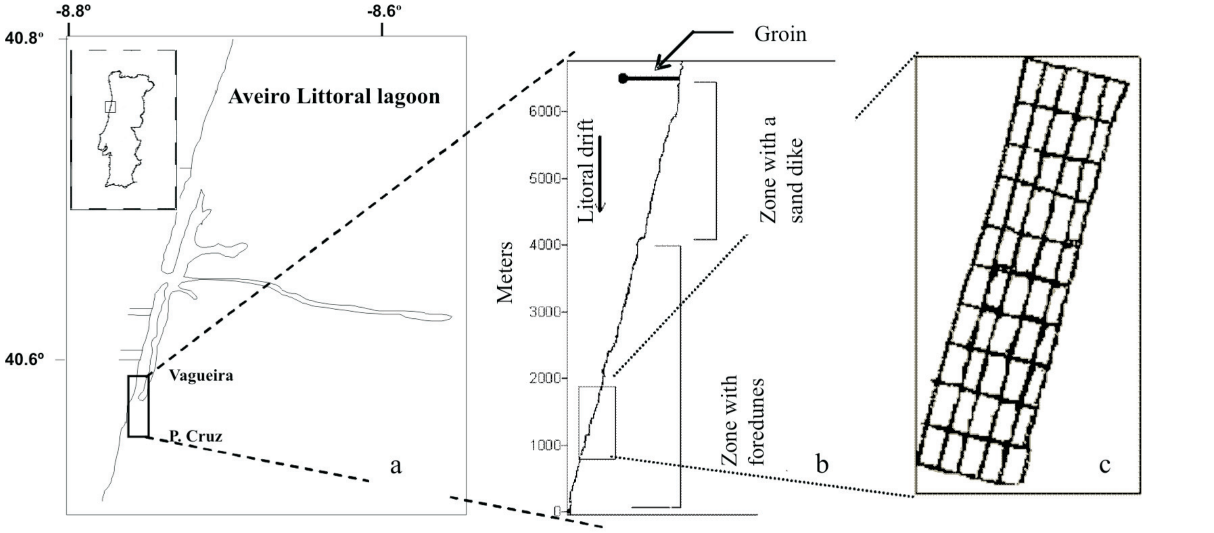

Figure 1. a) Aveiro littoral lagoon; b) Zoom over the 7 km coastal sector under study; c) Zoom over a short area to show the observed DGPS grid.

Between December 2001 and April 2002 the 3 km modified stretch under study was not surveyed due to the intense sand remobilization that was in course during that period.

In each campaign a grid of along and across shore DGPS profiles was obtained from low tide edge until the foredune baseline or, in the case of absence of the latter, to the upper limit of the backshore.

GPS data was processed by using GPSRTK software (CUNHA, 2002), through an algorithm dedicated to kinematic ambiguity fixed in L1 (HOFMANN-WELLENHOF *et al.*, 1992). Accuracy of the final DGPS positions is within 5 centimetres.

Interpolation was applied to convert data point observations to a continuos 3D surface. Several interpolation methods were tested by comparing the interloped surface with several control points. Best results were obtained with Triangulation using linear interpolation (TLN) and Kriging (BAPTISTA *et. al.*, 2003). In the present work are discussed only the results from the TLN method. For each one of the campaigns the average beach volume (m^3/m) above the mean sea level and the beach face slope for both the non-disturbed and modified stretches under study were determined. Cross correlation analysis between morphological data of the exposed beach and wave parameters was done. The average beach volume and the average beach face slope were correlated with the significative wave height for the last thirty, fifteen, seven and the most energetic five days prior to each survey. To obtain wave parameters data were obtained from an offshore wave rider buoy, of Leixões harbour, which is located 70 km north of the study region, was used. The data collected was shoaled and refracted using the WBREAK2 wave transformation model. This model includes shoaling and refraction and assumes a regular and parallel bathymetry in the nearshore which is quite acceptable considering the bathymetry offshore of Aveiro. Wave parameters used comprised the significative wave height, the peak period and the wave direction.

RESULTS

The absolute volume (m^3/m) and the cumulative volume changes (m^3/m) above the mean sea level, for both the non-disturbed and the human modified stretches under study, are shown in Figures 3 and 4.

During the observation period the absolute sand volume present in the non-disturbed stretch was higher than the volume present in the modified stretch, except in the first campaign where both stretches attained similar values. The maximum difference occurred in October 2002 with more 97 m^3/m in the non-disturbed stretch.

The seasonal behaviour of the non-disturbed stretch shows that during the winter period the beach volume never reached 200 m^3/m, while after May 2002 the volume gradually increased reaching the maximum of 242 m^3/m in October 2002. The modified stretch also shows an increasing tendency after May2002, but only reached the maximum of 144 m^3/m in October 2002.

The computed cumulative volumetric changes show a similar behaviour for both the non-disturbed and the modified stretches from May 2002 on, but before that the modified stretch shows a non-matched erosion of 55 m3/m.

The non-disturbed stretch shows a smooth accretionary tendency between March 2002 and September 2002 and a strong volume decrease between October and November 2002 with less 59 m^3/m. The modified stretch after the two campaigns gap (January and March 2002) recovered the behaviour of the non-disturbed stretch.

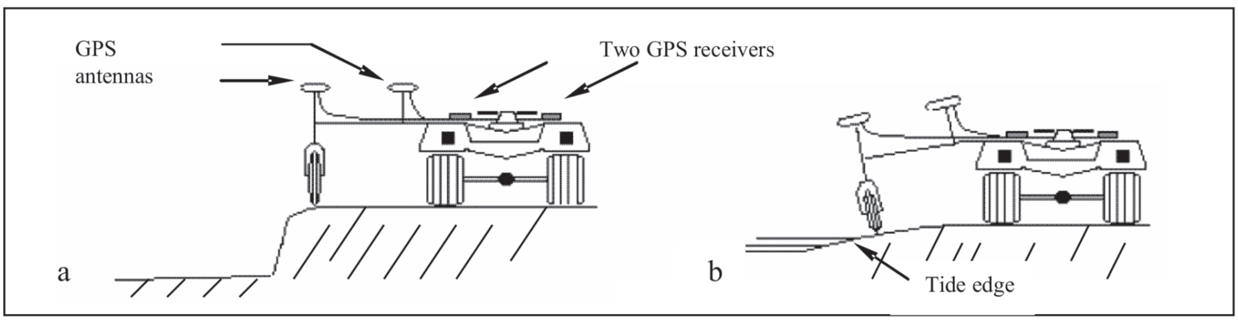

Figure 2. DGPS multi-antena system adapted on a four wheel motor quad. a) near an berm; b) near the tide edge.

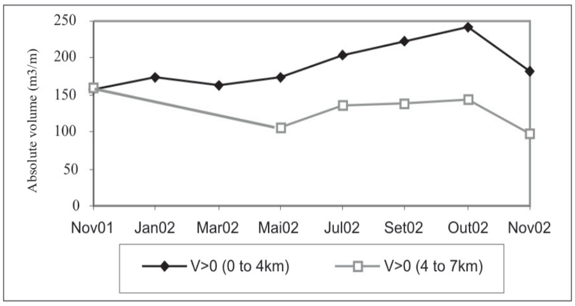

Figure 3. Absolute volume for both non-disturbed (0 to 4 km) and modified (4 to 7 km) stretches of Vagueira-Poço da Cruz sector.

The average beach face slope was also determined for both the non-disturbed and the modified stretches (Figure 5). After the anthropic sand remobilization the modified stretch shows a lower slope than the non-disturbed stretch. However the behaviour of both stretches becomes similar in September 2002.

During the period under study the non-disturbed stretch shows greater slope changes. Average beach face slope values of 0.060 in May, 0.093 in September and 0.047 in November 2002 were found. The modified stretch show also great slope changes with average beach face slope values of 0.045 in May, 0.092 in September and 0.047 in November 2002.

During the observational period the offshore wave climate (from the Leixões wave rider buoy) was dominated by NW incident waves. The average and the maximum significative wave height for the previous 30 days prior to each campaign in Leixões wave rider buoy are represented in Table 1. Storm periods, defined when the significative wave height overtakes 5 meters, occurred during 27 hours in 23-24 January 2002 with significative wave height of 6.1 meters and an associate peak period of 14.6 seconds.

Significative wave breaking height computed by WBREAK2 for the study zone is indicated in the Table 2.

Cross correlation between average wave height at breaking zone and average beach volume and average beach face slope for several different periods was tested. The correlation including the day before each survey and seven, fifteen, thirty as well as to the most energetic five days of the month prior to each survey. It was also tested the average significative wave height for thirty days of the three months prior to each survey. The correlations were calculated for both the non-disturbed and modified sites under study (Figures 6 and 7). Negative correlation means that higher waves induce reduction on beach volume and smaller beach face slope.

Distinct correlation values were found in the two stretches under study.

In the non-disturbed stretch the correlation between volumes and wave height in the breaking zone indicates higher values for the last 30 days and the most energetic five days previous to each campaign. In the modified stretch the higher correlation's was found for the period between one and seven days (Figure 6).

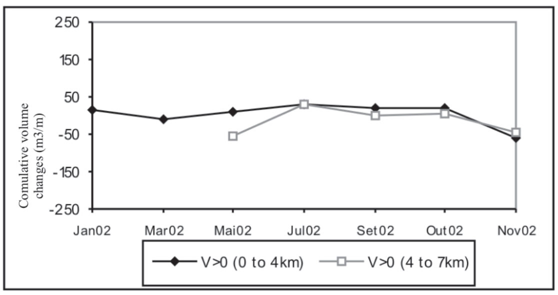

Figure 4. Cumulative volume for both non-disturbed (0 to 4 km) and modified (4 to 7 km) stretches of Vagueira-Poço da Cruz sector.

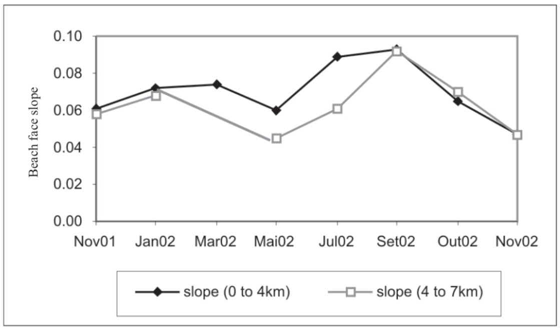

Figure 5. Beach face slope for both non-disturbed (0 to 4 km) and modified (4 to 7 km) stretches of Vagueira-Poço da Cruz sector.

Maximal correlation values of 0.73 for the last thirty days in the non-disturbed stretch and 0.91 for the day previous to each campaign in the modified stretch were found. Lower correlation values were found for the three months prior to each campaign.

Correlation between beach face slope and significative wave height shows quite different results when compared with those referring to beach volume. According to Figure 7 it is possible to deduce a distinct behaviour for the to stretches involved.

The weakest correlation values were found in the non-disturbed stretch. The beach face slope in this stretch is more correlated with the most energetic five days of the month prior to each campaign A correlation value of 0.45 was found.

Higher correlations for all the periods were found in the modified stretch. However, Figure 7 highlights the correlation for the last thirty days previous to each campaign and for the most energetic five days of the month prior to each campaign with values of 0.77 and 0.73 respectively. Lower correlation values were found for the three months prior to each campaign.

DISCUSSION

The sedimentary balance for both the non-disturbed and modified stretches under study, which are expressed by the cumulative volumetric changes, shows a similar behaviour.

However, the modified stretch never recovered the sedimentary volume lost during the human intervention. This fact is also related to the downdrift effect of the Vagueira groin field.

The beach face slope values found seem to indicate the presence of an intermediate beach during most of the year, with more reflective tendency during summer period. Similar conclusion for this region has draw by Ferreira (1998). The lower beach face slope values found between May and July 2002 in the modified stretch are probably related with the sedimentary extraction operated in the foreshore during the preceding months.

The cross correlation carried out indicates a faster sedimentary volume recovery period for the stretch where the sediments had been artificially removed than in the stretch with no direct human intervention. The recovery period in the

Table 1. *Offshore wave climate in Leixões wave rider buoy for the period under study. Values represent the average and the extreme values of significative wave height for the 30 days previous to each campaign.*

Campaign date	Hs (average)	Hs (maximum)
16 Nov 01	2.0	4.0
30 Jan 02	3.1	6.1
21 Mar 02	2.9	4.1
28 May 02	2.4	4.6
11 Jul 02	1.7	2.5
6 Sep 02	1.2	1.8
7 Oct 02	1.7	3.5
6 Nov 02	2.5	4.7

Table 2. *Wave breaking climate for Aveiro region during the studied period Values represent the average and the extreme wave height for the 30 days previous to each campaign.*

Campaign date	Hs (average)	Hs (maximum)
16 Nov 01	2.7	5.0
30 Jan 02	4.0	7.5
21 Mar 02	3.6	5.2
28 May 02	2.8	5.8
11 Jul 02	2.0	3.0
6 Sep 02	1.4	2.0
7 Oct 02	2.1	4.2
6 Nov 02	2.9	4.4

modified stretch seems to be between one and fifteen days. In the other stretch the recovery period is close to thirty days. Correlation with the most energetic five days of the month prior to each campaign, in which storm events are included, indicates best results for the non-disturbed stretch. This result confirms that the higher waves induce strong erosion of the beach in this stretch.

The modified stretch is not apparently so sensitive to the higher energetic conditions, certainly because, in these cases, the erosion of the sand dikes is so intense that an important upper shoreface sand prism is removed seaward.

The relationship between the beach face slope and the breaking waves seems to indicate that both stretches under study are especially sensitive to the most energetic five days of the month preceding each campaign. Higher waves in the breaking zone induce reduction of the beach face slope. This effect is more evident in the stretch where sediments were artificially removed than in the stretch without human intervention. A fact can be attributed to the generally small sedimentary volume, inducing greater sensitiveness to the breaking waves.

CONCLUSIONS

The morphodynamic behaviour of two contrasting beaches stretches located in the Aveiro lagoon littoral was studied by comparing the morphological parameters of the exposed beach with the breaking wave height. The morphological parameters of these two contrasting stretches were different, due to an anthropic intervention with significative sand removal in one of then.

For difference also contributed the location of this stretch immediately downdrift of a groin field.

The breaking wave height regime was similar in the entire region under study. Therefore, beach behaviour differences in the results can only be attributed to the morphological characteristics.

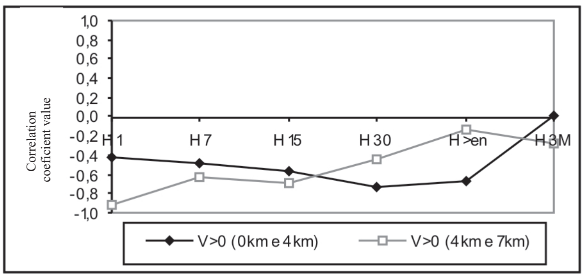

Figure 6. Correlation values between average beach volume and average wave height for different periods. Wave data collected from Leixões wave rider buoy and refracted by WBREAK2. Average breaking wave height for H1: the day before to each campaign; H 7: the seven days prior to each campaign; H 15: the fifteen days previous to each campaign; H 30: the month previous to each campaign; H>en: the more energetic five days of the month prior to each campaign; H3M: the thirty days of three months previous to each campaign.

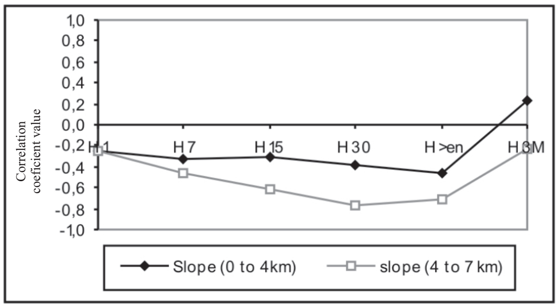

Figure 7. Correlation values between beach face slope and average wave height for different periods. Wave data from Leixões wave rider buoy and refracted by WBREAK2. Average breaking wave height for H1: the day before to each campaign; H 7: the seven days prior to each campaign; H 15: the fifteen days previous to each campaign; H 30: the month previous to each campaign; H>en: the more energetic five days of the month prior to each campaign; H3M: the thirty days of three months previous to each campaign.

The mean time to recover the sedimentary volumes in the stretch with no direct human intervention seems to be one or two weeks more than in the non-disturbed region.

The fast sedimentary response to breaking wave height in the stretch where sand had been artificially removed may be interpreted as indicating that the littoral drift has significant capacity to refill, in a short time, the places where more lack sediments. However, since the upper shoreface and sand dikes are partially eroded it is also true that the across-shore sediment exchanges are enough to refill and produce measurable profile change.

Another important aspect is the relation between the morphological parameters and the storm events. As expected the most energetic five days of the month prior to each campaign when storms occurred are well correlated with volumetric changes in the areas with no direct human intervention. This seems to favour the idea that the availability of sediments in the sand dikes is effective in beach recovery.

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