Sediment Grain Size variation on a coastal stretch facing the North Atlantic (NW Portugal)

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ABSTRACT

In a context of continued erosion, as is the case for the northwest Portuguese coastal zones over the last two decades, it is common to find urban settlements at risk along shorelines. To protect economical, social and environmental assets it has become increasingly important to effectively plan coastal defense interventions (beach-fill designs, coastal structures functioning and placement studies, and sediment budgets formulations). The sediment grain size is an important parameter involved in these studies and it should be adequately characterized, however it is common to see it categorized by its median diameter, through a reference value. Beach morphologic features frequently change in form and sediment distribution but these changes in sediment dimensions are not as significant as the differences found for different geographical locations. Alongshore and cross-shore trends of sediment grain size in a given location reflect its cumulative energy (wave climate) and stability (cross-shore profile evolution). In the paper, seeking for a relation between beach profile and sediment distribution, a contribution is given to the characterization of the sediment grain size at some locations along a stretch of the Portuguese northwest coast, between port of Aveiro and Mira beach. Data from three campaigns conducted between 2006 and 2007 was used in the analysis. The observed values of mean median grain size are within the range 0.39 and 0.57 mm in the study site. The mean beach face slope values are between 0.07 and 0.09.

ADDITIONAL INDEX WORDS: Coastal planning, numerical modeling, morphodynamic parameters

INTRODUCTION

In a context of continued erosion it is common to find urban settlements at risk along shorelines. This is the case for the Portuguese northwest coast over the last two decades. To protect economical, social and environmental assets it has become increasingly important to effectively plan coastal defense interventions (beach-fill designs, coastal structures design and performance, identification of sediment burrow and dredged materials discharge sites, and sediment budgets formulations). Measures to solve the erosion problem must be incorporated in coastal zone planning and management of coastal policies, at least at a medium term horizon. The sustainable management of coastal zones is also related with the ability of predicting its morphological evolution. This prediction is difficult and usually affected by large uncertainty, due to the amount and complexity of the processes involved, their interaction and the lack of field data that allow their characterization. Numerical models may be helpful in the assessment of different anthropogenic and natural scenarios. Based on different approaches several models for the simulation of the morphological evolution have already been developed resulting in tools with different capabilities/limitations and input data needs. Nevertheless, most of these models use semi-empirical formulations, and, therefore need calibration and validation. In order to increase the degree of confidence in their application it is important that morphodynamic parameters, often used as calibration parameters, assume values within established ranges, for which they have physical meaning. Beach morphologic features frequently change in form and sediment distribution but these changes in sediment dimensions are not as significant as the differences found for different geographical locations. Alongshore and cross-shore trends of sediment grain size in a given location reflect its cumulative energy (wave climate) and stability (cross-shore profile evolution). The sediment grain size is an important morphodynamic parameter that should be locally and adequately characterized.

Several attempts to characterize sediments along the Portuguese northwest coast have already been made, Coelho (2005), Ferreira (1998) and the references therein. However, these studies are occasional, use different methods and sometimes have contradictory conclusions. This way it is common to see the sediment grain size categorized by a reference average median diameter of 0.5 mm (Ferreira, 1998) for this whole coastal stretch.

In this paper, seeking for a relation between beach profile and sediment grain size distribution, a contribution is given to the characterization of the sediment grain size at some locations along a stretch of the Portuguese northwest coast, south from the port
and lagoon inlet of Aveiro. Three field campaigns have been conducted between 2006 and 2007. The campaigns consisted on a topographic survey using a DGPS (Differential Global Positioning System) survey system and simultaneous collection of georeferenced sand samples in several points along the study site and in key points of the beach profile above Chart Datum (CD) (aerial beach), representing important features.

METHODS

The Study Site

The study site is located at Portuguese northwest coast, which is essentially a sandy coast approximately N21°E oriented, facing the Atlantic Ocean, Figure 1. It is a highly energetic coastal stretch with a wave regime typically from northwest, characterized by a mean significant wave height of 2 m and a mean wave period of 12 s. Storms, occurring especially in the winter, come predominantly from northwest with offshore significant wave heights that may reach 8 m persisting for up to 5 days. The mean sea level is +2.0 m CD. The tide regime is semi-diurnal with a tidal range between 2 m and 4 m in spring tides. The potential alongshore transport, mainly due to the wave action, is southward directed with an intensity approximately 1-2 million m$^3$/year (VeloSO-Gomes et al., 2006). The sediment supply needed to saturate the wave potential transport capacity and maintain this coastal system in equilibrium comes from two major sources: the Douro River and coastal erosion. In its natural regime the Douro River used to supply sediments at a rate of 1.8 million m$^3$/year, but this value has been decreasing, showing a cessation tendency (Oliveira, 1997) and, as a consequence, coastal erosion has increased.

The Aveiro coastal region is one of the most dynamic stretches in the Portuguese northwest coast, Figure 1. The region is dominated by the Aveiro Lagoon, which has several sediment deposits that sometimes give rise to small islands, and is inserted in a low lying plain of uniform topography. The Lagoon communicates with the ocean through a sand spit which is presently highly occupied. The coastline is characterized by the presence of sandy formations and long sandy beaches, inland limited by dune structures of several kinds and morphologies. This kind of morphology is usually associated with high sedimentary deposition supplied from rivers transporting large amounts of sediments, especially in flood seasons. Due to its morphodynamic and sedimentary nature, the coastline has suffered several changes over time. This sector is also one of the most affected by erosion, having its coastline a clear retreat tendency (Silva et al., 2007). The main causes are the high exposition level to the energetic sea action, the non consolidated materials composing it, the reduction of the sediment supply from rivers, and the anthropogenic pressures. To prevent land loss, several coastal protection structures, groins and longitudinal walls, have been constructed along this coastline stretch. In almost all of its extents there are several dune systems, only interrupted by population settlements. The presence of these systems reflects the historical high sediment supply, followed by wind mobilization. The past sand invasion of cultivated areas and habitations has been overwhelmed by forest plantation. The primary littoral dune is almost continuous, with a general orientation parallel to the coastline, corresponding to the sub-aerial beach limit. The beach/dune contact consists of continuous sand barriers, dunes and erosion cliffs. The ongoing erosion tendency felt in this zone over the last decades induces constant adaptations of the beach/dune system, which may turn into dune disruption in multiple points, with floods and loss of low lying inner lands, +5 to +8 m CD, occupied with people and edifices. The dune crest ranges from +7 to +18 m (CD). On high waters in spring tides, wave run-up frequently reaches the dune base, which reflects high vulnerability to coastal erosion. The beach presents a mean width of 60 m but values between 40 and 180 m may be found (Ferreira, 1998).

Data Collection Campaigns

The sub-aerial beaches inserted in the study site were surveyed using a DGPS topographic survey system. For that purpose the study site was segmented into four coastal adjacent stretches, from north to south: Costa Nova – Vagueira (CNV), Vagueira – Areião (VA), Areião - Poço da Cruz (APC) and Poço da Cruz – Mira (PCM). Sand samples were also collected along cross-shore beach profiles and geo-referenced. The data collection campaigns were conducted in early October 2006 (for CNV, VA and APC), in spring 2007 (APC and PCM), and late September 2007 (for CNV, VA, APC and PCM).

Topographic Data

Topographic data was acquired with a DGPS multi-antenna system (Batista et al., 2008). This system is composed by two kinematic antennas installed on an articulated arm fixed to a four-wheel motor quad. The external wheel supports this articulated arm, being in permanent contact with the surveyed beach. The arm is about 1 m length and has been designed in order to allow secure bottom survey of the near shore zones and the beach’s berms. By
using these two GPS antennas it is possible to accurately obtain the coordinates of the bottom of the external wheel, not only when the GPS antennas are in the vertical position but also when they are tilted. The survey procedure includes a local reference station established in a geodetic benchmark of the IGP (Geographical Portuguese Institute) with coordinates in the Portuguese National Datum Hayford – Gauss – Melriça (Datum 73). The length of the baseline connecting the local reference station and the four wheel motor quad vehicle is always less than 10 km. As a standard base of work, a network of longitudinal and transversal profiles is defined with a mesh chosen according to the shore surface characteristics. The outland profile limit is the shoreline, defined as the contact between the wave swash and the foreshore. The inland profile limit is the frontal dune baseline, whenever it is present, or the first topographic change representing the inner relief. The study site has been surveyed over a network composed by alongshore and cross-shore profiles spaced 50 to 100 m, aligned with slope changes.

Sand samples
During the topographic sub-aerial beach surveys, superficial (15 to 20 cm) sand samples were also collected from the beach foreshore and backshore, in several points along the study site. At each sampling location, according to the beach wide and morphological characteristics, three or four sand samples were collected in key points representing important features. The sand samples were collected during spring low tide permitting access to the low-tide-terrace, whenever it was present. In general, the sand sampled profiles were 500 m spaced. Each sand sample was geo-referenced by GPS for positioning over the surveyed topography.

ACQUIRED DATA

Beach Profiles
GPS data was post-processed with Trimble Total Control software (2002). Since the positioning precision of the kinematic DGPS processing technique (with ambiguity resolution on-the-fly) is around 0.02 m and 0.04 m in planimetry and altimetry, respectively, the overall precision of the determined ground point coordinates will be of the same order of magnitude, with a random behavior around the mean zero value. After post-processing the resulting Datum 73 coordinates are converted to three local coordinate systems, which have their axis aligned with the
Sediment Grain Size

The sand samples were used for the determination of the particle’s size distribution using a dry sieving method, according to the European Standard (EN 933-1, 1997). The sieving tests were performed with 400 - 500 g of each referenced sample, using a series of sieves, with 1 φ interval, ranging between -6 to 4 φ, according to the Standard. Grain size distribution and statistics were obtained using the GRADISTAT® package (BLOTT and PYE, 2001), considering the logarithmic FOLK and WARD (1957) graphical measures.

RESULTS AND ANALYSIS

The alongshore median sediment grain size, d[30], obtained for the sample collected near the low water line, was analyzed through its representation against the coastline; for each of the surveyed stretches, in an attempt to relate alongshore grain size variation with coastline configuration and the presence of coastal structures, Figure 2. The coastline was extracted from a topographic survey from IGP (2001). In the mean time two groins (Arcão and Poço da Cruz) were constructed and are also represented, schematically, in Figure 2. From the Figure, a higher variability in the median grain size seems to occur away from coastal structures, in the less constrained locations of beach. A certain tendency to an increase in median grain size from north to south is also apparent.

For each of the coastal segments surveyed, and for each of the campaigns, sub-aerial beach profiles were plotted in their own local coordinate axis. The stretches are morphologically different. In the after summer, tidal terrace, beach face and berm are easily identified in CVN and VPC, but not in PCM. The first two stretches have wider beaches. In Figure 3, the profiles obtained for CVN in fall 2007 are shown, together with the position of the sand samples collection, in that campaign. In almost all of the extent of this coastal stretch three points for sand collection along the sub-aerial beach profiles could have been identified: low-tide-terrace; beach face and berm. In some of the profiles a fourth point near the dune was also considered. In the majority of the profiles from VPC coastal stretch the four points have been identified and sand samples collected for all of them, Figure 4. However, in PCM segment only three points have been sampled in a greater part of the profiles, Figure 5. The sub-aerial beach in this last segment is significantly straighter and the beach profiles are much more dissipative.

The cross-shore profiles positioning changes slightly alongshore (∼100 m) between campaigns; therefore profile evolution analysis must be restricted to the tendency observed in the whole surveyed stretch. A general comparison of the profiles in fall 2000 and fall 2007 has shown a beach straighten tendency, denoting erosion.

The sand samples have been classified according to the designations: swash limit (low-tide-terrace limit or position at low water line); beach face; berm (not always clearly developed) and foredune (for samples taken at the neardune, erosion cliffs or vegetation lines). This way, the estimated medium grain size was also classified. The beach face slope, m, was graphically measured for all of the profiles. In Table 2 a summary of the obtained results is presented. From the analysis of the table some comments may be addressed. The mean beach face slope values are between 0.07 and 0.09, in the study site. The values of the median grain size in the swash limit are within the range 0.39 and 0.57 mm in the study site. A tendency to an increase in this value and in its variability from north to south may be observed. For the stretch’s CVN and VA the median diameter is quite uniform cross-shore, but a slight increase may be found for the ‘berm’s samples. Along PCM and APC more dissipative profiles, higher variability in median grain size is found.

The samples collected in CVN segment were analyzed using the GRADISTAT® package. The samples are essentially of medium sand (more than 95% of the samples in fall 2006 and more than 80% in fall 2007) with only a few observations of coarse sand.
of the samples are moderately to very-well sorted. In what concerns Skewness, most of the samples are coarse skewed (48% in 2006 and 63% in 2007) the remaining samples are either fine skewed or symmetrical. The Kurtosis analysis places the samples in one of three classes: platykurtic, mesokurtic or leptokurtic. A pattern could not be found for samples taken at different positions over the cross-shore sub-aerial beach profile.

CONCLUSIONS

This paper intends to give a contribution in the knowledge of the sediment grain size distribution along a coastal stretch of the Portuguese northwest coast, seeking for a relation between the sediment grain size at the foreshore limit and beach face slope. A firm relation between these two parameters could not be found.

Table 1: Mean and standard deviation of sediment medium grain size along sub-aerial beach profiles and mean beach face slope for each coastal stretch surveyed in fall 2006, fall and spring 2007.

<table>
<thead>
<tr>
<th>Stretch</th>
<th>Swash limit</th>
<th>Beach Face</th>
<th>Bemm</th>
<th>Near Dune</th>
<th>Beach Face</th>
</tr>
</thead>
<tbody>
<tr>
<td>CNV</td>
<td>0.39</td>
<td>0.39</td>
<td>0.43</td>
<td>0.39</td>
<td>0.07</td>
</tr>
<tr>
<td></td>
<td>±0.02</td>
<td>±0.03</td>
<td>±0.12</td>
<td>±0.04</td>
<td>±0.03</td>
</tr>
<tr>
<td>VA</td>
<td>0.44</td>
<td>0.55</td>
<td>0.43</td>
<td>±0.07</td>
<td>±0.06</td>
</tr>
<tr>
<td></td>
<td>±0.06</td>
<td>±0.18</td>
<td>±0.13</td>
<td>±0.03</td>
<td></td>
</tr>
<tr>
<td>APC</td>
<td>0.52</td>
<td>0.38</td>
<td>0.36</td>
<td>±0.17</td>
<td>±0.04</td>
</tr>
<tr>
<td></td>
<td>±0.03</td>
<td>±0.18</td>
<td>±0.03</td>
<td>±0.02</td>
<td></td>
</tr>
</tbody>
</table>

The establishment of ranges with physical meaning for morphodynamic parameters, namely sediment grain size, will increase the confidence in numerical simulations of coastal evolution.

For the analyzed data, the median grain size at the swash limit appears to have a higher variability away from coastal structures, in less constrained locations of the beach. A certain tendency to its increase from north to south is also apparent. The observed values of this parameter are within the range 0.39 and 0.57 mm in the study site. The mean beach face slope values are between 0.07 and 0.09.

Cross-shore sediment grain size sorting seems to be highly related with the morphology of the profile. Profiles having a berm (Costa Nova - Vagueira and Vagueira - Areão) demonstrate grain size changes in time especially over the berm. While more dissipative profiles, as in the stretch Povo da Cruz - Mira, show significant changes along the whole profile.

LITERATURE CITED


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