Beach Volume Changes: Vertical Datum Definition

C. Sá-Pires†; R. Taborda†; Ó. Ferreira‡ and J. A. Dias‡

† Universidade de Lisboa, Faculdade de Ciências, Bloco C2, 016 Lisboa, Portugal, cspires@fc.ul.pt
‡ FCMA, Universidade do Algarve, Campus de Gambelas, 8000-117 Algarve, Portugal, oferrein@ualg.pt
rtaborda@fc.ul.pt

ABSTRACT


Variations on beach volume have been widely used to quantify beach changes and to understand the beach response to coastal process. The definition of the vertical datum above which is determined the beach volume is not consensual and different authors have adopted different values. The main goal of the present work is to identify the most adequate vertical datum to characterize the beach behaviour at short-term scales (days to months). For this purpose periodic topographic and nearshore bathymetric surveys were made and an analysis of beach volume changes and their dependence on vertical datum was performed. The beach volume was computed using a vertical interval of 0.5 m and a relative beach volume, above each level, was computed considering the first survey as reference. Results have shown that volumetric changes across the profile are strongly dependent on the chosen level above which they are computed. The higher relative beach volume variability was found to be between -0.5 m and 3 m MSL. As a consequence for the study area the short-term scale beach behavior is mainly associated to the beach volume changes at the upper sub-aerial beach. This interval encloses many vertical data used by different authors; however, further studies should be made for other time scales (e.g. storm action, long term changes).

ADDITIONAL INDEX WORDS: Beach profiles, beach changes, Portugal.

INTRODUCTION

Periodic topographic and nearshore bathymetric surveys constitute the most direct and accurate mean of assessing geologic and geomorphic changes over modern time scales. Evaluation of continuous and repeated beach and nearshore profiles documents the entire active profile envelope and provides a complete picture of the profile to coastal processes response (U.S. ARMY CORPS OF ENGINEERS, 2002). Interpretation of beach response to coastal processes can be done with geometric and volumetric comparison of beach profiles sets (U.S. ARMY CORPS OF ENGINEERS, 2002). For this reason volumetric analysis is one of the most used methods for the quantification of beach changes. When using beach profiles, the beach volume is defined as the volume of sand seaward of a benchmark and above an usually defined vertical datum, per unit of width. However, the definition of the vertical datum is not consensual and different authors have adopted different values. For example, the following vertical data have been used: the National (USA) Geodetic Vertical Datum of 1929 (NGVD 29) (DUBOIS, 1988; JOHNSTON and BORKUNIEWICZ, 2001), the mean high water mark of neap tides (MULRENNAN, 1992), the mean sea level (MSL) (BIRKEMEER, 1979; DAIL et al., 2000; KLEIN and MENIZES, 2001), the mean low water spring tide mark (JAGO and HARDIESTY, 1984), the seaward limit of the shorter profile (ALONSO, 1994), above -2.1 m MSL (SWALES, 2002), among others. These values were used for meso- and macro-tidal beaches. In general, the referred authors do not justify the use of a specific datum or why they choose one datum instead of another. The main purpose of the present work is to identify the most adequate vertical datum to characterize the beach behavior at short-term scales (days to months). For this purpose, periodic topographic and nearshore bathymetric surveys have been made in Ancão Peninsula (on the western part of Ria Formosa) and an analysis of beach volume changes and their dependence on vertical datum was performed.

STUDY LOCATION

The Ria Formosa is a barrier island system located in the south of Portugal (Figure 1). This system is highly dynamic, exposed to both wave action and tidal currents. The mean wave energy is low to moderate with an average offshore significant wave height of 0.92 m (COSTA, 1994). However, storm events (significant wave heights > 3 m) are frequent during winter (COSTA, 1994). Mean tidal range is about 2.5 m, reaching up to 3.5 m at spring tides. The Ancão Peninsula is located on the western part of the Ria Formosa. The beaches at the Peninsula can be classified as Low Tide Terrace + Rip, with a generic reflective to intermediate behaviour (FERREIRA et al., 1997). Wave breaking type also changes from plunging at high tide to spilling at low tide. The average beach slope is 0.13 for the beach face and 0.06 for the low tide terrace (MARTINS et al., 1997). ANDRADE (1990) described the presence of beach-cusps on the beaches in the Ria Formosa. These cusps can have wavelengths of 20 to 50 m with heights of 0.5 to 1.0 m due to storms. In the central sector of the Ancão Peninsula, the dune has been destroyed and human occupation dominates. For this reason, overwashes are more frequent in this sector with some dramatic consequences (PILKEY et al., 1989). The field
site is at the eastern end of the Ancão Peninsula where natural beach and dune conditions still exist and direct human influence is small. ANDRADE (1990), estimated the closure depth for the barrier island system using the formulation of HALLERMEIER (1981). This was done using wave heights estimated visually or obtained from a non directional wave-buoy and the value of 8 m below MSL was obtained. The comparison between bathymetric surveys made by ANDRADE (1990) revealed an occasional existence of an along-shore bar.

METHODS

Between June 2001 and July 2003 a series of shore-normal profiles were obtained and analysed. Surveys adequately covered the beach profile from the dune to depths of about 15 m below MSL. The beach topography was performed using a total station with auto tracking. For the nearshore surveys a RTKGPS was used for positioning, an echo-sounder for water depth measurement and navigation software (HYPACK Max) installed on a laptop PC for data collection and assimilation as well as navigation. The existence of beach cusps influences the spacing of the cross-shore profiles. To effectively cover the spatial scale of this morphology and its influence on cross-shore processes, eleven profiles were defined with a spacing of 10 m. In the nearshore such close spacing is not necessary because the morphology in this zone is dominated by an offshore bar, with smaller alongshore changes than the beach cusps. Thus, the nearshore profiles have a spacing of 20 m. Each survey covers an alongshore distance of 100 m and a cross-shore distance of 1500 m. The survey periodicity ranged from days to months to characterize the significant changes at short- and medium-term scales. The number of topographic and bathymetric surveys made on each month is described on Figure 2. A total of 57 topographic surveys were made, however, only 20 are completed with bathymetric surveys.

All data were processed using MATLAB® software library. The beach profiles were analyzed in order to obtain the morphological evolution. The slope of the main morphological features (beach face, terrace and upper shoreface) was computed for each profile. The closure depth (obtained by morphological comparison) was cautiously determined at each profile. The beach volume was computed for each profile using a vertical interval of 0.5 m. The land- and sea-ward limits were levels at which no sand movement due to wave action was observed. For the upper limit was chosen the origin of the profiles at the dune crest (5.5 m MSL) and for the lower limit the closure depth (considering the study period). For each survey, the beach volume was obtained from the along-shore average of all profiles. The beach volume was computed above each vertical level (from the closure depth to 5.5 m MSL, with a vertical resolution of 0.5 m). A relative beach volume (percentage of beach volume variation) above each level was computed considering the first survey as reference (representative of “typical” summer conditions). The negative and positive percentages of volume variation respectively represent losses and gains of sediments considering the first survey as a reference (0% of variation).

RESULTS

During the study period, significant changes occurred in the morphology of the beach (Figure 3). An along-shore bar was occasional present (at July, August and September 2001 and at May 2003) and a terrace was frequent (at the rest of the period). The average beach face slope was 0.12 (ranging between 0.06 and 0.17) being most of the time, reflective (> 0.10). The average terrace slope was 0.03 (ranging between 0.02 and 0.03). The upper shoreface slope was 0.01 with no measurable variations trough time. The closure depth computed by direct comparison of successive beach profiles was found to be 11.5 m below MSL.

The relative beach volume above each vertical level was computed. The time variation above eight vertical levels is represented in Figure 4: a) 5.5 and -11.5 m MSL (levels with “no sand movement”); b) 3, 1.5, 0, -1.5 m MSL (levels belonging to the shore or beach) and c) -3, -6 and -9 m MSL (levels from the nearshore). This selection was made in order to simplify the analyses of the results.

As shown in Figure 4a, the percentages of beach volume variation above vertical data 5.5 and -11.5 m MSL are almost insignificant, with values in the order of 5% of variation.

At Figure 4b and 4c, the variation through time of the relative beach volume presents a similar pattern, however the ranges of variation are quite different. For the shore levels (Figure 4b) the observed variation of the relative beach volume are high (maximum range of about 30%), while for the nearshore levels (Figure 4c) these changes are much smaller.

During the first summer (July to November 2001) the volume computed for all levels shows accretion. After November 2001 until March 2002 there was accentuated erosion. From March to June 2002 there was an accretion period. A stable period occurred between June and September 2002. After September until October 2002 another erosive period occurred and the recovery was after January to July 2003. These changes were particularly significant for volumes computed above levels 1.5 and 0 m MSL.

DISCUSSION

Results have shown that volumetric changes across the profile are strongly dependent on the chosen level above which they are computed. For example, during the studied period beach volumetric changes showed a large variation for levels 0

![Figure 2](image2.png)

Figure 2. Number of surveys made on each month during the study period.

![Figure 3](image3.png)

Figure 3. Example of beach envelope based on the plot of monthly profile surveys for the study period (including topographic and bathymetric surveys).
The volumetric comparison of beach profiles sets is very important to understand the beach response to coastal processes. However, the definition of the vertical datum has been ambiguous or even unexplained and different values have been used for meso- and macro-tidal beaches. For short-term scales (days to months) at study area the beach volume variation should be determined using levels between 0.5 m MSL and 3 m MSL. This interval encloses many vertical data used by different authors such as BIRKEMEIER (1979), JAGO and HARDISTY (1984), DUBOIS (1988), MULREENRAN (1992), DAIL et al. (2000), JOHNSTON and BOKUNIEWICZ (2001), and KLEIN and MENEZES (2001). As a consequence for Ancão Peninsula short-term scale beach behavior are mainly associated to the beach volume changes at the upper sub-aerial beach.

ACKNOWLEDGEMENTS

This work was funded by the CROP project (CROss-Shore Process on Contrasting Environments, PDCTM / P / MAR / 15265 / 1999). The authors would like to thank the authorities of the Parque Natural da Ria Formosa and the Capitania de Faro for giving permission to carry out the fieldwork. Thanks also to all the people from CIACOMAR that helped during fieldwork. Thanks also to Nálida Ruiz. This is a DISEPLA contribution.

LITERATURE CITED


Séminário sobre a Zona Costeira, Algarve, EUROCOAST, Portugal, p. 67-76.


TAUSSIK and MITCHELL, J. (Eds.), Partnership in Coastal Zone Management, Samara Publishing, 615-622.