Morphodynamics of a swash bar in the context of the evolution of a swash platform associated to an ebb delta.

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Within the European MAST III - INDIA Project, the westerly tidal inlet cutting through the barrier island system of the Ria Formosa (South Portugal) was studied during an important fieldwork from January to March 1999. Morphodynamics of the updrift swash platform associated to the ebb delta was described (Balouin *et al*., in press) and revealed a rapid migration toward the inlet under waves and tidal current action. Moreover evidences for sedimentary exchanges were described, and the longshore drift supply was quantified. The present study focuses on the main swash bar of this system which dynamics was investigated by a multidisciplinary approach: hydrodynamics, sediment fluxes (fluorescent tracers experiments), grain size trend analysis. Combination of these methods permits to quantify morphodynamics of this part of the swash platform. Hydrodynamics over this bar is dominated by the flood current which is longer and stronger. This flood current combined with waves meanly from West yields a sediment transport toward the inlet. The grain size trend analysis shows that the transport in this area is important and homogenous over the bar. This sediment transport is quantified by a fluorescent tracer experiment which gives a sediment displacement of 14 m in one tide toward the inlet. The grain size trend analysis allows the estimation of the width of the area concerned by this direction of transport, and permits to calculate the sediment flux toward the inlet. This study permitted to validate a theoretical formulation of sediment transport over the swash bars of this swash platform.
Keywords : sediment transport, tidal inlet, swash platform, swash bar, fluorescent tracers, grain size trend analysis.

Introduction

Long term morphological evolution of tidal inlets cutting through the barrier island system of the Ria Formosa is well known (Bettencourt, 1985, Dias, 1988, Pilkey *et al*., 1989), and it has shown that under the dominant westerly waves regime, these inlets are used to migrate eastward, to close up gradually, and new inlets are used to breach westerly through the barrier island.
The "Barra Nova" inlet is the westerly tidal inlet of the Ria Formosa. This inlet was artificially opened in June 1997 to improve water circulation within the western part of the lagoon where fishery activities give the main support to the local population.
Since its opening, this artificial inlet had to adjust to the local hydrodynamics, becoming rapidly larger and deeper then reaches a morphological equilibrium after one year following its opening (Vila et al., 1999).
In this context the survey, understanding and modelling of the morphological evolution of the "Barra Nova" inlet are the one topic of the European MAST III project "INDIA" (Williams *et al*., 1998; O'Connor *et al*., 1998). The study presented here is part of this INDIA project and focuses on the functioning of the updrift swash platform associated with the ebb delta at "Barra Nova" inlet.
This study aims to quantify, by the way of a multidisciplinary approach, the morphodynamics of this updrift swash platform, and in particular, to quantify sediment fluxes over the swash bars for typical winter hydrodynamic conditions. The terminology in this paper follows that of Hayes in 1975.

1 - Morphodynamics of the swash platform during fair weather conditions.

The swash platform associated to the ebb delta on the updrift coast of the Barra Nova inlet was monitored during 6 weeks, within the MAST III - INDIA European Project (Balouin *et al.*, submitted). Hydrodynamics conditions during this survey remained relatively calm with waves from W with a significant height from 0.3 to 1 m, and periods from 4 to 6 sec.
During these fair weather conditions, morphodynamics of this swash platform was characterised by a sand accretion, a migration toward the inlet, and a construction of a sandy spit at the extremity of the shoal platform which connects with the terminal lobe of the ebb delta (Fig. 2) (Balouin *et al*., in press).
This swash platform is formed by three sandy swash bars separated by small channels (Fig. 1). The first bar B1 is attached to the berm on its western part, and separated on the eastern part by a trough, the channel 1 (C1). The second bar extends on the major part of the zone, and the third bar B3, is located on the seaward south part. The extremity of Ancao peninsula is characterised by a 4 m cliff cut in the dune, a well developed berm which backshore extends on approximately 50 m, and a berm slope very steep which sink directly in the inlet.
Under the combined action of flood currents, waves from W, and refraction over the ebb delta shoals, these swash platform migrates toward the inlet. This migration was approximately 15 m in 8 days from 25/02 to 5/03 on the bar 2.
Action of waves on the adjacent beach yields to an important longshore current which concentrates on the berm slope. Sediment supply by the adjacent updrift coast is about 10500- 11000 m^3/month. This longshore drift supplies exclusively the first bar attached to the berm, generating sand accretion and a rapid migration toward the inlet of 60 m in one month. An important erosion was quantified at Ancao peninsula extremity, which represents a displacement of the top of the berm by 14m North-westward in one month, and a volume of 4000 m^3/month. This erosion coincides with the construction of a sandy spit at the internal extremity of the ebb tidal delta. This spit is formed by the progressive migration of megaripples along the ebb channel.

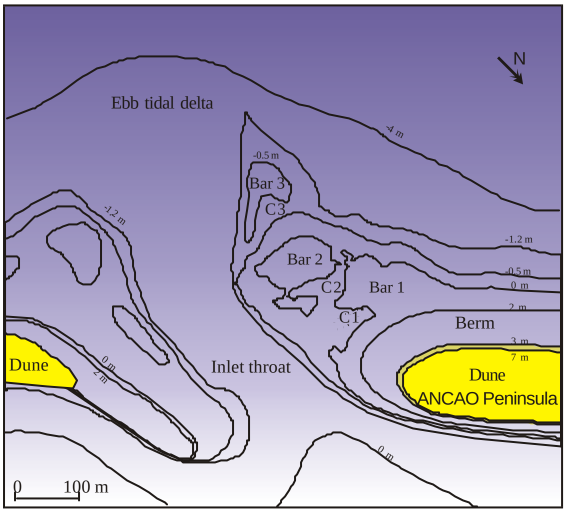

Fig. 1: The Barra Nova inlet, morphology of the swash platform associated to the ebb delta. Levels in meter from the MSL.

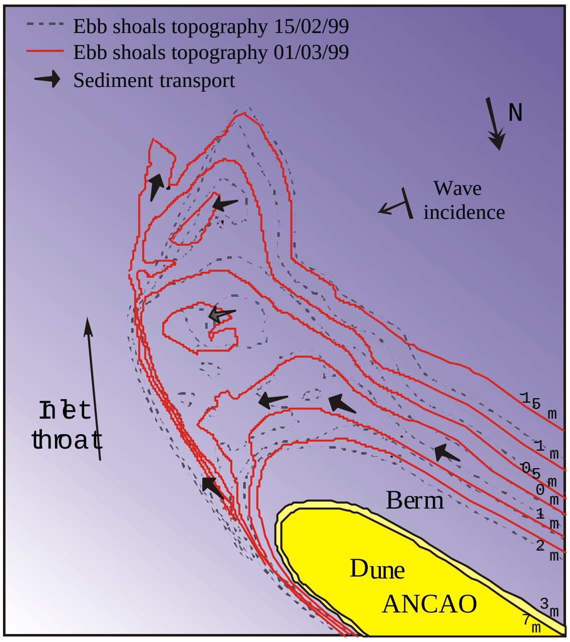

Fig. 2: Morphological evolution of the updrift coast swash platform between the 15/02 and 1/03 1999.

2 - Quantification of the sediment flux over the swash bar B2

Within the context of this migration of the swash platform toward the inlet, this study aims the quantification of the sediment transport on the second swash bar B2. Hydrodynamics conditions were measured during the whole experiment, offshore and nearshore. Moreover, a fluorescent tracer experiment was done on the bar, and sediments were sampled in order to investigate the grain size trends in this area.
Hydrodynamics conditions during this experiment were typical of calm winter conditions, with waves from W with a Hs ranging from 0.6 to 1.2 m. Measurements were done on the bar B2 by way of a wave-gauge / current-meter S4 ADW during the fluorescent tracer experiment the 1st of march.
Flood current were measured from 11h to 14h26 (206 min), and ebb current from 14h40 to 17h13 (153min), so there is a strong asymmetry between ebb and flood periods. Moreover, velocities of the flood current are stronger

than the ebb one (Fig. 3). Currents reach 80 cm/s during the flood tide, with a mean velocity of 60.5 cm/s, whereas maximum ebb currents are lower than 50 cm/s, with a mean velocity over the bar of 35 cm/s. Mean direction for the flood current is Eastward (99.6°), whereas ebb current mean direction is South south-westward (201°) (Fig. 3).

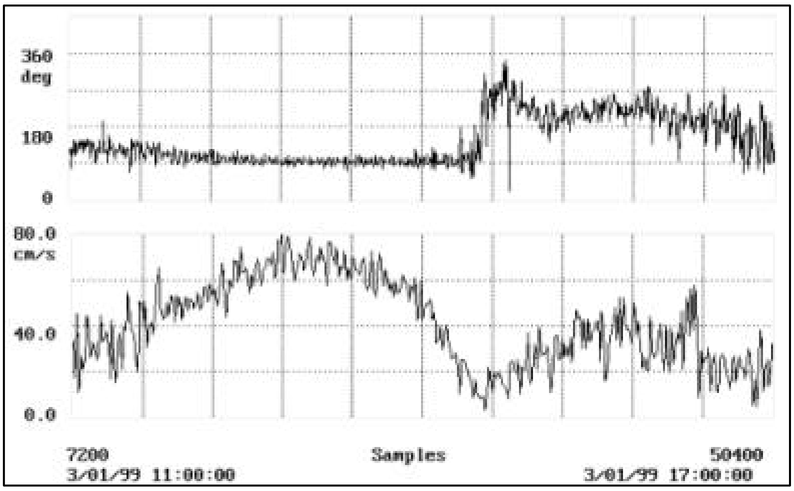

Fig. 3: Direction and velocity of tidal currents over the swash bar (right), and progressive vector of currents during the tidal cycle (Left).

Knowing the mean d50 of sediment, which is about 0.75mm, the duration of transport during the tidal cycle can be estimated. Such a grain size needs a current velocity superior to 20cm/s to be eroded ($u_{*,c}$=19.71). This value permits to estimate the duration of transport during the tidal cycle. During the flood tide, velocities are superior to this critical value during almost all the tide, 3h19, whereas during the ebb tide, this velocity was reached during only 1h26. That means that the transport during the flood tide should be very important regarding the ebb tide one, that can be seen on the progressive vector representation (Fig. 3). That means that sediment on this bar can be eroded and transported during 4h45 per tide.

In order to quantify sediment transport occurring on the bar, a standard fluorescent tracer experiment (Yasso, 1966, Duane and James, 1980, White and Inman, 1989) was done following the methodology described by Howa and De Resseguier (1994), Howa *et al.* (1997). This experiment was done on the western part of the sandy bar. The recovery rate, which is used to control if the motion of the dyed sand has been adequately monitored during the detection, is about 65 %, and allows the quantification of the tracer transport.

Direction and velocity of transport are determined on the basis of movement of the mass centroid of the tracer divided by the time of submergence between injection and first detection or between two subsequent detections. Fluorescent data should be calculated in terms of concentration (rate between fluorescent grain mass and native sand mass). The coordinates (X_i, Y_i) of the mass centroid of the tracer is given as:

$$X_i = \frac{\sum_{j=1}^{n} c_j (x_j - X_{i-1})}{\sum_{j=1}^{n} c_j} \qquad Y_i = \frac{\sum_{j=1}^{n} c_j (y_j - Y_{i-1})}{\sum_{j=1}^{n} c_j}$$

where c_j is the tracer concentration measured at sampling grid point j, with coordinates x_j and y_j. n is the total number of measuring grid points, whilst X_{i-1} and Y_{i-1} are the former coordinates of the mass centroid defined from the previous detection (or the coordinates of the injection point).The transport velocity vector $\vec{U}$ and magnitude U may be expressed as :

$$\vec{U} = (U_x, U_y) = \left(\frac{X_i}{t_i - t_{i-1}}, \frac{Y_i}{t_i - t_{i-1}} \right) \qquad U = \frac{\sqrt{X_i^2 + Y_i^2}}{t_i - t_{i-1}}$$

Using this methodology, we obtained a sediment movement of Xi = 14.315m East and Yi = 0.868 m North, which gives a residual movement of 14.34 m toward the inlet (Fig. 4). Currents velocities able to transport sediment over the bar were reached during 3h19 during the flood tide, and 1h26 during the ebb tide. The transport duration during the tidal cycle is 4h45, which permits to calculate the transport velocity Ux = 0.183 m E / h, and Uy = 3.014 m N / h, so a transport velocity of 3.01925 m/h toward the inlet, or 8.387. 10^{-4} m/s.

Sediment transport is expressed either in volume of sand per unit width in a unit time (Q, m^3/s per m width (m^2/s)) or immersed weight (*I*, kg/m/s^2). The volumetric transport rate (Q) is calculated considering that the activation layer of Z_0 (m) thickness is moving with the speed U (m/s) :

$$\vec{Q} = N_0 \,.\, \vec{U} \,.\, Z_0$$

where N_0 is the volumic concentration of sediment within the sand bed (N_o = 1 - porosity = 0.6 here).
The activation layer thickness was measured on the swash bar, and is about 14 cm. So we obtain a sediment transport rate Q = $7.045.10^{-5}$ m²/s which gives 1.2 m²/tide.

In order to validate the homogeneity of the transport direction, and to estimate the width of this sediment transport, a grain size trend analysis was used following the procedure described by Gao and Collins (1992). This method is based on the assumption that spatial changes in surface sediment can yield the residual transport paths. Grains size parameters are compared between pairs of samples, considering the increase or decrease of three parameters at the time: mean size (m), sorting coefficient (s) and skewness (Sk). Consequently, 8 cases are theoretically possible, of which only two are representative for a physical reality in non-extreme marine environment (McLaren and Bowles, 1985; Gao and Collins, 1992, Gao and Collins, 1994). If transport takes place from site 1 to site 2, two cases can be valid, either: case 1: s2<s1, m2>m1 and Sk2<Sk1 (in downstream direction, sediments become finer, better sorted and more negatively skewed); or case 2: s2<s1, m2<m1, and Sk2>Sk1 (in downstream direction, sediment becomes coarser, better sorted and more positively skewed). Pedreros *et al*. (1996) already used this methodology in intertidal environments. The DERSEDI software (© Service Hydrographique et Océanographique de la Marine) was used, which performs the entire calculation protocol (grain size parameters, trends and vectors).

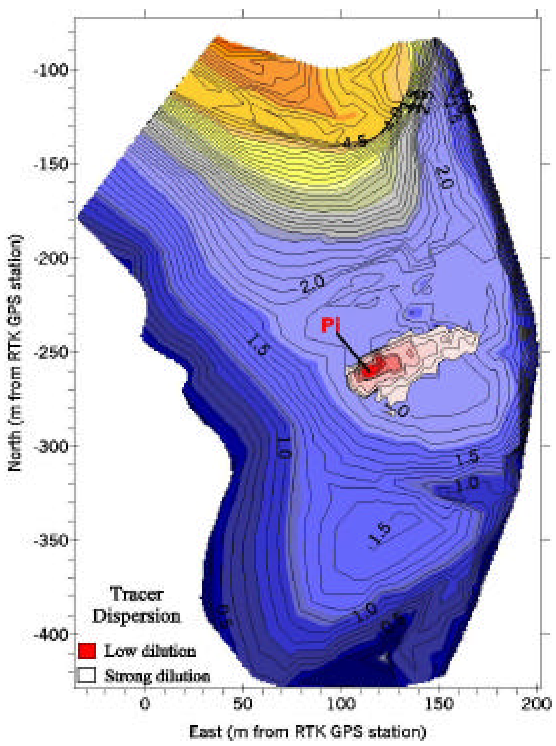

Fig. 4: Fluorescent tracer dispersion. Topographic levels are referred to the O Hidrografico Portuguese (2 m below MSL).

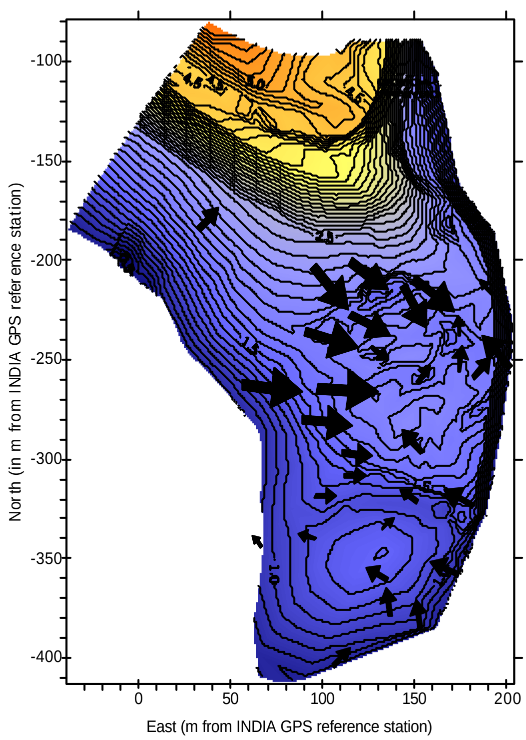

Fig. 5: Results of the grain size trend analysis: vector of sediment transport over the bars. Topographic levels are referred to the O HP (2 m below MSL).

Sediment was sample over the swash platform during the topographic survey. 44 superficial samples were analysed by means of a Malvern (MASTERSIZE IM 100 version 3) grain size analyser. According to the sampling grid, the critical maximum distance for the vectors calculation was 60 m. Figure 5 represents the transport vectors calculated with the filtering method developed by Gao and Collins (1992, 1994). Considering the transport vectors over the studied swash bar, it can be seen that the transport over this bar, which is oriented

toward the inlet, appears to be homogenous and important, in particular on the western flank of the bar. This first result agrees with the migration of bars observed in this area, and with the fluorescent tracer results. On the adjacent beach, sediment transport vectors show a onshore movement. On the bar B1, sediment transport vectors are oriented toward the bar 2 and confirm the hypothesis of sediment supply by the longshore drift to the swash platform vie the first bar. On the eastern part of the platform, vectors show a north- westward transport, which could correspond to the refraction of wave on the bars. This hypothesis should be validated by a further analysis using a simulation of the refraction/ diffraction of waves on the ebb delta.
The repartition of vectors on the bar B2 permits to evaluate the width of the transport toward the inlet, which is approximately 60 m. This value can be used to calculate the sediment flow over the bar. The volumetric transport rate was $7.045.10^{-5}$ m²/s, 1.2 m²/tide which give a transport rate over the bar of Q = 72.28 m^3/tide.
If we consider that the hydrodynamic conditions remain stable during the experiment, this value can be extrapolate, and we obtain a sediment flow of approximately 4300 m^3 /month.

Using the hydrodynamic parameters measured with the S4 wave-gauge/ current-meter, theoretical formulations for sediment transport were tested (Van Rijn, 1984; Yalin, 1963; Bijker, 1967). Cayocca (1996) already used these formulations in a similar environment on the tidal inlet ebb tidal delta of Arcachon.
Van Rijn approximated equation (1984) gives a sediment transport of 6.91719.10-5m²/s, which agrees with the estimation done by the fluorescent tracer techniques. A further comparison of different transport theoretical equations should be done in the following months.

Conclusion:
The aim of this study was to quantify the sediment flow over the swash bar which migration was quantified by the topographic surveys comparison. The fluorescent tracer experiment permitted to estimate the residual transport over the bar that is about $7.045.\ 10^{-5}$ m²/s. This sediment flow was extrapolated for the entire bar using the grain size trend analysis which shows a homogenous transport toward the inlet.
Theoretical equations were used to estimate the instantaneous sediment flow for the hydrodynamics conditions measured on the bar, and permitted to validate in a first approximation the Van Rijn equation for sediment transport over the bar.
The grain size trend analysis shown different transport pathways over the swash platform which will require a further investigation, in particular using simulation of refraction / diffraction of waves on the bars that could permit in particular to explain the sediment transport along the ebb channel.

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