The importance of the topo-hydrography in the prediction of the short- and medium-term evolution of the coastal zone

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Abstract: The prediction of the short- and medium-term evolution of a coastal zone is performed when it is necessary to estimate its future hydro-sedimentologic behavior, frequently if interventions of rehabilitation and/or protection which need to be tested and evaluated are being planned. In this paper are presented the methodologies to predict the evolution of the coastal zone out of inlets presently applied in LNEC. These methodologies are based on the application of mathematical models of hydrodynamics and sediment dynamics suitable to the time and space scales to which they are applied. The objective of this paper is to point out the fundamental importance of the topo-hydrographic data to obtain prediction results through these methodologies. Two international case studies in which these methodologies were applied aiming to obtain rehabilitation solutions for two beaches in critical erosion condition are presented.

Keywords: coastal evolution, prediction, morphodynamics, shoreline, beach

1. INTRODUCTION

The main objective of this paper is to point out the great importance of the topo-hydrographic data in obtaining accurate predictions of the short- and medium-term morphodynamics of natural and interventioned beaches through the main methodologies presently used in LNEC.

These methodologies are frequently applied to estimate the future hydro-sedimentologic behaviour of littoral stretches where interventions of rehabilitation and/or protection are projected and therefore there is need to test and evaluate their effect. They are based on the application of numerical models (of hydrodynamics, sediment transport, morphodynamics and shoreline evolution) with different characteristics, suitable to the time and space scale in which they are applied.

By short- and medium-term it is understood time periods of the order of days (time scale of maritime storms) and decades, respectively.

Within the scope of the present paper, two international case studies in which the methodologies were applied to obtain solutions for the rehabilitation of beaches in critical erosion process (Hac-Sá beach, Macau, China, and Colwyn bay beach, Conwy, United Kingdom) are presented.

2. CASE STUDIES

2.1 Hac-Sá beach

The objective of this study was: i) to characterise the sediment dynamics of Hac-Sá beach, its recent evolution, and thus, to diagnose the causes of the erosion observed; and ii) to propose and evaluate alternative solutions for beach rehabilitation and complementary interventions for beach improvement and maintenance of the recommended solution.

Hac-Sá beach, confined between the two headlands of Hac-Sá bay, in Figure 1, is located in the SE coast of Coloane island, Macau, a Special Administrative Region (SAR) located in the south coast of People's Republic of China, at the end of the great delta of Pearl River. It is a narrow pocket beach with 1.2 km long and a NNE-SSW general orientation. The northern side of Hac-Sá headland and the southern side of Ká-Hó headland have in the recent decades advanced over the sea through reclamation works. The slopes of the enlarged banks are protected against wave action by rock revetments. The beach backshore zone is occupied with constructions and infrastructures, particularly advanced in the southern stretch of the beach.

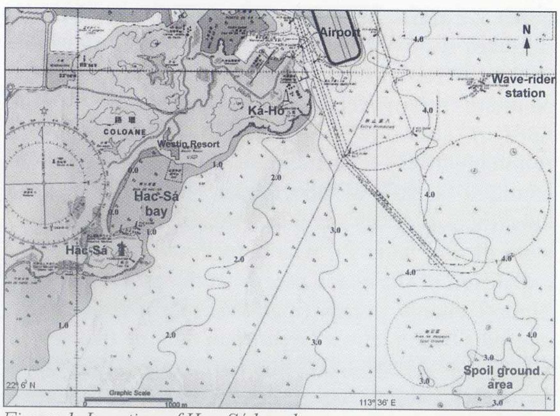

Figure 1. Location of Hac-Sá beach.

The main phases of the study were: the analysis of the natural agents that intervene in the Hac-Sá beach dynamics; the identification and evaluation of the major beach dynamics processes and their interaction mechanisms; the characterisation of the recent evolution of the beach system; and finally the prediction of the beach future evolution considering the implementation of the alternative interventions.

The Hac-Sá beach hydrodynamics and sediment dynamics were characterized for the coastal conditions of 1985 and 2002. For both conditions, the numerical results obtained from the propagation of the representative annual wave regime were used as input to the sediment transport numerical models. Numerical simulations of short- and medium-term sediment transport and morphodynamics were performed to: interpret the longitudinal equilibrium configurations of the beach; evaluate the cross-shore distribution of the longshore transport along the year in both directions; characterise the seasonal patterns of morphological variations; evaluate the influence of morphological and wave propagation changes on the erosion events; and analyse the impact of maritime storm events on the beach profile development.

2.1.1 Short-term evolution

The cross-shore evolution of Hac-Sá beach is characterised by medium-term cyclic morphological changes due to a seasonal wave regime and short-term morphological changes due to the occurrence of maritime storm events.
In order to assess Hac-Sá beach cross-shore behaviour, a numerical model, Litprof (DHI, 2000), was applied to simulate the beach profile response to a maritime storm event. Two cross-shore profiles were used to represent the northern and southern sectors of the beach. The evolution of each profile was simulated for two situations, 1985 and 2002. In 2002, at mean sea level (MSL), the profile in the northern sector showed a beach retreat that is about 63% of the retreat occurred in 1985, and the profile in the southern sector, which in 1985 was not significantly affected, showed in 2002 a retreat about 2.2 times higher than the one observed in the northern sector of the beach. Such results show the increase, from 1985 to 2002, of the retreat of the southern sector relatively to the retreat of the northern sector in the presence of a storm event (Oliveira, 2003). This increase of vulnerability of the southern sector of the beach was due to the construction of an advanced infrastructure (vertical seawall, in Figure 2), which, by limiting the natural expansion of the beach profile in the presence of the highest energy events (maritime storm conditions), caused a beach retreat larger than the one that would happen in its absence. In fact, the presence of a highly reflective structure (without dissipative conditions) on the top of the beach profile promotes erosion conditions by increasing the seaward sediment transport and thus the lowering of the beach face.

2.1.2 Medium-term evolution

The morphological evolution of Hac-Sá beach adjacent area in the last three decades was characterised based on comparisons between hydrographic data available from several chart surveys from the 1966-2001 period. The data were processed with a digital terrain model and the volumetric results obtained from the comparisons allowed to conclude on the rates of erosion and accretion. The morphological evolution of the coastal area in the vicinity Hac-Sá beach is characterised by a general deposition, with an average accretion rate of 2-3 cm.year^{-1}. Since 1985, this accretion rate observed had a tendency to increase offshore and decrease nearshore Hac-Sá bay. Most likely, this evolution tendency is a consequence of the changes on the hydrodynamic conditions introduced by the construction of Macau International Airport. An evidence of its effect is the increase of deposition observed in the surroundings of Ká-Hó cape, which can be interpreted based on the sheltering effects of the airport, favouring sediment deposition. Another new morphological feature is the existence of a distinct accumulation zone of disposal of dredged material, the spoil ground area, in front of Hac-Sá beach.
The beach morphological evolution was analysed based on the shoreline positions at MSL and the backshore occupation of the beach. These data were obtained from aerial photographs of Hac-Sá beach, shoreline surveys and charts showing the occupation of the backshore area for the 1966-2002 period. The main evolution aspects were: a significant retreat of the shoreline at the southern stretch; remarkable land reclamation at the north and south headlands; and a progressive occupation of the backshore zone with infrastructures and other constructions resulting in the narrowing of the beach.

Figure 2. Vertical seawall at Hac-Sá backshore.

In order to assess the wave climate evolution in the nearshore area of Hac-Sá beach, two cases of propagation of the representative wave regime towards the coast have been studied: one correspondent to the situation in 1985 (prior to the construction of Macau International Airport) and the other correspondent to the situation in 2002. The comparison of the results for the two cases, 1985 and 2002, allows concluding on the effect of the recent morphological (depth and sea bottom geometry) and land contour changes on the wave climate in the nearshore area (Oliveira, 2006). One of the major impacts of the wave propagation changes on the beach was the significant increase of the gradient of the incident wave energy in the longshore direction due to the presence of a recent irregular shoal, resultant from disposal of dredged material in the nearshore region in front of the beach, which generates a complex wave transformation pattern with several convergence zones, i.e. peaks of energy concentration, between this new morphological feature and the shoreline.

Hac-Sá beach longshore transport, confined between the north and south headlands, produces a constant displacement of the granular sediments in both longitudinal directions, according to the varying incident wave directions. Two numerical models (Vicente, 1991 and DHI, 2000), based on different mathematical approaches, were applied for the past equilibrium situation of the beach (1985) to evaluate the annual and seasonal longshore sand transports and their cross-shore distribution for a profile at the central part of the beach. The shoreline evolution for this past equilibrium was also simulated. The results revealed the following:

- The shoreline had a long-term stability with a net transport almost null, as expected, taking into account the good confinement of the beach by the headlands;
- There were cyclic shoreline oscillations along the year consequent of the seasonal variation of incident wave directions. Between April-September there was a net transport directed northwards that produced enlargement of this part of the beach, and beach width reduction at the southern part. Between October-March occurred an opposite sand mass displacement, with beach enlargement at the southern part and decrease of the beach width at north;
- The average annual cumulative transport was approximately $120x10^3$ m^3 with about $60x10^3$ m^3 directed to north and about $60x10^3$ m^3 directed to south;
- The longshore sediment transport occurred was not significant 1 m below chart datum (CD), which is 1.8 m below MSL.

The medium-term evolution of the shoreline was also simulated for the beach conditions in 2002 (Figure 3). When comparing these results of the new equilibrium configuration with the results of the past equilibrium configuration, it can be observed a retreat of the shoreline positions in the southern stretch of the beach, counterbalanced by shoreline advance at the northern stretch.

The geographic features of the beach, confined between the two headlands, grant ideal natural conditions to keep the beach sand trapped, therefore the success not only of the implementation of a beach nourishment solution as well as its natural self-maintenance. Thus, two alternative solutions, which grant the enlargement of the beach width, were proposed and analysed: the first one based exclusively on beach nourishment; the second based on beach nourishment and implementation of a cross-shore structure in the central part of the beach. The feasibility of both alternative solutions was investigated through the same numerical models used for the analysis of the beach longshore dynamics in 1985 and 2002. After comparing their advantages and disadvantages, LNEC recommended the implementation of the solution based exclusively on beach nourishment.

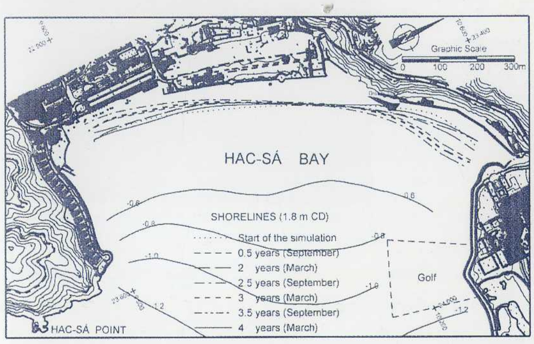

Figure 3. Numerical results of shoreline evolution (2002).

2.2 Colwyn bay beach

The objective of this study was: i) to characterise the sediment dynamics of Colwyn bay beach and its recent evolution (erosion process); and ii) to test numerically different schemes of coastal protection based on beach nourishment with control structures.

Colwyn bay beach, in Figure 4, is located in the NW of England and faces the Irish Sea. The bay is limited at the western end by Rhos Point and at the eastern end by Tan Penman Head. From Rhos Point to Old Colwyn, the existent beach, with approximately 3 km, undergoes a severe process of erosion. It is backed by a masonary wall, dated back to the 19th century, which has been subjected to a great deal of repair and reconstruction. The latest intervention occurred in 1990 when a number of long low groynes were constructed aiming to encourage beach recovery, however, without success.

2.2.1 Sort-term evolution

In this study the prediction of the short-term coastal zone evolution consisted in the simulation of the resilience of the equilibrium beach profile of the projected nourished beach to the worst storm event registered near Colwyn bay. Different combinations of profile geometry and sediment grain size were tested. The numerical simulation of the cross-shore sediment transport and morphologic evolution allowed to predict the parameters retreat of the beach foreshore at different levels, volume of sand extracted from the foreshore and coordinates of the sediment accumulation zone in the nearshore.

The objective of these tests was to estimate the berm width of the future beach initial profile, for each combination of profile geometry and sediment grain size, which allows to guarantee a minimum width left intact after the occurrence of the storm event, needed for beach defence (to avoid direct wave action on the seawall) and for the beach future use (bathing and recreational).

Figure 4. Location of Colwyn bay beach.

2.2.2 Medium-term evolution

In this study the objective of the medium-term simulations was the prediction of the shoreline evolution for the different schemes of beach nourishment with and without control structures. Two shoreline evolution models, Litmod (Vicente, 1991) and Litline (DHI, 2000), based on distinct approaches (a classical one-line model and a profile based shoreline model, in which the longshore sediment transport is calculated for both modes, bed load and suspension) were calibrated for the 5-year period 2001-2005, during which five foreshore surveys were available. The reason for using both models is because they have different capacities and limitations. For example: i) the first considers the sea level constant and the second allows the sea level variation (which is very important for this study site where spring and neap tide ranges are 7.14 m and 3.81 m, respectively); and ii) the first allows the simulation of classical and fishtail groynes and the second only allows the simulation of classical groynes.

Prior to the shoreline models application for the different alternative defence schemes, a 2D-vertical sediment transport numerical model was applied to calculate the cross-shore distribution of the longshore transport along the beach profile active zone for the 19 years of hydrodynamic data available (every 3 hours). These results consist on calibration parameters for the Litine model. At a first stage, both models were applied to simulate the shoreline medium- to long-term evolution for the case of nourishment without control structures. However, at a second stage, according to the characteristics of the beach defence scheme to be tested only the most suitable model was applied.

3. CONCLUSIONS

The two case studies here presented illustrate well that the topo-hydrographic data, i.e., the information on the levels of the nearshore zone, beach face and beach backshore zone, at different dates, were essential for: i) the evaluation of the changes occurred recently in the respective coastal zones and thus to diagnose the causes of erosion and degradation of the beaches; ii) the characterisation of the present sediment dynamics; and iii) the calibration and validation the numerical models to predict the evolution of the coastal zones and thus test the alternative beach rehabilitation and protection solutions. If systematic topo-hydrographic surveys had not been done, the application of the methodologies described to predict the evolution of the coastal zones and thus recommend the best beach rehabilitation and protection solution could not have been possible.

The methodologies applied in LNEC for predicting the short- and medium-term evolution of the coastal zone are usually applied in two stages:

1) a stage of calibration, when the numerical models are applied to simulate with continuity the main coastal processes responsible for the recent morphological evolution;
2) a stage of prediction, when the numerical models are applied to estimate the future hydro-morphological behaviour of the littoral stretch and thus its morphological evolution.

The refinement and amount of topo-hydrographic data used in the first stage affects greatly the accuracy of the results obtained in the second stage. Thus, methodologies to accurately process the topo-hydrographic data and characterise its variability in space and time (described in a different paper presented by LNEC in this scientific meeting) are also a very important area in development in LNEC.

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