Journal of Coastal Research	SI 64	1170 - 1174	ICS2011 (Proceedings)	Poland	ISSN 0749-0208

Waves, wind and tidal forcing on a sandpit morphodynamics

J.Rosa†, P. A. Silva†, X. Bertin‡ and A. B. Fortunato§

† Departamento de Física, CESAM Universidade de Aveiro, Aveiro 3810-193, Portugal
jpsrosa@ua.pt
psilva@ua.pt

‡ Université de La Rochelle, Institut du Littoral et de l'Environement (ILE), La Rochelle 17000, France
xbertin@univ-lr.fr

§ Departamento de Hidráulica e Ambiente, Laboratório Nacional de Engenharia Civil, Lisboa 1700-066, Portugal
afortunato@lnec.pt

ABSTRACT

Rosa, J., Silva P.A., Bertin, X., Fortunato A.B., 2011. Waves, wind and tidal forcing on a sandpit morphodynamics. Journal of Coastal Research, SI 64 (Proceedings of the 11th International Coastal Symposium), 1170 – 1174. Szczecin, Poland, ISSN 0749-0208

Due to the increasing demand of sand for construction and beach nourishment, offshore extraction is being considered as an alternative source. Long term morphological changes caused by such an extraction must be predicted because they can affect the sediments budget and potentially promote coastal erosion. Numerical models are powerful tools that can help in the evaluation of environmental impacts induced by this activity.
The objective of this study is to describe the morphodynamics in the area surrounding a sandpit through the use of the MORSYS2D modelling system. The sandpit under study is located offshore Vale do Lobo, an important beach and golf resort located on the Southern Portuguese coast. The numerical solutions of the mean flow and the wave height around the pit were obtained with MORSYS2D between March 28 and April 29, 2008 when two storm events with significant wave height (Hs) greater than 2.5 m occurred.
The numerical results are analysed in terms of the sand fluxes and bathymetry changes induced by wind and tidal currents and wave orbital velocities. The results show the strong impact of storm events in the morphologic evolution of the pit and surrounding area. The value for Hs > 2.5m was also confirmed as determinant for the sediment dynamics.

ADDITIONAL INDEX WORDS: *sand extraction, continental shelf, morphodynamic model*

INTRODUCTION

Marine sand and gravel extraction is increasingly gaining significance due to an overall growing demand, supply shortages of land-based aggregates, improved mining technologies and advantages with respect to quality, availability and transport (Diesing *et al*., 2004). The mining areas need to be situated in the offshore shoreface zone to minimize the effects on nearshore coastal erosion. Simultaneously, the mining cost increases with depth and the distance from shore. Therefore, finding the optimum balance between the effect on the coast and the costs of mining is required (Van Rijn *et al*., 2005).

The presence of the dredged pit may change the location of wave breaking and modify the wave field through refraction and, to a lesser extent, diffraction. These changes lead to modified long-shore sediment transport patterns that can alter the shoreline plan-form (Demir *et al*., 2004). Modification of the tidal- and wind-induced mean flows at the sandpit and surrounding areas may also change the local sediment transport balance. The hydrodynamics conditions also dictate the movement of the sandpit and its infilling rate, and therefore the persistence of the bathymetric perturbation in time.

A recent example of beach erosion and coastal retreat is the Vale do Lobo beach case, located on the Southern Portuguese coast.

This coastal stretch presents vertical cliffs with maximum heights of 26 m. Between 1991 and 1999 the cliffs have retreated, on average, 1 m/year (Oliveira, 2005). In order to mitigate the intense coastal erosion affecting the coastline stretch along Vale do Lobo, beach nourishment was undertaken. Two nourishment operations were performed, in 1999 and in 2006. In both cases, sand was extracted from the shoreface, at depths between 15-20 m. Figure 1 presents the bathymetry in the vicinity of the sand pit at Vale do Lobo coastal zone, in May 2006, immediately after the second extraction. The sandpit had approximately a rectangular shape, with 750 m length and 250 m width, and was located 4000 m away from the shore. The longest side was aligned with the bathymetric contours. The average depth of the excavation was around 3 m.

The objective of the present study is to assess the importance of storms in the sediment transport field and in the morphological variations of the 2006 dredged pit bathymetry.

For this purpose, the following research questions were set:

1) What is the impact of tidal and wind induced current velocities, wave height and near bed orbital velocities on the dredged sandpit evolution?

2) What is the area of morphodynamic influence of the pit?

To answer these questions, the morphodynamic model MORSYS2D was applied to the study area, considering the 2006 bathymetric configuration.

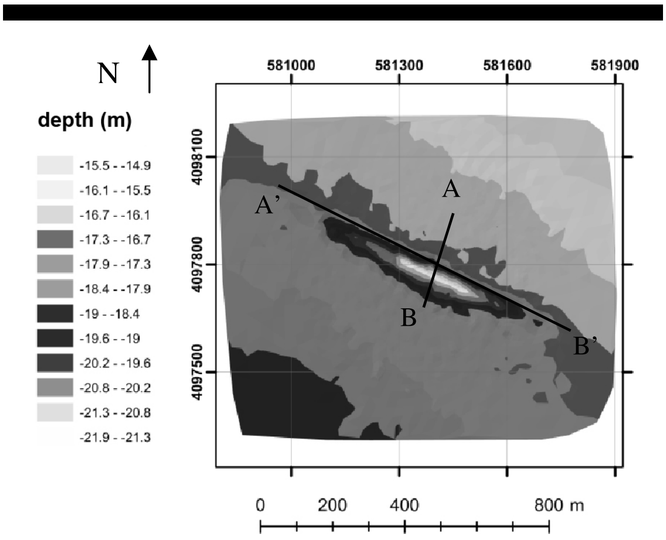

Figure 1. Sandpit bathymetry and transects.

SETUP OF THE NUMERICAL MODELS

The MORSYS2D morphodynamic modelling system (Bertin *et al.*, 2009) couples the sand transport and bottom evolution model SAND2D (Fortunato and Oliveira, 2004), the hydrodynamic model ELCIRC (Zhang *et al.*, 2004) and the wave propagation model SWAN (Booij *et al.*, 1996).

ELCIRC is an open-source three-dimensional baroclinic shallow water model that combines finite volumes, finite differences and Eulerian-Lagrangian concepts to obtain stability, accuracy, and mass conservation to solve the shallow water equations. The horizontal domain is discretized with a triangular mesh for flexibility, and z-coordinates are used in the vertical. The unstructured grid used for ELCIRC in the present study, has 6710 nodes a minimum spacing of 5 m at the sandpit location and a maximum of 1500 m. Within MORSYS2D a single vertical layer is used.

SWAN is a wave model that computes random, short-crested wind-generated waves in coastal regions and inland waters. SAND2D is a sand transport and bottom evolution model that computes sediment fluxes through semi empirical formulae (for example, Soulsby & Van Rijn and Bijker; Soulsby 1997). Figure 2 shows the computational grids used for the three models.

The numerical model configuration for the present application includes the most representative forcings (tides, wind and waves), provided by regional models of tides (Fortunato *et al.*, 2002) and waves (Dodet et al., 2010).

From the different sediment transport formulae available in MORSYS2D, those of Soulsby-Van Rijn and Bijker were chosen, with prescribed values of bottom roughness that yield the best results for the morphodynamics pit evolution. A constant value for the sediment median grain size, d50, of 0.77 mm, was assumed.

IMPACT OF HYDRODYNAMICS IN THE SANDPIT EVOLUTION

Waves, Wind and Flow

The numerical solutions of the mean flow and the wave height around the pit obtained with MORSYS2D between March 28 and April 29, 2008 are shown in Figure 3. Figure 3a represents the corresponding WW3 wind field for this region. Two storm events with Hs greater than 2.5m occurred between the 5th and 20th of April (Figure 3 b).

The time series of depth-averaged flow velocity components contain tidal fluctuations, as previously confirmed by analysis of the tidal ellipses (Lopes *et al*., 2009; Figure 3c). Maximum tidal currents reach 0.15 m/s when considering the whole domain. In the vicinity of the study area, the tide is well polarized, aligned along the N-S direction and the velocity amplitude reaches maximum values of 0.05 m/s in spring tides (Lopes e*t al.*, 2009).

The mean currents are well correlated with the wind field: in periods of calm wind, both u and v values are small, fluctuating around 0. The storm events (Hs greater than 2.5m, coming mainly from SSW), coincide with strong winds from NW (Figure 3a) which induce strong currents standing for SE of approximately 0.2 m/s (Figure 3a, d). The wave orbital velocities (not shown) are always very low (less than 0.1m/s) except for the storm periods when they reach maximum values of 0.5 m/s.

Fluxes and bathymetric changes

The computed sediment fluxes values present non-zero values only during storm events, as depicted in Figure 3 b. The estimated sediment fluxes computed with the Bijker formulation present higher values than for the Soulsby-Van Rijn formula.

Figure 4 shows the magnitude and direction of sediment fluxes around the pit and within the pit computed with the Bijker formula for 9 April. The sediment flux presents a preferential direction NW- SE according to the wind-induced mean currents but its magnitude is also determined by the wave orbital velocities.

The fluxes, in general, are southward at the northern border of the pit and at the south border are parallel to the longitudinal axis of the pit.

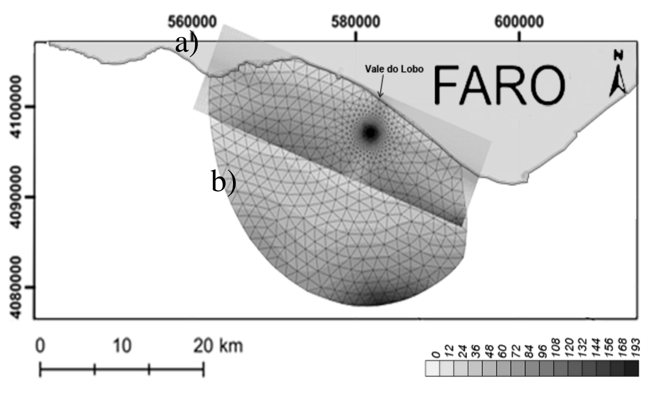

Figure 2. (a) SWAN nested grid and (b) Finite element grid used in ELCIRC and SAND2D. (Depths in meters relative to chart datum)

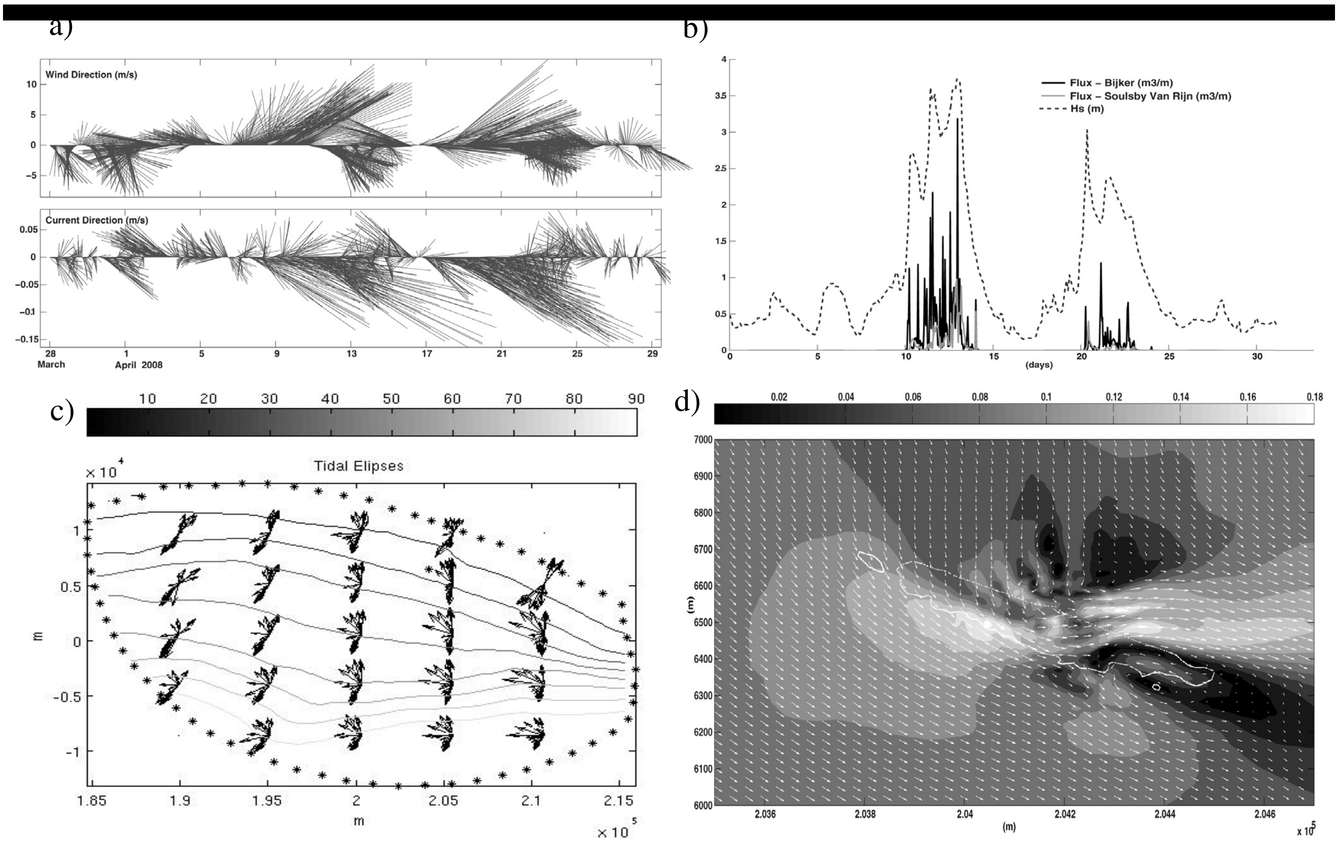

Figure 3. MORSYS2D results between March 28 and April 29, 2008: a) wind and current – velocity, direction and magnitude; b) wave height (Hs) and sediment flux for Soulsby Van Rijn and Bijker formulations; c) tidal ellipses (whole grid); d) current velocities in the vicinities of the pit at 9 April (m/s). The time series in a) and b) refer to a location inside the sandpit.

The infill rate and the pit migration were also evaluated from the numerical results and compared with bathymetric observations. Figure 5 shows the bathymetric profiles along two transects at the sandpit – longitudinal and transverse - as represented in Figure 1.

The "May 2006" and "Nov. 2008" curves correspond to the bathymetric surveys just after the extraction and 2.5 years later, respectively. The final bathymetry simulated from March 28 to April 29, 2008 is denoted as "MORSYS2D simulated storm". The numerical results reproduce the tendency and patterns of the observations: the sand pit tends to fill in the inner regions while erosion takes place at the pit side walls.

To estimate the area of morphodynamic influence of the pit, and the erosion/deposition pattern, Figure 6 presents the relative variation of bathymetry computed with MORSYS2D after 12 days of simulation between March 28 and April 9 (negative values are erosion and positive values are deposition).

The influence area of the sandpit is restricted to the surroundings of the pit. There are two zones, north and inside of the pit, where the magnitude of these variations is higher, up to 6%. Within the pit, the relative variation increases as much as 6% in the deepest area - deposition area - while in the south and north side walls the relative variation decreases - erosion areas.

CONCLUSIONS

In the present work the hydrodynamic impact on a sand extraction at the Vale do Lobo shoreface was characterized in terms of the fluxes and bathymetry modifications induced by the tide, wind and the wave orbital velocities.

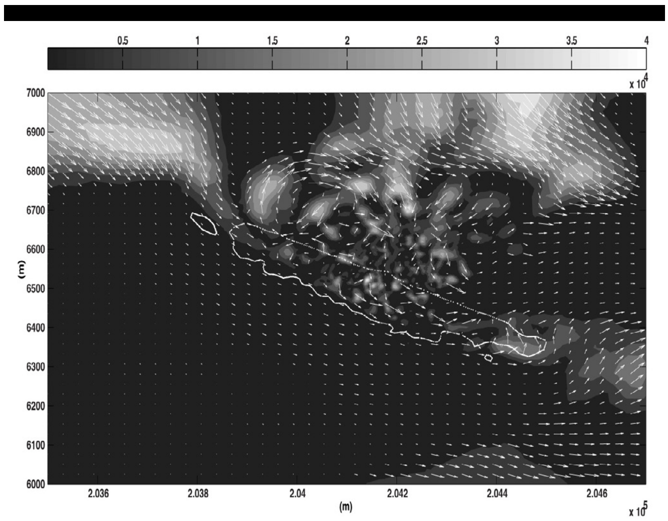

Figure 4. Sediments fluxes (m^3/m) for Bijker formulation surrounding the pit.

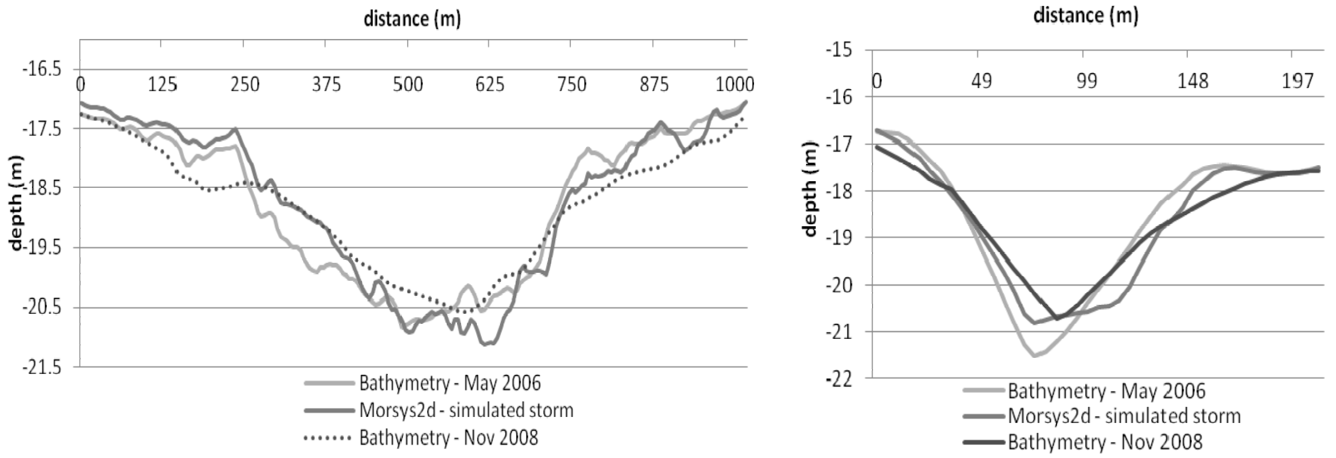

Figure 5. Bottom profiles along the longitudinal (A´-B´) and transverse (A-B) transects in the dredge sandpit.

The numerical results show a strong dependency of the morphologic evolution of the pit and surrounding area on storm events. Significant wave heights higher than 2.5m when combined with strong winds produce a mean current and wave orbital flows that are capable of mobilizing the bottom sediments.

The tidal currents do not represent an important forcing to the morphodynamics of the sandpit. For mean wave conditions the net transport rates are equally smaller.

The magnitude and direction of sand fluxes within the pit and neighbouring areas are determined by the hydrodynamic conditions: the magnitude of the mean velocity decreases within the pit and shows maximum values at the north and south borders of the pit, where convergence effects are noticed.

The decrease of the mean flow and orbital velocities within the pit indicates that the sediment transport capacity decreases and therefore the pit will tend to fill over time. The extent to which the morphodynamics influence of the sand pit is noticed is restricted to its surroundings.

The patterns of the morphologic modifications of the sandpit simulated in one month (with two storm events) agree with the observations in a time span of 2.5 years.

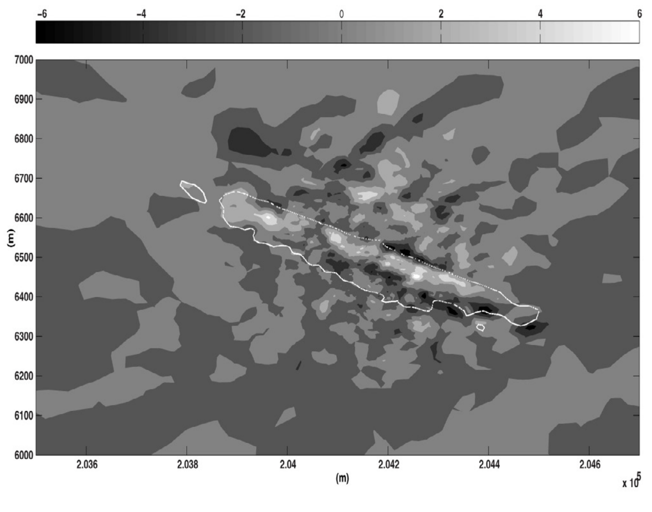

Figure 6. Relative variation of the bathymetry - Area of morphodynamic influence of the pit (%).

Therefore, the present results suggest that significant changes in the sandpit morphology are only detectable during the storm events and that long term morphological changes of this pit or other conceptual sand pits in the study area (e.g., with different geometries) can be investigated through the simulation of a succession of storm events.

The present results also reveal a good performance of the MORSYS2D morphodynamic modelling system for the inner continental shelf.

REFERENCES

Bertin, X., Oliveira, A. and Fortunato, A.B., 2009. Simulating morphodynamics on unstructured grids: description and validation of a modeling system for coastal applications. *Ocean Modelling*, 28/1-3, 75-87.

Booij, N.R., Holthuijsen, L.R., Ris, R.C., 1996. The SWAN wave model for shallow water, *ICCE'96*, Orlando, USA, 668-676.

Demir, H., Otay, E.N., Work, P.A. and Borekci, O.S., 2004. Impacts of dredging on shoreline change. *Journal of Waterway, Port, Coastal and Ocean Engineering*, 130(4), 170-178.

Diesing, M., Schwarzer, K., Zeiler, M. and Klein H., 2004. Comparison of marine sediment extraction sites by means of shoreface zonation. *Journal of Coastal Research,* vol2, 783-788.

Dodet G., Bertin, X. and Taborda, R. 2010. Wave climate variability in the North-East Atlantic Ocean over the last six decades. *Ocean Modeling*, 31 (3-4), 120-131.

Fortunato A.B., Pinto, L., Oliveira, A., Ferreira, J.S., 2002. Tidally generated shelf waves off the Western Iberian Coast. *Continental Shelf Research* 22 (14), 1935– 1950.

Fortunato, A.B. and Oliveira, A., 2004. A modeling system for tidally driven long-term morphodynamics. *Journal of Hydraulic Research* 42 (4), 426–434.

Lopes, V., Silva, P. A., Bertin, X., Fortunato, A., Oliveira, A., 2009. Time-evolution of an offshore sandpit: validation of a morphodynamic model, *Journal of Coastal Research*, SI56, 529-533.

Oliveira, S., 2005. Evolução recente da linha de costa no troço costeiro Forte Novo-Garrão (Algarve), University of Lisbon, Master's thesis, 115p.

Soulsby, R, 1997. *Dynamics of marine sands*. Thomas Telford Publications, London, 249 p

Van Rijn, L,, Soulsby, R., Hoekstra, P. and. Davies, A.G., 2005. *SANDPIT, Sand Transport and Morphology of Offshore Mining Pits*. Aqua Publications, The Netherlands, pp:156.
Zhang, Y., Baptista, A.M. and Myers, E.P., 2004. A cross-scale model for 3D baroclinic circulation in estuary-plume-shelf systems: I. Formulation and skill assessment, *Continental Shelf Research*, 110(10), 1431-1456

ACKNOWLEDGEMENTS

This work has been supported by FCT and by the European Union (COMPETE, QREN, FEDER) in the frame of the research project POCI/ECM/70428/2006– SANDEX - *Sand extraction in the Portuguese continental shelf: impacts and morphodynamic evolution*. The authors thank the developing teams of the models ELCIRC and SWAN for making their source codes available and Dr. Sebastião Brás Teixeira and Dr. Marcos Rosa from the Administração da Região Hidrográfica do Algarve (ARH) for providing the bathymetric data.