# SAND FILLED CONTAINERS IN DUNE EROSION CONTROL: EXPERIMENTAL STABILITY ANALYSIS

**Luciana das Neves[1], Maria de Lurdes Lopes[2], Fernando Veloso-Gomes[3], Francisco Taveira-Pinto[4], Gregorio Iglesias[5] & Susana Garcia[6]**

[1] *Civil Eng., MSc, PhD Researcher, Faculty of Engineering, University of Porto, Portugal (e-mail: lpneves@fe.up.pt)*
[2] *Associate Professor, Faculty of Engineering, University of Porto, Portugal (e-mail: lcosta@fe.up.pt)*
[3] *Full Professor, Faculty of Engineering, University of Porto, Portugal (e-mail: vgomes@fe.up.pt)*
[4] *Associate Professor, Faculty of Engineering, University of Porto, Portugal (e-mail: fpinto@fe.up.pt)*
[5] *Associate Professor, Universidad de Santiago de Compostela, Spain (e-mail: iglesias@lugo.usc.es)*
[6] *Civil Eng., MSc, Faculty of Engineering, University of Porto, Portugal (e-mail: susanapgarcia@gmail.com)*

**Abstract:** In an ongoing research project, GeoWAVE©, running since September 2005, the stability and hydraulic performance of sand filled geotextile containers under wave loading is investigated through model tests. These model scale tests are performed at small scale at the Hydraulics Laboratory of the Faculty of Engineering of the University of Porto and at large scale at the Hydraulics Laboratory of the Centre of Technology Innovation in Building and Civil Engineering (CITEEC) of the University of Coruña.

Dune systems are of great importance to hinterland areas, acting as buffer zones existing between the land and the sea. The positive effect of these zones is enabling shoreline movements without increasing the vulnerability and risk of the populations living along the coast. However, in several places worldwide, due to sediment harvesting, which drive to progressive decreasing of beach width, dunes are often submitted to the direct action of wave run-up. In several others, they are irreversible lost.

In coastal areas where it is still possible to preserve and consolidate existing dune systems, and where there is not a reasonable expectation of a significant increase in the volume of sediments transport by the littoral drift currents, sand filled containers made of geotextile fabrics can be a successful alternative to concrete or rubble.

The paper describes the model tests and presents the results obtained for the behaviour of sand filled geotextile containers in dune erosion control systems under extreme wave loading.

**Keywords:** Erosion control, geotextile containers, laboratory test.

## INTRODUCTION

For many years, geosynthetics have been predominately used as filters in Coastal Engineering. This application is though still very limited considering the number of feasible applications that is still growing over recent years. Linked to the improvements achieved at the level of the materials, the strong dynamics of the fabrics industry, with the continuous release of new products, and the lower acceptance of some of the common protection devices, namely due to environmental and visual impacts, the incorporation of geosynthetics in coastal protection is a topic at the forefront of Coastal Engineering research and practice. The market is still looking for sound alternatives to traditional solutions and geosynthetics can play a definitive role especially in areas of low-risk-management, where the capital at risk is not significant due to the non-existence of endangered important urban seafronts.

The benefits associated with the incorporation of synthetic fabrics in coastal protection works concern mainly their cost-effectiveness, as well as the fact that they can, wherever possible, slow down erosion with a limited and non-permanent impact on natural coastal processes. Despite the relevant benefits the application of synthetic products can provide over the use of more traditional materials such as concrete and rubble, there is still a long way of research and experiments to go through in terms of its use in Coastal Engineering, especially at more exposed hydraulic conditions, as it is in the Portuguese coastal zone.

Running since September 2005, GeoWAVE© aims to study the performance of geotextile sand-filled containers in dune erosion control systems, when submitted to extreme wave conditions. The study is based on the results obtained from model tests to be performed at two different scales, at the Faculty of Engineering of the University of Porto and at the University of Coruña; and field studies carried out in the Portuguese northwest coast, from which the model characteristics have been derived. This paper presents some of the research carried out under the GeoWAVE© project.

## FIELD STUDIES

### General characterization

As aforementioned, the model characteristics have been defined based on two case studies located on the Portuguese northwest coast where erosion control systems using geosynthetics were implemented. The first case study concerns an erosion control system of the dune ridge of Estela, municipality of Póvoa do Varzim. This dune ridge of ca. 3 km length is established along the northwest coast of Portugal, facing the North Atlantic. It is located at ca. 9 km to the north of the city harbour of Póvoa do Varzim and southern of the Protected Area of the Littoral Park of Esposende. The entire coast updrift the dune ridge of Estela is undergoing severe erosion mainly due to the shortage of sediment supply. The progressive weakening of nourishment from the updrift sediment sources is resulting in the progressive beach retreat, ultimately leading the sea to encroach upon the land; this has not yet occurred due to the protection provided by the existing coastal defences (das Neves *et al.*, 2005; das Neves, 2003).

The second case study is located further south at Leirosa beach municipality of Figueira da Foz. The installation of a pipeline which compelled the cut of the dune together with the progressive weakening of nourishment from the updrift sediment sources is resulting in the progressive exposure of the dune system to wave attack.

In both the sites, coastal morphodynamics is mainly shaped through wave action. Waves are indeed the dominant force, driving the littoral processes on this coast. Although the wave climate changes seasonally, it can be characterized by medium significant wave heights from 2 to 3 m, with periods ranging from 8 to 12 seconds (Veloso Gomes *et al.*, 2006; Veloso Gomes *et al.*, 2004). Seasonal storms, particularly between October and March can produce significant storm surges when they coincide with astronomical tides. Waves can reach heights of more than 8 m, with periods reaching 16 to 18 seconds (Veloso Gomes *et al.*, 2006; Veloso Gomes *et al.*, 2004). The tide amplitude from low to high water can range between 2 and 4 m at spring tides, twice a day due to the semidiurnal characteristics of the tide. Furthermore, local wave phenomena, especially refraction, diffraction, shoaling and also the bathymetry can influence tremendously local wave conditions.

Meteorological tides have little influence on water levels outside semi-enclosed, protected water bodies. Another important process is the littoral drift currents. Along the northwestern Portuguese coast, these currents have a dominant North-South direction, except local deviations due to specific hydrodynamic processes (e.g. near river mouths). The wind climate also affects coastal morphodynamics. Beyond its indirect influence on waves and currents it has also a direct effect on the formation of dunes. Sea currents end up having negligible importance when compared to the other actions involved (Veloso Gomes *et al.*, 2006; Veloso Gomes *et al.*, 2004).

**Coastal erosion driving forces**

Shorelines worldwide are eroding and re-shaping through various physical processes. Most shoreline changes are natural responses to these processes, either at a time scale of days (e.g. between tides) or of several years (e.g. global climate change). However natural, coastal morphodynamics is many times incompatible with the increase of human development along the coast (das Neves, 2008).

For many different reasons several coastal areas worldwide are doomed to undergo severe erosion. Indeed, even with coastal defences, many shore stretches have not yet reached equilibrium with the present littoral processes; thus both populations and economical assets are at risk. Driving forces have to be properly reviewed to describe what was done in the past, to understand critical factors, which are behind the present state of vulnerability, and to try to find solutions to mitigate coastal erosion processes in specific locations.

More and more, coastal populations are facing high risk situations, even in areas protected by coastal defences. Lessons learnt from the past show that in several places, the approaches to counteract coastal erosion provide only local solutions which do not address the underlying cause of erosion, namely the shortage of sediment supply. By disrupting longshore drift of sediment transport, beaches located further downdrift of hard constructions in many cases have been deprived of sediment and as a result suffered from increased erosion (European Commission, 2004).

Over the last decades, investment priorities concerned engineering interventions while the importance of developing preventive measures and policies were neglected. Although essential, these interventions have created a misperception of the problem: through the blind reliance on technical structures one forgets that without sediment supply nor natural rock protection, it is just a question of time before erosion starts (Veloso Gomes *et al.*, 2004).

Main erosion driving forces are related to damming, coastal defences, harbouring and related dredging activities. Other phenomena, such as climate change, including accelerated sea-level rise, can have influence in specific cases. Human development along the coast tends to exacerbate the consequences of falling river sediment discharges.

**What is at stake?**

The progressive weakening of nourishment from updrift sediment sources has driven to the progressive decreasing of beach width and consequent increase of the dune system vulnerability, once it is then submitted to the direct action of wave run-up. The importance of dune systems is usually linked to their relevance to the protection of the hinterland areas whilst performing as buffer zones between lowlands and the sea, avoiding the flooding of low lying coastal plains. This way, and without a reasonable expectation of a significant increase in the volume of sediments transport by the littoral drift currents, it is necessary to seek a medium to long term solution for the dune system preservation and consolidation.

**Figure 1.** Esmoriz and Cortegaça urban waterfronts, high risk erosion areas at the Portuguese northwest coast (photo: DRAOT, 2001)

## EROSION CONTROL SYSTEM AT ESTELA

### Solutions and measures in field

To slow down the erosion process affecting the dune of Estela a coastal erosion control system using sand-filled geotextile containers is being implemented since recent years. The effectiveness of this solution is though not yet satisfying. However, it has proven to have good potentialities even when submitted to severe wave conditions and it is believed that its effectiveness can be significantly increased if some technical improvements are incorporated into the solution.

An in-depth review and discussion on the interventions made to reinforce the dune ridge of Estela and on the factors which are driving current erosion trends on this coastal stretch, as well as the analysis of the undertaken monitoring campaigns, developed during the winter seasons of 2001/2002 and 2002/2003, of which a summary is presented hereafter, is given in das Neves (2003).

### Review of measures

First documented interventions in the dune ridge of Estela are date to April 1999, and consisted of the local reinforcement of the dune through mechanical sand replacement, which was later strengthened with woodpiles and very small bags (~50 N) filled with sand (Figure 2).

**Figure 2.** Dune consolidation with woodpiles and small bags full with sand, April 1999

Invariable spring tides or some severe storm resulted in the partial destruction of the dune system and thus from April 1999 on, several interventions of mechanical sand replacement of the dune had already taken place. The winter of 2000/2001 was particularly severe with a high sequence of storm episodes happening very close to each other. Though in general wave heights have not reached a return period higher than 10 years within this period, the persistence of storms generated a very unusual case of consecutive events that compelled the execution of emergency works for dune replacement several times within the period from November 2000 to January 2001.

December 2000 marks the beginning of the use of a new technique. The severe storms that had attacked the dune and had caused significant damages, since October, required the use of a new protection scheme. This new protection scheme was constructed with sand filled containers of ~1 $m^3$ which were placed on a sand core with a geotextile filter cloth underlay. Sand filled containers have been placed at the dune slope in sections of 350, 70 and 50 m length.

**Figure 3.** Sand bag used in the dune of Estela

**RESEARCH OBJECTIVES**

Arguably the hydraulic stability of coastal defence structures made of synthetic fabrics cannot be assure by means of the usual and far well-known formulations used for other materials, such as concrete units or rip-raps. Although significant research has been carried out in recent years, namely at the Leichtwei$\beta$ Institute in Germany and at GeoDelft in The Netherlands, there is still knowledge lacking concerning the incorporation of geosynthetics in coastal protection works. For some specific structural conditions design recommendations have been derived; however, their extrapolation beyond that range is rather risky.

GeoWAVE© aims at identifying the most relevant parameters and processes in the hydraulic performance and stability of sand filled geotextile containers when submitted to extreme wave conditions; identifying most heavily loaded parts of the structure; assessing scale effects; assessing the potential impact of wave reflection to the structure toe and stability of the foundation. The study is based on the results obtained from model tests to be performed at two different scales, at the Faculty of Engineering of the University of Porto and at the University of Coruña; and field studies carried out in the Portuguese northwest coast, from which the model characteristics have been derived.

The experimental stability analysis of geotextile sand-filled containers in the frame of GeoWAVE© project should result in some recommendations to assess the potentialities of the implementation of this type of coastal defences at more exposed hydraulic conditions.

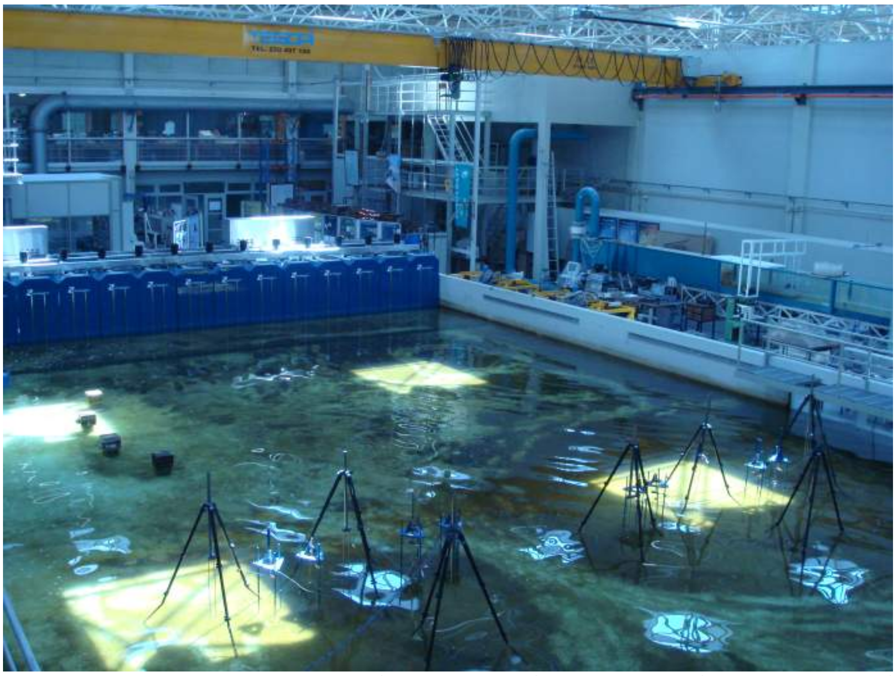

**Figure 4.** Hydraulics Laboratory of the Faculty of Engineering of the University of Porto (28X12X1.0 $m^3$)

**Figure 5.** Wave flume of the Centre of Technology Innovation in Building and Civil Engineering (CITEEC) of the University of Coruña (70x3x3 $m^3$)

**Physical modelling**

The type of model used is a suspension-dominated model. Sediment transport in some coastal regimes is typified by high levels of turbulent water motions that lift the sediment grains up into the water column where they are moved by water currents in the suspended mode of transport. Capability to model turbulence-dominated suspended mode of sediment transport in a physical model is important because this mode is associated with beach erosion, deposition, scour, and other coastal engineering problems resulting from storms or energetic wave action (Hughes, 1993).

As much as possible, mean sediment characteristics of Estela and Leirosa will be reproduced in the physical experiments. Samples have been collected at those beaches; several parameters were determined in laboratory and will be used in the sediment modelling process. For a geometrically undistorted movable-bed model, the prototype-to-model scale relationships would be: grain size Reynolds number criterion; mobility number criterion; relative sediment density criterion; relative length criterion; and relative fall speed criterion. It is however impossible to satisfy all of the former scaling criteria (Hughes, 1993).

The dissimilarities between the prototype and the model lead to “scale effects”. In order to properly quantify the potential impact of those “scale effects” in the results achieved through the physical model experiments, the research programme will be carried out with models built on two different scales: 1:15 at the Laboratory of Hydraulics of the Faculty of Engineering of the University of Porto – Portugal; 1:4 at the Centre of Technology Innovation in Building and Civil Engineering (CITEEC) of the University of Coruña – Spain. The comparison of results allows having an idea of the magnitude of scale effects.

**CONCLUSIONS**

This paper has summarized some of the key aspects of the GeoWAVE© project on the performance of geotextile sand-filled containers in dune erosion control systems, when submitted to extreme wave conditions. The study is based on the results obtained from model tests and field studies carried out in the Portuguese northwest coast.

The experimental stability analysis of geotextile sand-filled containers in the frame of GeoWAVE© project should result in some recommendations to assess the potentialities of the implementation of this type of coastal defences at more exposed hydraulic conditions.

**Acknowledgements:** GeoWAVE© is being funded by the Portuguese Science and Technology Foundation (FCT) through the POCI/FEDER programme (project reference: POCI/ECM/60807/2004).

FCT Fundação para a Ciência e a Tecnologia
MINISTÉRIO DA CIÊNCIA, TECNOLOGIA E ENSINO SUPERIOR

EU FEDER Governo da República Portuguesa

Luciana das Neves has a PhD grant from the Portuguese Science and Technology Foundation (SFRH/BD/22626/2005). The authors would also like to acknowledge the University of Coruña, for making available the facilities of the Centre of Technology Innovation in Building and Civil Engineering (CITEEC) to perform the higher scale tests.

**Corresponding author:** Miss Luciana das Neves, Faculty of Engineering, University of Porto, Hydraulics and Water Resources Institute, Rua Dr. Roberto Frias, Porto, 4200-465, Portugal. Tel: +351 22 5081924. Email: lpneves@fe.up.pt.

**REFERENCES**

das Neves, L. 2003. Geosystems and Geosynthetics in Coastal Engineering. MSc Thesis (in Portuguese), 206pp., Faculdade de Engenharia da Universidade do Porto. Porto, Portugal.

das Neves, L., Garcia, S.; Lopes, M.L., Veloso Gomes, F. & Taveira Pinto, F. 2008. Decision Support System for Incorporating Geosynthetics in Coastal Protection Works, COPEDEC VII, 2008, Dubai, UAE, P085 D-096, 11pp. (cd).

das Neves, L., Veloso-Gomes, F. & Lopes, M.L. 2005. Coastal Erosion Control Using Sand-Filled Geotextile Containers: A Case Study from the NW Coast of Portugal. ICCE2004, Proceedings of the 29th International Conference Coastal Engineering (ed. Jane McKee Smith), World Scientific, Volume 4, pp. 3852-3864. ISBN 981-256-994-4.

European Commission 2004. Living with Coastal Erosion - Sediment and Space for Sustainability. Office of Official Publications of the European Communities, Luxembourg, 40pp. ISBN 92-894-7496-3.

Hughes, S.A. 1993. Physical Models and Laboratory Techniques in Coastal Engineering, Advanced Series on Ocean Engineering, Vol.7, World Scientific, Singapore, ISBN: 981-02-1541-X.

Oumeraci, H., Hinz, M., Bleck, M. & Kübler, S. 2002. Großmaßstäbliche Untersuchungen zur hydraulischen Stabilität geotextiler Sandcontainer unter Wellenbelastung. LIW – TUB, Nr. 878, Braunschweig, Germany, unpublished (in German).

Pilarczyck, K.W. 2000. Geosynthetics and Geosystems in Hydraulics and Coastal Engineering. A.A. Balkema Publications, Rotterdam. ISBN 90 5809 302 6.

Veloso-Gomes, F., Taveira-Pinto, F., das Neves, L. & Barbosa, J.P. 2006. EUrosion - A European Initiative for Sustainable Coastal Erosion. Pilot Site of River Douro - Cape Mondego and Case Studies of Estela, Aveiro, Caparica, Vale do Lobo and Azores, 317 pp. ISBN 972-752-074-x.

Veloso-Gomes, F., Taveira-Pinto, F., das Neves, L., Barbosa, J.P. & Coelho C. 2004. Erosion Risk Levels at the NW Portuguese Coast: the Douro Mouth - Cape Mondego Stretch, Journal of Coastal Conservation, Volume 10: 1-2, December 2004, OpulusPress, ISSN 1400-0350, pp.43-52.