SAND FILLED CONTAINERS IN DUNE EROSION CONTROL A CASE STUDY FROM THE NW COAST OF PORTUGAL

L. das Neves, F. V. Gomes
Faculdade de Engenharia da Universidade do Porto Hydraulics and Water Resources Institute

R. Silvano, M. L. Lopes
Faculdade de Engenharia da Universidade do Porto, Porto, Portugal

ABSTRACT: The whole Northwest coast of Portugal is undergoing a severe erosion process and there are several areas at high risk of erosion. Some of those areas were already submitted to coastal engineering interventions, using mainly groynes and/or seawalls made of big rock and/or concrete units, sometimes complemented with artificial sand nourishment. The long term effectiveness of these interventions is, however, questionable, since in many cases they have failed to address the underlying cause of erosion and have accelerated the erosion problems downdrift the protected areas. The case study in analysis reports on a dune erosion control system in Estela, municipality of Póvoa do Varzim. In this case – and for the first time in Portugal – a soft coastal engineering solution constructed with geosynthetics was tried with the objective of slowing down the ongoing process of erosion. A summary review of its main aspects will be presented throughout this paper.

1 INTRODUCTION

The whole Northwest coast of Portugal is undergoing a severe erosion process. On certain locations, there are several houses very exposed to the attacks of the sea, which has led national authorities to protect a significant part of the shoreline with coastal defences.

However, in spite of the undertaken protection measures, the long term effectiveness of these coastal defence strategies is in many cases questionable. Indeed, they generally provide very local solutions to erosion and fail to address its underlying cause (shortage of sediment supply). Designed with a focus only on the protection of specific assets invested along the coast, the built coastal protections have often accelerated the erosion problems downdrift the protected areas. Although essential, considering the risk some areas are currently facing, these works have in many cases shifted erosion problems to other locations.

Hence, erosion is still an ongoing problem, with many (and) important consequences, despite the engineering interventions. To some extent, coastal erosion can be considered as a natural process by which a natural equilibrium is restored after some kind of disruption of sediment transport processes. This can be caused either by sediment trapping or extraction and may result in sediment deficit downdrift and thus, in erosion. Damming, coastal defences, harbours and related dredging activities are among the most influential factors on the evolution of current erosion trends.

Lessons learnt from past experiences show that indirect and cumulative causes and effects, related with a very limited understanding of coastal processes and dynamics, are the origin of coastal erosion problems. In many cases, while protecting a very limited stretch of the shoreline, mostly using groynes and seawalls, other problems were created a few kilometres away. Moreover, less attention was paid to the protection of the buffer zones (e.g. dunes) 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.

More recently, with the approval of the Coastal Zone Management Plans and following some European guidelines on integrated coastal zone management, several changes on coastal defence and coastal management strategies have been launched. Special attention was paid in correcting the existent problems and preventing new ones, namely through the delimitation of coastal land uses and the preservation of dune systems.

The study case in analysis reports on a dune erosion control system in Estela, municipality of Póvoa do Varzim, located at approximately 9 km North from the city harbour and right away South of the Protected Area of the Littoral Park of Esposende (Figure 1). This dune system is established along the NW coast of Portugal, faces the Atlantic Ocean and has approximately 3 km length.

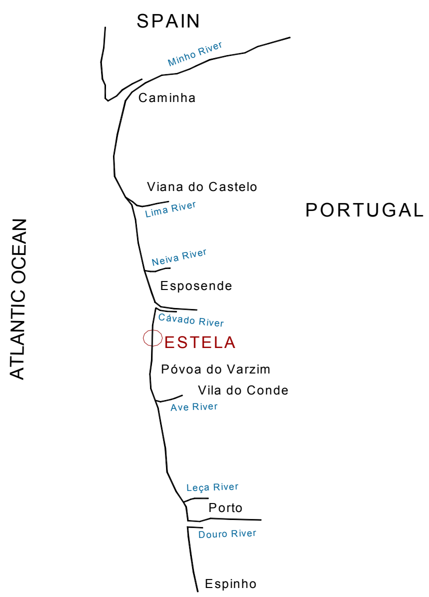

Figure 1 Location of the dune system of Estela.

To slow down the erosion process affecting the dune system of Estela a dune restoration system is being implemented since recent years, using soft coastal engineering techniques. 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 coastal engineering interventions made to reinforce the dune system 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 campaign, developed during the last two winter seasons, were included into this research and a summary review of its main aspects will be presented throughout this paper.

2 PROBLEM DESCRIPTION

The whole coast updrift the dune system of Estela is undergoing severe erosion. 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 this dune system in the wider context of the hinterland areas is considerable: it protects a golf course green, which is an important facility for tourism and also constitutes a buffer zone 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.

2.1 *Description of the eroded sites*

The first documented interventions in the dunar system of Estela are date to April 1999. However, on the first letter sent to the Ministry of Environment – Regional Directorate for Environment and Natural Resources regarding the licensing of the interventions in the dunar system, it was referred that there had been made some dune reinforcement by sand ripping, as it can be seen through the aerial survey of 24th June 1997 (Figure 2).

Photos: F. Piqueiro.

Figure 2 Mechanical sand ripping.

The referred letter was accompanied by a technical report from the Hydraulics and Water Resources Institute (IHRH) of the Faculty of Engineering of the University of Porto (FEUP) where it was stated that as a result of the decrease in the volume of sediments transport by the North/South littoral drift currents, with the consequent decrease in the beach width, the dune system of Estela was being furthermore submitted to the direct action of wave run-up (IHRH, 1997).

As a consequence of this direct wave action, the dune system was becoming more and more fragile. This state of fragility was particularly visible in the decrease on the beach width and dunes and the coming in sight of dune erosion cliffs. At the time of the 1997's aerial survey there were two stretches of the dune where the erosion was more critical (Figure 3).

Photos: F. Piqueiro.

Figure 3 Critical erosion zones.

The two designated stretches correspond to holes 5 at North (top), assigned has critical zone 1 (CZ1) and 13 at South (bottom), assigned has critical zone 2 (CZ2). The dune restoration interventions are taking place in these two stretches and will be discussed more ahead in this paper.

2.2 *Review of measures*

The first documented intervention to the dune system of Estela dates from 1 to 12 April 1999. This intervention consisted of the local reinforcement of the dune through mechanical sand replacement. This replacement was later strengthened with woodpiles and very small bags (~50 N) full with sand (Figure 4). The same intervention was made in critical zones 1 and 2.

Figure 4 Dune consolidation with woodpiles and small bags full with sand, April 1999.

It was still in October 1999 that a new reinforcement intervention using the same technique was necessary, but at this time only in critical zone 1. Figure 5 shows the aspect of the dune before this intervention. As it can be observed, its state was of an advanced degradation, being the limit of the eroded dune very close to the golf course fence. Before the end of the 1999/2000 winter season it was necessary to proceed with two more interventions, one in January and the other one in March.

Figure 5 Aspect of the dune in CZ1, October 1999.

The 5th intervention in CZ1 took place in October 2000 after the spring tides of September, which had resulted in the partial destruction of the dune system. Once more it was necessary to carry on with mechanical sand replacement of the dune. The 2nd intervention in CZ2, still using the same technique, was only necessary in November 2000. At this time, already 5 interventions had been made in CZ1, and yet another one would be made.

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, both in CZ1 and CZ2.

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 (Figure 6). 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. As observed in Figure 7, sand filled containers have been placed at the dune slope in sections of 350, 70 and 50 m length. Figure 8 shows some aspects of the execution of this technical solution – forming the dune platform trough sand ripping, placing and anchoring the geotextile filter cloth and settling the sand containers.

Figure 6 Aspect of the dune in CZ1, November 2000.

In October and December 2001 and May 2002 new sand containers were placed along the dune slope without installing the geotextile filter used in the previous intervention. Similar reinforcements were necessary during the winter of 2002/2003.

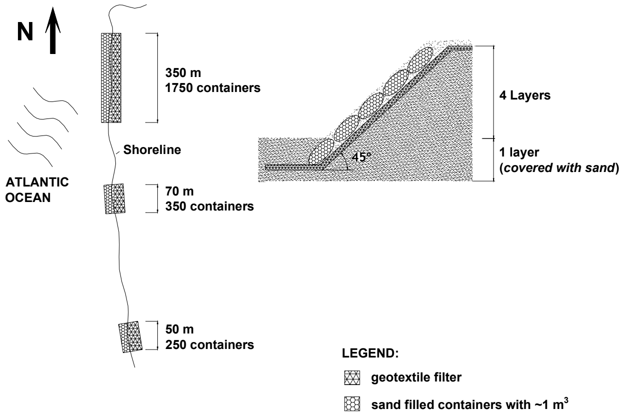

Figure 7 Protection scheme of the 7th intervention in CZ1, December 2000.

Figure 8 Construction sequence of the installation of the geotextile sand containers, December 2000.

2.3 *Effects of measures*

The measures taken so far to control the ongoing erosion process in the dune system of Estela can be classified as rather ineffective, in a medium to long term basis. Nevertheless, this last protection scheme constructed with geotextile sand filled containers is keeping the dune erosion within certain limits, even when submitted to severe wave conditions (Figure 9), and thus, it is reasonable to expect that some improvements at the level of materials and design will enhance its effectiveness.

Figure 9 Aspect of the dune in CZ1, January 2003.

Indeed, when comparing the state of damages caused by similar wave climate conditions to the dune (Figures 5, 6 and 9) one can easily conclude that these are much less when the dune is strengthened with sand filled containers.

Regarding the hinterland areas, this soft protection has achieved the goal of limiting sea invasion to the golf course green and thus, the risk of flooding of the adjacent low lying agricultural plains. This is a very important achievement, not as much in the sense preservation of assets - once the capital at risk is not high due to the inexistence of houses although the golf course represents an important source of tourism revenues - but especially for the perspectives it opens in terms of the possibility of using this type of coastal defences with more exposed hydraulic conditions.

3 TECHNICAL CONSIDERATIONS

After the monitoring campaign undertaken in the last two winter seasons in the dune system of Estela it was possible to make some remarks about the feasibility of using this type of soft coastal defences in Portugal. Although in its early stages, this research as so far demonstrated that this new type of protection schemes might, in specific cases, play an important role in coastal erosion control. In the following sections some technical considerations about the solution currently in use at Estela will be discussed. At the end, the solution which will be incorporated in the next stage of this research will also be presented. This stage corresponds to the set-up of a pilot project in Estela to be monitored during this winter.

3.1 *Geotextile characteristics*

The geobag currently in use at Estela is a woven geotextile manufactured from polypropylene fibres. Its dimensions are 0.96x0.96x1.50 m^3 widthxlengthxheigth of which corresponds a volume fill of approximately 1.00 m^3 (Figure 10).

Figure 10 Geobag currently use in the strengthening of the dune of Estela.

Mechanical characterization tests to this geobag were carried on in the Geosynthetics Laboratory of the Faculty of Engineering of the University of Porto. The results of these tests show that this material has good strength properties. However, and even though hydraulic characterization tests have not been made, it is possible to say, just through the observation of the geobag, that it is practically impermeable, thus not the most suitable for this application since it does not favours the release of pressure that is generated by wave flow. The friction behaviour of the material is also inadequate for the application once it does not promote the behaviour of the structure as one, enhancing its overall stability.

All in all - considering strength, hydraulic and friction properties - one can conclude that if better structural performance is to be achieved then the type of material of which the sand filled container is made has to be changed. At this purpose is possible to find many documents published on the advantages of using geotextile sand filled containers made of needle-punched non-wovens. These are related not only to the good hydraulic properties but also for its elongation and friction behaviour.

In Heerten *et al.* (2000) and Heibaum (1994) an important discussion about the use of woven or non-woven geotextiles in sand containers is discussed. These authors refer that woven fabrics have the advantage of a high tensile strength; however, they perform like a sieve and not like a grain filter with a 3D pore spectrum. When, in addition, wheft and wharp are not fixed at their crossing points, the danger of shifting is given so that larger openings appear which do not grant that the soil is retained at this spot. A non-woven fabric offers as a filtration length the pore-spectrum of a 3D labyrinth which makes it possible that flow processes appear in the filter in their dimension. A sufficient strength can – by means of today's technique – also be achieved with non-woven fabrics.

The function of the underlying geotextile filter cloth is filtration, separation and increase of friction in the interface avoiding bags to slide along the slope. The geotextile used in the 7^{th} intervention in the CZ1 is a commonly used geotextile in filtration but its properties are not suitable for this application. This way, its non-application in the following interventions did not affect the effectiveness of the coastal protection.

3.2 *Structural behaviour*

The coastal protection of the dune system of Estela should work by gravity through its weight and in a lower degree, by the mobilized friction. This way, the unit weight of the bags and its positioning, are essential in the overall stability of the structure.

For traditional coastal defences design, the weight unit is determined using Hudson's empirical formula:

$$W = \frac{\gamma_r H^3}{K_D \left(\frac{\gamma_r}{\gamma_w} - 1\right)^3 \cot g\alpha} \qquad (1)$$

where, W is the block weight [KN], γ_r is the volume weight of the material of the block [KN/m^3], H design wave height [m], γ_w is the volume weight of sea water [KN/m^3], K_D is na empirical coefficient and α is the slope angle with the horizontal. The results obtained with this formula are included in Table 1.

Table 1 Weights determined using Hudson's formula.

Considering: α = 45º , H_s = 2 m and γ_r = 20 kN/m^3	
K_D	**W**
2	80 KN
3	53 KN
5	32 KN

The use of this formula to this type of structure is though very arguable. There is not sufficient information to establish γ_r and the stability coefficient, K_D, and thus the values of weight presented must be considered only as an estimative. Nevertheless, to obtain for instance a bag with an approximately unit weight of 30 kN it would be necessary at least a bag of 1.5 m^3 volume fill. More research is need in this field.

The probable mechanism of failure of this coastal protection is the sliding of bags along the dune slope, has indicated in Figure 11. This way it is most important to intervene in order to keep the bags in position allowing only very small movements.

Figure 11 Probable mechanism of failure.

This sliding has though the positive effect of creating a wave breaking berm, because the bags remain buried in the frontal beach, which allows the dissipation of some wave energy before it reaches the dune. Nevertheless, the structure is in fail so it is necessary to proceed with replacement works of the washed way sand. The frequency of these works is related with the occurrence of storm surges and this is why it is necessary to seek other solutions with higher longevity.

3.3 *Proposed solution*

Before presenting the proposed solution it is important to refer that the erosion caused by a shortage of sediment supply in a sandy beach is, in the majority of the cases, impossible to be controlled only using one type of structure. Hence, in the following stages of this research, the hypothesis of using an active coastal protection (e.g. a temporary groyne in the South limit of the dune or a submerged breakwater made of geotextile sand containers) will be investigated. The feasibility of implementing this active coastal protection depends also on the current legislation and policies.

Figure 12 shows the layout of the proposed solution for the strengthening of the dune system of Estela. This layout was developed on the basis of past experiences with the use of geotextile sand filled containers, developed worldwide. In particular, the following design aspects should be taken into account:

- non-woven geotextile sand container instead of a woven one;
- careful design of the underlying geotextile sheet used as filter;
- the containers should be placed preferably with the long side perpendicularly to the shoreline;
- the containers should be placed like brickets in layers with a beach slope of about 1:1;
- the lowest layer should be placed beneath to the existing mean water level (at least one layer);
- the top layers should be placed above the maximum design water level (above 0.50 m freeboard);
- a sand trap fence should be placed again to keep the golf course free of sand.

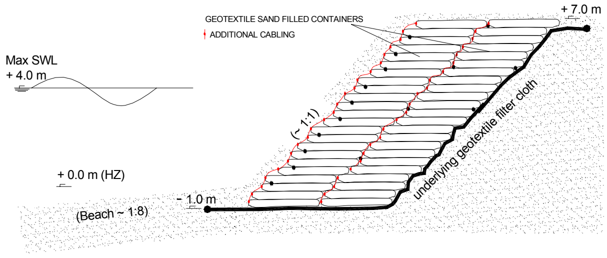

Figure 12 Layout of the proposed solution.

Regarding the geotextile sand filled containers they should be made of a needle-punched non-woven and provide a minimum volume fill of 1.5 m^3 for 80% of fill rate. Their characteristics must be established considering local hydrodynamic conditions and the grain size of the fill material. The characteristics of the underlying geotextile filter cloth must be made compatible with the ones of the containers.

Considering the undertaken monitoring to the dune system of Estela is reasonable to have some good expectations about the effectiveness of this enhanced design in a medium term. Even so, the high level of wave energy that occurs in the West Portuguese coast requires prudence even with the improvements introduced. Nevertheless, and although this type of solutions is normally recommended for mild wave climates, there is not, at this moment, any evidence showing that this solution cannot behave well and thus, is important to set-up this pilot project and carry on with postproject monitoring. The information gathered from this experimental station will be a step forward on the knowledge of the hydraulic performance and stability of dune protection systems constructed with sand filled containers.

4 CONCLUSIONS

Soft coastal engineering solutions using sand filled containers can provide significant advantages over more traditional coastal defences made of concrete or rocks. The option for this type of coastal defences described in this paper is not only an example of an innovative coastal protection scheme, but also and especially an example where the option made corresponds to the most sustainable solution considering the low-risk-management of the area. These soft techniques are quite cost-effective and can, wherever possible, slow down the erosion process with a limited and non-permanent impact on natural coastal processes.

This pioneer case study is a good opportunity to experiment the use of this type of solutions and improve the knowledge on the hydraulic performance and stability of this type of structures at more exposed conditions. Its added value will be a positive contribution to better understand the behaviour of these structures under severe wave attack and to obtain more reliable design recommendations. The structure will be submitted to one of the most energetic wave climates worldwide and, at this moment, its medium term performance is unknown and unpredictable. Nevertheless, through the undertaken monitoring it is possible to have some good expectations about it.

The application of sand filled containers in coastal engineering in cases as the one described in this paper has clearly from start many advantages which must be considered. The lack of knowledge about the application and performance of geosynthetics in coastal engineering, especially at more exposed hydraulic conditions, makes people to neglect and misbelieve the potentialities of this kind of solutions, thus not being treated as a serious alternative to the traditional solutions. However, they have both their fields of application.

The study case of Estela represents one of those cases. Indeed, a hard solution using rock stones or concrete units does not meet the coastal defence strategy goals for this coastal stretch and is completely out of question. This way, there are only two possible options: to try using a soft coastal engineering solution or to re-settle the threatened assets into more hinterland areas. Both hypotheses are being considered and if the medium-long term performance of this coastal protection scheme turns out to be not feasible, the golf course will most certainly be re-settled. Its importance as a buffer zone to avoid the flooding of low lying coastal plains and its tourism importance, as well as the good indicators so far gotten, forces the prosecution of this research.

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