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Ofir spit (Portugal): an assessment of geotubes performance in coastal protection

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ABSTRACT: The Ofir spit is located at the estuary of Cavado River (NW coast of Portugal), and is the natural protection of Esposende city, ensuring also the navigability of the river and preventing from the maritime invasion of its estuary or the flooding of the riverine part of that city. It has been subjected to the actions of nature, especially from the Atlantic Ocean, known for its energetic regime and, more recently, those of human activities. Considering that, in Portugal, the use of geosynthetics on coastal protection is not yet a usual solution, it is relevant to investigate it, especially in this case of high-energy wave agitation. The paper presents a summary on the interventions conducted to the sandbank along time, it refers also the solution implemented as well as the monitoring campaign conducted after December 2015, discussing its results and the viability of the structure itself as a permanent solution.

1. INTRODUCTION

Coastal erosion can be defined as the continued retreat of the coastline in time. The coastal dynamics, e.g. the advance and retreat of the coastline, is a natural phenomenon that has always existed and that allowed, over time, to model the coast to its current shape.

However, in addition to the natural causes, nowadays there are the anthropogenic ones, such as: dredging of rivers bars, reducing the flow of rivers through dams construction, degradation of dunes, land use, etc.

The Portuguese costal territory concentrates most of its population, infrastructures and economic activities. The continuous growth of construction near the coastal area increased the exposure to potentially hazardous damages. Given that the erosion's causes cannot be eliminated, and that the increased vulnerability to hazards does not prevent people from settling on the coast, it is necessary to adopt measures that ensure the safety of goods and people without disregarding the sustainable development of coastal areas.

A coastal defence structure can be defined as being a total or partial intervention by man on the coastal or marine environment concerning the protection or recovery of natural systems - sand, dunes, beaches or wetlands; or construction's protection - buildings or infrastructures (Morais, 2010).

Regarding the selection of the type of structure for coastal protection, many factors are preponderant, not only those related to the implementation site of features but also, according to CIRIA (2007 cited in Marinho 2013), the function to which the construction work was designed, the policy planning for the coastal line, relations with adjacent coasts areas and the environmental impact caused by the construction.

Conventional coastal protection infrastructures including groins, breakwaters, seawalls or others have been built using materials as cement, rocks or wood, known as hard, expensive and environment "unfriendly" materials.

The environmental awareness that has occurred since the last decades of the 20th century and the limitation on rock sources led to a search for alternative materials. Recently there has been everywhere an increased use of geosynthetic materials in coastal engineering. Considering that, in Portugal, the use of geosynthetics on coastal protection is not yet a usual solution; it is relevant to investigate it, especially in the case presented hereafter, near the town of Esposende - Figure 1, a high-energy wave agitation coast located in the northwest of the country.

Figure 1. Esposende, NW of Portugal, and Ofir spit at Cavado River mouth (41°32'29.89"N 8°47'32.35"W), with the study area in red (Google Earth)

This paper presents a summary on the interventions conducted to the Ofir spit along time, a sandbar stretching north-south located immediately south of Cavado River mouth (Figure 1); it refers also the solution implemented as well as the monitoring campaign conducted during construction in 2015, discussing its results and the viability of the structure itself as a permanent solution.

2. GENERAL CONSIDERATIONS ON GEOSYSTEMS

According to the International Society of Geosynthetics (IGS), a geosynthetic is a polymeric material, natural or synthetic, used in contact with natural materials, as soil or rock, or any other material used in civil engineering applications.

Although they are relatively recent materials, it is understood that they had a significant development mainly due to the arrival of a large range of products whose properties came as an answer to a series of difficult situations presenting, when compared to conventional materials, the same quality as material for construction, fastness and simplicity of application and low cost.

The raw material of excellence in geosynthetics is plastic, a synthetic organic material obtained from oil. They are organic, synthetic and polymeric materials formed by chemical reactions.

The possibilities for incorporation of geosynthetic materials in engineering projects are vast and they may play effectively, individually or together, functions like filtering, drainage, separation, protection, reinforcement, among others.

In the scope of this paper, geosystems are an important group of geosynthetics frequently used in coastal protection works. To facilitate the distinction between structures, it is used the term geosystems comprehensively when referring to geotubes, geocontainers and geobags in general.

Geosystems used in marine hydraulic consist in sediments confined by geosynthetics that can be used as substitutes for rubble mound and/or artificial concrete blocks conventionally used (Morais, 2010). In fact, geosynthetic fabrics, composed mainly of polymers of polypropylene (Koffler et al., 2008), are used to confine soils with many applications particularly in coastal protection.

2.1 Geotubes

A geotube is a tubular structure composed by an extremely resistant geosynthetic wrapper filled by sediments, by hydraulic pump. The sand is the favourite filling material due to its incompressibility (Koffler, et al., 2008). This structure is built on the site and filled in its final position. This way its dimensions are only limited to the project's criteria, not being necessary any transport or placement mechanisms.

The geosynthetic used in the wrapper is porous in a way to retain the injected material, however, and due to its high permeability, allows the water evacuation during the pumping phase. In addition, both the used geosynthetic and the seams are highly resistant to withstand the stresses during the filling and maintain its geometric form.

Morais (2010) considers that the application of these systems is ideal for surface or, in cases of submersion, to a maximum of 5 m of depth. It also points out that the soil capacity per linear meter of geotube varies between 2 and 10 m³.

2.2 Geocontainer

This is a distinctive type of geosystem due to its larger dimensions. Like the name suggests, it contains a greater volume of aggregates or drained soil.

It is usual to use this component in submerged applications over 5 m of depth, being the only restriction in terms of dimensions that of the split bottom hopper barge that are used to transport and position the geocontainer. Its filling can be accomplished through pumping or mechanically.

The geosynthetic used for the wrapper needs to resist to the demands of both the infilling and the installation.

According to Koffler et al. (2008), the installation is phased. First, the wrapper is placed on the barge's deck. Then the barge is filled with the material that will be contained by the geocontainer and is stitched with a high resistance thread. Finally, the barge is positioned on the site where the geocontainer is going to remain and the hull opens, sinking the geocontainer in its final position.

2.3 Geobags

Geobags are geosynthetic elements of large dimensions and filled usually with sandy material. Normally are customized to meet the project's requirements and installation, being provided in various forms and dimensions - Figure 2.

According to Morais (2010), these are the geosystems with smaller dimensions with each unit containing between 1 to 10m³ of soil.

The filling is held in a place near the structure, by mechanical means or pumping, and are further positioned by equipment that allow its lifting in what will be its final position that can either be on the surface or submerged, at any depth.

Figure 2. Placing of a geobag (Morais, 2010)

3. OFIR'S SPIT BACKGROUND

The Ofir spit, located at the estuary of Cavado River - Figure 1, is the natural protection for the urban front of Esposende city and for the navigability of the river, preventing it from the maritime invasion as well as the flooding of the riverine part of the city.

The estuary of the river Cavado - Figure 1, presents an artificialized right bank, due to the existence of a vast area of port infrastructure, fishing, sailing and shipbuilding.

In the west bank, the estuary is separated from the sea by a spit, nearly 2100 m long and with variable width, upstream of which there is a main marshy area. In this area, there are three coastal infrastructures that influence the development of the coastline: to north, the breakwater on the right bank of the mouth of the Cavado River; the groin of the sandbank and Ofir's groin, approximately 1.5 km south of the tip of the spit - Figure 1.

The spit responds to the actions of both river and sea with natural changes to its morphology. It is a natural sandbar that resulted from the evolution of the Portuguese coast in the last five centuries, namely the advance of Cavado River estuary (Figure 1) and, on top of it, the progression of dune cords. These ones have been suffering significant marine erosion, especially since the beginning of the XXI century, but it was also detected some erosion on the riverside.

A series of sand nourishment operations were implemented throughout the years, between 1994 and 2006 (Table 1).

Figure 3 shows the results after the first nourishment and before the first maritime winter.

Table 1 Volumes of sand nourishment at Ofir spit over the years (Polis, 2013)

Year	Volume or area of sand nourishment	Observations
1994	105,000 m^3	Spit's height elevated to + 9m
1998	300 ha	Spit's height elevated to + 10,5 m
2001	15,000 m^3	-
2006	112,000 m^3	Spit's height elevated to + 6 m

After an important storm in January 2013, there was a significant alteration on the spit - Figure 4, with its head separated from the main body and the river mouth segmented in two.

Figure 3. General view of the spit in 1995 after the artificial sand nourishment of 1994 (Polis Litoral Norte, 2013)

Figure 4. The spit along the ocean, after a storm in January 2013; view to south (Polis Litoral Norte, 2013)

Its weaknesses lead already to a rupture and the need of artificial nourishment at its northern tip.

Figure 5 displays the last survey made in November 2011, before it was decided to design a solution with geosynthetics to maintain and reinforce the dune cord at the sandbar. The main body of the spit it is at +9 m, although its head is approximately at + 5 m.

4. A SOLUTION USING GEOSYSTEMS

Solutions of coastal protection using geosynthetics are relatively new. And not without a certain degree of uncertainty, especially due to their dimensioning, since it is usually empirical and/or complemented by experimental models.

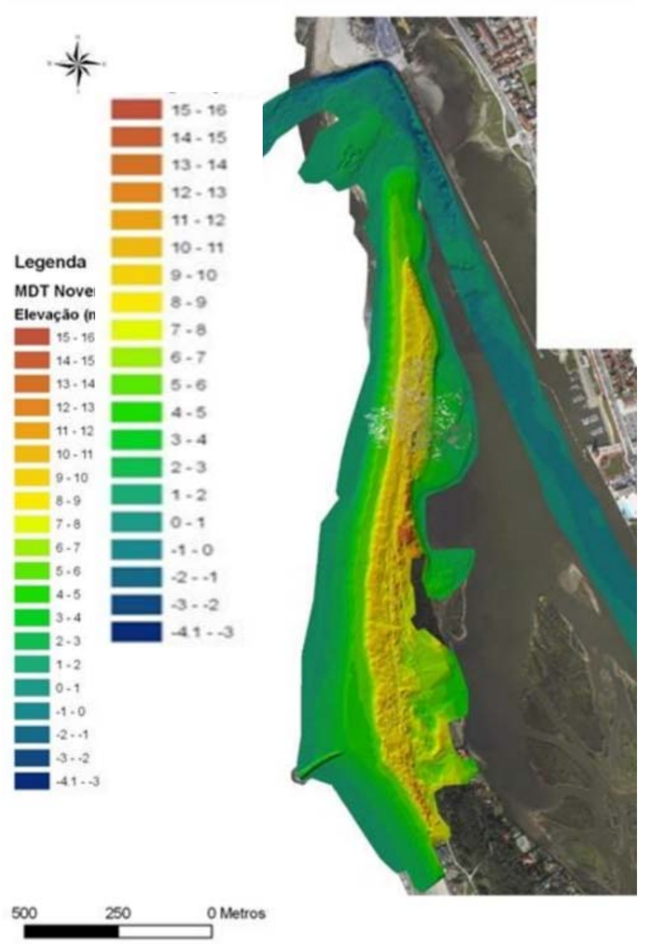

Figure 5. The last DEM – elevation in meters, of the area using a survey from November of 2011 (Polis Litoral Norte, 2013)

Furthermore, a solution of this type using geosynthetics in Portugal it is pioneer.

The solution adopted for the target area had the following characteristics - Figures 6 and 7:

- Maximum crowning height of + 9.1 m and width of 50 m - Figure 7;
- The ocean slope with a gradient of 1(V):2(H), and the one by the riverside with 1(V):2(H) and 1(V):1.5(H);
- Exploration of a borrow area in the Cavado River - Figure 7, in order to dredge sand and artificially nourish the spit area, to build the embankment core protected by the geotubes;
- The geotubes are placed empty on site and filled by hydraulic pumping, from the same borrow area, with water-sand mixture through openings located in the upper part. Usually they are filled until 80% of its capacity;
- The main aim is to connect the actual body of the spit to the sandbank which lies to the north of it, causing an increase of speed in the terminal stretch of the Cavado River, thus contributing to a smaller siltation of this area.

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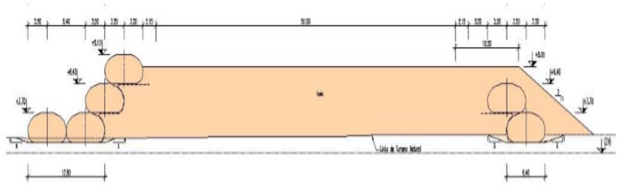

Figure 6. Profile of the project, view to north, with the ocean on the left and the river on the right side; the crest is elevated at +9.1 m and +8.0 m, respectively at ocean and at river (Polis Litoral Norte, 2013)

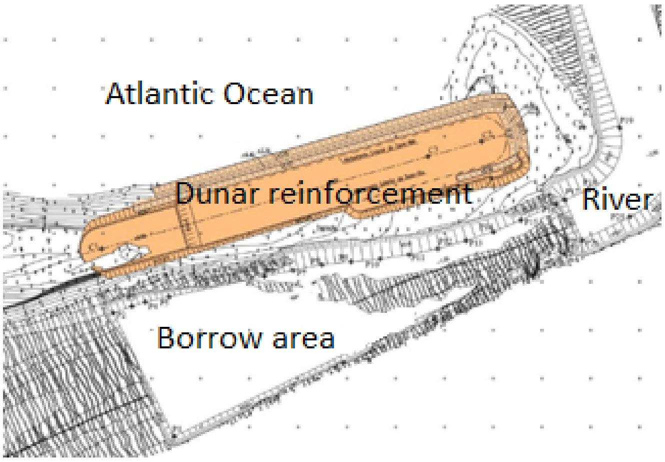

Figure 7. Overview of the intervention area (in orange), circa 400 m x 100 m, on a topographic survey; the spit, as well as the geotubes, are aligned in south-north direction (Polis Litoral Norte, 2013).

For the dimensioning of the geosystems, the published formulae on hydraulic stability were used (Polis Litoral Norte, 2013):

- Wouters (1998 cited in Polis Litoral Norte, 2013), developed for geocontainers;
- Oumeraci et al. (2002 cited in Polis Litoral Norte, 2013), developed also for geocontainers;
- van Steeg and Vastengurg (2010 cited in Polis Litoral Norte, 2013), developed using an experimental model.
- In order to contain the artificial nourishment sands for longer, 49 geotubes, with a diameter of 5 m and a length of 50 m, were placed to reinforce the spit, as follows:
- By the oceanside, three rows of geotubes until + 9.1 m, and the rows staggered in plant – Figure 6 and 7;
- By the riverside, two rows of geotubes until + 6.4m;
- The bottom row of the geotubes contains a protective foot slope consisting of a geotextile as a scour apron; this one also connects a geotube from the lowest row to another geotube with 5 m in diameter on the oceanside.

The geotubes used, of high resistance as they must resist the wave's solicitations, and having a large diameter, are made of a woven polypropylene material and were hydraulically filled with a mixture of sand and water.

The geotubes placed along Cavado River were covered with sand, to not introduce an artificial element in the landscape.

The construction work begun in June 2015 and ended November 2015 – Figure 8.

Figure 8. Overview to north along the ocean of the staggered geotubes

5. PROBLEMATIC ISSUES

As mentioned previously, the design of this geosystem was mainly empirical. Porto (2013) conducted a small scale model test of the solution adopted, but although the geotubes arrangement tested was the same, the geosynthetic material was not scaled. Nevertheless, he concluded that the geotubes at the bottom, located immediately bellow the sea level, had a tendency to slide as result on internal sand movements.

Although the geotubes were planned to protect an existing dune, which was in fact what the spit originally was, an artificial nourishment was made and an embankment was hydraulically filled in place of the dune itself. Furthermore, its overtopping was inevitable considering the height of the crowning postulated on the project - a landscape requirement. Indeed it occurred and the erosion was relevant – Figure 9.

During construction stage, quality control and quality assurance is always a key aspect to ensure a successful project.

The woven geosynthetic must be resistant - chemically and to UV. But although this is true in laboratory controlled conditions, one must wonder if this is also real under the specific environmental conditions of the construction site and, in this particular case, under the pH and biochemical conditions of the Cavado River waters.

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The seams, which were made in factory, must overlap and fold - Figure 10 e 11. The extremities of each geotube should overlap the other one on 1.5m.

Regarding the placement and handling of the geotubes, other features have to be considered, mainly the infilling quality has to be controlled, so that the geotextile is not ripped, besides the filled volume control (80%).

The geotubes near the foot of the slope have to be filled first and they shouldn't be handled with hooks or other sharp instruments. Additionally, the surface upon which they are placed should be levelled and clear of roots, debris, depressions or any other terrain irregularities that might damage the integrity of geosynthetic.

The contractor had significant difficulties in infill the geotubes near level +1m, more susceptible to tide effects. One must emphasize that this was also a type of intervention new in Portugal. Finally, the two bottom rows of geotubes located on the oceanside are uneven – Figure 6, and this might be due to a project adaptation during construction (mentioned but not specified at PROMAN, 2015), due to the reported problems of the contractor, or else to some kind of settlement. Nevertheless this late hypothesis is difficult to accept due to the regularity and amount of the unlevelling.

6. DAMAGES REPORTED

After the first maritime winter in 2015-2016, the structure itself stood up with minor damage and fulfilled the purpose it was designed for.

In the first inspections, it was noted that the Atlantic Ocean overtopped the structure, but the hydraulic fill confined between the rows of geotubes remained mainly intact - Figures 12 and 13.

The sand covering the geotubes was eroded on both sides, exposing them to people and the natural elements.

There were some geotubes with the seams disjointed on the top - Figure 13.

Figure 9. Evidence, at the beginning of 2016, of the hydraulic fill erosion after its overtopping by the sea; view to west

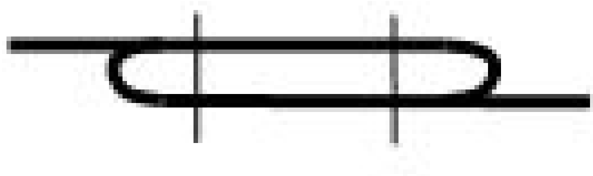

Figure 10. Scheme exemplifying a seam overlap and folding (Morais, 2010)

Figure 11. Detail of the overlapping of geotubes

Figure 12. Overview to south of the spit at the beginning of 2016 with geosynthetics at its northern tip exposed after winter storms

There was actually one geotube, on the riverside, which ruptured to the extent of emptiness - Figure 13. The rupture was first noticed after an important storm. The causes on the rupture of this geotube are inconclusive, although suspicions fall in either vandalism acts or else may be some sharp debris transported by the river - a tree branch perhaps.

Figure 13. Riverside view of one of the geotubes (50 m long) that ruptured

Table 2 includes a summary of all damages reported during the construction (PROMAN, 2015) distributed according to the type of damage and its location: by the oceanside (west), by the riverside (east) and by Cavado River mouth (north). Some rupture locations are identified in Figure 14.

Table 2 Damages registered on the geotubes and their location, monitoring campaigns of 2015

Damage	Location	Aug.	Sep.	Oct.	Nov.
Seams disjointed	West		1		
	North	1	3		
	East				
Rotation	West				
	North	1	1		
	East				
Rupture	West			1	2
	North	2	2		
	East			3	
Rupture around the mouth opening	West				
	North		1		
	East				

Figure 14. Location of damaged geotubes (in blue) in October and November 2015; Atlantic Ocean is located at the top (PROMAN, 2015)

7. FINAL REMARKS

The structure presented above is subject to two different hydraulic environments with different requirements: the riverside, at east, and the oceanside, at west. Although it was the first time such structure was built in Portugal, it is also the first geosystem to be exposed, above sea level, to the Atlantic Ocean storms.

The project adopted essentially empiric methods, but back then some other methods might have been used.

One must refer that the conditions under which the small scale model test was conducted do not match the ones implemented on ground.

In the project, it was also determined that the bottom level should have two rows of geotubes, at the same level, on the oceanside – Figure 6. The ground observation determined that the external row of geotubes is located at a lower level than the other one - Figure 8. This configuration was not studied, as it was not the one designed.

At the riverside, once the sand covering was removed, the geotubes are exposed and accessible to vandalism. Additionally, they become exposed to anything the river brings to its mouth during floods.

The oceanside is subject to a high-energy regime, both in winter as in summer time. For now, the geosystem has withstood as expected. Although it may benefit from the implementation of an additional infrastructure to diminish the wave energy and/or promote the sediment deposition.

Nevertheless, this type of protective structure and especially since it is located under the influence of the North Atlantic, will always require a rehabilitation intervention after winter season, namely to cover it with a protective cap of sand before the next winter.

8. ACKNOWLEDGEMENTS

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