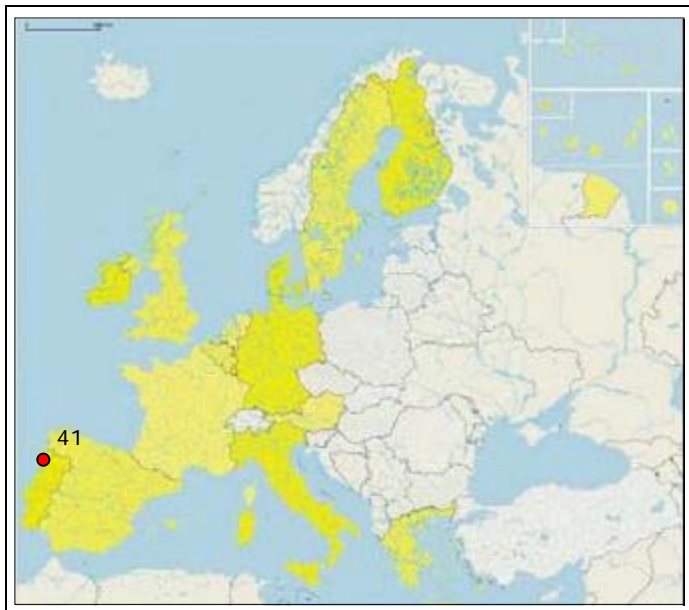


ESTELA (PORTUGAL)



Contact:

Fernando VELOSO GOMES
Francisco TAVEIRA PINTO

**Instituto de Hidráulica e Recursos
Hídricos - IHRH**

Rua Dr. Roberto Frias, s/n
4200-465 Porto
(Portugal)

e-mails: vgomes@fe.up.pt
fpinto@fe.up.pt

1. GENERAL DESCRIPTION OF THE AREA

The Estela Golf course is located in Estela, municipality of Póvoa do Varzim, approximately 9 km North from the city harbour and right away South of the Protected Area of the Littoral Park of Esposende (APPLE). It is established along the North Western coast of Portugal in a dunar system of approximately 3 km, (Figure 1).



Fig. 1: Estela Golf course location.

1.1 Physical process level

1.1.1 Classification

The Estela golf course shoreline stretch is a Coastal Plain of about 3 km length characterised by sandy beaches with sand dunes.

1.1.2 Geology

Two main sectors can be established in the North Western coast of Portugal. The sector where Estela is located, Caminha – Espinho, is characterized by the presence of estuaries with sand spits rooted in the southern bank, by dunes and by the inexistence of active coastal lagoons except for the residual Apúlia Lagoon (Figure 2).

In a closer approach, Estela is on Aguçadoura *Tijuca*¹ formation. This formation includes beds with peaty layers that prove the presence of a boggy environment dated 3.250 ± 100 to 360 ± 50 yr BP (Granja & Carvalho, 1994). Furthermore, it includes also beds with lenticular diatomites, in which the identified diatoms testify to a fresh water environment periodically invaded by saltwater intrusions (*idem*). The modern deposits are of fine sand dunes.

1.1.3 Morphology of the coast

The coastal stretch where Estela is located is a wide sandy low coast with dunes along almost its extension and only a few rock outcrops (mainly, schists and quartzites) that emerge close to the shoreline during low tide. These outcrops are mainly located between Fão and Apúlia (Figure 2). The orientation of this coastal stretch is North-South.

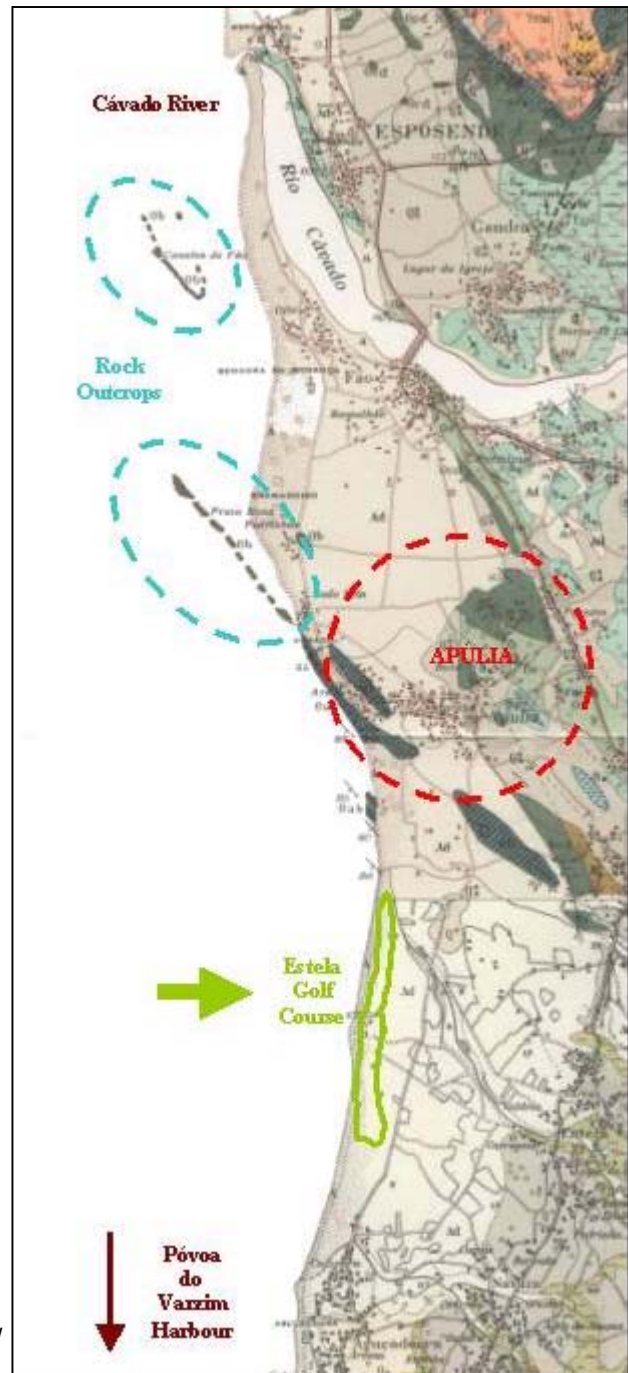


Figure 2: Geological Map of Portugal, 5-C & 9-A (DGMSG – General Directorate for Mining and Geological Services, 1965).

¹ *Tijuca*: popular and local word meaning silty sand, dark and plastic when wet (Granja & Carvalho, 1994).

1.1.4 Physical processes

The main storms reaching the North Western coast of Portugal come from the North Atlantic, particularly between October and March. The wave climate is characterized by medium significant wave heights ranging from 2 to 3 m, with periods ranging from 8 to 12 s and storm significant wave heights exceeding 8 m, with periods reaching 16 to 18 s. Almost all waves come from the N-W quadrant and the dominant wave direction is NW (~ 50%). Very occasionally there are waves coming from SW. The local wave conditions differ from the offshore ones due to the effect of the bathymetry and local phenomena, especially refraction, diffraction and shoaling. These local phenomena affect mainly the direction and height of the waves.

The tides on the Portuguese North Western coast are of the semidiurnal type, reaching a medium range of 2 m and a maximum of 4 m. The average tides in Leixões near Porto are:
Medium level: + 2.00 m (HZ);

Spring tides:

- Maximum high tide: + 3.88 m (HZ);
- Minimum low tide: + 0.12 m (HZ);
- High tide: + 3.55 m (HZ);
- Low tide: + 0.45 m (HZ);

Neap tides:

- High tide: + 2.5 m (HZ);
- Low tide: + 1.5 m (HZ);

The tide and wave values indicate that this is a macro-mesotidal, tide-dominated coast. Meteorological tides are not significant outside enclosed waterbodies but they can contribute to increase onshore consequences when occurring simultaneously with spring astronomical tides or severe storms. Longshore transport is dominant along the shoreline and is mainly wave induced. The dominant direction is mainly from North to South. The sedimentary cell has ~ 20 km from Cávado River to Póvoa do Varzim harbour (Figure 2) and the main source of sediments is Cávado River. Another possible source of sediments is the one provided by beaches on process of erosion.

1.1.5 Erosion

Type

The frontal dune has been shaped into a dune erosion cliff with tendency to migrate inland. This migration, consequence of beach thinning caused by the decrease on the volume of sediments transported by the littoral drift, is being stopped throughout dune restoration interventions.

Erosion Causes

There are several major erosion problems identified in the shoreline stretch updrift the dunar system of Estela, due to natural causes and reduction of sediment supplied from the updrift areas – caused by dredging activities works at the Cávado River and morphological changes on the river basin. Indeed, some of those erosion problems were already object of coastal

engineering interventions as it can be observed in Figure 3. The first coastal engineering intervention was the groyne of Pedrinhas made to protect some buildings of the leisure and tourism centre of Ofir (Esposende). This intervention motivated the construction of other groynes and adherent works, namely in the barrier island of Ofir and in the coast of Cedo Bem and Apúlia (Figure 3).

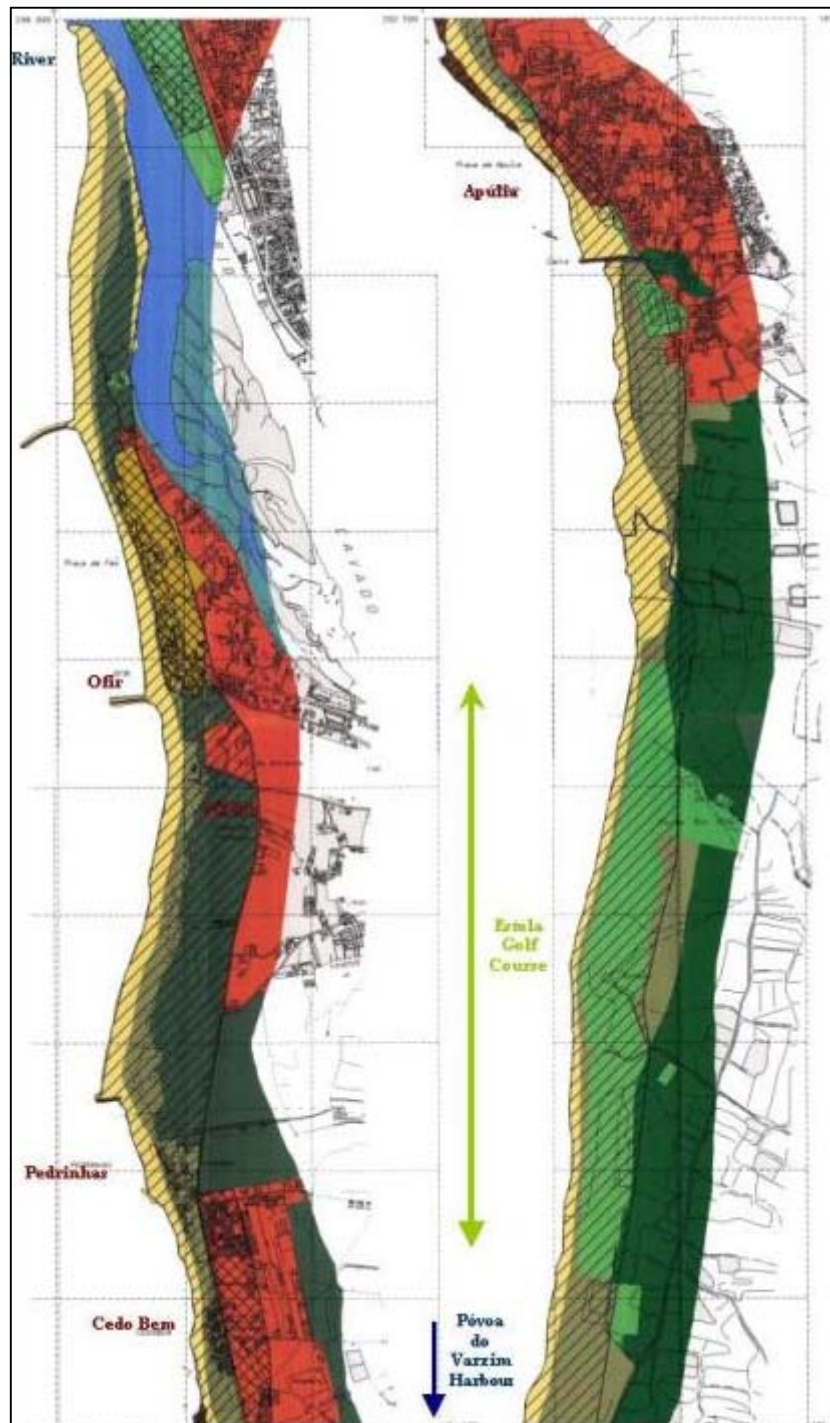


Fig. 3: Coastal engineering interventions updrift Estela golf course (Plano de Ordenamento da Orla Costeira Caminha – Espinho, 1997).

These interventions were however not very successful, especially due to the coastal erosion problems generated downdrift and in an attempt of reestablish former conditions some of the built groynes were reduced in length. Even so, it was not possible to reestablish former conditions and for instance, both the Protected Area of the Littoral Park of Esposende (APPLE) and the dunar system of Estela suffered a significant retreat of the shoreline. This retreat is widely visible on the decrease of the width of the beaches and it affects the stability of the dunar system which is becoming more and more vulnerable owing to wave breaking and wave run-up directly on the dune. In consequence, it is frequent to occur in winter the overtopping of dunar system and its total breaking along large extensions and therefore the destruction of the Estela golf course fence and even some of its courses. Downdrift the Estela golf course, in Aguçadoura, it was necessary to built an adherent work to face the existent erosion problems.

1.2 Socio-Economic Aspects

Estela is located in the lively summer resort of Póvoa do Varzim. Once one of the most important Portuguese fishing centres, Póvoa do Varzim is now also one of the most visited beaches both by national and international tourists, especially due to the great variety of leisure and cultural activities and facilities it has to offers and to the quality of its beaches.

The growth of Póvoa do Varzim is intimately linked to the fishing industry and particularly to the existence of the fishing harbour of Póvoa do Varzim (Figure 4). In fact, it has been at the heart of Póvoa do Varzim's growth, helping it to become one the most progressive and densely populated areas of Portugal. As it can be observed in Table 1, Póvoa has a density population of about 3 times the average density of the Portuguese littoral and near 7 times the density population of Portugal. Estela has a density population very close to the littoral density population average.



Fig. 4: Póvoa do Varzim fishing harbour.

Table 1: Area, resident population and density in Estela and in Póvoa do Varzim.

	Area (km ²)	Resident Population (Inhab)	Density (Inhab/km ²)
Estela	11.7	2.596	222
Póvoa do Varzim	82.1	63.470	773.5
Littoral	15999.7	3.907.117	244.2
Portugal	92141.5	10.355.824	112.4

Source: National Statistics Institute (INE), preliminary results of the 2001 Census

Included in the designated Tourism Region of Costa Verde, the city of Póvoa do Varzim is, in reality, one of its capitals. Furthermore, incorporates also the municipalities of the Porto Metropolitan Area together with Vila do Conde, Maia, Valongo, Matosinhos, Porto, Gondomar, Vila Nova de Gaia and Espinho (Figure 1) which indicates that this is as much as residential place as a summer resort.

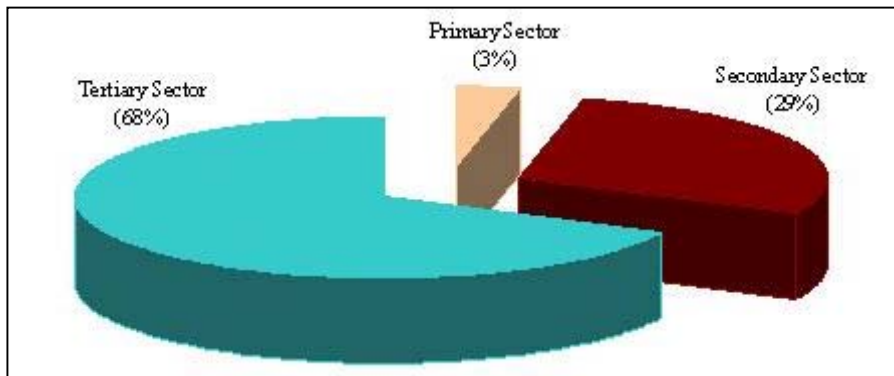
The urban area of Póvoa is wide and flat and has developed regarding the sea. Its new and tall buildings mostly characterize it. The city beach is wide, easy to access, constituted by rather coarse sand and characterized by a set of rock outcrops that emerge close to the shoreline during low tide. The maritime promenade, long, wide and recently improved, provides an amazing platform for looking at the sea, the beach and the town itself. Moreover, the level of facilities, leisure and cultural activities offered by the city is very high and varied, just to mention some, the Casino, the Estela golf course and the International Music Festival.



Fig. 5: Póvoa do Varzim city (Source: <http://www.povoavarzim.com.pt>).

All in all, tourism is becoming the main economical sector of Póvoa do Varzim. In fact, it is probably the main reason why the municipality, and especially the city, is well known in Portugal and abroad. In addition fishery and agriculture are also important economic sectors. Figure 6 shows the economic structure of Póvoa do Varzim municipality per sectors of activity.

Regarding Estela socio-economic structure in particular, it must be referred that this is mainly a population living from agriculture – mainly, horticultural products often raised in greenhouses – and civil construction. More recently, the settlement of some tourism facilities, especially the golf course and the camping park of Rio Alto has increased the tourism in the region.



Source: National Statistics Institute (INE).

Fig. 6: Economic structure of Póvoa do Varzim municipality per sectors of activity.

2. PROBLEM DESCRIPTION

2.1 Description of the eroded sites

The first documented interventions in the dunar system of Estela are from April 1999 even though, on the first letter sent on 30th September to the Ministry of Environment – Regional Directorate for Environment and Natural Resources asking for the license to intervene on the dunar system it is referred that there have been made some interventions of dune reinforcement trough sand ripping, as it can be seen trough the aerial survey from 24th June 1997 (Figure 7).



Aerial photographs: F. Piqueiro, 1997.

Fig. 7: Mechanical sand ripping.

The referred letter was accompanied by a technical report from the Institute of Hydarulics and Water Resources (IHRH) of the Faculty of Engineering of the University of Porto (FEUP) where it was mentioned that as a result of the decrease on the volume of sediments transported by the North/South littoral drift currents, with the consequent decrease on the beach width, the dunar system of Estela is being furthermore submitted to the direct action of wave run-up (IHRH, 1997). As a consequence of this direct wave action on the dunar system it is becoming more and more fragile – decrease on the beach width and dunes and the coming in sight of dune erosion cliffs. At the time of the aerial survey of June 1997 there were two dunar stretches where the erosion was more critical (Figure 8).

The above mentioned stretches, corresponding to the golf course holes number 5 at North and 13 at South, are where the dune restoration interventions are taken place with relative success, they avoid the destruction of the golf course green in the adjacent areas of holes 5 and 13 without stopping the sea invasion of the dunar system. In fact, it is frequent to occur during spring tides and storms the overtopping and breaking of the dune with the consequent destruction of the golf fence in large extensions. These interventions are therefore considered as being rather ineffective for dune consolidation even though they mitigate the sea invasion effects. Following is a short report on the emergency interventions made so far.



Fig. 8: Estela golf course, critical erosion zones (Aerial photographs: F. Piqueiro, 1997).

3. SOLUTIONS/MEASURES

3.1 Policy Options

This is a Limited Intervention made only to protect the golf course areas. Due to the fact that the interventions made in Estela are short-term solutions, the owner of golf course is considering, as suggested by the research team of the IHRH, the acquisition of adjacent fields and the re-location of the golf course to a more inland position. Even so, this dunar system must be preserved, as it is the main protection against flooding of the inland fields – mainly agricultural areas with significant value.

3.2 Strategy

The option for the coastal defence of Estela Golf is soft. 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.

3.3 Measures

The first documented intervention, made during the period of 1 to 12 April 1999, consisted on located reinforcement of the dune toe through mechanical ripping with sand from the frontal beach and consolidation of this sand deposit with wood piles and small sand bags with ~ 5 kg (Figure 9). This intervention was simultaneously made on the critical zone 1 (CZ1), near the 5th hole and on critical zone 2 (CZ2), near the 13th hole. Figure 10 show how the dune stayed after this intervention.



Fig. 9: Dune consolidation with wood piles and small sand bags, April 1999.



Fig. 10: Aspect of the dunar system near the 13th hole, April 1999.

It is still in 1999, during October, that a new intervention of reinforcement and dune consolidation is made on the critical zone 1, again using mechanical sand ripping and woodpiles and small sand bags. As it can be observed in Figure 11 the aspect of the dune before this intervention was of an advanced state of erosion with the erosion cliff very close to the golf fence. Before the 1999/2000 winter there were needed two more interventions, one in January and the other on March. In addition to the used technique it was also put, transversely to the shoreline, some fences to favour the aeolian effect on the dune (Figure 12).



Fig. 11: Aspect of the dunar system near the 5th hole, October 1999.



Fig. 12: Aspect of fences to favour the aeolian effect on the dune.

The 5th intervention near hole number 5 was made on October 2000 after the spring tides occurred on the 28th and 29th September that had as a consequence the partial destruction of the dunar system in that area which motivated once more the need to prosecute with dune repositioning works (Figure 13).



Fig. 13: Aspect of the dunar system near the 5th hole, October 2000.

The 2nd intervention on the 13th hole – still using the same dune consolidation technique, is only needed on November 2000 after having already done 5 interventions on the critical zone 1 near the 5th hole. In fact, it is only a year after the first intervention that the dune in this area exhibits erosion signs, Figure 14, this fact leads to conclude that the erosion phenomenon is significantly more severe on the North extreme than on the South one.



Fig. 14: Aspect of the dunar system near the 13th hole, November 2000.

The winter of 2000/2001 was particularly severe with a high sequence of storm episodes happening very close to one another. In fact, even though in general wave heights with a return period higher than 10 years were not reached, the persistence of the storms generated a very unusual case of consecutive storm events in a way that it was necessary to carry on with emergency works of dune repositioning several times in the period from November 2000 to January 2001 both in the North and South extreme limits of the golf course. In this period they were made the 6th, 7th and 8th interventions in the adjacent area of the 5th hole and the 3rd intervention near the 13th hole.

The 6th intervention on the North extreme limit of the golf course was carried out during the period of 14th to 27th November 2000 following the spring tides that occurred in November in which the dune was significantly affected (Figure 15). The emergency intervention consisted on mechanical sand ripping from the frontal beach to the dune (Figure 16).



Fig. 15: Aspect of the dunar system near the 5th hole, November 2000.



Fig. 16: Emergency intervention on the dunar system nears the 5th hole, November 2000.

December 2000 marks the beginning of the use of a new technique of coastal defence in association with the sand ripping. The severe spring tides and storms that affected this area since October, causing a series of dune destruction events (Figure 17), were responsible for the decision to make use of a more solid reinforcement technique that consisted on a slope protection of the dune with a geotextile filter cloth underlay and sand containers with $\sim 1 \text{ m}^3$. The layout of this intervention is included in Figure 18. As it can be observed, the intervention was carried out in 3 stretches with 350, 70 and 50 m and consisted on the placing of a geotextile filter cloth and sand containers along a 45° slope. Figure 19 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.



Fig. 17: Aspect of the dunar system near the 5th hole December 2000.

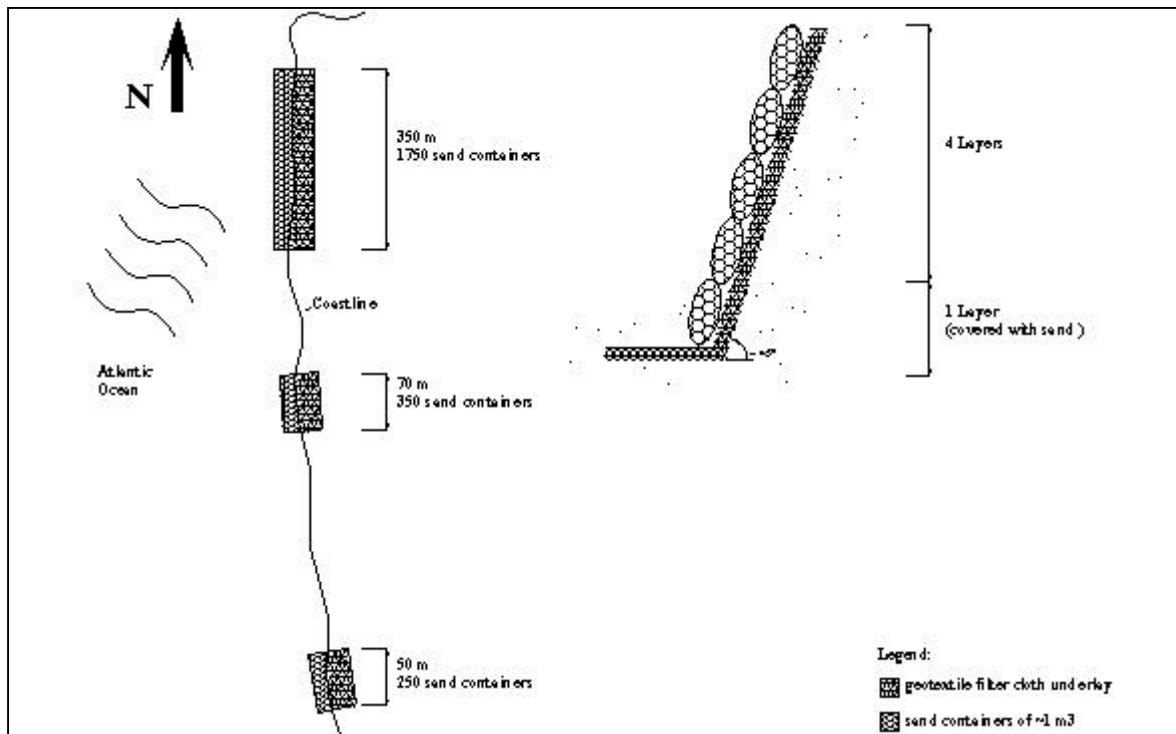


Fig. 18: Scheme of the 7th near the 5th hole, December 2000.

During October and December 2001 and May 2002 new sand containers were placed on the dune slope but this time, the geotextile filter cloth underlay was not placed. The costs associated to the above mentioned coastal defence interventions are the ones included on Table 3 and were all supported by the owner of the golf course. The costs of these emergency interventions were low but, regarding the frequency of new needed interventions and the uncertainty of its efficiency in a short to medium-term, it is most likely that it will be necessary to design a solution with better technical approaches.

Table 3: Dates and costs of the interventions.

Date	Costs (in euro)
April 1999	12.500
October 1999	15.000
January 2000	10.000
March 2000	7.500
October 2000	12.500
November de 2000	22.500
December 2000 & January 2001	-
October / December 2001 & May de 2002	-



Fig. 19: Aspects of the execution of the technical solution using geotextile sand containers, December 2000.

4. EFFECTS AND LESSONS LEARNT

4.1 Effects of Measures

The soft protection structure using geotextile sand filled containers has proven to have good potentialities that might solve, in a short term, the erosion problems existing in Estela but its effectiveness is not yet satisfying. At the moment, this case is the aim of a research study and in a near future it will be settled up a pilot study station using an improved solution of geotextile sand filled containers.

The capital at risk in Estela is not as much as in other littoral areas due to the inexistence of important urban seafronts endangered. Nevertheless, the golf course is an important facility to local, regional and even national tourism – there are many National and International Opens being held in Estela – that must be well preserved. Moreover, the golf course is also the defence line of several low land agricultural areas that are essential to local economy.

4.2 Conclusions

This is the first time, in Portugal, that a coastal erosion problem is being taken cared with a coastal defence solution using geotextile containers. The fact that the incident waves on the West Portuguese coast are among the most energetic worldwide makes people to misbelieve the potentialities of these kind of solutions, especially in cases similar to Estela. Nevertheless, these type of solutions can effectively control some coastal erosion problems, in a short term, but need to have a design procedure similar to any other coastal defence structure since at the moment there are still significant lacks of information regarding the design and behaviour of these defence systems.

Concerning the characteristics of the solution used in the dunar system of Estela the following details should be improved:

- 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 bricks 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.

Furthermore, during the research studies on the erosion control of the dunar system of Estela two basic solution will be studied. These solutions can be combined together to minimize the wave energy impacts on the dune that consist of:

- A passive coastal protection: dune barrier made of stapled geotextile containers as second line of defence and dune stabilisation, which is covered with sand;



-
- An active coastal protection: construction of one or two temporary groynes made of geotextile containers (in addition it can also be investigated the suitability of a submerged breakwater made of geotextile containers).

The importance of this case study is the opportunity to use these soft protections solutions without stress. Meaning that, in a long term is expected for the golf course to retreat further inland but in the meanwhile is possible to experiment this type of solutions under severe wave climate conditions to protect not only the golf course but also several low land agricultural areas that are still essential to local economy.



5. REFERENCES

BBG Bauberatung Geokunststoffe GmbH & Co. KG (2002). *Proposal for a geotextile coastal protection – ESTELA (golf course).*

Das Neves, L. (2001). *Geossintéticos e Geossistemas em Obras de Engenharia Coteira.* MSc Thesis in Environmental Engineering (in elaboration). Faculdade de Engenharia da Universidade do Porto.

DGMSG (General Directorate for Mining and Geological Services) (1965). Geological Maps 5-C & 9-A of Portugal.

ESTELAGOLF, S.A. (1999/2002). *Obras na Orla Costeira – Fotografias e Outros Diversos.*

ESTELAGOLF, S.A. (2001). *Cordão Dunar da Estela – Póvoa do Varzim.* Exposição.

Granja, H.; Soares de Carvalho, G. (1994). *How can Holocene Help to Understand Coastal Zone Evolution? (The example of the NW coastal zone of Portugal).* Littoral 94, September 26-29. Lisbon, Portugal.

IHRH (1997). *Cordão Dunar da Estela – Póvoa do Varzim.* Parecer.

Mota Oliveira; Veloso Gomes; Pedro Bettencourt (2002). *Zona Costeira Esposende/Ofir – vulnerabilidade/segurança das ocupações edificadas.*