COASTAL AND PORT ENGINEERING IN PORTUGAL. PAST, PRESENT AND CHALLENGES AHEAD

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ABSTRACT

In the beginning of the XX century the "Coastal and Port Engineering" in Portugal was mainly Port Engineering. Construction and development of some ports were under way at that time. There were signs of coastal problems in some stretches, but no reason to act since they were not seriously threatening people or property. The first coastal engineering works in the country were constructed in the city of Espinho, on the west coast, in 1910. However, after the fifties, the crescent instability associated to the strong coastal urban development brought Coastal Engineering to a much higher level. The need to protect urban areas at risk made extensive use of coastal defence structures throughout the country.

The economic growth of the country and the increase on maritime transportation lead to the expansion of the existing ports during the XX century and the creation of new ports specialized in certain activities: commercial, fisheries and leisure. It is worth mentioning the development of the port network for the fishing industry in the eighties, the creation of a deep water port in Sines, with oil and coal terminals, and latter expanded to receive LNG tankers and last generation of containerships. In the seventies, for the leisure craft, the first marina in the south coast in Vilamoura was created with one thousand berths. Towards the end of the XX new facilities were built mainly in the south coast. The number of berths in marinas and small craft harbors surpasses today the number of ten thousands. In the meantime, most entrances in lagoons and estuaries used for navigation were fixed with jetties or breakwaters, permitting in this way a safer navigation.

By the end of the end of the XX century, a small revolution took place with the creation of the so called "Coastal Management Plans". These plans cover coastal land from the bathymetric line -30m to a conventional line which is 500m from the high water mark. The plans were promoted by the Public Administration and developed by multidisciplinary teams including the academia, consultants and research labs. Most investment

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on the coast is now guided by what is set in the "Coastal Management Plans" and the transformation of the coast can be seen in many places. Coastal engineering played a central role on these plans, but many other disciplines gave also their contribution. Coastal and Port Engineering in Portugal relies on several institutions playing different roles: Research laboratories, the largest by far is LNEC – Laboratório Nacional de Engenharia Civil, which was created in 1947 soon after the second world war, the Hydrographic Institute of the Army, several firms of Consulting Engineers specialized on the subject, Contractors, Port Administrations, the IPTM - Instituto Portuário e do Transporte Marítimo and finally Universities teaching and doing research. These institutions are also international players either designing, studying or constructing ports or coastal works abroad. Well known examples are the design of the enlargement and the artificial nourishment of the Copacabana Beach in Brazil and the Bahrein shipyards.

Many challenges are still ahead. A interesting document published in 2009, "Hypercluster da Economia do Mar – Hypercluster of Sea s Economy" reports that all the activity linked to the Portuguese maritime sector can have a huge increase in the percentage of the GNP. In 2025 the so called sea's economy can reach 12% of the Portuguese GNP. "Port and Coastal Engineering" will have an important impact on this growth.

In this paper presented to the 2nd Mediterranean Days of Coastal and Port Engineering, held in Valencia, an account is given of the activity of Coastal Engineering in Portugal in the Past, in the present and of some challenges that are still ahead. Examples are given of a selection of some of the most representative works, studies and projects.

INTRODUCTION

Coastal and Port Engineering, past present and challenges ahead. The choice of topics to cover is naturally a matter which the author decides based on its own experience, personal view of the subject, and the information available. A timeline is used helping us to understand the historical background of the time, both in the country and abroad. Most events took place in the XX century, but the history of "modern" coastal and port engineering may be considered as starting with the artificial opening of the Aveiro lagoon inlet on the Portuguese west coast.

It is interesting to note that some of the first coastal engineering works were done to improve navigation in rivers and to stabilize the river mouth in the transition to the ocean. Despite a river morphology that was not favorable for navigation it is known that rivers were used, mainly to carry bulk cargo and specialized boats were adapted to the conditions of each waterway. One of the most famous, still in display in the estuary of the river Douro, is the so called "Rabelo" boat used to bring the barrels of port wine to Oporto for exportation. Following a chronological order some projects are presented that show the evolution of coastal and port engineering in Portugal since 1808, Table 1.

AVEIRO LAGOON ARTIFICIAL INLET. 1808

There are several historical accounts showing how the Aveiro Lagoon was formed. In fact a sand spit progressing from north to south having as a source of sand the

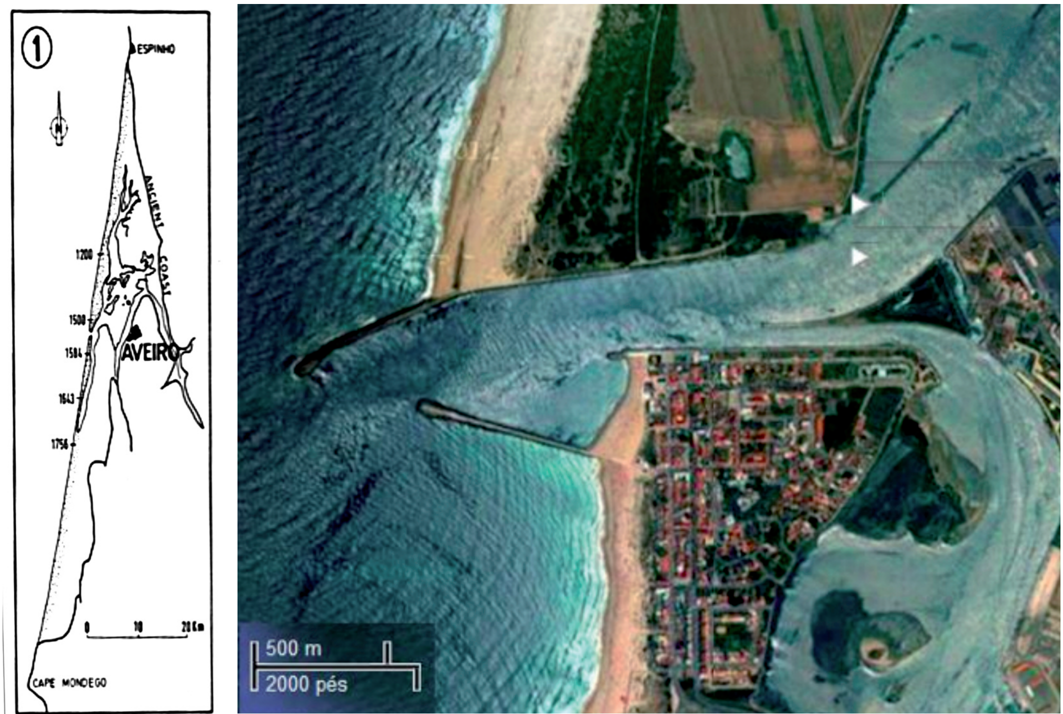
1808	Aveiro lagoon artificial inlet
1808	The Cavado Estuary mouth
1884-1892	Port of Leixões – 1st Phase
1887-1907	Port of Lisbon
1935	1st Physical Model Test – Breakwater of Port of Funchal – (at Copenhagen)
1936	2nd Physical Model Test – Submerged breakwater of Leixões – (at Lausanne)
1946	Use of Irribarren formula to study the stability of armour units
1952	LNEC first physical model test of a breakwater.
1968	Copacabana beach artificial widening and nourishment
1973	Vilamoura Marina -1000 berths in the south Coast
1978	Port of Sines West Breakwater accident
1981	The beaches of Espinho.
1993	Coastal Management Plans.

Table 1. Important dates for Coastal and Port Engineering Works in Portugal.

huge watershed of the river Douro. The spit closed the existing gulf of Aveiro forming a very large lagoon not connected to the sea. Stagnation waters in the lagoon and the lack of a direct navigation to the sea, lead to the decline of the population of Aveiro for a very long time. A decision was taken to open an artificial inlet linking the lagoon to the sea. In 2008, the two hundred years of the inlet opening into the sea were celebrated. The project is well documented since a map was drawn of the progression of the works, showing the position of the tip of the channel (trench) that was dug across the sand spit from the lagoon to the ocean. In the 3rd April 1808 the fresh water was running into the ocean from the lagoon. Since that time further intervention were done in the inlet to adapt it to navigation and flushing requirements, but it has been open ever since. The lagoon accommodates a commercial port, a fishery a rowing training lane, and small leisure facilities and it is known for its outstanding beauty. At present a new reshaping of the training works in the mouth is under way comprising the extension in 200m of the northern breakwater, this to improve navigation and sand bypassing conditions. Figure 1a) shows a map of the lagoon with the dates of the position of the sand spit. Figure 1b) shows an aerial view of the present day configuration of the inlet. The opening of the Aveiro lagoon is certainly one of the first Coastal/Port Engineering works.

THE CAVADO ESTUARY MOUTH. 1808

This is an interesting and difficult project aiming to make the Cavado River navigable from the ocean to Braga, which was a important urban center at that time. There were problems of siltation in the estuary and a channel fluctuating continuously, a river with narrow bents, marshes and not enough depth for navigation. To solve the siltation problem in the mouth of the estuary the project considered training works to in-



a) b)

Figure 1. a) Aveiro lagoon and ancient coast; b) Aveiro lagoon inlet (2012).

crease the velocity and direct the ebb flow jet. The project makes reference to an interesting solution, which consists in holding the water at high tide with gates, and releasing it suddenly to boost the self cleaning capacity of the inlet. A plan of the works is known and some questioning by a public inquiry about the sustainability of this project. It should be kept in mind that at the time some projects were financed by special taxes imposed locally. Some works in the river mouth were implemented but the project was not finished and the chief engineer killed accused of collaborating with the French invaders.

PORT OF LEIXÕES. 1884-1892

The Port of Leixões was created in the north of the country in 1884. The construction of the first phase lasted eight years. The port is located in the small estuary of the river Leça, north of Oporto and is protected by two breakwaters. Since that time the northern breakwater was extended to create a terminal to receive large oil tankers. In 1936, a submerged breakwater was designed and tested in a physical model, to give additional shelter to the outer port. The design is quite unusual for the time and makes uses of 90t cubic blocks. Figure 2 shows: a) An aerial view of the port (2012); b) The special barge to place the 90t cubic blocks and c) the cross section of the submerged breakwater.

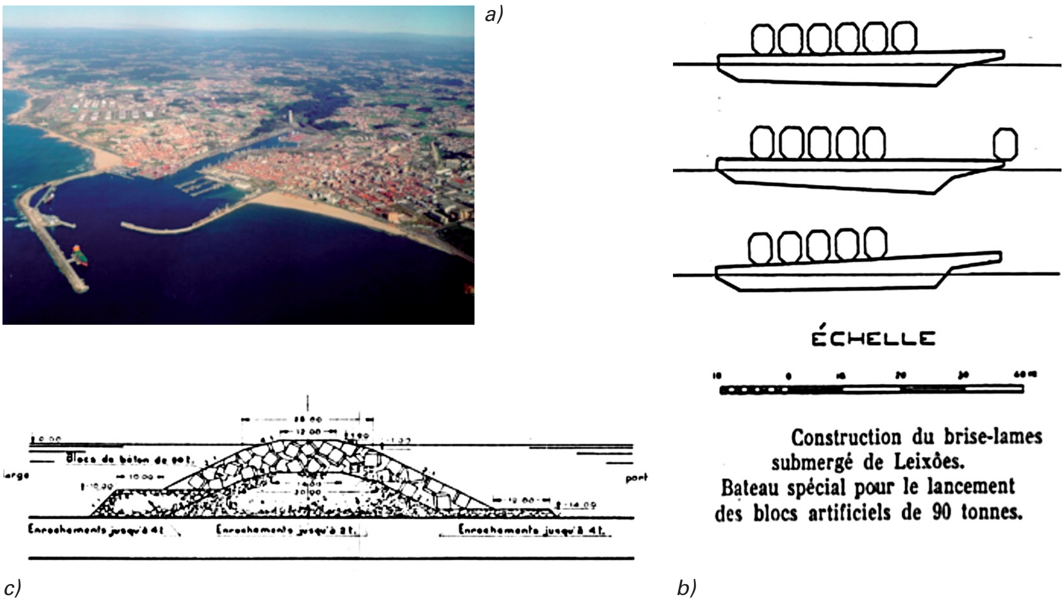


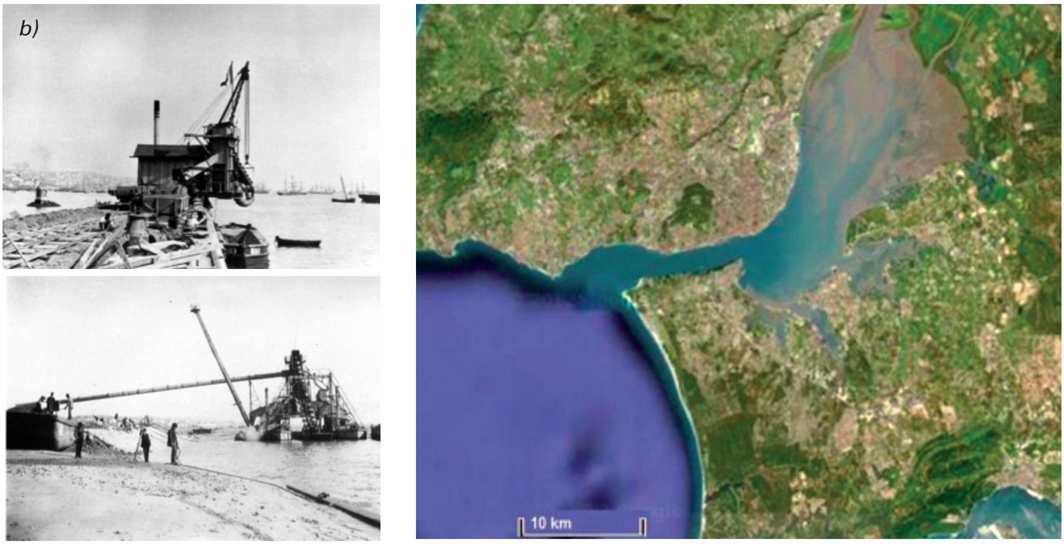
Figure 2. a) Aerial view of Port of Leixões (2012); b) Special barge to place the 90t cubic blocks in the submerged breakwater; c) Cross section of the submerged breakwater (1935).

PORT OF LISBON. 1887-1907

The Port of Lisbon is within a natural sheltered harbor with a safe access from the sea. From 1887 to 1907 major port facilities were constructed in the north margin from Sta Apolónia to Alcântara: a large area was reclaimed alongshore; docks, dry docks, quay walls, retention works and ramps were built. The construction works lasted almost twenty years and reshaped completely the margin of the city along the estuary. Apart from minor changes and small extensions, the layout of the port is still very much the same as it was in the beginning of the XX century. There are a great number of photographs from the construction phase which are kept in the municipal archives in Lisbon. In 1907 the Port of Lisbon Administration was created to manage the port facilities. Figure 3 shows the Alcantara dock during construction and a satellite view of the Tagus estuary which is the natural harbor for the port of Lisbon.

LNEC FIRST PHYSICAL MODEL. THE GOLDEN AGE OF PHYSICAL MODELING. 1952

In 1947, soon after the end of the Second World War the National Laboratory of Civil Engineering was created. This was an initiative that had a great impact on the standard of the construction and design of civil engineering works in Portugal, and in particular breakwaters and coastal protection works. A section for Coastal and Port Engineering was created within the Hydraulics department. The first physical model test of overtopping and stability of a breakwater was done in 1952. This was the case for the breakwater of the Port of Funchal in the island of Madeira where for the very first time the



c) a)

Figure 3. a) Tagus estuary natural harbor for the port of Lisbon); b) Alcantara dock construction 1900; c) Port of Lisbon construction (1887).

tetrapode armour unit was used. The golden age of physical modeling has started and breakwater started to be tested on a routine basis for stability and overtopping. Large models were constructed to study the hydrodynamics of almost all estuaries in the country and the flushing and equilibrium depths. The "remains" of the model of the Tagus estuary can still be seen in LNEC in Lisbon. Moveable bed models were also used to study littoral drift and reproduce natural processes. One remarkable moveable bed model study was done for the protection of the Lobito sand spit in Angola. The model was calibrated to reproduce the growing of the sand spit driven by the swell waves and protection schemes using groins and wooden piles were tested in the model. Figure 4 shows: a) the initial sand spit; b) the physical model and c) the spit after the construction of the groin field.

COPACABANA BEACH WIDENING AND NOURISHEMENT. 1968

The Copacabana beach in Rio de Janeiro, Brazil, is probably one of the most famous beaches in the world. In 1968 the widening of the beach using artificial nourishment was studied in LNEC. For that a physical model study was carried out and a conclusion was reached that a 90m in width stable beach could be created. Actually, 40m were used to enlarge the sea avenue and 50m for the beach itself. A total of 3,5 x 10^6 m^3 of sand was used in the nourishment. The study revealed that the beach is selfcontained (a coastal cell with little sedimentary exchanges with the neighboring stretches), prediction that revealed accurate. The beach proved to be stable with no need of further nourishment. Many people walking along the sea side in the "calçadão", a typical portuguese promenade made of white and black stones, is not aware that today's Co-

a) b) c)

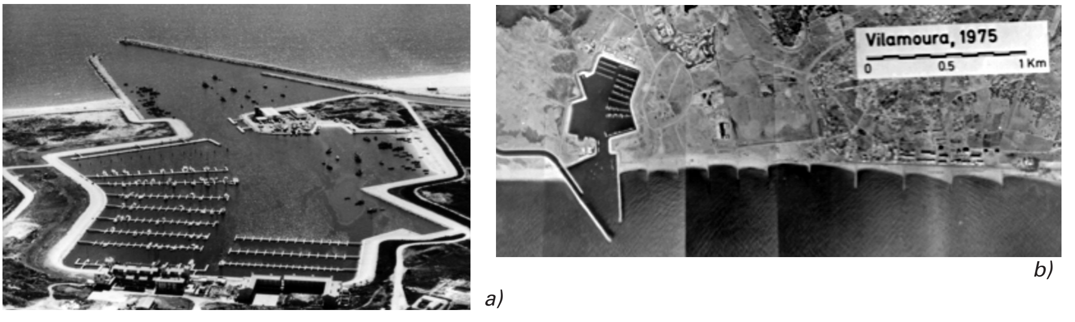
Figure 4. a) the initial sand spit, b) the physical model and c) the spit after the construction of the groin field. (LNEC).

pacabana is the result of a Coastal Engineering intervention. Figure 5 shows the a) Copacabana beach in 1956; b) Copacabana beach after the widening in 90m with artificial nourishment.

Figure 5. a) Copacabana beach in 1956; b) Copacabana beach after the widening in 90m with artificial nourishment. Studies and design of LNEC between 1968-1971.

VILAMOURA MARINA. MARINAS AND SMALL CRAFT HARBOURS

Apart from very small facilities there were no Marinas for the leisure craft in the country till the seventies. In fact the first Marina was created in the south coast in 1973, the Vilamoura Marina. To the present day this is still the largest Marina in the country with one thousand berths, able to accommodate boats up to 30m in length and 3,3m in draft. In spite of its age, the marina is a modern facility and was able to display the European blue flag when it was introduced. Looking at the layout one can see that the mooring basin was dredged inland and an outer harbor was created with two convergent breakwaters. The designers of the marina were aware of the impact the breakwaters will have, blocking the littoral drift and engineered a solution to sustain erosion downdrift. A groin field was designed and built at the same time. This was in the seventies well before environmental impact assessments were enforced in the country and proves that there was a clear perception that port works can have an effect on the neighboring position of the shoreline. The groin field played an important role in "protecting" the small fishing village of Quarteira. Vilamoura was the only marina for a very long time, but in the last two decades facilities for the laiseure carft were created both on the south and west coasts. A recent estimate (Trigo-Teixeira, 2004) shows that there are around twelve thousand berths in Marinas. Due to the mild wave climate offered by the south coast most of the marinas are located there. Figure 6 shows: a) Vilamoura marina and b) the groin filed constructed in the downdrift coast of Quarteira in 1975.



a) b)

Figure 6. a) Vilamoura Marina and b) groin field on the downdrift coast of Quarteira. 1975.

PORT OF SINES WEST BREAKWATER. 1978

The decision to construct a deep water port in the west coast, which was able to receive the largest ships was taken. This was a demanding project since the breakwater was constructed on the open coast reaching in the head a depth of almost 50m. Wave data availability were very limited and the design wave was fixed based on six years of observation in Figueira da Foz (on the west coast further north) and using some data from the buoy installed in Sines in 1973 (Morais, 1974). The design wave for a return period of 100 years has fixed in H=11m. The armour layer of the breakwater was designed with dolosses. During the winter of 1978, the breakwater that was in the final stage of construction was hit by a storm (Hs=8m). In the following year another storm attacked (Hs=11m), (Dias, Abecasis, Pita, 2000). The two storms caused massive destruction in the superstructure and the cover layer of the breakwater, which had to be rebuilt. The event draw international attention and the causes of the accident were investigated. The Sines Port Administration and the ASCE promoted technical panels and meetings and two publications came to light: one soon after the accident

a)

b)

Figure 7. a) Aerial view of port of Sines today b) West breakwater destroyed after the storm in 1978.

ASCE/APS(1982) and a second one after the repair/reconstruction work were concluded in 1992, ASCE/APS(1994). The Sines breakwater accident marks clearly a turning point in the design of rubble mound breakwaters around the world. With time more wave data became available and the statistical analysis of the significant height revealed a much higher estimate for H_s for the return period considered in the design, H_s=14m (Carvalho, 1998). Figure 7 shows: a) a aerial view of port of Sines today and b) the west breakwater destroyed after the storm in 1978.

THE BEACHES OF ESPINHO. 1981

Taking into account the past (and lost) importance of Espinho as a sea-side resort, the defence scheme aimed not only at the protection of the town but also at the rehabilitation that means the re-creation of beaches along its maritime front. By the end of the seventies this one was so deprived of sand and the risk of heavy damages on some seaside constructions was so high that the need for "doing something" became a priority for the coastal authorities. The design of a "defense and rehabilitation scheme"

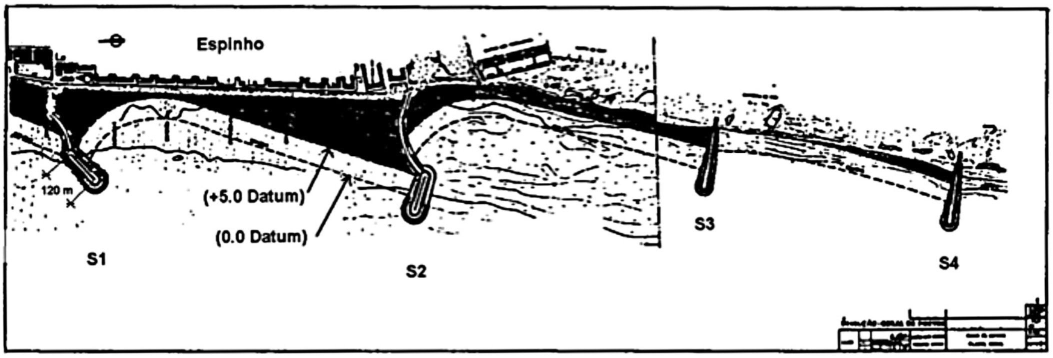


Figure 8. Plan view of the beaches of Espinho rehabilitation scheme. 1981. The black line shows the project predictions for the shoreline position.

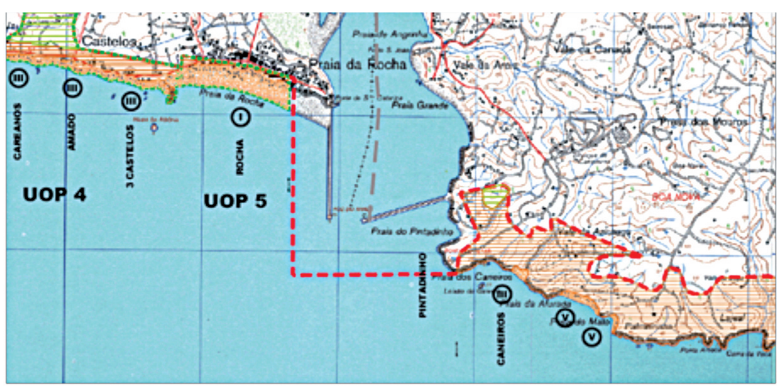
for the beaches of Espinho, covering a coastal stretch 4 km long was concluded (Mota Oliveira et al, 2000). Figure 8 shows a plan view of the rehabilitation scheme.

COASTAL MANAGEMENT PLANS. 1993

During the eighties several studies of "Coastal Problems" were done. Some stretches of the coast were eroding and the authorities felt that more comprehensive studies were needed. In 1993 the law creating the "Coastal Management Plans" was published. The Portuguese continental coast was divided in nine sectors and a management plan was created for each one, Figure 9. The plans cover a narrow band of land going from the -30m bathymetric contour to a line 500m inland measured from the high water mark. Port areas are excluded from the plans. Each plan should make a detailed characterization of the bio-physics of the space, look at the landscape and scenery values, study erosion and accretion, classify the beaches according to their carrying capacity, study urban occupation, define risk areas and state, after consultation of all the relevant bodies, a map for the coastal land use: urban land, agriculture, leisure, nature protection and other uses.

One of the main issues addressed by the plans was urban expansion in areas identified as to be at risk of erosion or areas that should simply be protected from urban expansion due to some other factors. The Coastal Management Plans were promoted by the Ministry of the Environment (Central Administration) and are above in hierarchy from the Municipality Plans (Local Administration). The land use defined in the Coastal Management Plan is mandatory and the Municipality plans have to be conforming. This was the way to control urban development in coastal areas, because everyone

a)



b)

Figure 9. a) Coastal Management Plans; b) Beach classification.

wanted a "room with a sea view" and to build close to the shoreline. Coastal Management Plans are valid for periods of ten years. After this they may be changed, according to the coastal dynamics and the evolving social and economic reality. Some of the plans were already changed after the initial period of ten years. Plans have also a major role in promoting coastal protection and regulating beach use. They include also the so called beach plans. On those plans the beaches are categorized according to their carrying capacity: from urban beach (maximum) to protected beaches (minimum). The entire beach infrastructure including access roads, parking, restaurants and other facilities are designed to meet the carrying capacity of the beach. Beach concessions are now given for longer periods allowing the concessionaire to recover the investment made and promoting a higher standard in the infrastructure.

CHALLENGES AHEAD

Many challenges are still ahead for the coastal and port engineering profession in the near future in Portugal. Two of them can be clearly identified: coastal erosion and hydraulic stability of breakwaters and other shore protection structures. In addition, climate change and the relative sea level rise will cause flooding in coastal and estuarine areas.

Erosion affects mainly the sandy low lying land on the Portuguese west coast. The main cause of erosion is the reduction of the sediment supply by the main rivers to


a)


b)


c)

Figure 10. a) Groin field on the portuguese west coast in the region of Esmoriz-Cortegaça; b) Groin and seawall in Esmoriz c) Pine tree forest eroding.

the coast (Vasco Costa et al 1996). Sand is blocked by dams and mining to maintain navigation channels in estuaries play also an important trapping role. Due to the violence and fast rate of erosion in certain locations, mainly those with coastal villages at risk, the schemes used in the past to sustain erosion used revetments, headlands, seawalls and groins. The severe wave climate require continuous maintenance and rehabilitation for this structures at a very high cost, but a cost-benefit analysis shows clearly the net positive value of coastal protection. Figure 10 shows examples of such structures built in Esmoriz-Cortegaça on the west coast, south to the city of Espinho.

A Map of land at risk was prepared that shows very large areas of coastal land that will be eroded in the near future on the coast of Aveiro (Trigo-Teixeira et al 2000). The sandy cost is eroding controlled by the coastal protection structures, mainly groins, but in some places the new "shoreline equilibrium position" is far from being reached. A more sustainable and "clever" way of sustaining erosion in a high energy sandy coasts is needed. Research on experimental structures either in the laboratory or in the field must be encouraged. The problem is even more complex since in some places the sandy coast is in fact a sand spit. In case of breaching very large areas of the lagoon behind will be immediately exposed to the sea and to the wave action.
The second challenge is the hydraulic stability of breakwaters and other shore protection structures. Certainly, the most famous accident happened is the Sines western breakwater in 1978. However accidents and failures due to hydraulic instability of breakwaters have been reported both in the Portuguese continental coast and the islands of Madeira and Azores. From slender units used in the past (tetrapods and dolos) the trend has been to move to bulky massive units (antifer cube mainly) when design the cover layer of the rubble mound breakwaters. A debate is still open on the failure mechanisms of this type of structures and the level of damage that should be accepted on the initial design to reduce capital costs. However, experience shows that when repairing or rehabilitating structures that were seriously damaged by storm a smaller level of damage is usually accepted and more robust structures are designed. Further investigation is needed on the hydraulic stability of units exposed to sever wave climates.
A third aspect that needs to be addressed is climate change and relative sea level rise. Port infrastructure and urban areas will be affected in the future due to the elevations that are not high enough to avoid flooding. The issue is not simple and strategies for adaptation must be studied. The combined effects of tide, storm surge and waves must be taken into account. A couple of centimeters in sea level elevation is enough to cause flooding in most places. Since estuaries and lagoons in Portugal are harboring port infrastructure propagation effects should also be taken into account. There are also reports of increased flood frequency in some places and pressure that is being put on the drainage system of urban areas unable to cope with sea level rise.

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