CHAPTER 186

Submerged breakwaters for the defence of the shoreline at Ostia Field experiences, comparison

by
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Summary

An important study case with different defence structures and the results of the monitoring data of are reported. Field éxperiences are specially usefull to compare two soft structures used to defend the Lido of Ostia, i.e. the coastline of Rome at the mouth of river Tevere (Tiber)[2]

Introduction

Erosion phenomena along the almost 7500 km of the Italian coast are widespread and certainly have been increasing more and more during the last decades. The main causes of this aggravation are the large number of protection works against the landslides, the use of material from the river basins for building purposes and the construction of reservoirs for water supply.

Disappearance or reduction of the sandy beaches often determines a too heavy damage for the economy related to the tourism. This encorauges the State or the local administrations to try to contrast the phenomena. A large number of defence interventions has been realized starting since the sixties and their importance and cost have been raising through the years. Adopted techniques have been paying an increasing attention to the results effectiveness and to the costs benefits optimization. For this last evaluation, the enviromental parameters have assumed a big importance. In fact, it is clear that every defence intervention in areas which have particular tourist attractions can only be directed towards protection and, possibly, improvement of these amenities. During the recent years, the deeper attention for the environment has induced preference for soft structures like the beach nourishment and the submerged breakwaters. Even if the experience from the wide use throughout the sixties to the

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[2] *Rome was for many centuries the Caput Mundi = Capital of the World (Tiber is the name in latin language; in the Roman time usual its pronunciation was Tiver, from wich many scholars consider to deduce the common name river).*

eighties of tbe detaebed emerged breakwaters is only sufficient, tbis strueture resulted to be effeetive for tbe defence of eroded beacbes witb a reasonable eost. A detached emerged breakwater interrupts the natural sediment longshore transport therefore the sand material which is entrapped in the sheltered area is subtraeted to the downdrift coastline.
This phenomena, like tbe domino game, is visible at most of tbe Italian coasts and has given extension of this type of strueture to very long eoastlines (e.g. the Adriatie coastline).
Of eourse, tbeir environmental result is not bigbly appreciated. Infaet in addition to an ineovenience in tbe sometime wonderful seawiews, tbe emerged breakwaters bave often indueed a worsening of tbe water quality in the protected area together with a strong and fast erosion phenomena at the openings hetween the barriers.
If the seeond effeet, as well known, gives troubles to the swimmers, the first ean induce the Health Authority to forbid the recreational use of tbe beach. If we realize that, generally, the defence work aim is to preserve the beach for a recreational use, the previous discussion shows, ad abundantiam, the unacceptableness of tbe emerged structures. In fact, during the Summer season, the water cireulation, wbich is ensured only by the openings, is often unsufficient for a tendentially eutrophic water. These are some of the reasons which have driven to tbe use of soft defence interventions, like the combination of a beach nourisbment with the submerged breakwaters.
Sand material which is compatible for a beach nourisbmcnt can not easily be found in the Italian seas.Tberefore, tbe required large volumes of necessary material for a beach nourishment are usually taken from quarries whose travel distanee from the intervention area is giving sometime a too higb cost. Use of the quarry must consider that the Italian territory is highly used for different purposes and, enviromentally speaking, the areas still free of buildings are not less important and sometime they are in a preserved zone. On tbe otber hand, tbe submerged detached breakwaters offer big benefits. They can be considered as soft structures; in fact, their enviromental impact is soft (nature uses tbe coral reef) and they offer a low cost and effective defence of the beaches. Tbe submerged breakwaters bave been recreating sandy beaches which were completely lost with only a small negative impact on the adjaeent coastaline and, more important, without any reduction of the water circulation in the sheltered area during the summer. These henefits are attainable under the condition of a eareful structure design. The design should consider the stability of the rubhle mound, the trasmission eoefficient (which is related to the crest width, its submergenee and wave climate) and the verification that the residual wave energy is not ahle to erode further the beacb.
Many laboratory tests and field study bave been carried out in Italy. The results from these studies allowed a verifieation of the indications publisbed on this subject sinee the seventies and a better calibration of the relationships used for the design. Ohviously, tbe field gives the best results for tbe interpretation of the phenomena and tbe calibration of the interventions.
The present paper aims to refer about and to diseuss one of the most noising Italian defence work intervention. In particular, tbe purpose is to carry out a technical economical comparison between two different defenee structures (beaeb nourishment

with reef and submerged breakwater) which have been built along two adjacent coastlines at Ostia (Roma). Their behaviour we compare. The first is an expensive - composite structure (beach nourishmnent and submerged barrier or reef defending a 3 km stretch). The second is a submerged rubble mound breakwater defending a 1 km long strecth. Results obtained suggest a preference for the second cheaper structure.

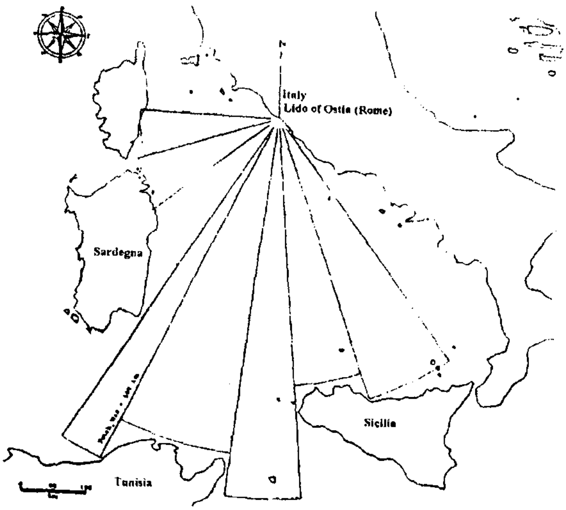


Fig. 1 *The site of Lido of Ostia in front of Tirrenian sea*

The littoral of Ostia

The littoral of Ostia extends itself to South-west and to South-east of the two mouths in which the sacred river Tevere forks itself, before flowing into the sea.
History says that the area around theriver mouth has always been eztending seaward. The increment of the distance between the shoreline and the antique port of Ostia, the port of Rome at Empire time, was very rapid, causing not few problems to the transport from the Africa and Sicily regions of the provisions for the two millions of citizens.
Fig.2 (an old map of year 1680 by Mayer) shows the distance betwcen the ports of Traiano and Claudio (Roman Emperors of the first century a.C.) and the sea. It's interesting to remember that the Port of Traiano and the next of Claudio were interested by silting up, soon after the end of their construction.
In fig. 3 (Caputo and al., 1992) the shoreline changes among 1873 and 1987 are represented. So, until year 1950, a shoreline advancement of about 2-3 m/y it has verified. No more accretion of the land area after 1950, due to the drastic reduction of the sediment transport from the river Tevere (use of material from the river basin for building purpose and the construction of about 20 reservoirs for water supply).

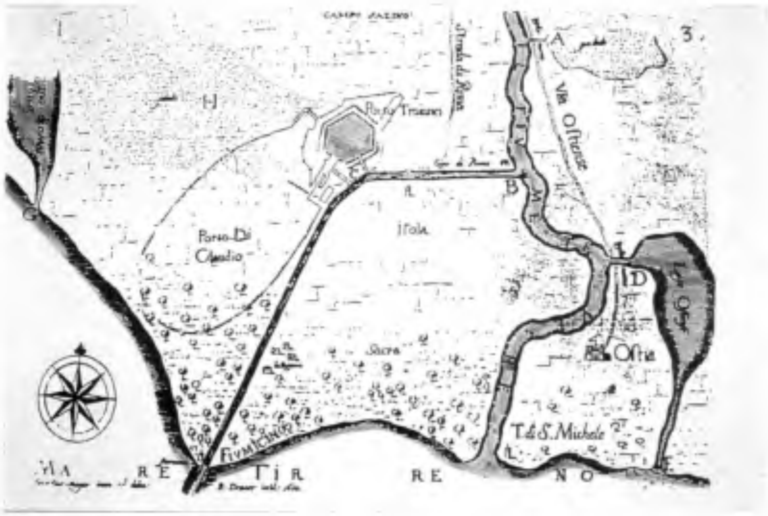
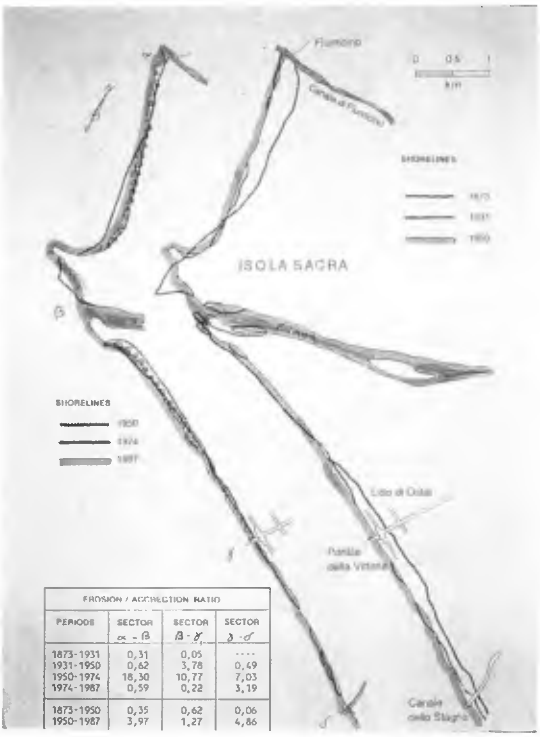


Fig. 2 *Coastline as in old Map of Mayer (1680)*



EROSION / ACCRECTION RATIO			
PERIODS	SECTOR $\alpha-\beta$	SECTOR $\beta-\gamma$	SECTOR $\delta-\sigma$
1873-1931	0,31	0,05	....
1931-1950	0,62	3,78	0,49
1950-1974	18,30	10,77	7,03
1974-1987	0,59	0,22	3,19
1873-1950	0,35	0,62	0,06
1950-1987	3,97	1.27	4,86

Fig. 3 *Shoreline changes in the last century and in the last decades*

Actually the river bed of the terminal zone has retreated, on the average, of 2 meters and the sediment transported by river has a very little size, not sufficient to stay in the inshore zone.

The result of this new situation was the erosion of the beach, in the left of the fig.3.

In the fig.4 the Lido of Ostia from the Nautical Map of 1983 is reported; in the same map four zones are distinguished (A, B, C, D) according to the years of the construction of the defence structures (the letters from A to C indicate the real time sequence of the building).

Fig. 4 *Shoreline in a map of 1983. The four zones A,B,C,D.*

Fig. 5 *In the map of Consiglio Nazionale delle Ricerche, many results of study.*

In the map (fig.5) many results of investigations and studies by National Research Council are presented: arrow shows the direction of the net longshore transport, as monitored by the sedimentolologist research group.

Defence works in two last decades

To stop the shore erosion and its unacceptable effects, some defence structures were built, beginning from the years seventies; in the eighties was an hard structure consisted in a few segments of detached emerged rubble mound breakwaters (about one meter over the m.s.l.) founded in 2-3 meters depth with the crest 3-5 meters width.

Each one of the four zones (fig. 4) corresponds to a different defence structure used. The emerged detached breakwaters are in the **zone A**.

That hard structure, being the first structure downdrift to the mouth, was able to capture large volume of sediment transported by longshore and to enlarge the beach. Such design solution corresponds to the people request of that time.

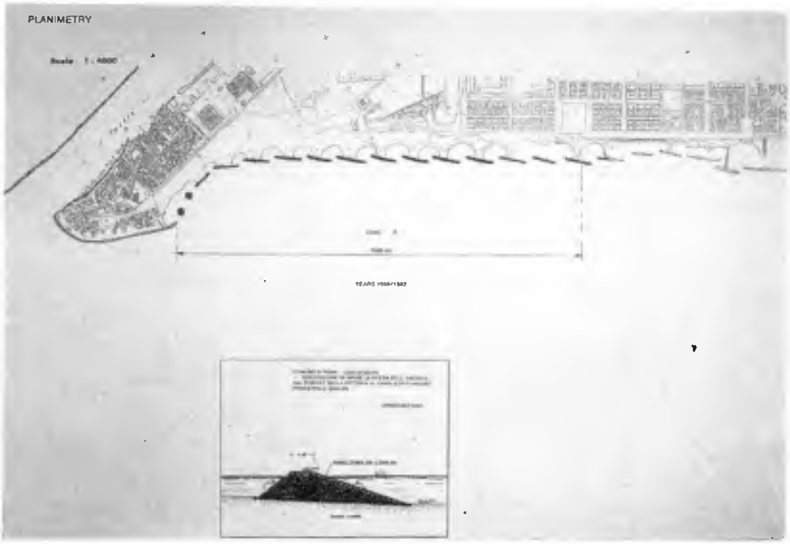


Fig. 6 *Aerial photo of zone A and cross section of the emerged segmented breakwater*

Aerial photo (fig.6) shows the increase of land **area A** with the formation of the tombolos.

This result is good for the defence of the beach from the erosion but is not well accepted for the bathing use of the sea water in the tombolo areas. In fact, these areas are too receptive to the bacterial colonies, and so they are interdicts to the bathers like dangerous for their healthiness. (Italian law permits the water bathing use only if the number of the bacteria coli, per liter, is less than 100; for many other national laws - as in USA - is 500/liter). Also the emerged rubble mound breakwaters are very good sites for the development of the bacterial colonies (expecially in the sea level exchange band by tide).

It's clear that each one structure, going from North to South, has conditioned the downside structure behaviour.

New design demands. Soft structures for the defence of the zones B and C.

In the second part of the years '80, the demand of more space for the recreational use of the beach increased very fast; moreover, the environmental culture was more developed in the people. Consequently, in order to prevent the erosive action of the sea in the littoral of Ostia, where the sediment balance is poor, to reduce the impact of the works on the environment, to limit the effects on the adjacent beaches, to ensure the exchange of protected areas, many technical solutions were investigated.
Mathematical and physical models were used to study the beach stability and to reduce the cost (first and of the maintenance) of the intervention.
The preference went, not without oppositions, to the soft structures, and mainly to the beach nourishment.
But, where to find the borrow areas for so large volume of suitable sand for an artificial beach, both from a quantitative as a qualitative by?
Many environmental investigations, supported by scientific criteria, were done; the search of the suitable sand was very difficult and the results suggest to take all the necessary materials from the land quarries (that means a greater cost of the intervention), relying the artificial beach nourishment and submerged rubble mound (a reef), as in fig. 7 for the **zone B**, 3000 m. long.
The width of the artificial beach in the design was of 40+90 m. (gravel and gross sand nourishment), while the crest of the reef was 15 m wide and 1,5 m deep under m.s.l. with the slopes 1/3 seaside and ½ landside on the bottom of about 4 m under m.s.l. (quarry stones among 5 and 1000 kg). The reef section hydraulic stability was tested in wave flume.
This solution was the more pleasant to the people of the bathers, but the question was: how will the reef be able to reduce significantly the wave energy and to maintain sufficiently stable that artificial beach throgh the years?
Due to the very high cost of the intervention, the Public Administration financed it as sperimental project. Obviously a monitoring plan was also financed.
The construction was carried out 1989-1991 (not in the Summer season). But, already when the works weere in progress and soon after, a not neglegible erosion phenomenon started updrift (see aerial photos Fig. 9). The dimension of erosion pointed out the necessity of a periodic maintenance having a too high cost for the public administration.
So, in the 1992 decided to use a different cheaper soft structure to defend the neighbour new part of the coast, 700 m. long (zone C in fig. 8.). Fig. 8 shows also the cross section of the submerged breakwater used for the **zone C** and the aerial photos fig. 9 the shoreline exchanges between 1991 and 1995 years.
The depth of the crest of submerged barrier is this case was lowered only to 0,5 m under m.s.l., while the bottom is on 3 m about. In the zone C no artificial nourishment was done. Main reason of this decision was the reduced money availability. The first idea was to provide the artificial nourishment of the zone C, if necessary, in the future.

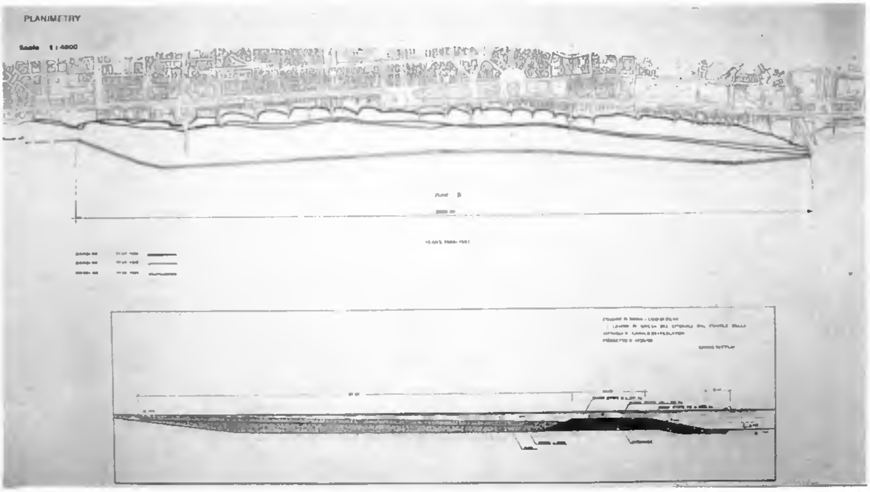


Fig. 7 *Aerial photo of the zone B and cross section of the defence composite structure*

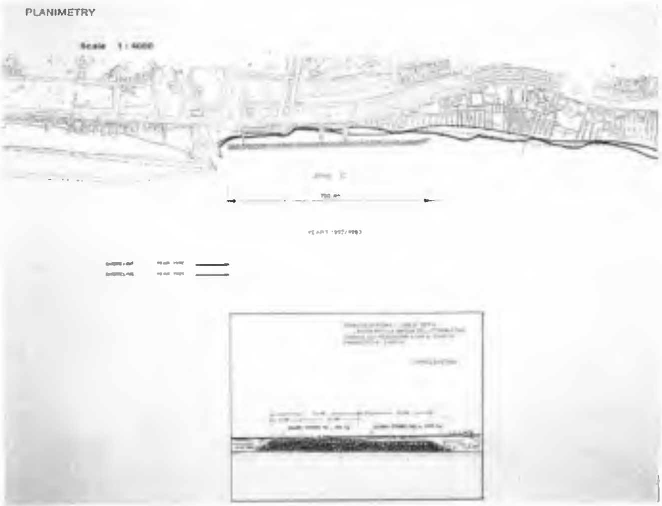


Fig. 8 *Aerial photo of the zone C and cross section of the defence structure*

It can be also observes that between the zones B and C there is a big groyn (the inlet of the Canale dei Pescatori) that reduces significantly the sediment transport capacity of the natural drift. In spite of this, not few inspectors hoped too much in submerged breakwaters defence action.

Pay attention that we distinguish between submerged barrier, like breakwater, and reef; the first is able to reduce significantly the wave energy, the second can not (in the submerged breakwaters depth of the crest has to be not large than 50 cm.).

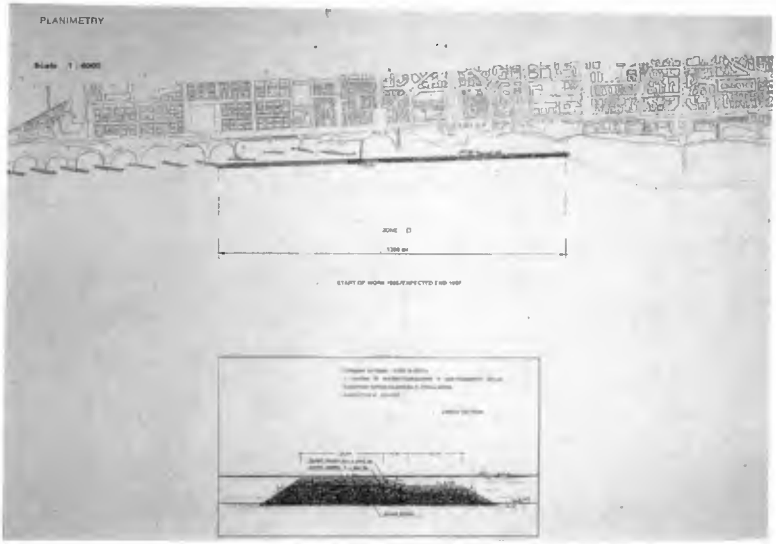


Fig. 9 *The Zone D - Works in progress*

Both the defence soft structures used for the zones B and C are able to assure the healthiness of waters in the protected areas.
In fact, thinking that the water transport by sea waves travels in maximum part on the surface, it means that a well designed submerged barrier can defend the shoreline stability by reducing the highest waves energy and can permit the transmission in protected area to the low waves mass transport (low waves and high temperatures are characteristic of Summer time in Italy) to assure a well exchange of water between offshore and inshore areas (id est the healthiness of recreational bathing water).
But, already at the end of the construction of the submerged rubble mound breakwater for the zone C, it was possible to see there a not little shifting of the shoreline seaward due to the natural sand capture.

Monitoring results

The aerial photos in fig. 10 show the shoreline exchanges of the artificial beach in the **zone B** between the years 1991-1995.
Cross sections (Figg. 11 and 12) northside and in the middle of the zone B taken in the year 1989 (before the works), in the 1992 (one year after the end of the works) and in the year 1995. Erosion action by waves is evident; southside is smaller due to long groyn (at the inlet of the Canal).

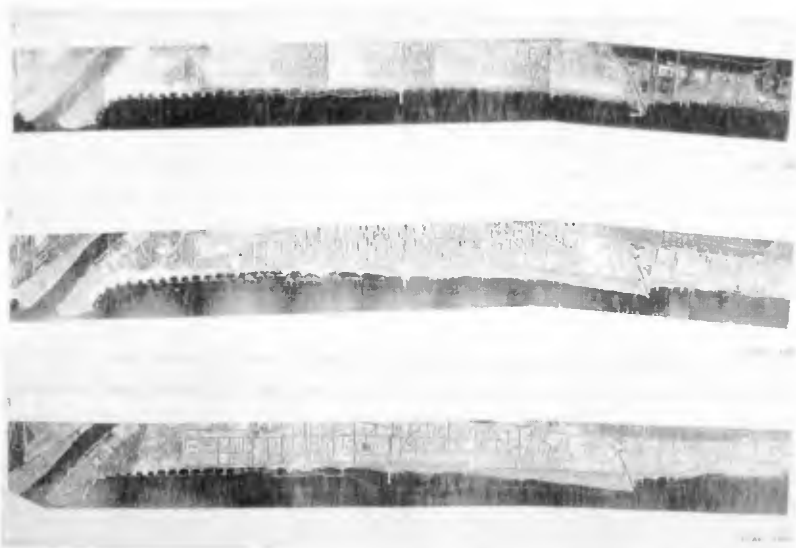


Fig. 10 *In the aerial photographs the shoreline exchanges among 1985 - 1995 years*

The width of the emerged beach northside is reducing almost at the same size of the 1989; in all cases the erosion action by waves on the artificial beach is very clear both landside and seaside the reef.
As in Dean tests (1995), these results make evident that a similar reef can't defend the beach by waves and, also, breaking, does not reduce significantly the energy of waves passing in the area, increases the erosion in both sides; so, its presence can be, at the limit, dangerous rather than useful.
Viceversa, for the **zone C**, the defence utility of the submerged breakwater of the fig. 8 is demonstrated from the aerial photos in Fig. 10 and from the profiles of the cross section of Fig. 13.
No sand artificial nourishment was done in the zone C, so it's easily understandable that the submerged breakwaters can not only defend the coastline but it is able to capture the fine sediments by longshore drift and to assure them a dynamic sufficient stability.
These results have been observed also in not few field experiments (as at the mouth of Volturno river Napoli, like other example) and in laboratory tests (Chiaia and al., 1992). These results suggested to the public administration to continue in the defending of the **zone D** with the same structure as in zone C (works in progress).

Costs and benefits, comparison

First cost of the defence structure of the zone A (segmented detached emerged breakwaters) is the same of those of the zones C and D, fig. 9 (continuous submerged breakwaters), i.e. about 2 million US dollars/km.

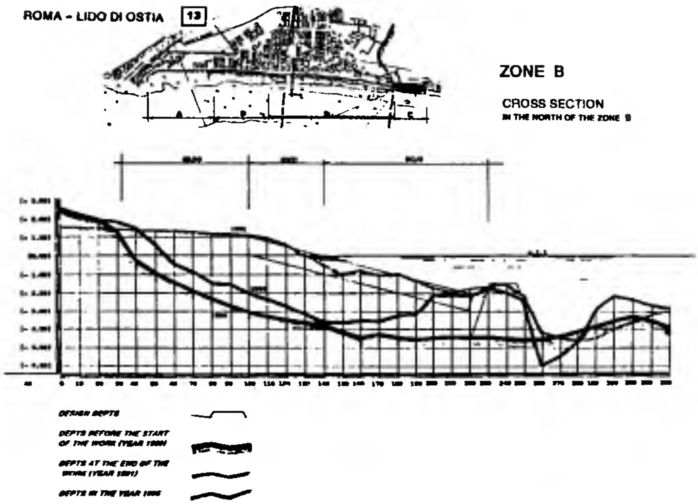


Fig. 11 *Zone B - Cross section in the north of zone B.*

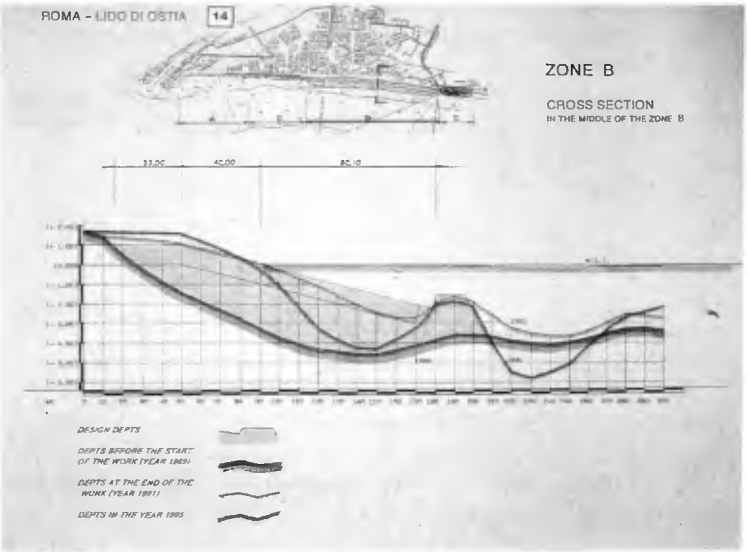


Fig. 12 *Zone B - Cross section in the middle of zone B.*

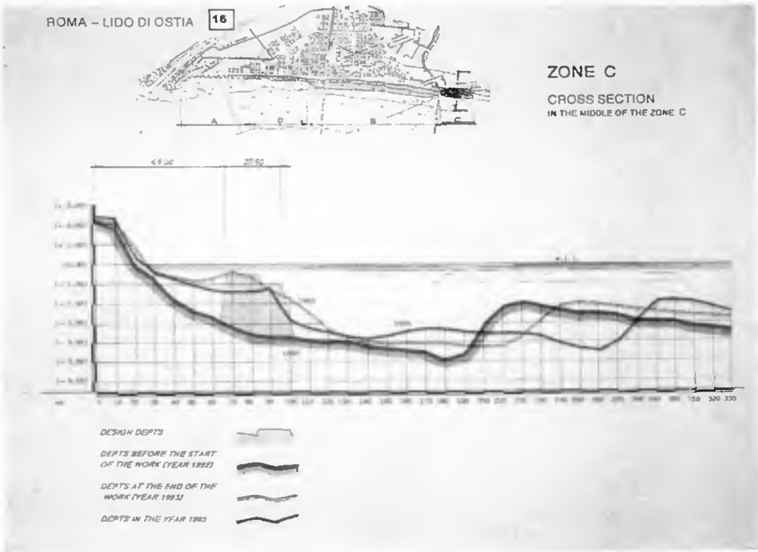


Fig. 13 *Zone C - Cross section in the middle of zone C.*

The barrier of the zone C is long 700 m, that of the zone D 1,300 m. For the nourishment of the zone B (3 km long), cubic meters 502,000 of fine sand and 880,000 of gravel mixed with coarse sand were used; the cross section volume of the stone reef in the zone B is very similar to that of the submerged breakwater in the zone C. So the first cost of the artificial beach in the **zone B** (artificial sand nourishment and stone reef) is very bigger (about 6.2 million US dollars/km) that the cost of the defence structure (only a submerged breakwater) in the **zone C** (about 2 million US dollars/km).

The monitoring control of the works suggests, also, a necessity of about 15,000 cubic meters/km of sand supply for the maintenance of the artificial beach in the zone B; none cost of the maintenance for the beach in the zone C, because there the nourishment is natural, i.e. it is due to the capture action of the downdrift sediment by the submerged breakwater. Comparison of the above results shows that in both cases of the two soft structures used for the zones B and C the principal scope of the defence from waves erosion has been obtained, also the healthiness of the bathing water was assured; moreover in the zone B a large artificial beach results (in the year 1995 the width was between 30 and 100 m. in going from north to south), while in the zone C the width of the natural beach was smaller (between 15 and 30 m.). It is interesting, also, to look at the favorable action of the special shape of the cross section of the submerged barrier used (two different steps to reduce the reflection of incident waves and, consequently, the energy of the breaking waves at the foot seaside of the barrier). Above the costs of both the soft structures are reported with the benefits for all the beach of very high tourist interest: the comparison is easy.

Fig. 14 *Zone B - Before and after the works*

Fig. 15 *Zone C - Before and after the works*

Considerations

The above experiencies suggest the following considerations:

a) both the soft structures have a very low environmental impact;

b) well designed submerged breakwater is able to defend the coastline from erosion by seawaves, permits a sufficient water exchange between offshore and inshore areas during the summertime, can capture the sediment transport (when it there is) for a natural, low price and enough stable sand beach (pay attention that, for the Italian seas, the maximum spring-tide is generally about 30 cm);

c) a reef does not assure the stability of the shoreline and increases the erosion landside due to the waves breaking on it (it's too much the energy of the highest waves that comes in the landside area);

d) the costs of construction and maintenance of the defence soft structure, as in the example of the zone B, is very high and hardly supportable from the community. As benefits, it is a very acceptable soft structure, the area of emerged sand beach is large and better responds to the requests of the people for the recreational and bathing use. But, really, the defence structure is the coarse sand and gravel nourishment, while the effect of the reef is more negative than doubtfull. The laboratory tests demonstrate that an increase of the sand and gravel dimensions are more usefull to stabilize the beach (Aminti,1987).

e) use of a submerged breakwater as in zone C and D has to be favourite when you want to defend from erosion the shoreline and also to build an artificial beach to reduce the sand supply necessity.

f) In fact, it does not disturb the landscape scenery, permits to preserve the healthiness and the bathing use of the water in the protected area, assures a good shoreline stability because it can reduce notably the energy of the highest erosive waves.

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