CHAPTER 182

ITALIAN EXPERIENCE ON SUBMERGED BARRIERS AS BEACH DEFENCE STRUCTURES

by Alberto Lamberti* & Alessandro Mancinelli**

Abstract

The use of submerged barriers in Italy is rather new starting in the first 80's. Since that time more than 50 submerged barrier defence system were constructed and this type of structure is progressively complementing and substituting the traditional use of parallel emerging breakwaters.

The paper presents documentation about the experience gained on the topic and describes and compares to prototype experience the design criterion suggested by the authors, based essentially on the selection of a proper wave attenuation necessary to obtain to desire profile modifications.

1 Introduction

Since the XV century, beach erosion has been taking place in many parts of the Italian coastline. The numerous historical maps document, for instance, erosion due to the construction of channel-harbour in the Adriatic Sea such as Cesenatico, Rimini, Pesaro, Fano, Senigallia, Pescara, etc. The extension of jetties in these ports carried out at different times in order to avoid silting up of the entrance, gave rise to down drift erosion (in the Adriatic sea north of these structures).

The first coastal defence structures built in Italy date back to the beginning of this century. An exception though, is to be found in the Venetian Republic which had already started to construct seawalls in the XVII century, to protect the sandy strip which separated the lagoon from the sea, the so-called "murazzi".

The erosion phenomenon remarkably increased between the 50's-60's largely due to the extension of existing ports or to the construction of new harbour and to the first structures of river engineering works.

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In addition to the causes mentioned above, the indiscriminate extraction of sand and gravel from the low-water bed of rivers was also responsible for the rapid beach erosion.

The first defence interventions carried out on the Adriatic coast consisted of natural rubble-mound seawalls or breakwaters of the emerging type. Instead, in Liguria, beach nourishment using a narrow strip of sand has been adopted since the 1950's (Savona, Lavagna).

The construction of longitudinal detached emerging breakwaters which determine down drift erosion, forced the Administrations of Emilia Romagna and Marche to build breakwaters of the emerging type for almost 80 km. Beaches are essential in supporting the tourist economy which has been rapidly growing since the 1960's.

At the end of the 1970's, the erosive phenomenon aggravated and this was particularly severe in Emilia Romagna because of subsidence. Therefore, the Administrations of the two Regions predisposed for legislative interventions which prohibited extraction of sand and gravel from the low-water bed and limited the gas and water extraction from the subsoil. Regional Plans were also set up to protect the coast. Their aim was to study and gain knowledge on this phenomenon in addition to finding alternative interventions to breakwaters of the emerging type.

Thus, at the beginning of the 80's, submerged barriers were tested. When the first author was performing his first analysis and tests on this type of structure, Lamberti & Tomasicchio (1981), only very few real life applications were observable in Italy and all of them were using a very special technology (Longard tubes). Since then, more than 50 submerged barrier defence systems have been constructed and this type of structure is progressively complementing and substituting the traditional use of parallel emerging breakwaters.

Two main types of structures have been constructed:

- sand-bag barriers, mainly used in combination with beach nourishment, and characterised by a high submergence and small section; they do not provide a significant reduction of wave height nor an effective retaining capacity on sand, but they are supposed to provide stabilization of natural sand bars and are appreciated because of their very low impact;
- rubble-mound submerged breakwaters, used alone or in combination with nourishment, with or without gaps, with or without a bed protection at the gaps, used to reduce wave transmission through the gaps of emerging parallel breakwater systems or to protect the bed from erosion in correspondence of the gaps.

In the meantime, many model tests have been carried out, Aminti & al. (1983), Lamberti & al., (1985), DH (1983, 1989, 1990) and others. Detailed moniring of their behaviour in nature was also performed in some cases, Ferrante & al. (1992).

The evolution of defence systems with the introduction of submerged barriers will be examined for typical cases in three italian regions: Veneto, Emilia Romagna and Marche situated on the Adriatic sea.

The Adriatic Italian coast is low and very flat in the Northern reach pertaining to Veneto and Emilia Romagna, and is an alternation of alluvial plains and moderately high erosion coasts in Marche region. Tidal escursion at spring ranges from 1.0 m in

Venice to 0.6 m in southern Emilia Romagna. Tide is substantially lower and mainly diurnal in the Marche region. Extreme storm surge ranges from 1.1m in Venice to 0.8 m in Ancona.

Typical 1 year return period waves are about 3.5 m and extreme about 6.0 m

2 Case histories

2.1 Emilia Romagna

The protective systems built after 1983 are nourishments protected by submerged barriers formed with sand-bags. Transversal groins made with sand-bags or rock in the emerging part and connected to the submerged barriers, are almost always present.

The new intervention extend for about 13.8 km in length with the use of 2.130.000 m^3 of sand nourishment coming from borrowed land quarries.

In these first interventions, sand-bag barriers had a small section, a volume of 1 m^3 and were generally arranged in two rows of 3 and 2 bags at a depth of -2.50, -3 metres.

The high submergence of these barriers does not produce any appreciable reduction of wave action. The barriers, however, stabilize the natural sand bars giving rise to a localized inshore erosion and to raising of the bed offshore (see. Fig. 1).

Frequently sand-bag barriers can undergo static failures. To avoid erosion produced by breakers falling on the sand, the dimensions of the sand-bags and the width of the barriers were enlarged during subsequent interventions (see Fig. 2).

The only work carried out in Emilia Romagna with submerged barriers of natural rock is that of Lido di Dante (Ravenna) (see Fig. 3) where a series of emerged groins had been incapable of preventing erosion. The subermerged barriers have a crown width of 12 m and are 0.5 m deep in water, as shown in Fig. 3. The last groin is connected to the barrier in order to prevent leakage of the sediments northwards. The volume of nourishment is such that the equilibrium profile has a closure depth between the coastline and the submerged barrier, producing a maximum shoreline advancement of about 30 metres from the.

Figure 4 shows the beach of Lido di Dante after the above intervention was carried out. Before the intervention the shoreline was just at the toe of the house.

2.2 Marche

Since 1982-83, in alternative to breakwaters of the emerging type or rubble-mound seawalls, a series of defence interventions were performed in the Marche region. Submerged barriers with nourishment were used for low coasts while those without nourishment were used for rocky coasts [Fiorenzuola (PS), Sirolo and Numana (AN)]. In some cases (Pesaro, Fano, Montemarciano) the typology was the same as in Emilia Romagna with sand-bag barriers or Longard tube barriers. In other cases, south of Ancona, the first submerged barriers in natural rock were used, both as breakwaters and as a defence at the foot of the nourishment. Figure 5 shows an intervention at Grottammare; the characteristics of a submerged barrier can be seen

with a crown width of 3.00 m and a submergence of 0.90 m. The barriers have gaps of 30 m and link two stretches of emerged breakwater barriers.

The drawbacks of these first submerged barriers are the following:

- heavy erosion in the gaps and in the terminal head arising from strong return currents;
- scouring effects at shore-side foot of the barriers;

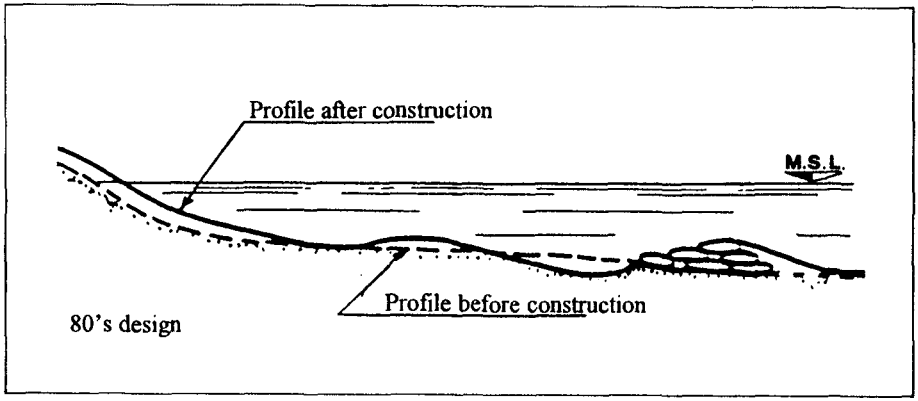

Fig. 1 – Sand bags submerged barriers and their effects - First intervention.

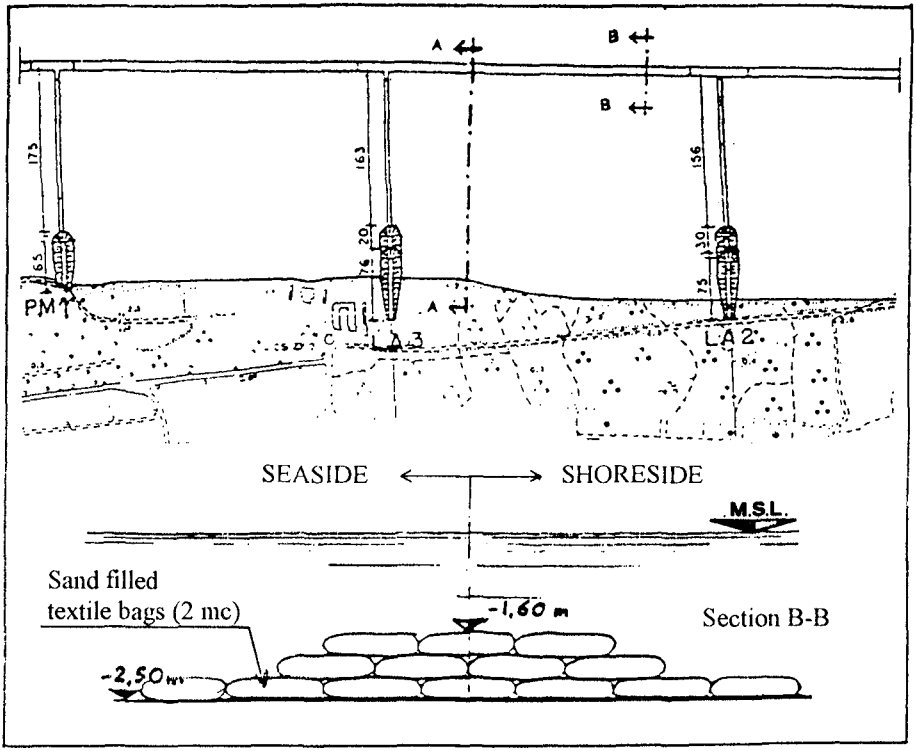

Fig. 2 – Protective system whit sandbags - New intervention.

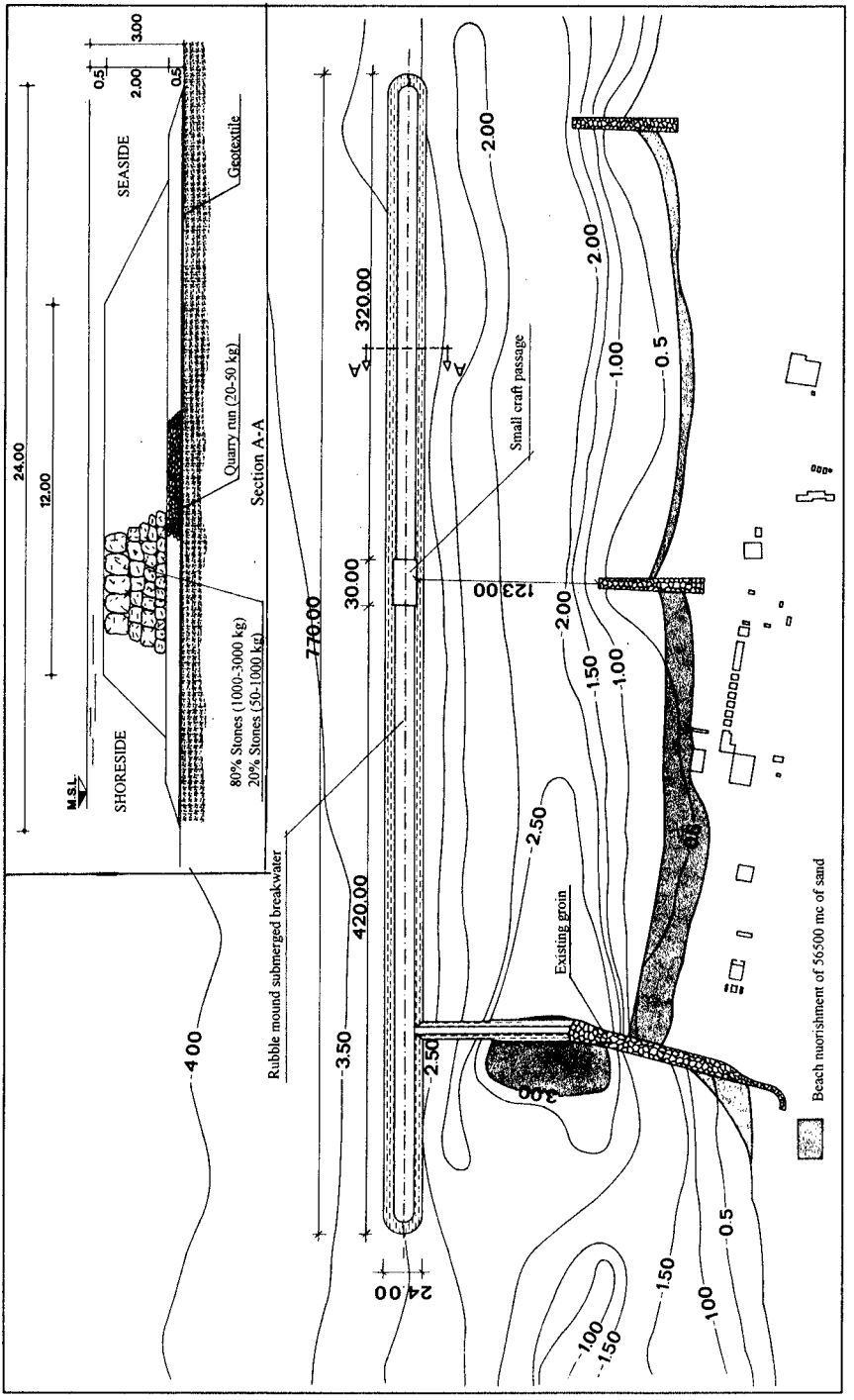

Fig. 3 – Protected nourishment at Lido di Dante (RA, Emilia Romagna): plan of the area and section of the submerged breakwater.

Fig. 4 – Lido di Dante after intervention.

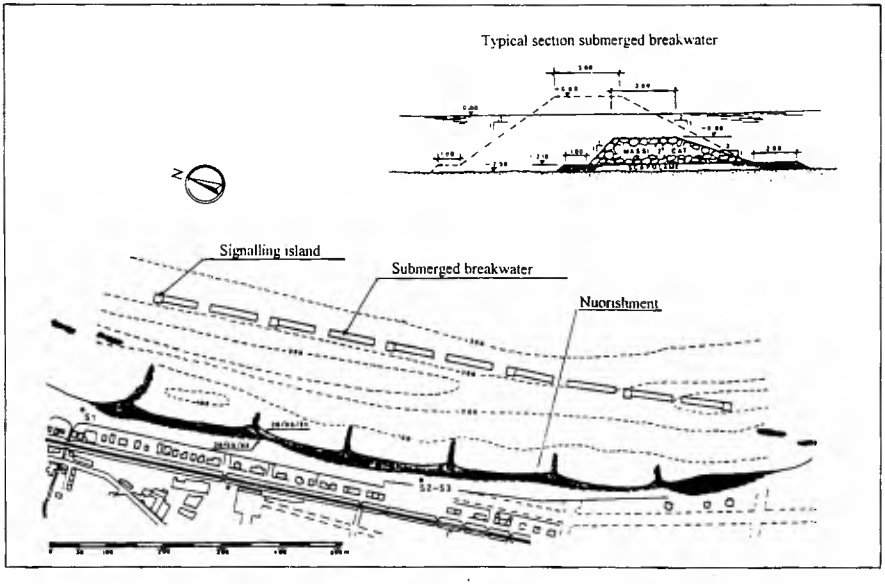

Fig. 5 – Protective system at Grottammare (AP, Marche)

- rock displacement due also to an imperfect execution when building the barriers, since it is difficult to place rocks in cloudy water;
- high submergence particularly stressed during Southeast sea-storms characterized by a remarkable rising of the average sea level. This produces an insufficient dissipation of wave energy.

The second generation of submerged barriers carried out in the Marche region have a considerably wider transversal section. This was done by increasing the crown width to 10-12 m, by lowering the submergence to -0.5 m and by increasing the slope of both barriers sides (see Fig. 6).

The gaps between the barriers are covered with a quarry run mattres in order to extend the base of the foundation between one gap and the next.

Second generation submerged barriers were used in place of emerging breakwaters or along stretches of the coast subjected to new erosion, without nourishment (see Fig. 7 on the intervention in Montemarciano (AN)). These replacements were carried out with the aim of improving the quality of the water and the sediments.

When emerging barriers are placed close to the shoreline, an insufficient water circulation is created which leads to the formation of slimy and annoying deposits of material for bathers.

In Montemarciano, the submerged barriers defend the facing coast. These barriers have been subjected to displacement of the stones along the slopes facing the shore and sea. The erosive process moves down drift (see Fig. 8), similarly to what happens with the emerging barriers.

Bathymetric measurements carried out at different intervals, show the formation of scouring effects both offshore and inshore of the structures and in proximity of the head of the extreme segments.

In Senigallia, the substitution of emerging barriers with submerged ones has lead to the disappearance of sand "tombolo" and subsequent withdrawal of the shoreline by 20-30 metres (see Fig. 9).

Longard tubes and sand-bag barriers have not been used anymore in the Marche. The negative results of these typologies were seen in those beaches with a steep bed slope.

2.3 Veneto

In interventions regarding the defence of venetian beaches which began in the 60's, the structures used were mainly groins with rigid seawall. Breakwaters of the emerging type were used only in a small stretch off the coast of Jesolo.

On the coast of Caorle (1985), submerged barriers in Longard tubes or sand-bags were experimented to create a protective nourishment.

At present, a project predisposed by the Consorzio Venezia Nuova is underway for interventions regarding the defence of the Cavallino and Pellestrina shores situated in the stretch of coast which separates the lagoon of Venice from the sea. The work which has been underway since 1995, foresees the construction of an artificial beach contained inside areas delimited by lateral groins, in part submerged and in part emerging, and by a submerged structure which connects these groins.

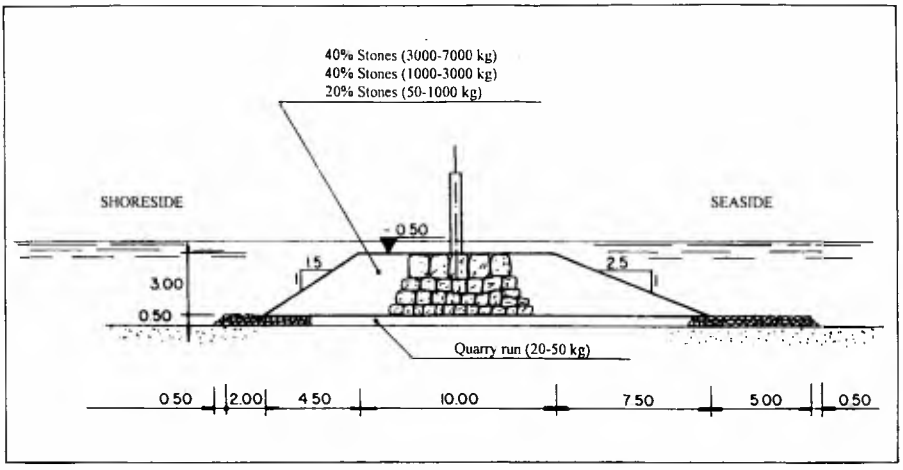

Fig. 6 – Submerged breakwater at Marina di Montemarciano (AN, Marche).

Fig. 7 – Protective system at Marina di Montemarciano (AN, Marche).

Fig. 8 – Down drift erosion of the submerged breakwater Marina di Montemarciano.

Fig. 9 – Protective system at Senigallia (AN, Marche).

Once finished, the artificial beach will stretch for 9 km with an average width of 100 metres at the time of sand-filling which should stabilize around 70 metres.

The main source supplying nourishment sand (12.000.000 m^3) has been individuated off Malamocco, 20 km from the coast at an average depth of -20 metres.

The characteristics of the intervention are visible in figures 10, 11 and 12.

3 The suggested design criterion

3.1 Relevant components of the dynamics of submerged barriers

The most important effect of submerged barriers is the depth induced wave breaking; even in the absence of breaking relevant effects on wave agitation take place. The limited submergence cause the generation of higher harmonics, see Fig. 7, and the relevant friction exterted by armour stones in the shallow stream flowing over the crests cause significant energy dissipation and modification of wave spectrum.

The breaking of wave over the crest is the cause of a potentially high wave set-up inshore the barrier. Set-up is significantly reduced by gaps in the barrier or at the ends of the barrier, but contemporary strong currents are induced through the gaps, where the bed must be adequately protected.

The mutual effects of energy dissipation by breaking and by friction must be adequately balanced because while they cooperate in reducing wave energy, they act in an opposite direction on wave set-up and currents, which are recognized as negative effects of the barriers.

3.2 Criterion For Global Retaining Efficiency

As a consequence of turbulence induced by breakers, the resuspension capacity of waves just inshore of the barriers is greater than for normal waves of the same height. Therefore, if sand is transported from the shore to the barrier, it will probably be resuspended and transported out of the barrier.

In order to be retained, sand should not reach the barrier, i.e. the reduction of wave height on the barrier should be strong enough to ensure the formation inshore of the barrier itself of a beach profile down to its closure depth.

Wave transmission is evaluated by formulae or experiments. Approximately $H_{st} \cong s_c$ (H_{st} = transmitted wave; s_c = barrier submergence).

Transmission coefficient depends on scaled values of:

- barrier submergence
- crest-berm width
- stone size
- wave steepness

Closure depth (h_c) for sandy beaches is evaluated by formulae or, approximately, as $h_c = 2H_{st}$. On gravel beaches a no movement condition at the foot of the inshore barrier can be imposed. The equilibrium beach profile is evaluated according to Dean 2/3 power relation. The turbulence decay area of the breaker can be approximately evaluated as *10h*.

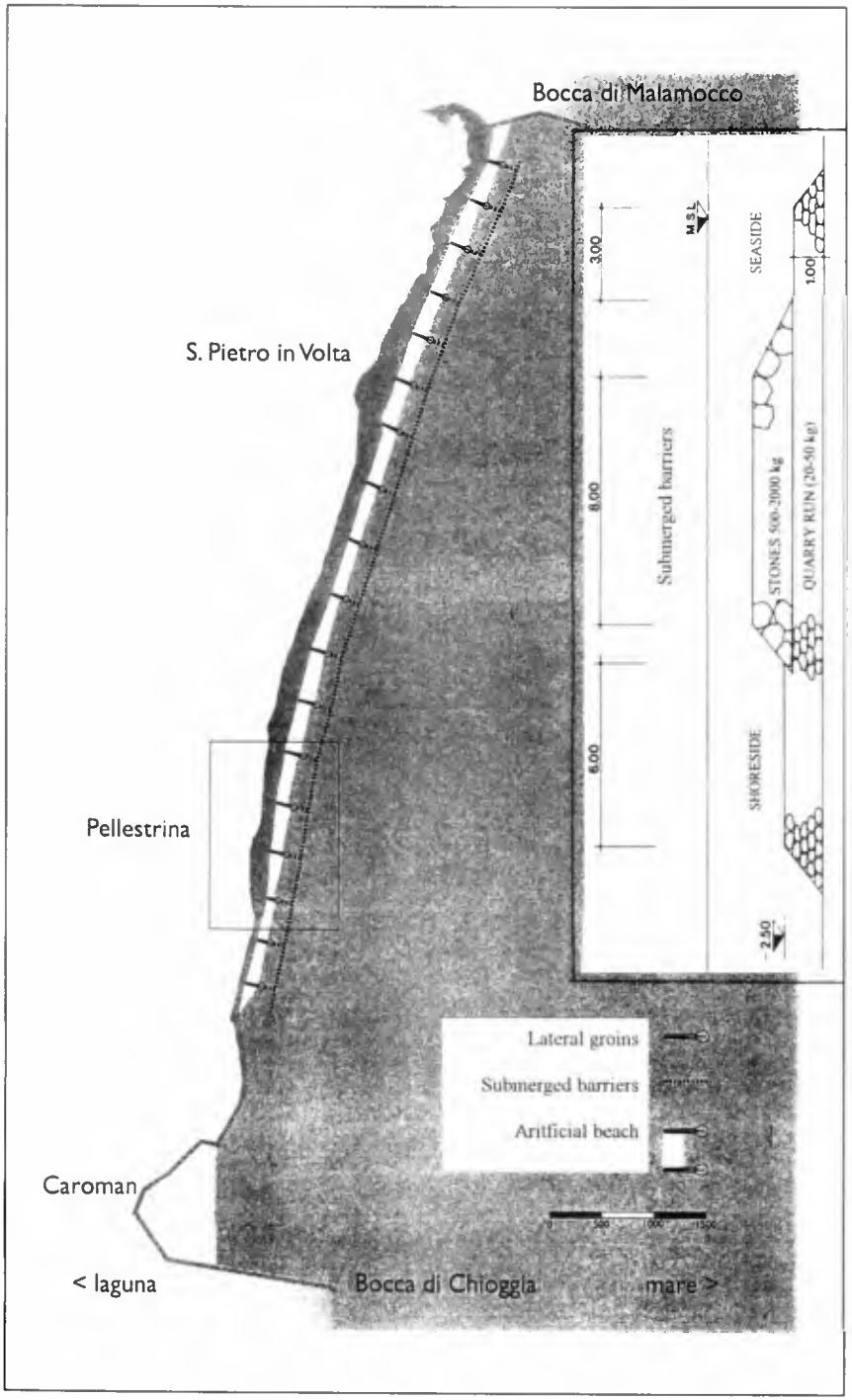

Fig. 10 – Protected nourishment at Pellestrina (VE, Veneto): plan of the area and section of the submerged barrier.

Fig. 11 – Pellestrina litoral before the works.

Fig. 12 – Pellestrina litoral after the interventions.

High water conditions are obviously the most severe for the beach stability; since $h_c \cong 2s_c$, a sea level rise cause an almost double increase of closure depth and an almost equal lowering of the closure point.

3.3 Most frequently used formulae

The Goda-Seelig (SPM), (Goda, 1985) and Van der Meer & Daemen (1994) formulae are most frequently used to calculate the wave transmission from the barrier.

For the closure depth of the equilibrium beach profile, Hallermeir's (1980, 1981) formula is used for sandy sediments.

For gravel beaches a modified Shield criterion is used in combination with a friction formula returning shear velocity from the orbital wave velocity at the bed.

For the armour stones stability Van der Meer (1993), Vidal (1995) and other formulae are normally used.

4 Open problems

The development of currents induced by the barrier is a 3-D complicated phenomenon, since the limited size of the barrier make the use of a mild slope approximation questionable. As a consequence the capacity of providing quantitative and reliable predictions of sediment transport by rip and longshore currents is limited and consequently of erosion in the vicinity of the structure and of effects on the beach.

Even if barriers made of rocks are stable according to the calculation formulae used, their transversal section show changes probably due to sinking of the rocks in the sediments of the bottom. This could be due to a probable underestimation of the structure-foundation interactions caused by the dynamic actions induced by the waves.

The structural resistance of sand bags showed to be insufficient. Most works constructed with this technique were destroyed after few years and in some case the remnants could not be found after 8-10 years.

Some damages to bags are probably caused during construction. During lifetime bag are covered with vegetation and mussels, the effects of which is poorly known, or abided by sand.

Finally quite often the sandy bed on which they are posed is ploughed by mussels fishers damaging the barrier.

5 Conclusions

In order to be efficient sand retaining structures, submerged barriers should be:

- sufficiently high and wide, so that they cause a significant reduction of the transmitted wave height and avoid erosion of the bed at their inshore foot:
  $s_c < h/2$ ($s_c=h/3$ at high water level)
  $b_c < 3h$ ($b_c=3h$ at high water level)
- sufficiently distant from the shoreline, so that turbulence produced by induced

breakers decays before reaching the inner beach.

Wave transmission and hydraulic stability of their stones are rather well known, particularly in the absence of cross-currents.

The knowledge of barrier behaviour is nevertheless still insufficient regarding several aspects:

- induced set-up and currents influencing sediment transport and water quality;
- related sediment transport causing littoral sand trapping efficiency or sand losses;
- local bed erosion at inshore and offshore toe of the barrier and in the gaps;
- barrier sinking mechanism, which must be controlled in order to preserve barrier submergence and efficiency.

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