Beach nourishment with nearshore sediments in a highly protected coast

Luigi E. Cipriani[1], Filippo Pelliccia[2] and Enzo Pranzini[2]

[1]Regione Toscana - Dipartimento delle Politiche Territoriali e Ambientali. Via di Novoli, 26 - 50127 Firenze, Italy. Phone +39 (055) 4383089; Fax 4383063; Email l.cipriani@mail.regione.toscana.it
[2]Dipartimento di Scienze della Terra - Università degli Studi di Firenze. Via Iacopo Nardi, 2 - 50132 Firenze, Italy. Phone +39 (055) 243486; Fax 241595; Email epranzini@cesit1.unifi.it

Abstract

Approximately 7 km of beaches at Marina di Massa are experiencing severe erosion as a consequence of the construction of an industrial harbor at Marina di Carrara in the early 1920's. The new structure intercepts the southward longshore sediment transport, inducing a sedimentary deficit to downdrift beaches.

Different types of hard structures, such as seawalls, breakwaters and groins, were built in the study area in order to protect the seaside resort and the coastal highway from shoreline retreat. A submerged breakwater connecting the offshore end of the groins was later added in order to decrease beach sediment loss. As a result, each kilometer of coastline is now protected by 1.4 kilometers of hard structures, and the coastline is subdivided in many adjacent artificial cells.

Nevertheless, beach erosion proceeded and tourist industry is now suffering from this retreat. A low-cost coastal restoration project financed by bathing establishment owners and the local authority was undertaken in June of 1997 inside one of the artificial cells. Approximately 4,125 cubic meters of sand (15 cubic meters/meter of coastline) were dredged offshore the submerged breakwater and dumped on the beach.

Native beach sediment's mean grain size is approximately 1.7 phi (0.31 mm), in contrast with the nearshore borrow material's mean grain size, which is approximately 2.25 phi (0.21 mm).

A morphological and sedimentological beach monitoring was performed by the authors to evaluate the effectiveness of the project. A total of five surveys were carried out between June 1997 and June 1998. Data show that approximately 66% of the borrow material was lost within one year, most of which between July and October. This is to be ascribed to the unsuitable borrow material texture. In addition, beach quality had worsened due to fine sediments that made the beach dusty. A benefit-cost analysis of the project, together with an evaluation of the opportunity of such a work, was also performed.

Introduction

Marina di Massa is located in northern Tuscany (Figure 1). In this area potential net longshore sediment transport is estimated to be directed southwards for approximately 150,000 cubic meters/year (Aminti *et al*., 1999). The sediment source for the beach in Marina di Massa is the Magra River, outflowing at the northern margin of the physiographic unit and feeding the beaches down to Forte dei Marmi (18 kilometers southward), as beach sediments petrography demonstrates (Gandolfi and Paganelli, 1975).

Figure 1 - Location map of the study area.

The construction of the industrial harbor at Marina di Carrara in the early 1920's caused the interception of the southward longshore drift, inducing rapid progradation in the updrift beach and erosion downdrift. Marina di Carrara beach has undergone shoreline progradation for approximately 300 meters since the harbor construction, even though in recent years (1985-1998) the trend has changed (Cipriani and Pranzini, 1999) and the shoreline has retreated due to a strong reduction in the Magra River sediment load (Pranzini, 1995).

Marina di Massa, which is located downdrift, has instead experienced severe erosion since the early 1930's (Albani, 1940), even though in those years the harbor updrift jetty was 400 meter long against the present time 900 meters. In 1930 the first seawall was constructed in order to protect the coastal highway, and in 1957 a series of breakwaters were added, even though the beach had already vanished for a stretch of coast long 2 kilometers south of the harbor (Berriolo and Sirito, 1977).

Figure 2 - Mean shoreline evolution at Marina di Massa between 1938 and 1995.

In the meantime, shoreline retreat was gradually shifting southwards, thus a series of hard structures, such as seawalls, breakwaters, groins and submerged breakwaters (Figure 2, top), were built along the coast. As a consequence, a 6.7 kilometers long stretch of coast south of the harbor is today protected by 9.3 kilometers of hard structures (1.4 kilometers of hard structures per kilometer of coast).

In 1970 a sand bypass system was designed in order to transfer approximately 200,000 cubic meters/year of sand from the northern side of the harbor to the south. After several interruptions, the experiment was definitively abandoned in 1974, due to the expensive maintenance procedures and to the structural instability of the harbor's northern jetty because of sand dredging at its foot. This induced local Administrators to ask for more hard structures in order to stabilize the shoreline. Indeed, between Lavello and Frigido Rivers (Figure 2, top), groins and submerged breakwaters were able to stabilize the beach that was retreating at a rate of approximately 1 meter/year in the period 1938-1978 (Cipriani and Pranzini, 1999).
However, beach erosion continued to increase southward. Figure 2 (bottom) shows the evolution of the shoreline between 1938 and 1995 at Marina di Massa. Sectors A and B show a decrease in shoreline retreat after the construction of coastal defences, while sectors C and D show an increase of beach erosion as a consequence of the construction of the same structures.

The study area

The beach under study is located inside the southern cell, bounded by couples of groins, and it is sealed offshore by a submerged breakwater (Figure 3). The cell's length is approximately 270 meters, and the submerged breakwater was originally built only on its northern side and was joined to a rocky island. Just before the beach nourishment, May of 1997, the breakwater was extended to reach the southern groin, which is shorter than the northern one (Figure 3). More recently an additional groin was built south of our cell, thus increasing the lenght of this type of defense to reach the present configuration.

Figure 3 - The cell under study with the position of the 5 surveyed beach profiles.

The original beach was wider in the northern part and thinner in the southern one, where incoming wave energy was not dissipated by the submerged breakwater. The asymmetry of the structures is reflected on the beach sediment texture (Figure 4); finer sediments (mean grain size ranging from 1 to 3 phi; 0.5 ÷ 0.125 mm) are present in the northern side, whereas coarse material (up to -2 phi; 4 mm) is present in the open side. Step sediments are characterized by mean grain size values ranging between 2 and -1 phi (0.25 to 2 mm).

Figure 4 - Beach sediments mean grain size before the artificial nourishment (May 1997).

The nourishment project

In June of 1997 approximately 4,125 cubic meters of sand were dredged offshore the submerged breakwater along the 5 meter isobath. Sediment was directly discharged on the backshore in the protected area. The work was carried out with a pump placed on a barge. The pump was able to mobilize a mix of sand and water at a ratio of 1/20. To favor the sand fraction deposition on the dry beach, a sand dam was constructed to allow water to backwash through some drains (Figure 5).

During this work, sediment samples were taken directly from the pipeline outlet, and grain size analysis was performed on dry material. Mean grain size of the borrow material resulted to be 2.25 phi (0.21mm), which is coarser than the surface sediments collected from the exploitation area during the survey preceding the work execution (2.5 ÷ 3.0 phi; 0.177 ÷ 0.125 mm). This is probably due to the fact that sand dredging reached deeper coarse levels, probably representative of storm conditions, not sampled during the previous survey. After the dumping phase, borrow material was spread on the beach by a bulldozer.

Figure 5 - The sand dam built in order to favor siltation.

Materials and methods

Beach evolution monitoring was performed between May 1997 and April 1998. Beach profile was surveyed along 5 sections using Emery (1961) method on the following dates 21/05/97, 14/06/97, 11/07/97, 18/10/97 and 24/04/98, and starting at the inner limit of the beach, where bathing huts structures are generally found, until the surf zone along the 1 meter isobath.

Shoreline position was surveyed as well (Figure 6). At the same time, approximately 6 sediment samples were collected along each section, for a total of 147 samples. Each sample was dry sieved at ½ phi intervals and Folk and Ward (1957) textural parameters were obtained.

Beach volume was calculated comparing beach profiles, and surface variations were computed from the shoreline position.

Grain size parameters were mapped for each survey and correlation between beach morphology and sediment texture were analyzed.

Beach morphology evolution

Shoreline monitoring (Fig. 6) shows that the beach was artificially expanded for approximately 1,480 square meters (mean shoreline progradation of 5.5 meters). However, the July survey indicates an additional beach growth of approximately 560 square meters, with a mean shoreline progradation of 2.1 meters. The reason for the summer beach expansion is to be correlated with the nourishment procedure, which made an artificial steep slope that was not stable. In addition, daily beach cleaning procedures induce flattening of the beach profile. Indeed, beach volumes computation indicates that in this period a loss of the fill occurred (Figure 8).

Figure 6 - Shoreline evolution during the monitoring period.

From this point on, sediment loss is relevant; in fact the October survey shows a beach area reduction of approximately 1,040 square meters, with a mean shoreline

retreat of approximately 3.8 meters. During the last survey (April of 1998) the beach area was reduced by some additional 520 square meters, with a mean shoreline retreat of approximately 1.9 meters (Figure 7). At the end of the monitoring period the beach was on average only 1.9 meters wider than of the original one.
As far as the beach volume is concerned, the artificial nourishment brought to the backshore 4,125 cubic meters, 4% of which was lost during the first month. Another 58% was lost between July and October, and an additional 4% was lost during the following winter. At the end of the monitoring period, less than one year after the end of the work, 66% of the fill was lost (Figure 8).
Figure 7 - Beach area (square meters) changes during the monitoring period.

Figure 8 - Beach volume (cubic meters) during the monitoring period.

Beach sediment texture changes

The second survey (June 1997) was undertaken on the day which followed the end of the nourishment, and it therefore shows the texture of the borrow material with a mean grain size of approximately 2.25 phi (0.21 mm). As a result, sediment texture in the northern side of the cell remains unvaried, whereas in the southern side fine sand covered coarser material (Figure 9).

Figure 9 - Beach sediments mean grain size after the artificial nourishment (June 1997).

Figure 10 - Beach sediments mean grain size at the end of the monitoring period (April 1998).

In July of 1997 (third survey; map not shown) beach sediment texture was approximately the same found at the end of the work, since no storm occurred in the meantime. However, coarse material was sampled in the surf zone; this was probably due to the offshore migration of fine materials.

In October of 1997 (fourth survey; map not shown) a strip of fine sediments was found on the swash zone and in the surf zone, while coarser sediments were along the step. The upper part of the backshore still hosted fine borrow material.

The last survey (April of 1998; Fig. 10, previous page) indicates a general increase in the grain size and a marked asymmetry between the two sides of the cell. In the northern side finer sediments are still present, whereas in the southern one coarser sediments were found both in the backshore and in the foreshore, with mean grain size of up to -2.60 phi (6.06 mm).

This shows that despite the presence of the submerged breakwater, winter storms were able to reach the upper part of the beach and build a gravel ridge at an approximate height of 2 m above mean sea level. This material was not found in the grain size distribution of the borrow material but it was detected, as secondary mode, in the native sediments and it should be considered as residual in the area where fines were lost during winter storms.

Benefit-cost analysis

As far as the fill longevity is concerned, the artificial nourishment of the beach inside the cell is to be considered ineffective (66% of the volume lost within one year); nevertheless, similar performances are quite frequent all over the world (Silvester and Hsu, 1993). A mean shoreline retreat of approximately 5 meters has occurred from July 1997 to April 1998 in the studied cell, whereas a mean shoreline progradation of 1 meter/year was experienced, in recent years, by the northern cells protected by similar hard structures. The present erosion rate in the studied beach is even larger than that registered in the previous period (2.1 meters/year between 1985 and 1995), when the submerged breakwater was only sealing the northern side of the cell. In our opinion, this was due to the unsuitable grain size of the borrow material, although in certain cases the grain size was proven to be insignificant on the beach fill longevity of sand beaches (Etiner, 1996). A Stability index (Pranzini, 1999) equal to 0.31 was computed for the borrow material; this value predicts a limited stability of the fill (0.50 is the Stability index for a material with an identical grain size distribution to the native's one; whereas zero and one are the Stability indices for extremely unstable and extremely stable borrow material respectively).

Nevertheless, establishment's owners were satisfied with the project, which stopped beach erosion for one year and gave them a wider beach for the summer period. This allowed to support their activities with additional rented beach umbrellas and deckchairs.

The total cost of the artificial nourishment was 90,000,000 Italian Lire (approximately US$ 50,000), *i.e.* 22,000 ITL (US$ 12) per cubic meter of sand. Each square meter of new beach had a cost of approximately 44,000 ITL (US$ 24). The net economic gain can be estimated in approximately 165,000,000 ITL (US$ 91,700) considering that each set of umbrella and deckchairs, which occupy 12 square meters of beach, is rented for 1,500,000 ITL (US$ 833) for the whole summer season. Actually the direct gain for the bathing establishments must be divided by two, only half of it going to the establishment's owners, since approximately 50% of the beach is public. No analysis was performed to evaluate the indirect income produced by all the commercial activities carried out inside the bathing establishments (bars, restaurants, electronic games, *etc*.), which are also open to the tourists using the public beach. From a purely economic point of view, the work was largely paying.

On the other hand, a loss of 66% of the fill volume in one year turns any scientific evaluation of the project into a negative one. In addition, sand dredging onshore the depth of closure makes the beach itself less stable and induces downdrift erosion. A benefit-cost analysis for the southern beach should be performed as well, but a long term monitoring should be necessary.

The limited longevity of this kind of beach fillings, mainly due to the inappropriate grain size of the borrow material, is leading to a loss of faith in beach nourishment by private owners, tourist operators and local authorities. This can also lead to the construction of additional hard structures when public opinion does not understand that beach nourishment, if correctly performed, is a sustainable way to manage coastal erosion.

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