Assessment of Nourishment Project at the Maresme Coast, Barcelona, Spain

By

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ABSTRACT

In 1986, the Maresme nourishment was the first carried out in Spain, and comprehensive monitoring has taken place since then. The monitoring results are analyzed with the aim of extracting conclusions to improve knowledge of coastal processes and at the same time to trigger defence measures if losses of sand reach a specific amount. It is concluded that the project has been successful, taking into account the maritime climate and the sediment transport in the zone.

Additional Keywords: Erosion, monitoring, hot spots

INTRODUCTION

Erosion along this coast has occurred mainly due to harbor blocking of the longshore current and sediment transport, and also due to a reduced sediment supply from rivers in the area, in particular, the Tordera River (Lechuga 1994). In the middle of the second half of the past century, development of this area led to the construction of the first railway in Spain (Barcelona-Mataró). The infrastructure of this railway was built on the previous beach along most of its length. Many years ago, the railway had to be protected with a continuous quarry stone bulkhead along the coast. The shore protection situation along the 47 km of coast north of Barcelona was dramatic.

After considering different alternatives of coastal defence, it was decided to use a soft method of defence based on artificial nourishment of the beaches. The works began in 1986 (Peña, Carrion, and Castañeda 1992). The challenge was severe taking into account that this was the first time that soft measures were undertaken in Spain. The project was not easily developed and had to be carried out while enduring criticism. A short geographical description of the coast, from northeast to southwest, is as follows (Figure 1):

Tordera - Arenys de Mar

First, we come across the mouth of the Tordera River. The point owes its shape to a deltaic origin, and the shape undergoes a sharp change of orientation, from ESE, to SSE.

Close to the Tordera River is the village of Malgrat and beaches: Santa Susana Beach, Pineda de Mar Beach, Calella, Sant Pol, Canet de Mar, and Arenys the Mar. Although not large, there are many groins and small structures in this area. Of course, we cannot consider them as total barriers to sediment transport, but they did cause a reduction in sand transport. As a result, erosion was seen along the length of this 22.4 km stretch of coast. Computed total transport using the CERC formula amount to 66,000 m^3/year (northeast to southwest).

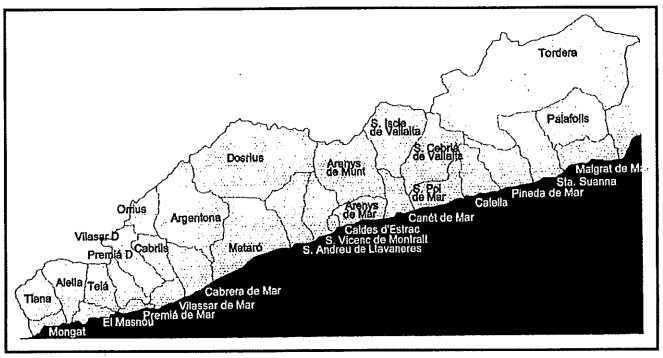

Figure 1. Maresme Coast, Barcelona Spain.

Arenys de Mar - Besos Mouth

From the east of the Arenys Harbour to the Besos River mouth, the Maresme Coast is heavily eroded and degraded due mainly to the construction of five marinas in this area: Arenys the Mar built in 1907, El Balis (1972), Mataró (1989), Premia de Mar (1971) and El Masnou (1972). In a first attempt to stop the erosion, several groins were built, for instance between Arenys and El Balis (11 groins), but the result was discouraging. In the end, a bulkhead of quarry stone had to be built along almost the entire coast to defend the railway. This stretch of coastline undergoes a smooth change of orientation, so at the Besos mouth, the coast faces the southeast. Computation of the total longshore sediment transport at this location yields a value of 90,000 m^3/year, that we can consider as a maximum for that area. Of course, this value, while not very large, refers to the potential total amount of sand that could be transported in one direction (east to southwest), assuming the sand was available on the beaches (as is not the case for most of them).

In this paper, we examine the first zone, between the Tordera mouth and Pineda Beach. The total length of this stretch is approximately 7 km and does not include major maritime structures, but some groins are in the area and a bulkhead of quarry stone runs along most of it. The eroded situation was remarkable along these beaches and they were almost unsuitably for tourist use. The recession of the coast led to some damage to the railway that had to be defended. This was the situation prior to beach nourishment.

Considering that the main causes of the erosion remain, it was clear from the start that the zone was going to need periodic renourishment. When, how, and where that coastal zone has to be renourished depends on the coastal morphology and on the longshore transport.

OBJECTIVES OF THE NOURISHMENT

The beach nourishment project had two objectives. The first was to increase beach width so they could be used as a tourist amenity. These beaches are overcrowded since they are in the metropolitan area of Barcelona. The second objective was to defend the railway, removing, if possible, the bulkhead without loss of reliability, but still making sure that sediment could be carried along the coast by waves. To do that, conditions must be similar to natural beaches excluding for that reason coastal defense measures involving structures that might block, totally or partially, the longshore sediment transport. Of course, in a severely receding coast, natural conditions are difficult to achieve (sand size becomes coarser and beach slope steepens as erosion proceeds.

Although the nourishment was carried out along the total length of the Maresme coast (over 44 km), our study only refers to 7 km between Tordera Mouth and Pineda Beach. From the monitoring point of view, this zone was split into subzones to optimize surveys and field data analyses. As far as erosion is concerned, this zone was comparatively in better condition than the rest. However, the deficit in sediments was still remarkable, and the nourishment project was similar to the more eroded coastal stretches.

BEACH NOURISHMENT

In March 1987, the first nourishment amounting to 1,037,000 m^3 of relatively coarse sand (0.4-0.5 mm) was carried out using a borrow area located just seaward of the site in 20 m water depth (Peña, Carrion, and Castañeda 1992). This source of sand close to the coast was one of the main reasons nourishment was feasible along the entire Maresme coast. The approach taken was:

1. Sand was taken from the borrow zone using a suction dredger.

2. The self-propelled suction dredger moved toward the beach.

3. Sand was pumped to the beach using a flexible pipeline submerged or floating depending on the distance to the beach.

This procedure proved to be efficient taking into account the specific conditions of sources and beaches.

The initial beach after nourishment was roughly 90-100-m wide (dry beach, with an elevation ranging from 2.5 to 3.0 m landward to 1 m at the shoreline. The sand on the dry beach was slightly compacted, leaving the submerged profile on its natural slope. The idea was to use wave action to shape the beach. Taking into account the equilibrium profile at that area, sand characteristics, and average maritime climate, the dry beach width was thought to be at least 60 m in most conditions, except perhaps for major storms. Determining whether that requirement was satisfied or not is the main objective of the monitoring. It is important to point out that the causes of the eroded situation were and are still present on the coast, so beaches need to be renourished occasionally (Figures 2 and 3).

Table 1. Maximum Significant Wave Height

Year	Hs (m)	$T_{z,s}$ (seg)
1987	3.85	10.5
1988	4.80	11.1
1989	3.46	9.9
1990	3.06	8.3
1991	4.38	8.7
1992	3.70	9.8
1993	3.64	10.0
1994	3.76	10.2

The maritime climate was determined from data from two sources: (1) a buoy located at the Golfo de Rosas, near Maresme Coast, and (2) visual data. The data are complementary with the second source providing wave direction to the first. The main direction of swell waves and sea waves is EN. Table 1 lists the maximum significant wave and period in the shown year.

The maximum significant wave ranges between 4.80 and 3.06 m in the record. However, the maximum wave height was more than 8 m in the same period. These data compare reasonably well with the expected distribution used to compute sediment transport.

It is important to note the extreme obliqueness of waves incident on the Maresme Coast. That wave angle is greater than the theoretical transport maximum of 45 deg, and it leads to major consequences, i.e., in that area, a comparatively small structure blocks the sediment transport and impounds a long beach updrift of the obstacle.

MONITORING SURVEYS AFTER THE NOURISHMENT

Extensive monitoring was carried out after the first nourishment. Surveys have been made since May 1987 (Figure 4). At the beginning, surveys took place every half-year and after that they took place annually until 1994. The dates of all surveys are: May 1987, November 1988, June 1989, November 1989, July 1990, September 1991, September 1992, October 1993, and June 1994. Although there were some differences among the surveys,

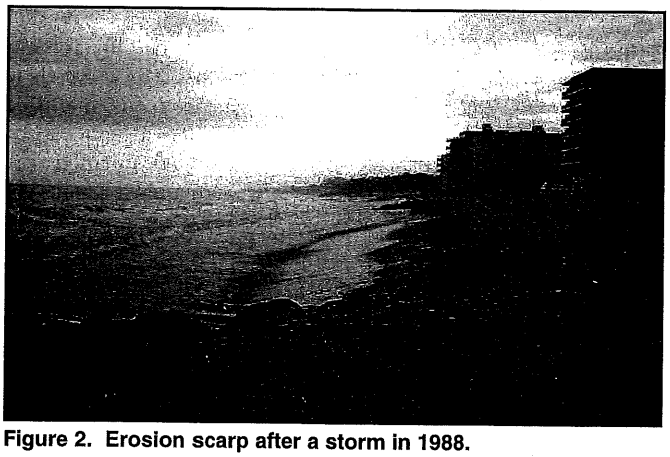

Figure 2. Erosion scarp after a storm in 1988.

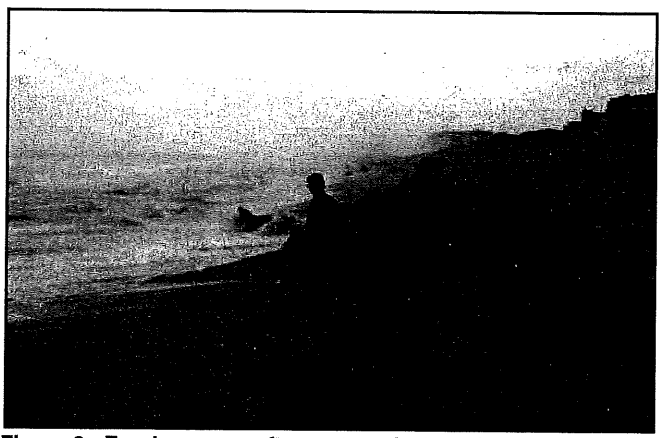

Figure 3. Erosion scarp after a storm in 1988 (note remains of the bulkhead).

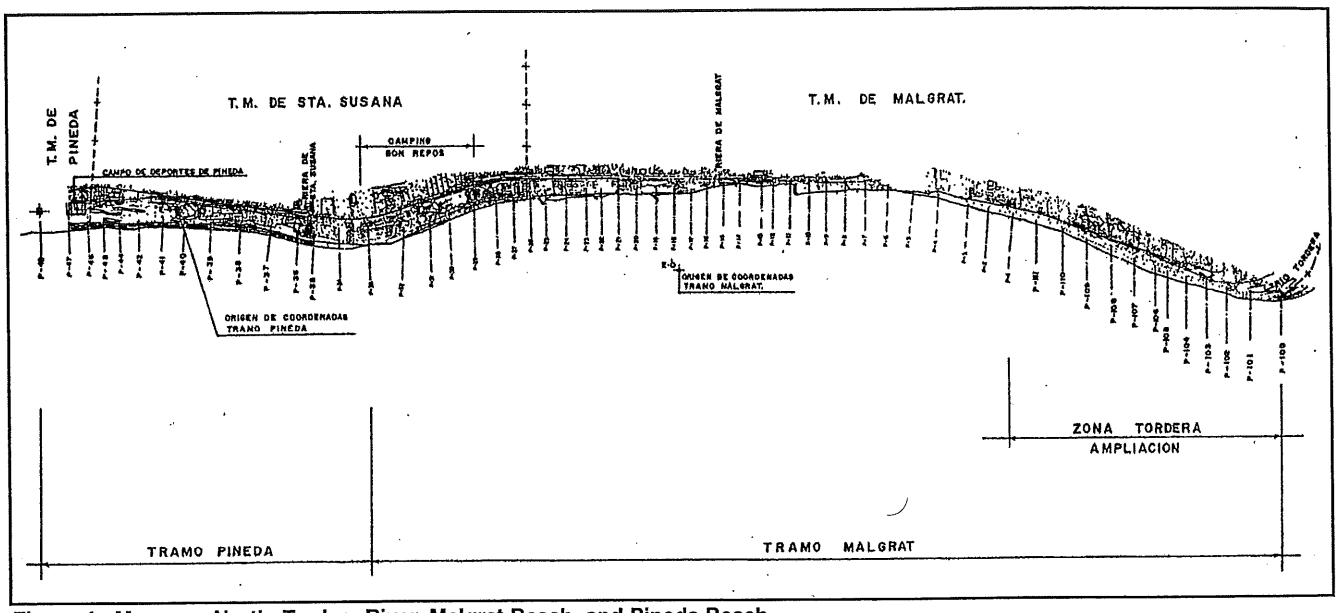

Figure 4. Maresme North, Tordera River, Malgrat Beach, and Pineda Beach.

the general procedure was common to all of them. Here, we examine three surveys in some detail: May 1987, September 1991, and June 1994 (Losada 1996). The survey basic area was as follows:

Stretch P.100 - P.1. Mouth of Tordera River. The length is 1,700 m. We have information since July 1990.

Stretch P.1 - P.33. Malgrat Beach and Urban area. The length is 3,800 m. The end of that stretch is located at the Mom Repos Camp Site.

Stretch P.33 - P.48. Pineda Beach. The length is 1,400 m. The end is defined by a "bunker" on the beach.

SELECTED RESULTS

The closure depth is an important concept involving both cross-shore dynamics and longshore transport. Most of the surveys were carried out up to 15 m, but to summarize the data, we use two closure depths, 8 and 13 m, for two reasons:

1. 8 m is the theoretical depth as calculated with the Hallermeier (1981) formula as a limit depth taken into account our wave climate.

2. 13 m is convenient for comparing results (to assess the reliability of the surveys).

Comparisons between surveys were made by two procedures, profile checking and plan interpolation. The main aim is to examine shoreline evolution in the first case and sand volume differences in the second case. As a result of the monitoring, a replenishment was made. That replenishment was, to a certain extent, a measure of the sand lost at specific locations. We will see that the balance of sediments includes the renourishment.

The main features of the profiles at Tordera Mouth and Malgrat Beach (up to profile P.20) are: (1) a conspicuous bar 200 m from the shoreline (the crest is 3 m deep, Figure 5), and (2) an almost uniform slope of 3.7 to 4% (seaward to the bar).

Malgrat Beach (P.20 - P.33)

This beach segment has a two-bar system. The shoreward bar is the same as the above (less important in this case). The seaward bar is located 650-700 m from the shoreline. The crest depth is 5 m (Figure 6). The beach slope is 3%.

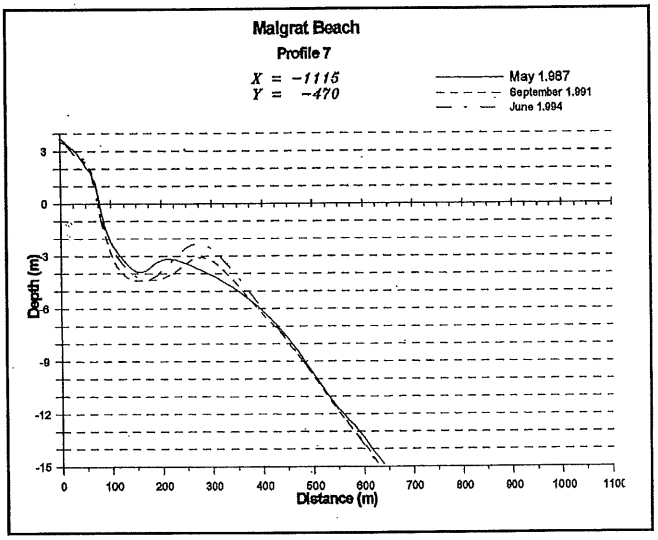

Figure 5. Close to Tordera Mouth, the beach has one bar.

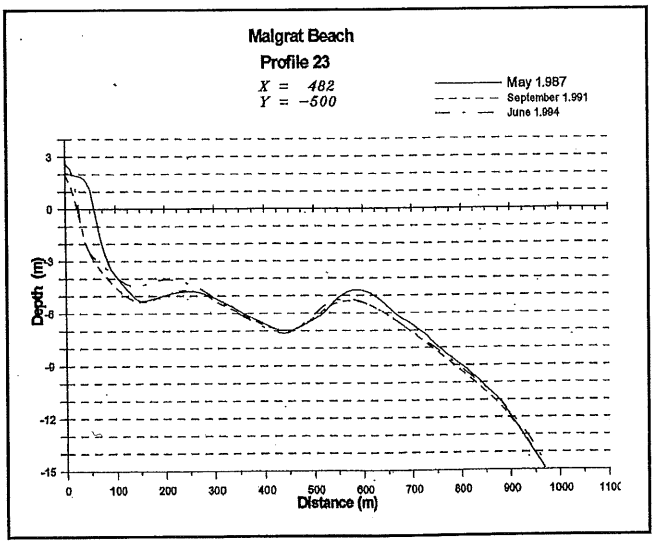

Figure 6. Two bars on Malgrat Beach.

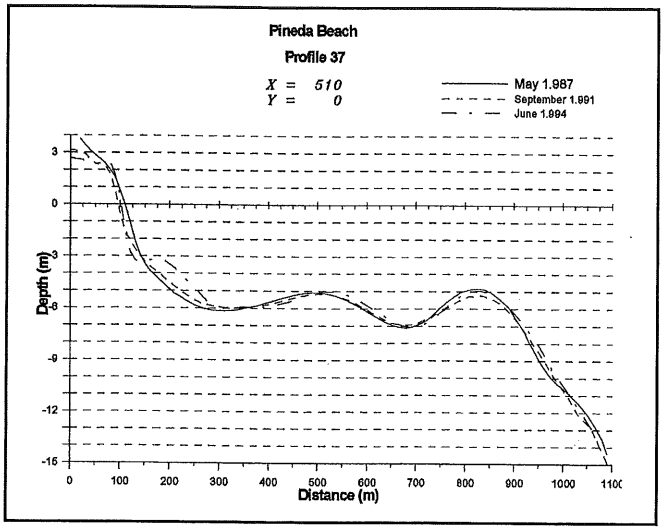

Figure 7. Three bar system at Profile 37, Pineda Beach.

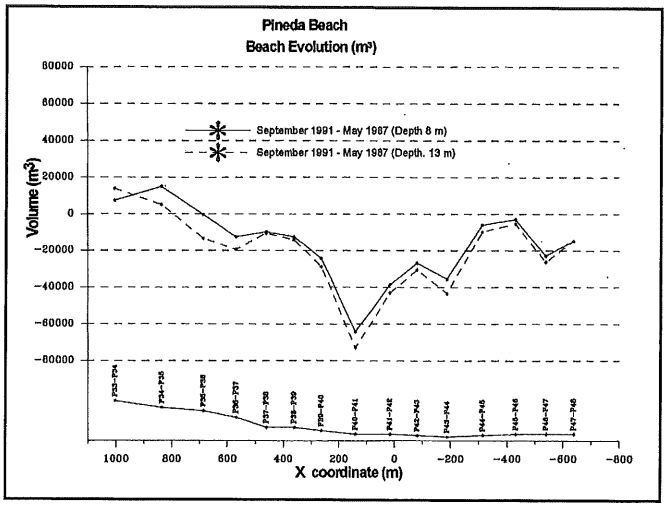

Figure 8. Volume changes between surveys at Pineda Beach, showing computations using different closure depths.

Pineda Beach (P.33 - P.48)

This beach has a three-bar system. The shoreward bar is barely detectable. The intermediate bar is located 450 m from the shoreline. The Seaward bar is 750 m from the shoreline. In both cases, the crest depth is 5 m. The submerged slope is 4.5% seaward of the outside bar (Figure 7).

VOLUME CHANGES

Volume changes during the monitoring can be summarize as follows (Losada 1996):

Malgrat Beach

Profiles P.100 - P.1. Between 1991 and 1994, there was accretion of 217,183 m³.

Profiles P.1 - P.33. Between 1987 and 1994, there was an erosion of 222,196 m³.

Apparently, that coastal stretch was balanced, but the zone had to be renourished twice during the period. The first was in April 1991, replenishing 90,000 m³ between profiles P.11 and P.15. The second was in October 1993, using 145,000 m³ placed between profiles P.11 and P.19. We can see that location as an area of critical erosion.

Pineda Beach

Profiles P.33 - P.48. That zone experienced erosion of 234,595 m³.

The total erosion was computed as 456,791 m³. From this figure we would have to subtract the accretion of 217,183 m³ yielding 239,608 m³. However, taking into account the amount of sand replenished in 1990 and 1993, 235,000 m³, we get to the total erosion of 474,791 m³.

The erosion was computed using the closure depth of 13 m. Another point is that most of the erosion took place between 1987 and 1991. The beaches began recovering to a certain extent after 1991 (Figure 8).

SHORELINE EVOLUTION

This index was used as a diagnostic to determine the amount of sand to be replenished (where and when). The relevant figures are as follows:

Malgrat Beach

Profiles P.100 - P.1. Between September 1991 and June 1994, there was a general advance of the shoreline (33.5 m at P.102).

Profiles P.1 - P.33. Between May 1987 and June 1994, there was significant recession throughout the area. The 63.8 m recession at P.15 marked the maximum.

Pineda Beach

Profiles P.33 - P.48. Between May 1987 and June 1994, there was moderate recession of about 20 m, and the maximum recession took place at P.41 (37.3 m).

CONCLUSIONS

The functioning of the beach fill and replenishment since 1987 can be assessed on the basis of continued monitoring. An important aspect for coastal management is that erosion was experienced at specific locations (erosion hotspots). Of these hotspots, a notable area is the shoreline recession of 63.8 m at P.15. The exact location of that area is in front of Malgrat Village between the old curve groin and La Riera de Malgrat mouth of a rivulet).

Other valuable information is the volume of sand loss. An estimate for this loss is about 470,000 m³, which corresponds with the total amount of sediment transport calculated for the 8 years of monitoring. If that conclusion is true, the supply of sediments by the Tordera River is irrelevant or, at least, has been irrelevant during that period. Another critical location is the area in the convex shoreline about 1 km westward to Malgrat village. Taking into account the replenishment needed in this zone, we can conclude for coastal management that this area requires special attention.

Although the assessment of the nourishment has to be made for the whole coast of the Maresme, it is clear that sand losses in the area are in agreement with the littoral dynamics. Monitoring has shown that expected Hallermeier (1981) closure depth of 8 m agrees with the surveys on the Maresme coast.

Overall, it has been concluded that the beach nourishment has been successful for two reasons. First, of course, is that the area had been degraded prior to the replenishment, so the improvement has been a remarkable benefit for recreation and for protection of the railway (Figures 9 and 10). Second, the borrow

Figure 9. Picture of Malgrat Beach after the last nourishment (1995). To the left is the Tordera River.

Figure 10. Picture of Malgrat Beach (1995) to the south. We can see the convex zone at Bon Repos.

material, coarser than the native sand on the beach and the wave climate experienced in the area have made sand losses smaller than expected.

Finally, it is mentioned that although monitoring is an expensive activity, it allows improved understanding of the processes involved, and suitable monitoring returns valuable dividends, direct and indirectly.

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