

The influence of Marina Construction in Beach Stability: El Milagro Case Study

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Abstract

The analysis of the behaviour of a beach, after the construction of a marina at one of its side, is made in this paper. El Milagro Beach, Tarragona, (Spain) is a 1.5 km long sandy beach. Two nourishment works were carried out along the beach, the first in 1986 and the second in 1993. Eleven surveys have been carried out since 1986. A marina was constructed in 1995. From the monitoring program, the shoreline evolution and profile changes have been determined before and after marina construction. It is concluded that the construction of the marina changed the beach stability.

Introduction

El Milagro Beach is located close to Tarragona, a city 100 km south of Barcelona, on the Catalonian coast, Spain. It is a 1.5 km long beach located between El Milagro Cape, on the east, and Tarragona Harbour breakwater, on the west. Figure 1 shows a location map. This paper analyses the nourishment projects carried out at the beach since 1986 by means of the morphologic data taken in two monitoring programs. The effect of a marina construction on the beach stability is also studied. Finally a set of conclusions will be made in order to understand beach behaviour and evolution.

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Description

Morphology:

This is a half opened beach located between El Milagro cape, on the east, and Tarragona harbour breakwater, on the west, whose end reach more than 20 m depth. The native sand had a mean diameter $D_{50} = 0.25$ mm and the borrowed sand had $D_{50} = 0.6$ mm. The submerged bottom slope, from the shoreline to bathimetric -5.0 m, changes from 1.5% on the east, near the El Milagro cape, to 3.0% on the west, near the Harbour breakwater. The last feature has an important relevance on beach behaviour and affects beach stability. The value of bathimetric -5.0 is considered the profile closure depth.

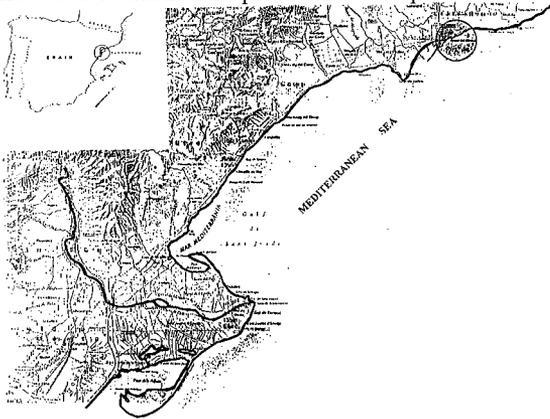


Figure 1.- Site location map.

Historical review

This beach has been noticed from Roman Times more than twenty centuries ago. This beach was graphed in several maps on the nineteen century. That means that the beach has been stable for a long time. The most recently changes are due to the human actuation from 1986 to now. On table 1 a resume of historical evolution and beach characteristics changes along the time is made

Beach nourishment projects

In 1986 a beach nourishment project was carried out with a 140.000 m³ of borrowed sand. In 1993 a new nourishment work was carried out with a 165.000 m³ of borrowed sand. The mean diameter of the sand was 0.6 mm. The

nourishment works were carried out because of the beach area reduction. This reduction is mainly due to the decrease of the sediment supply brought by the stream located in the middle of the beach. This has been theorised as a major factor in the erosion that has been witnesses in El Milagro beach.

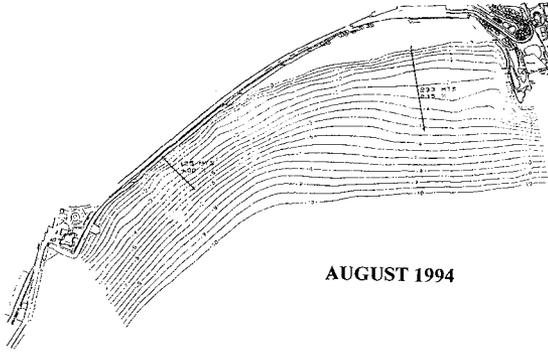


Figure 2.- Bathymetric map before marina construction.

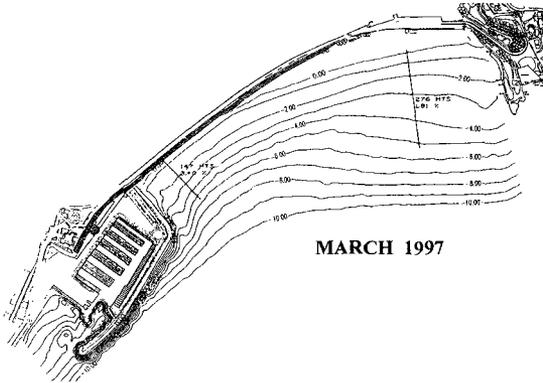


Figure 3.- Bathymetric map after marina construction.

Marina construction

In 1995 a marina was built in the West Side, near the harbour breakwater. Its breakwater reaches the bathymetric -10 m and it is a total barrier to the longshore transport. This marina changed the beach behaviour as it can be seen in

the next paragraphs. Figures 2 and 3 show the bathymetric maps before and after marina construction.

Monitoring program

Two monitoring programs were carried out, one from the first nourishment project to 1993, six bathymetric surveys were made: jun-86, mar-87, sep-87, oct-88, jan-88, nov-93. The other one from the second nourishment work to 1997, seven bathymetric surveys were made: aug-94, jun-95, feb-96, apr-96, oct-96, mar-97, nov-97. The data from the monitoring program can be used in order to evaluate the changes produced by the marina construction in 1995.

Wave climate

There are two predominant directions of wave approach: SW and E. More than three-quarter of deep-water waves approach El Milagro beach from those sectors. The annual average significant wave height is about 0.5 m with typical winter storm waves of H_s of about 3.0 m. Tides at El Milagro are negligible. In figure 4 a visual wave distribution is made and the affected area is shown, wave limits are defined before and after marina construction. The north limit is the same in both cases but the south limit changes with the marina construction, and the energy resultant is different.

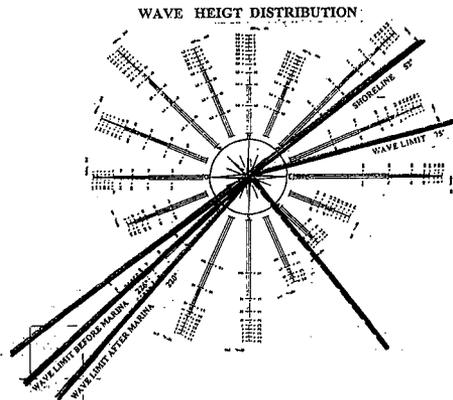


Figure 4.- Wave climatic

In order to understand beach behaviour qualitative and quantitative models have been run. Longshore currents have been obtained with different wave hypothesis, in order to analyse the influence of the marina in coastal dynamics, that are responsible of beach stability. Qualitative results have been obtained studying beach wave climatic and comparing with aerial pictures and topobathymetrics. Wave propagation and wave driven current models have been used considering pre and post marina construction behaviour. Different wave heights, periods and directions were used applying the REFDIF and COPLA programs computed by the parabolic wave propagation model that combines refraction and diffraction phenomena. Figures 5, 6, 7 and 8 shows the wave induced currents determined from the wave field, before and after marina construction considering different wave hypothesis, from the east and from the south-west approaching deep water angles. The wave height considered was 1.0 m and the angle approach was $\pm 45^\circ$. The object of these numerical models is to help to understand the beach behaviour from different hypothesis of wave climatic. It is not a real situation but it can be inferred from them the answer of the beach in these cases.

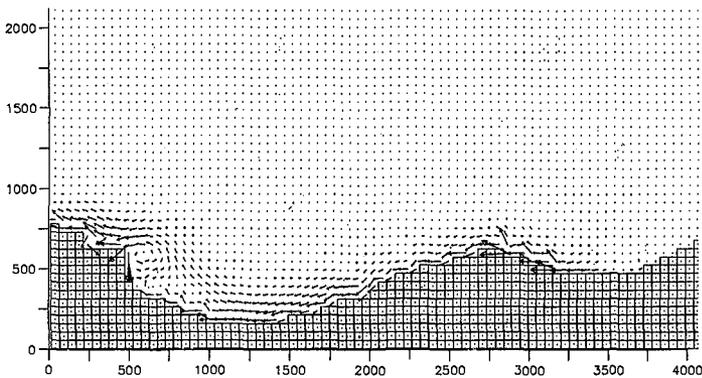


Figure 5.- Wave induced currents before marina construction, $H = 1.0$ m, $\alpha = -45^\circ$, $T = 10$ s.

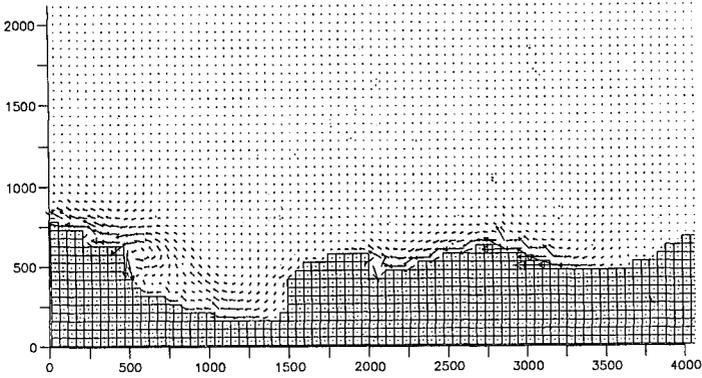


Figure 6.- Wave induced currents after marina construction, $H = 1.0$ m, $\alpha = -45^\circ$,
 $T = 10$ s.

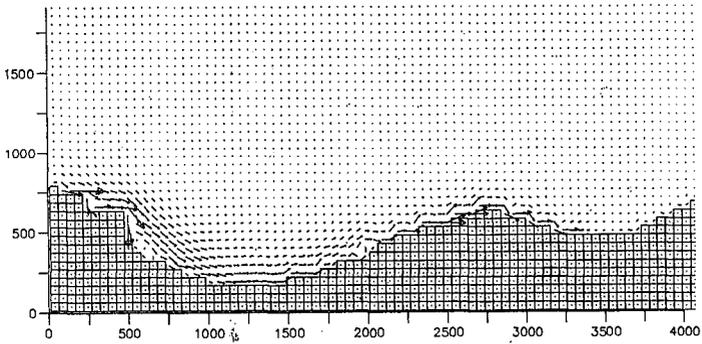


Figure 7.- Wave induced currents before marina construction, $H = 1.0$ m, $\alpha = +45^\circ$,
 $T = 10$ s.

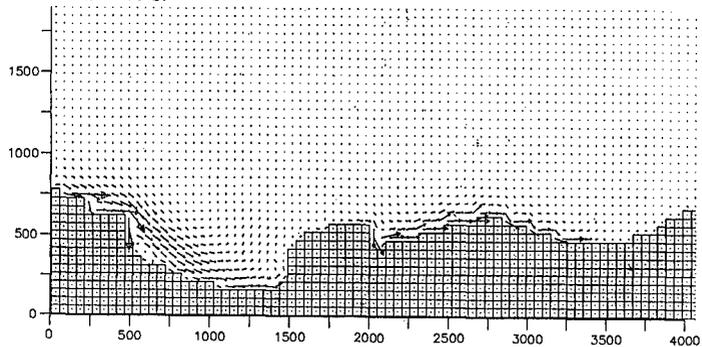


Figure 8.- Wave induced currents after marina construction, $H = 1.0$ m, $\alpha = +45^\circ$,
 $T = 10$ s.

It can be seen that the breaking wave induced currents direction decrease in the boundary of marina. It means that the sand in the west part of the marina is retained and accumulates in this area. The storms from the Southeast transport the sand to this area and the storms from the Southwest part can not return the sand to the beach, the dynamics in the area change the behaviour of the beach. Figures 9 and 10 shows the qualitative behaviour of the beach before and after the marina construction deduced from the wave climate models.

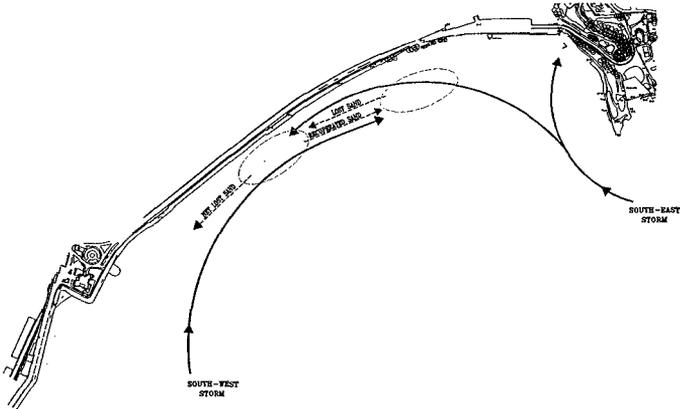


Figure 9.- Beach analysis before marina construction.

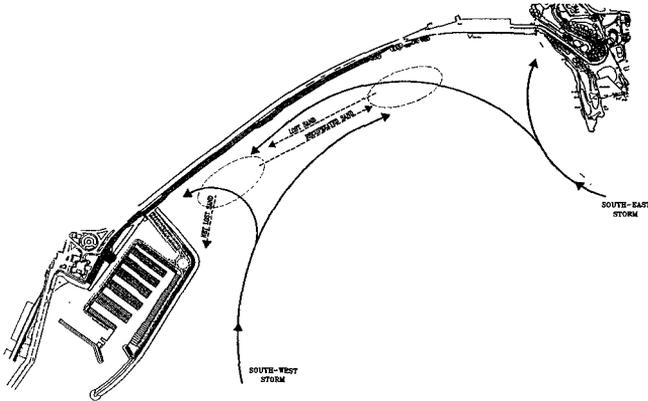


Figure 10.- Beach analysis after marina construction.

The recuperated sand, from the Southwest storms is minor after the marina construction than before, this sand is accumulated on the shadow area of the marina.

Morphodynamics

Topobathymetric data are a good information in order to analyse morphodynamic characteristics, to understand beach behaviour and to predict beach evolution. Shoreline evolution, planform analysis, longshore transport and profile analysis must be studied in this section.

Date	Beach Characteristic	Beach area (m ²)	A _t /A ₁	Sand volume lost/win (m ³)	Transport ratio (m ³ /year)	Grain size (mm)
jun-86	monitoring	15.069				0.2
nov-86	nourishment			+140.000		0.8
jan-87	works			(5.8 m ³ /m ²)		
mar-87	monitoring	39.200	1.00			
sep-87	monitoring	33.085	0.84	-35.067	70.934	
oct-87	monitoring	27.170	0.69	-69.774	119.613	
jan-88	monitoring	31.299	0.80	-45.826	54.991	
nov-93	monitoring	23.596	0.60	-90.503	13.575	0.6-0.2
jan-94	nourishment			+165.000		0.8
may-94	works			(6.8 m ³ /m ²)		
aug-94	monitoring	47.942	1.00			0.8-0.2
sep-94	marina					
may-95	construction					
jun-95	monitoring	45.784	0.95	-11.621	13.945	
feb-96	monitoring	45.952	0.96	-13.538	9.026	0.6-0.2
apr-96	monitoring	41.99	0.88	-40.412	24.247	0.6-0.2
oct-96	monitoring	40.113	0.84	-53.244	24.574	0.6-0.2
mar-97	monitoring	39.800	0.83	-55.366	21.432	0.6-0.2
nov-97	monitoring	36156	0.75	-80.145	24659	0.6-0.2

Table 1. Historical beach evolution

On Table 1 a summary of events that have incidence on beach performance is shown. The most representative dates of beach incidences can be found in it. That includes: beach characteristics (including beach monitoring surveys and beach nourishment works and marina construction); beach area evolution measuring beach surface from the shoreline to landward limits; sand volume lost/won (lost between monitoring surveys comparing the areas in each

monitoring with the first one after nourishment works and win from filling projects); longshore transport ratio deduced from the data obtained before and the grain size characteristic,

Figure 11 shows shoreline evolution taken from the most representative topobathymetric surveys, it is shown five shoreline position (jun-86, jan-88, nov-93, aug-94, mar-97) from the twelve it were taken. They represent the most significant date on beach behaviour the first one in before the first nourishment work, the second is after this works, the third is before the second nourishment works, the forth is after this works and before the marina construction and the fifth is after marina construction.

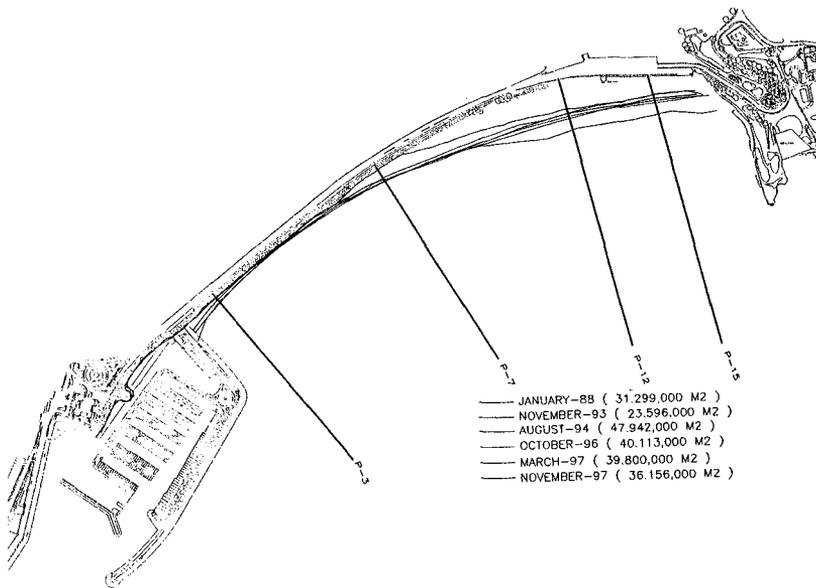


Figure 11.- Shoreline evolution from jun-86 to nov-97

In Figure 12 the analysis of beach area evolution is made. It is compared the relation between the relation A_i / A_1 , where A_i is the area corresponding to the i topobathymetric survey and A_1 is the corresponding to the post nourishment work, to the time. The figure shows the evolution before and after marina

construction, A_1 in the first case correspond to march-87 and in the second case august-94. It can be inferred from this that comparing the graphic the medium slope is bigger after than before marina construction. It means that the erosion ratio, in El Milagro Beach, has been increasing since marina construction. A new beach appeared on the protected marina area, it is difficult to infer from the actual data about its stability, some consideration to profile slope must be considered in this analysis. The longshore transport calculated according with the field data surveys of the monitoring programs changes from 13.000 m³ before marina construction to 24.000 m³ after marina construction.

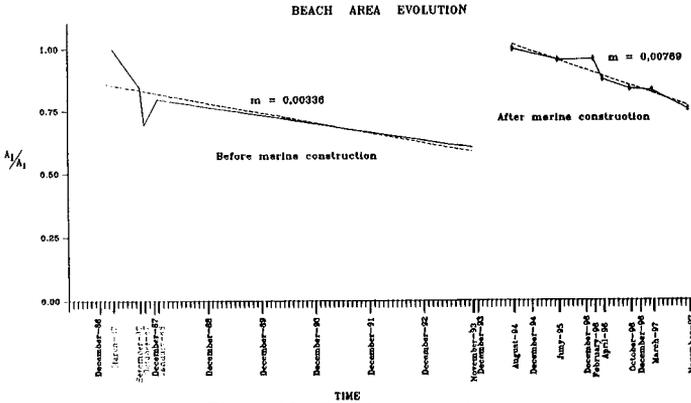


Figure 12.- Beach area evolution.

The analysis of beach profile can be made by comparing different profiles in the beach and each one in different topobathymetric surveys. The most interesting aspect in this case is how the natural bottom submerged slope change from the east to the west part. In the morphological description it can be seen how this slope change from the 2 % on the east to 4 % on the west. In Figure 13,14 15, 16 and 17 an overview of this changes is shown, four profiles have been selected for this analysis. Figure 13 give a location map of the situation of this profiles, the profiles are numerated from the west to the east the analysis will be made in the opposite order from profile P-15 to P-3, intermiddle profiles will be studied too. Profiles P-15 and P-12, Figure 14 and 15 have similar behaviour, profile changes has a range of variability from beach landward to bathymetric -5.0 m. The natural slope is around 2 % and beach nourishment works affect the slope of beach face and affect until bathymetric -2.5. Nourishment works were made from profile P-16 to P-7, it means that these profiles have the direct influence of the borrowed sand filling. The analysis of the three last bathymetries gives some information, after nourishment works a topobathymetric survey were made, august-94, in these

profiles the shoreline has an accretion compared with pre-nourishment shoreline, november-93, but the survey that was made in march-97 an erosion phenomena occurs in both in P-15 shoreline rise more than the situation in November-93 and in profile P-12 was in front of it. It means that the shoreline position is changing decreasing at the east part and accreting at the west.

The analysis of P-7 and P-3, Figure 16 and 17, show the sand accumulation that occurs in this area this phenomena is especially important on P-3. In this point sand accumulation is really significant, but the profile form with borrowed sand is not compatible with the natural bottom. It appears two peaks in the profile that broke the equilibrium profile, and the sand is lost on the foot of the profile.

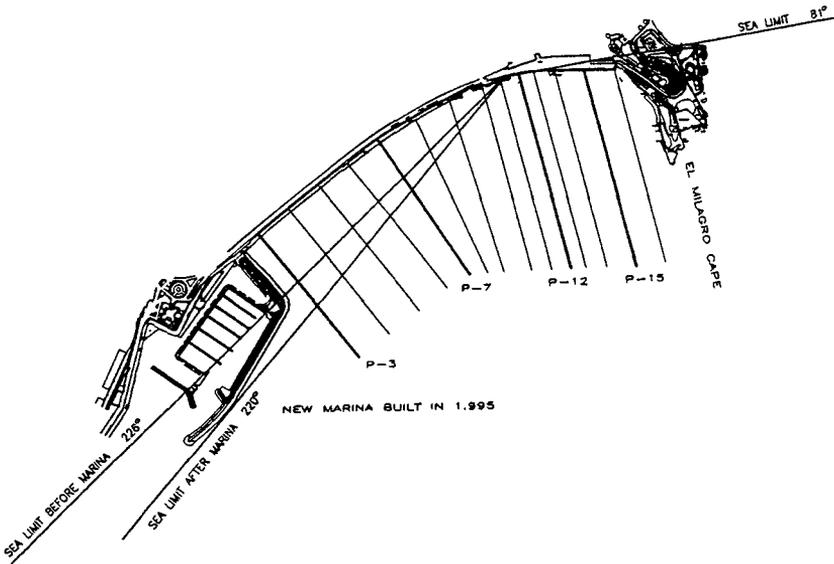


Figure 13.- Beach profile location map.

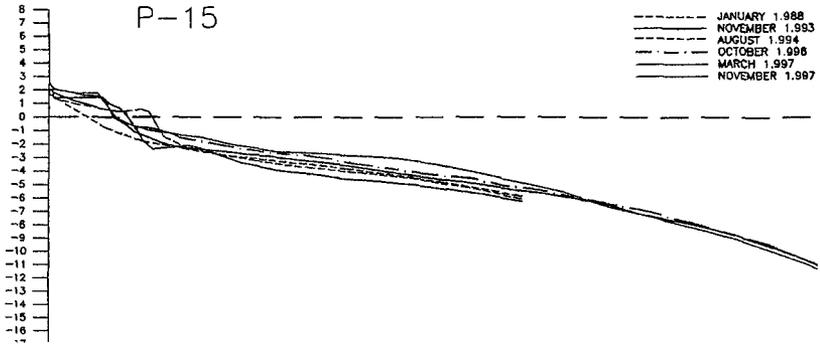


Figure 14.- Profile 15 evolution.

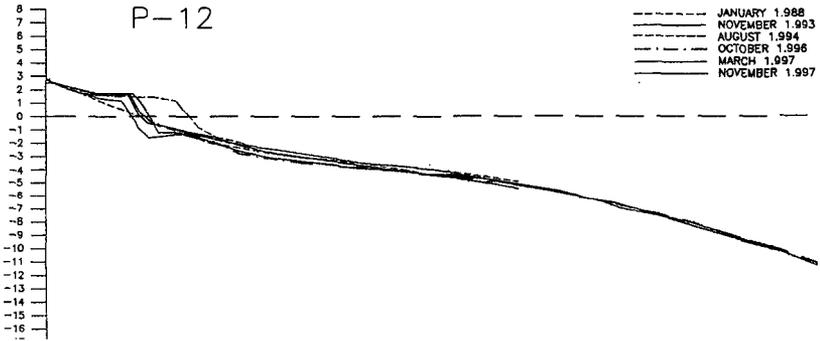


Figure 15.- Profile 12 evolution.

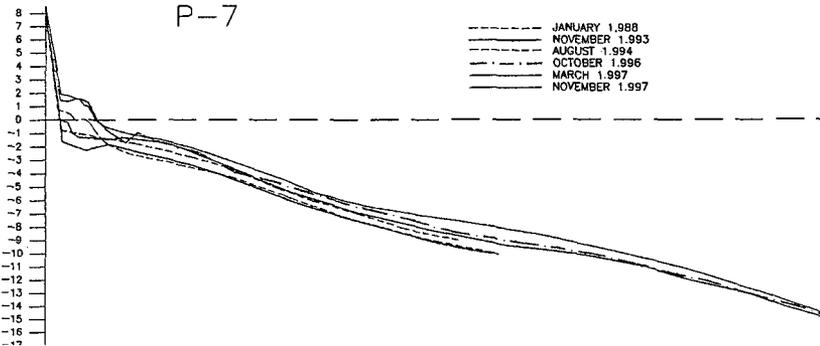


Figure 16.- Profile 7 evolution

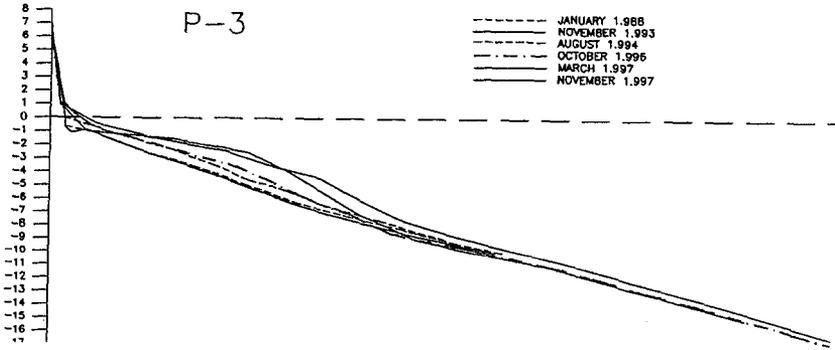


Figure 17.- Profile 3 evolution

Diagnosis

Marina construction has changed beach behaviour because fewer waves from the West Side arrive and some sand are retained in the protected area of the marina. Shoreline orientation changed due to the influence of marina on wave climatic.

The erosion ratio after marina construction is greater than before, $24.000 \text{ m}^3/\text{year}$ and $13.000 \text{ m}^3/\text{year}$ are the respectively values calculated with the field surveys data from the monitoring programs.

On the west part of the beach, close to the new marina, beach profile is milder than natural profile. In these area beach profile is not stable because of different bottom slope of natural beach and the profile formed by the borrowed sand. On the west part beach wide is decreasing.

Conclusion

-The analyses of the field surveys data from the monitoring program have been useful in order to understand beach evolution.

- From these data a beach behaviour have been obtained:

- . The difference on beach slope, from 2% on the east side to 4% on the west side, has a lot of incidence on beach stability.
- . The erosion ratio is greater after than before marina construction.
- . The beach is not stable on the west side. Several alternatives must be studied in order to guarantee beach stability.