Morphodynamics and harbor impacts in Rías.

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Abstract

A case of infilled port in a "ria" of the cantabrian sea in Spain is considered; "rías are the only areas whose natural harbor conditions have permitted the development of port facilities in this littoral, but the principal characteristic of this "ria" is its advanced process of infilling, which is a common factor of all of them. Anthropic, looking for the stabilization of the entry channel, and not only natural infilling processes recently led to a critical situation affecting the township's developement. A whole spit-barrier was suddenly washed out during channel works affecting on delay several beaches.

Although the erosion of the beaches was forecasted as well as the subsequent much higher infilling rates (Diez,1980), no appropriate protection was implemented until 1987. The project also tried to stop or reduce the infilling process of both the "ria" and the port, but some additional problems have kept a very low use of the harbor facilities, thus affecting fishing activities in the area; entry channel presents new difficulties and the whole interior port remais too much largelly infilled. Therefore, a new exterior artificial harbor is claimed to be necessary. A detailed summary of the evolution of the system can be found in this article. Littoral and "ria" dynamics have been considered to propose a morphodynamic model describing beaches and inlet/outlet evolution, and the changes in the infilling rates have been checked. The present situation is analized and the alternative solutions are discussed, taken into much consideration environmental, land menagement and economical factors. This can be considered a paradigme in all this coast.

1. Introduction

The port of Foz is located in the "ria" of Foz, in the middle of the Masma Gulf in the Cantabrian coast, very close to the tidal entry gorge between the bay and the interior zone of the "ria". The principal characteristic of the "ria" is its advanced process of infilling, which is a common factor of all Cantabrian "rias". The area under study is placed in the western stretch of the Cantabrian littoral of the Iberian peninsula, where for a very long time fishing has been the most important economic activity, with particular concentration in the "rias". Moreover, these are the only areas whose natural harbor conditions have permitted the development of port facilities in this littoral.

During the 60's the Port Authority decided to stabilize the entry channel through the construction of a jetty. The project was successful in fixing the tidal outlet of the channel but, when the stretch of the jetty to be placed just in front of the spit-barrier was constructed, the whole spit-barrier was suddenly washed out during the spring-tide of March 1978. This event had happened undoubtedly, for not having built a simultaneous second jetty supporting and protecting the barrier when the gorge became narrower, or for having built that interior and not strictly necessary part of the jetty, when dredging could have been a complementary alternative. Tides in this area reach levels of up to 4.50 meters and currents could reach speeds nearly 2 m/s, in accordance to our measurements (after the erosion of the spit the currents even widely exceeded 1.2 m/s).

Although serious beach erosion was forecasted (Diez,1980) no protection was implemented for several years except for a very insufficient rouble-mound covert which behaved like an additional destructor of beaches and cliffs. As the author expected, the interior of the "ria" remained infilling at much higher rates, being nourished from the sandy eastern annex beaches (Anguieira & Altar), which caused their fast process of disappearing

A project to protect the beaches was finally developed by the author under the charge and supervision of the Coastal Authority. The project tried to stop or reduce the infilling process of both the "ria" and the port, as it is described in the next paragraph, but some additional problems (also discussed later in this article) have kept a very low use of the harbor facilities, thus affecting fishing

activities in the area. Therefore, a new exterior artificial harbor is claimed to be necessary. A detailed description of the evolution of the system can be found in previous papers of the author (Diez, 1980,1992). For purposes of completeness, a summary is provided in this article.

2. Evolution of the process

The initial problem of the Foz fishing harbor has been the proximity of the tidal outlet to the rocks of Rapadoira which induced to build a warning light at the tip of a primitive short jetty perpendicular to the channel. This process gave a permanent curve to the inlet and accelerated the cyclic migration of the outlet. The great instability of the tidal outlet, used as entry channel to the harbor, produced several accidents and made unavoidable the stabilization of the channel. Similarly, the nature of the spit at the other side of the channel asked for the construction of two jetties, but only the western one was built finally, leaving the spit free. The progress in the seaward construction of the jetty was accompanied by a clockwise rotation of the spit which, nevertheless, remained stable. Only when the jetty was completed port-ward, modifying the whole geometry of the channel gorge beside the tip of the spit, this one was brusquely washed out by the combination of the spring tide and storms. The channel remained stable but became several times wider during over mean tides. At that time the author (Diez, 1980) proposed his morphodynamic model in accordance to which two kinds of damages would be expected:
(1) The natural process of infilling of the "ria" and port would become much more intense.
(2) The erosion of the nice beaches and dunes of the eastern side of the outer zone of the "ria" (see Figures) could disappear in less than five years.

As a matter of fact, a shoreline roubble-mound coat protection had to be suddenly implemented (although unsuccessfuly) as early as 1983, when the beaches had disappeared under high tide and the cliffs were in grave danger. Simultaneously, a permanent dredge had to be developed in the port and, in spite of it, the major quays became out of service immediately. Furthermore, fishing ceased in the interior zone of the "ria", obviously because of the notorious changes in the biotope.

After several discussions about the type of solution for a definite protection of beaches and cliffs, the criterion of the author prevailed and his project was carried out (Diez, 1992) with its first aim being the protection of the coast, and its complementary objective being minimizing the infilling rates coming back to a similar situation to the destruction of the natural spit. The fundamental part of the project was to rebuild the spit using part of the sands accumulated in the "ria", but it was advisible (taking into account the probable construction procedures) to contain them by constructing a "sand-impermeable" rouble-mound jetty shaping the interior side of the new artificial spit, from the rock of the east side of the mouth of the "ria".

Some possible administrative difficulties could be expected to arise taking into account that shore protection was the Central Government's responsibility, while the Port Authority depended on the Regional Government. Since this last authority had not decided what to do with the entry channel under the prevailing circumstances, and the shore protection project could interfere with such channel, it was decided not to reach it to avoid those foreseeable administrative problems and delays. On the other hand, the foundation and structure of the port were not adequate and its stability could be affected if the resultant artificial channel became too narrow. Therefore, the spit was designed shorter than optimum although it was expected to be efficient enough. The first behavior of this artificial spit and beach has been already discussed (Diez, 1992) and it was shown that the nourishment had been insufficient, even less than proposed in the project.

Since then the evolution of the system was as follows:
1- As expected, the beaches initiated a natural renourishement, nearly completing the project's objectives in the Summer of 1991.
2- An incorrect dredge (it was proposed in the basin and was made in the channel) took the support away from the beaches, whose sands shifted, suffering a new sudden important regression during the "Spring tide" of Autumn equinox.
3- A cartographic research was developed by the author, whose first results were proposed in Seattle (Escobar and Diez, 1991) and that in its final results perfectly doubly matched a sediment budget, thus checking the morphodynamic model.

3. Results from the budget

The cartographic research was based on the following bathymetries from different sources:
Foz Harbour Authority: 1963 & 1970. (Datums unknown)
C.E.P.Y.C:1985 (spring). Z, lowest low mean, from tidal tables
F.A.B.(Author): 1985 (summer); 1986 (spring & summer);1987(spring&summer); 1988 (spring & summer); 1989 (spring). Datum of Foz Harbour, related to National Datum of Alicante mean sea level.
Coastal Authority: 1987-89 Transversal Profiles.Z of Foz Harbour.
Bathymetries by ourself extended to interior and exterior zones of the "ria" in 1963-1970-1985-1988(summer) and1989. And to interior (plus intermediate) zone in 1986-1987 and 1988 (spring).

The major problem for any comparison among them was in the determination of the corresponding "datums". It was presumed that at least three different "datums" had been used, however, only one (namely the one used by the author in the previous studies) was well defined. The Datum of Foz is 1,65 m under Alicante Datum. La Coruña Datum is 1,8183 m under Alicante Datum.

The following evolving circumstances were assumed to search for the other "datums":
- The infilling of the "ria" has been a continuous and permanent progressive process.
- The destruction of the natural spit had to suppose a reduction of sands in that place.
- Littoral drift and sand movements have been very similar during years under similar morphologic situations because of potential littoral transport is much bigger than actual littoral transport (over twenty times), so that the last one is above all conditioned by sand availability.

Comparing the bathymetries, a determination of the datum of each of them was possible (Esobar & Diez, 1991) and the resulting budget was perfectly closed, which can be considered a complementary checking of the hypotheses and datums. The results obtained for the interior zone infilling rates can be summarized as follows: I)before 1978, 4,500 m3/year; II) 1978 - 1987, 125,000 m3/year; III) after 1987, 9,000 m3/year
The sand volume captured into the trap buit by the Rapadoira jetty is of 350,000 m3. And the sand volume trapped into the "ria" is of

1,000,000 m3 since 1978, over dredged mate"ria"ls. This has been the reduction of the tidal prism.

The aforementioned results permit us to establish that the project under consideration for shore protection and harbor maintenance can be considered highly successful, particularly if administrative and knowledge circumstances are taken into account. As a matter of fact, the present infilling rate is only twice (9,000 m3/year) than natural (4,500 m3/year) and less than 10% of the previous (100,000 m3/year) rate after damage of the natural spit. Finally, the morphodynamics has been very closely approximated for the project.

4. Morphodynamics

Littoral dynamics in this area is mainly governed by wind waves whose annual average resultant is from the fourth quadrant (NW). This means an eastward dominant littoral transport (potential) and drift (actual). Although the Cantabrian coast is straight under a large scale in the direction of the parallel (W-E), under smaller scales it shows a lot of geometric (bays and capes) and dynamic (isles and rocks) singularities, which induced local but important changes in waves. In the case of the "ria" of Foz, like in many others, diffraction, refraction and even reflection in the eastern cliffs of the outer part of the "ria" (San Bartolomé point) lead the waves to change their direction of attack to the shoreline of the barrier of the "ria". This barrier is thus generated as a spit, growing westward, in spite of the waves out of Escairo and San Bartolomé points can be from the 4th quadrant waves. This phenomenon can be observed with even N-W storm waves and only the inaccuracy of a model in small areas can explain their inability to show it.

On the other hand the "rias", as any other littoral bay, behave as a trap of sand. Although flood and ebb tidal fluxes are nearly symmetric and compensate each other, flood fluxes are more efficient in spite that ebb fluxes are reinforced by river discharges. The cause is in the asymmetry caused by wind waves, always discharging land ward, and more actively in high tide. The turbulence generated by breaking waves increases many times the transport capability of littoral longshore and tidal currents.
The consequence is a longitudinal growing spit becoming a barrier an not an emerging bar as in other case of barriers. The increasing

rotation of the spit induced by the progressive construction of the jetty was a consequence of the existing conditions of wind waves diffraction and refraction. And the washing out of the spit when channel gorge was narrowed was due to the alternative wave and tidal current erosion in both sides, accentuated by the corresponding level gradient. For several years currents and waves tried to rebuild a new spit, decreasing every year, from eastern beach materials of the "ria", but they could not for relative lack of materials in the new geometry of the "ria".

The expected infilling of Rapadoira beach and all these other processes led to a reduction of exterior littoral drift eastward, what necessary would produce a change in the equilibrium condition of the cliff beaches until next "ria" (Ribadeo). Presently their consequences are shown in the erosive situation of the important and nice beach and dunes of Reinante.

5. Present difficulties and alternatives

The harbor is currently under an infilled situation because of the natural redistribution of the sands into the interior zone of the "ria" and the main quays are useless; allthough some dredgings have been implemented, they have not been sufficient for getting a permanent draught beside those quays. On the other hand, some of the dredgings has been wrongly done in the channel, having affected its sandy latteral polder and caused notorious damages in the beaches as it was reported. The dredges had to be done in the middle of the "ria" to guaranty the maintenance of the basin.

Furthermore, although the entry channel remains stabilized, the harbor entrance has several new problems caused by the new "bar" produced at the end of the channel. This bar is caused by the littoral drift nourishing in Rapadoira beach. Rapadoira beach has been artificially created by the effect of the harbor jetty, which closed an actual trap of sand. It has expanded at the rhythm at which the jetty was being built and it is now totally filled with sands. As a consequence, the dynamic equilibrium leads to the exit of sands when new sands are received in the trap, following the dominant littoral transport at the outer end of the jetty, that is, eastward. Thus this real submerged spit advances in the exterior zone of the bay of the "ria" and fishers call it the "bar", dangerous under stormy situations.

For both reasons many interests are trying to establish a new outer harbor westward of the "ria", in front of the cliffs. Studies for a new wholly artificial port in that place have been developed during the two last years, showing the economical and functional feasibility of such a new port for fishing, pleasure and small trades. The author has shown this feasibility for a solution based on the dredging of cliffs and rocky reefs, so avoiding to extend it too far into the ocean; this very morphologically adapted solution with a small and functionally adjusted maximum depth (5.5 m) supposes a very small environmental impact. Our whole criteria admits the possibility of a small outer new harbor but complemented, in any case, with the recovery of the old harbor whose potentiality exceeds any of the exterior harbors under consideration. Several inmediate actions are necessary to get it:

- Entry channel has to be free of any bar (spit), therefore, Rapadoira beach has to be "drained" of sand until reducing its extension far of the tip of the jetty into the "trap".
- The interior part of the "ria" needs to be dredged, at least until the amount of sand accumulated during the last period of intense infilling. Such a dredge may be also used to nourish and restore the beaches eastern of the "ria" and, additionally, it will lead to a greater tidal prism which will keep the channel clean.

Acknowledgement. To the General Direction of Coasts, Ministry of Public Works, Transport and Environment.

Rererences

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Figures. The following figures can help to follow the descriptions of the text.

Summary of fluxes

	Before 1978	1978-1987	After 1987
a	$> 4000, < 18,000$ m^3/y	-100,000 m^3/y	$\geq 25,000$ m^3/y
$b = c$	4,000 m^3/y	$\geq 114,000$ m^3/y	9,000 m^3/y
$d = d_1 + d_2$	17,500 m^3/y	17,500 m^3/y	0

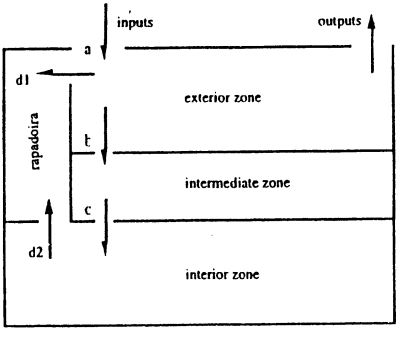

Figure 1: Scheme of Figure 2

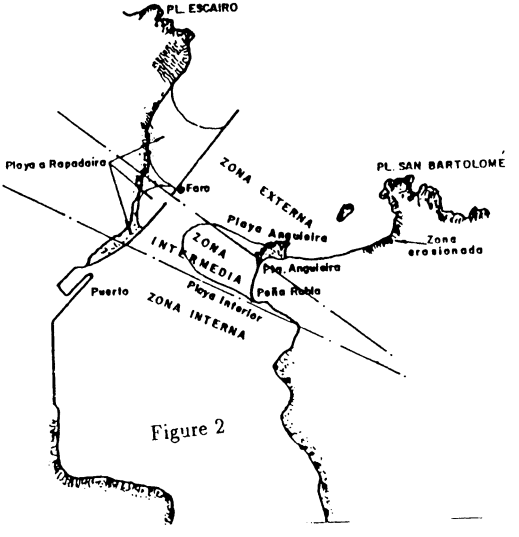

Figure 2

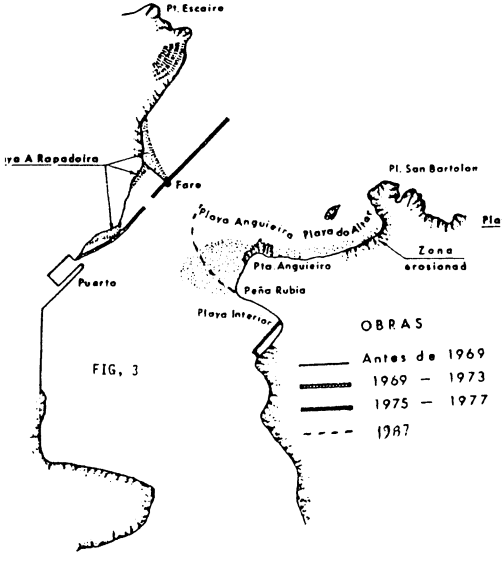

FIG. 3

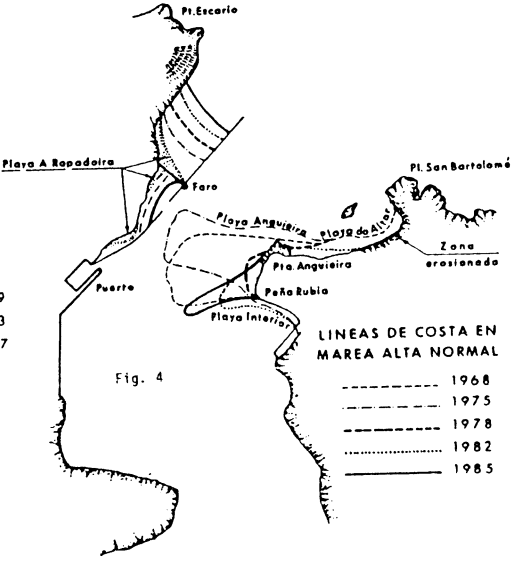

Fig. 4

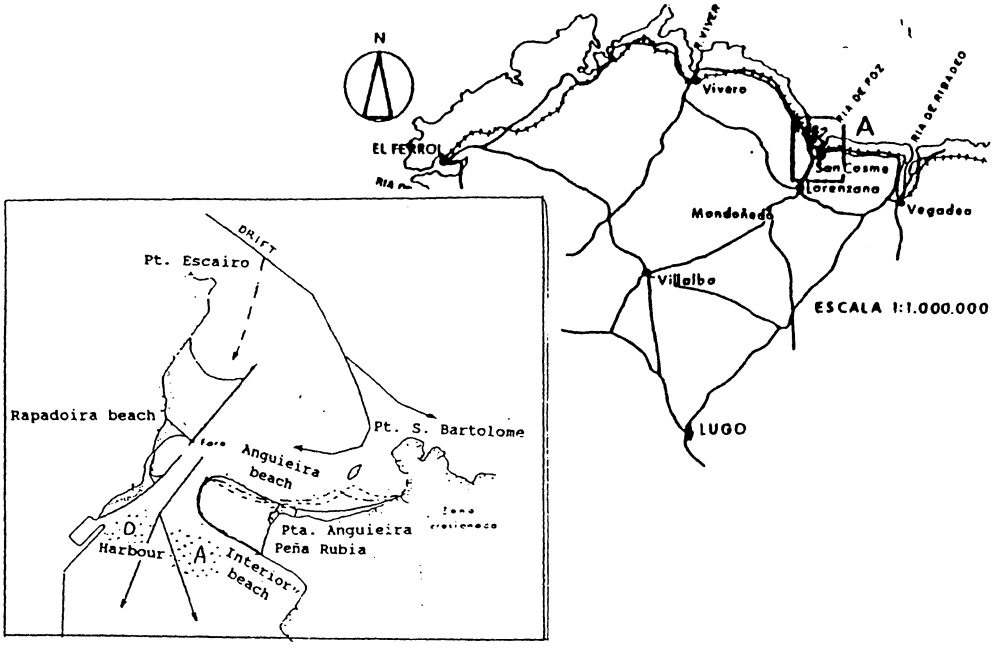

Fig. 5, Esquema de los procesos

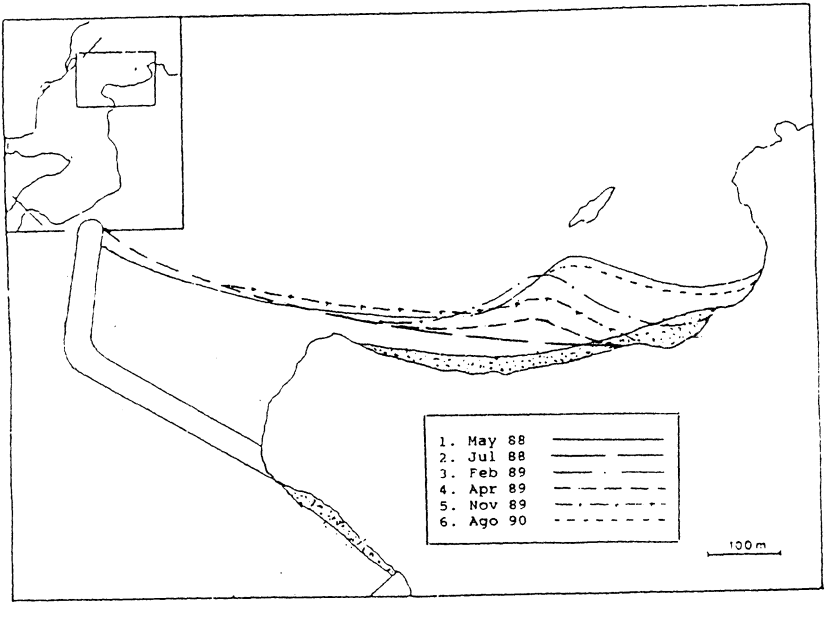

Fig. 6 Shoreline (Scheme) Evolution