

## CHAPTER 190

### AN ATTEMPT TO MODEL LONGSHORE SEDIMENT TRANSPORT ON THE CATALAN COAST

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#### Abstract

In this work, the main variables involved in one-line shoreline evolution models have been identified and typical values for them have been found for different zones of the Catalan Coast. These values have been employed in a shoreline evolution model. The model has been calibrated in several points of the Catalan Coast, adjusting the free parameters in a longshore sediment transport formula. Taking into account the quality of the results, the model seems to be an efficient tool for medium term coastal engineering purposes.

#### 1. Introduction

The estimation of longshore transport rates is an important problem in coastal engineering, in order to predict shoreline changes when coastal structures are constructed and to consider shore protection methods without unexpected effects.

Beach changes are controlled by wind, waves, currents, sediment nature and water level among other variables, which are necessary data to estimate these changes. Given the complexity of beach processes, efforts should be made to identify and analyze all relevant physical data needed for an efficient evaluation and interpretation of beach evolution.

Many often these data are not available in the target site. This situation increases the number of unknowns which must be obtained by reasonable estimates or by adaptation and extrapolation from other projects on similar or adjacent coasts. These assumptions should be considered when interpreting computed results because they could induce erroneous or misleading estimated beach changes.

However, sometimes, the methods used for predicting longshore transport rates and beach evolution, over a medium-term period of time (several years),

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fail in their predictions because the input parameters are not computed for local conditions and corrective procedures are not taken into account.

As an example, the Catalan Coast, located in the Mediterranean Sea, presents distinctive features from other coastal areas like Atlantic or Pacific ones. Among these features, we can mention beach slopes, grain size, tidal range (which is practically negligible) or the wave climate, which presents storms of smaller intensity than other zones due to the limited fetches.

For this reason, the input variables to predict longshore sediment transport rates and shoreline evolution should be expressed in terms of local parameters and conditions.

Therefore, the main goals of this paper are the characterization of input variables for shoreline models in terms of Catalonian coastal features and the application of the obtained results to the Catalan Coast in order to calibrate a shoreline evolution model.

## 2. Data employed

The Catalan Coast has a total length of 580 Km, 270 of them being sandy beaches. The northern part shows a predominance of rocky cliffs and reefs. In the central and southern areas, sandy beaches are dominant.

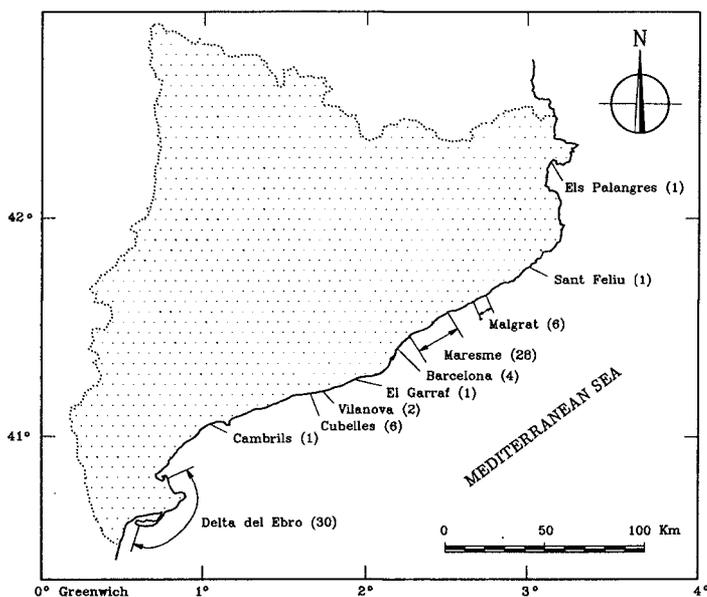


Figure 1. Location of the 82 beach profiles.

In this work, 82 beach profiles from the Catalan Coast have been used. These profiles are representative of 105.2 Km of beach (37.6% of the total length). In figure 1, the profile locations are shown.

The profile data have been obtained from several field measurement campaigns. Some of them are described in Serra et al. (1989, 1990) and Jiménez et al. (1992).

### 3. Variables characterization

The main variables involved in one-line shoreline evolution models are beach profile shape, closure depth, wave climate, sea level changes, sediment size, boundary conditions and interaction with coastal structures.

The boundary conditions and coastal structures will be defined in each individual case to be studied. On the other hand, sea-level fluctuations at geological and intermediate time scales have not been taken into account. Shorter recurrence intervals which are related to climatic effects, as e.g. daily tides, are practically negligible on the Mediterranean Sea, because tidal ranges are very small in this area (order of 20-30 cm). Other episodic events will not be considered either.

In this section, attention will be focused on the other mentioned variables and their characteristics along the Catalan Coast will be analyzed.

#### 3.1. Depth of closure

The depth of closure can be defined as the limit depth for appreciable longshore transport. It is a fundamental parameter in shoreline evolution models but it is difficult to quantify it.

Several expressions for the computation of the closure depth have been proposed. As an example, the Hallermeier (1978, 1981) expression has been widely used since it provides a guidance for the estimated closure depth:

$$d_{,e} = 2.28 H_e - 68.5 \left( \frac{H_e^2}{g T_e^2} \right) \quad (1)$$

where  $H_e$  is the wave height exceeded 12 hours a year,  $T_e$  is the associated wave period and  $d_{,e}$  is the estimated closure depth.

If possible, it would be better to determinate the closure depth from beach profile changes at the site, but the scarcity and accuracy of data is the main difficulty to estimate this parameter which has a statistical nature.

Based on the field measurements available from multiple profile surveys made over a 5 year period through the Catalan Coast, the depth of closure was estimated following a similar approach to the one employed by Kraus and Harikai (1983) on Oarai Beach. In this approach the closure depth was evaluated

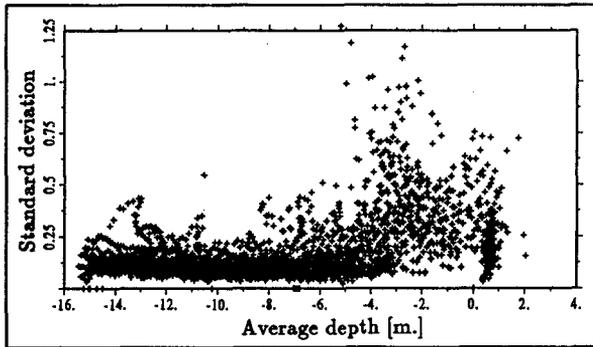


Figure 2. Depth changes

plotting the standard deviation of the measured depth values versus the average depth for the overall studied area, as it is shown in figure 2.

It can be observed that the most important deviations occur in depths shallower than 5.5-6 meters. On the other hand, if the closure depth is computed employing the Hallermeier expression (1) fed with the wave data from three existing buoys in the zone (as it will be explained later), the obtained values are of the same order of magnitude, as it can be seen in table 1.

Buoy	$H_e$	$T_e$	$d_{se}$
Tordera	3.5	7.3	6.4
Llobregat	3.2	7.4	5.9
Ebro	3.8	7.0	6.6

Table 1. Closure depths from Hallermeier expression

### 3.2. Beach profiles

The second analyzed variable is the beach profile shape. The aim here is the obtention of an analytical expression which provides the best possible representation of the equilibrium beach profile in the Catalan Coast.

Bruun (1954) based on the analysis of beach profiles for the North Sea and California Coast, developed an empirical equation with a potential function which relates water depth  $h$  and shoreline distance  $y$ .

$$h = A y^B \quad (2)$$

Later on, Bruun and other authors found theoretical justifications for this expression. Dean (1976, 1977), centering his study on linear wave theory and assuming that the ratio of breaking wave height to water depth is constant, justified from three different points of view this potential form for the equilibrium beach profile. He found a value of  $2/5$  or  $2/3$  for the exponent  $B$  and showed that the aforementioned equation with  $B = 2/3$  is consistent with uniform wave energy dissipation per unit volume across the surf zone. Other authors, who also adopted this equation, suggested a potential relationship between the shape parameter  $A$  and the grain size (Moore 1982, Hanson and Kraus, 1989).

The wide spread use of this profile equation, together with its simplicity, led to its application to numerous beaches, which present quite different characteristics from the beaches of United States Atlantic Coast. For this reason, the first step consisted in the evaluation of the Bruun-Dean expression fit to measured data. It was observed that this equation over-predicts depths, specially when the  $A$  parameter values of Moore (1982) are used (see figure 3).

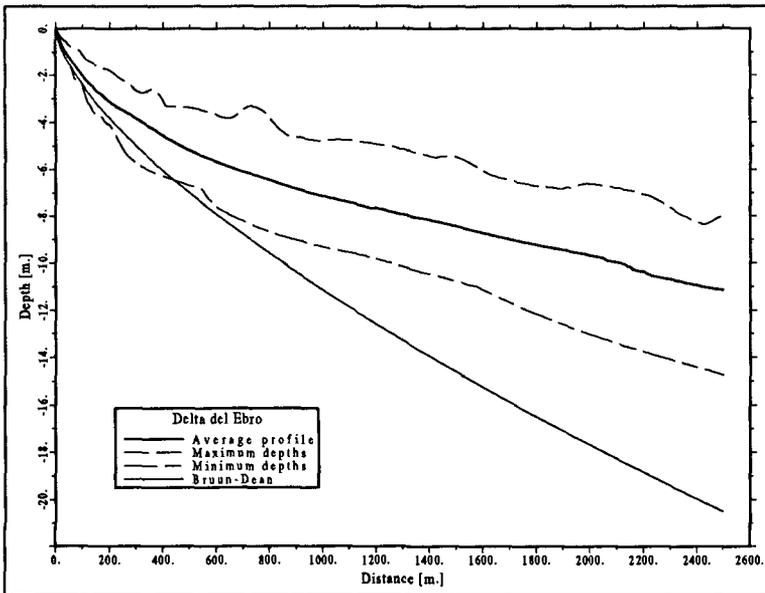


Figure 3. Bruun-Dean profile vs measured data in Ebro Delta area

Considering that the combination of the Bruun-Dean type profile with  $A$  values from Moore (1982) was not suitable for the available data, the following step consisted in the use of an inductive approach to find alternative expressions for the beach profile (Lo Presti, 1994; Sierra et al., 1994). The aim was to improve the fit with respect to the aforementioned equation for the Catalan Coast and to avoid an infinite slope at the shoreline.

This analysis of beach profile shapes was carried out with a purely statistical approach, without any in-depth analysis of the underlying physics. No attempt was made to relate the new profile expressions to the beach morphology or boundary conditions because of the limited number of surveyed profiles. The obtained expressions can be useful in the characterization of beach profiles for site-specific applications. It should be stressed that no attempt is here made to predict the actual beach shape parameters.

The selection of alternative expressions is based on the previous knowledge of general profile shapes. Two alternative expressions have been proposed for the equilibrium beach profile.

i) Exponential equation:

$$e^z = A(y + C)^B \quad (3)$$

ii) Rational equation:

$$z = \frac{y}{A + By} \quad (4)$$

Both equations will be compared with the power-law (potential) expression:

$$z = Ay^B \quad (5)$$

where  $z$  is the water depth,  $y$  the distance to the shoreline and  $A$ ,  $B$  and  $C$  are parameters to be determined.

In order to find the best fit curve, a suitable transformation of variables has been carried out followed by a straight line regression analysis using the least squares method. The curve that provides the best fit to the measured data is the one which shows the minimum vertical distance (or prediction error) to them.

Taking into account the prediction errors of the expressions, in the major part of the 82 profiles it has been observed that both proposed expressions (exponential and rational) fit better to the measured data than power-law equations. Moreover, the differences in fit quality between both expressions are minimal, as it can be observed in figures 4 and 5. These figures show, as an example, the fit of the three expressions to two different measured beach profiles. A potential expression with  $B = 2/3$  has also been plotted and referred with (D). The measured beach profiles are drawn with continuous line.

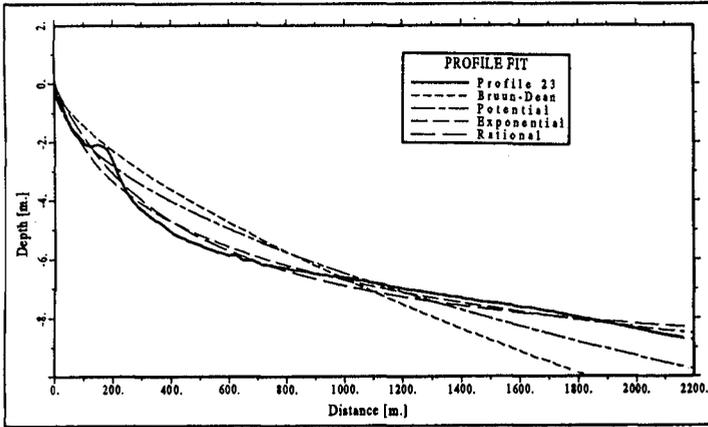


Figure 4. Fit of one profile in Ebro Delta area

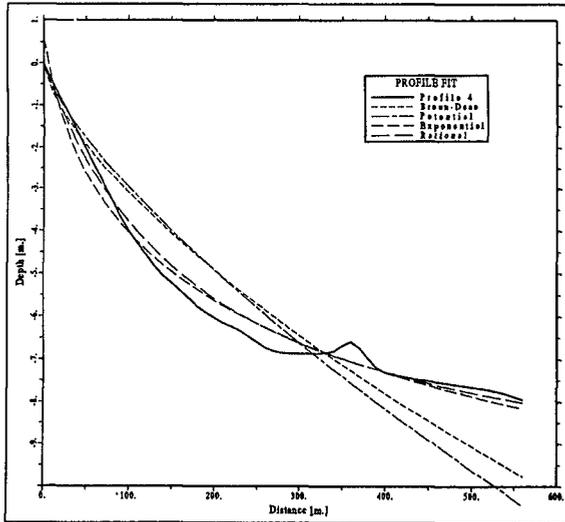


Figure 5. Fit of one profile in Maresme area

### 3.3. Sediment size

The next studied variable was the sediment size. In this case, the aim was to find relationships between the parameters of the analyzed beach profile and

the sediment diameter.

For the exponential equation no predictive relation was found. On the other hand, a poor relationship (with a correlation coefficient  $r = 0.50$ ) between the  $A$  parameter of the potential expression and the gran size appears to exist (see figure 6), while a reasonable relationship ( $r = 0.82$ ) between the  $A$  parameter of the rational equation and the sediment diameter  $D_{50}$  was found (figure 7).

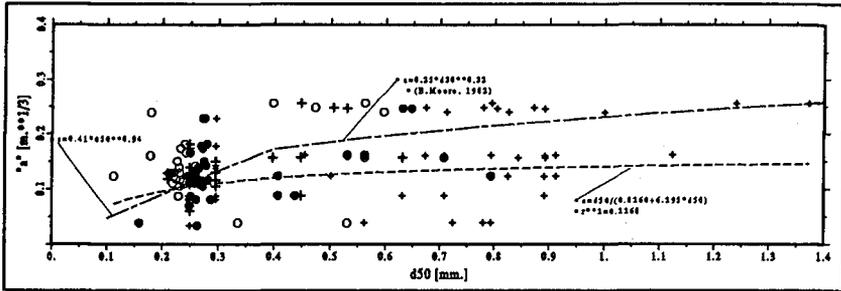


Figure 6. Relationship between  $A$  and  $D_{50}$ . Potential equation.

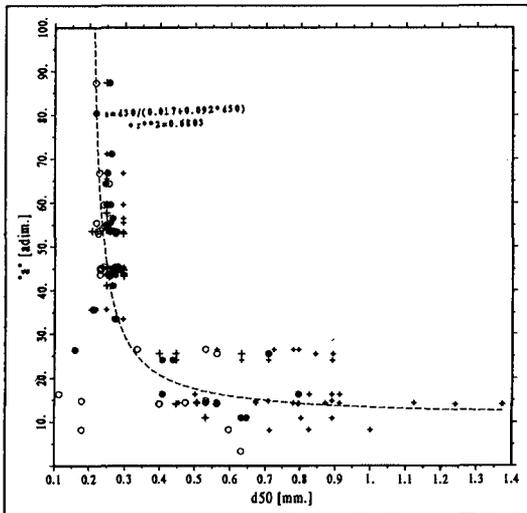


Figure 7. Relationship between  $A$  and  $D_{50}$ . Rational equation.

### 3.4. Wave data

As it is well known, waves are generally the most important external factor taking part in beach evolution at a short/medium time scale, while the variables before studied are beach parameters which graduate its response to wave action. For this reason, a good definition of waves characteristics in the studied zone is necessary in order to perform an adequate modelling.

In this work, different sets of wave data were used. The monitoring program of the Regional Authorities for the Catalan Coast includes 3 offshore buoys, one of which is directional and began to operate in June 1990. The other two buoys entered in service in May 1984. In figure 8, the three buoys locations are shown. Visual data (since 1950) are available too.

For obvious reasons of space limitation, a detailed analysis of the wave data can not be included here. As a summary of the available information, it can be said that the wave heights recorded by the three buoys present similar trends because the distances among them are relatively short (about 100 km).

Since the Catalan Coast is the West boundary of the Occidental Mediterranean basin, it is opposite to the coasts of France, Italy, Africa and some islands, and as a consequence the maximum fetch on this coast is about 750 Km. Due to this restriction in the fetch magnitude, the waves acting on this zone have a limited energy, as it was mentioned before. The most energetic storms are those coming from NE or E.

The directions of the most frequent waves change along the Catalan Coast. In the southern part, near the Ebro Delta, there are three predominant directions (with almost 80% of the occurrences) according to both visual and recorded data: NW, S and the sector comprised between E and NE. In the northern and central parts, there is no recorded directional information and the only source are visual data. According to this data, the waves are more uniformly distributed in all directions, with two predominant sectors: NE-E (about 40% of the events) and SW-W (about 28%).

## 4. Shoreline evolution modelling

### 4.1 Model description

After all the necessary variables were characterized and their typical values defined, a numerical simulation of beach changes produced by spatial and temporal differences in longshore sediment transport was carried out at several areas of the Catalan Coast. In order to predict the shoreline evolution, a model was developed following Hanson and Kraus (1989). It is an one-line model and therefore it only considers longshore transport.

Several longshore sediment transport expressions have been used in the model. The most frequently employed was the Ozasa and Brampton (1980) one:

$$Q_t = (H^2 C_g)_b \left[ a_1 \sin 2\alpha_{b_s} - a_2 \cos \alpha_{b_s} \frac{\partial H_b}{\partial x} \right]_b \quad (6)$$

in which  $H$  is the significant wave height (in m),  $C_g$  is the wave group celerity (in m/s),  $b$  is a subscript denoting wave breaking,  $\alpha_{b_s}$  is the angle between breaking waves and the local shoreline and  $a_1$ ,  $a_2$  are adimensional parameters given by:

$$a_1 = \frac{K_1}{16 \left[ \frac{\rho_s}{\rho} - (1-p)(1.416)^{5/2} \right]} \quad (7)$$

$$a_2 = \frac{K_2}{8 \left[ \frac{\rho_s}{\rho} - (1-p) \tan \beta (1.416)^{5/2} \right]} \quad (8)$$

where  $K_1$ ,  $K_2$  are calibration parameters,  $\rho_s$  is the sand density,  $\rho$  is the water density,  $p$  is the porosity and  $\tan \beta$  is the average bottom slope from the shoreline to the closure depth.

This formula is a modification of the well-known CERC expression, with an additional term in order to consider wave height gradients alongshore. The free parameters ( $K_1$  and  $K_2$ ) were calibrated as a function of the net volume changes between successive historical coastlines at several beaches on the Catalan Coast. The average shoreline trend for each historical line was estimated, to avoid misinterpretations due to seasonal variability.

Successive analyses were made to characterize sequential order and discretization fineness effects, particularly concerning wave angles. It was concluded that the effect of wave angle variation is very important because of nonlinearities. A small change in wave angle produces greater differences in beach evolution than small changes in wave height.

A sensitivity analysis of the coastline discretization size was carried out too. The importance of both discretizations (spatial and temporal) was analyzed. It was found (within engineering accuracy bounds) that small changes in the spatial discretization parameter ( $\Delta x$ ) do not give rise to significative differences in the results, if the stability condition (given by the Courant number) is satisfied.

On the other hand, changes in the temporal discretization parameter ( $\Delta t$ ) do not originate differences in the results, if the stability condition is preserved and provided that wave directions remain unaltered when a different discretization is adopted.

#### 4.2. Case study

As an example of the model performance, one of the analyzed cases will be

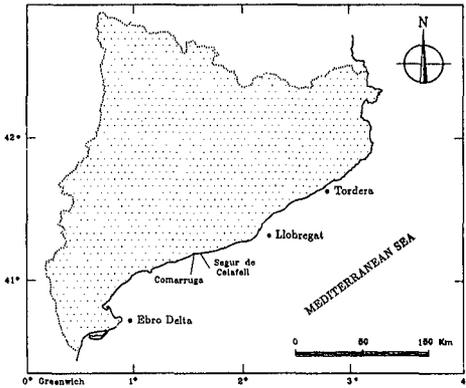


Figure 8. Comarruga-Calafell beach and buoys locations

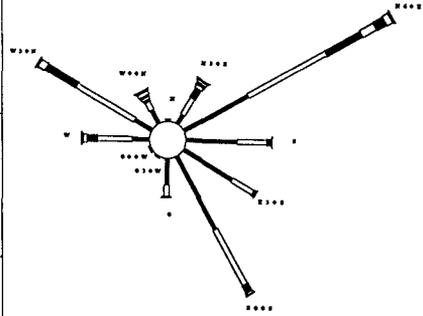


Figure 9. Wave climate for the simulated beach

described here. It deals with the beach between Comarruga and Calafell whose location is shown in figure 8.

This coastal stretch is a sandy beach with a length of 13 km. Originally it was in a relative dynamic equilibrium and the shoreline was approximately a straight line. The bottom contours were also approximately straight and parallel lines. In this zone, there was a rather large gross longshore sediment transport (about 200,000 m<sup>3</sup>/year) but the net rate of longshore transport was practically negligible (about 10,000 m<sup>3</sup>/year).

In the middle seventies two offshore marinas were constructed here, without taking into account the littoral dynamics and the important gross sediment transport existing in the area. The construction of both marinas induced important changes in the longshore sediment transport conditions and a tombolo was generated between the shoreline and each marina.

Shoreline position data were available immediately before and four years after the construction of the marinas. Using this data set, the one-line model was calibrated simulating the generation of both tombolos.

The main problem was the lack of recorded wave data during the tombolos formation. The necessary wave climate to feed the model was taken from the directional buoy wave data. This directional buoy provides wave parameters (height, period and direction among others) every 3 hours. The available wave data were from the nineties while the simulation period was from the seventies. It is nevertheless hoped that the recorded wave data are representative of average conditions in the zone so that they can be adopted to perform the simulation. A summary of the wave climate is shown in figure 9.

The selected boundary conditions were of pinned-beach type on both sides,

because the simulation bounds were enough far from the studied zone. This means that the transport rate gradients are zero and as a consequence the shoreline at these points does not move.

For other problem variables like closure depth, sediment size and beach profile shape, local values following the methodology described before were adopted. Correspondingly, a closure depth of 6 meters was employed in this case. The adopted grain diameter, obtained averaging several samples was  $D_{50} = 50$  mm. With this value, a profile of the rational type was derived taking into account the curve shown in figure 7. Therefore the only unknowns of the problem were the parameters  $K_1$  and  $K_2$  of the longshore sediment transport expression. These parameters were calibrated following a trial and error procedure. It was found that the more suitable values were  $K_1 = 0.3$  and  $K_2 = 0.7$ .

The value found for  $K_1$  is much smaller than the value of  $K_1 = 0.77$  originally determined by Komar and Inman (1970), although several authors have recommended in more recent works a decrease of the  $K_1$  magnitude. On the other hand, the value of  $K_2$  seems too large. This is probably due to the difficulty in reproducing with accuracy the behaviour of the marinas since they are coastal structures with a complex geometry.

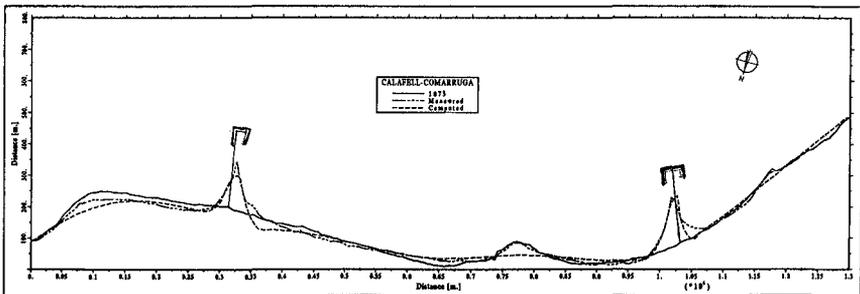


Figure 10. Model calibration in terms of shore-line evolution

The obtained prediction of shoreline evolution is shown in figure 10. A reasonable agreement between measured and predicted shoreline positions can be observed. It is also noticeable that the model reproduces the tomboles at the proper locations.

Finally, a sensitivity analysis of the  $K_1$  parameter was carried out, as shown in figure 11. In this figure, the deviations between measured and predicted

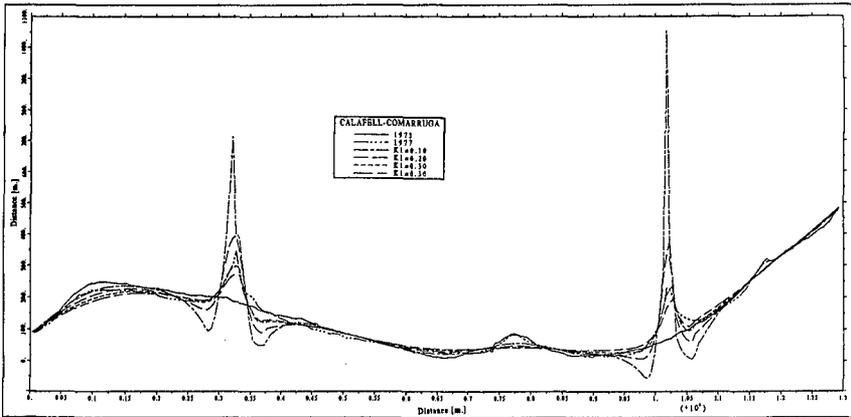


Figure 11. Sensibility analysis of  $K_1$

shorelines for other  $K_1$  values can be seen.

## 5. Summary and conclusions

The essential variables involved in shoreline evolution models have been identified and corresponding typical values have been determined for different zones of the Catalan Coast. The improved description of the relevant physical data in terms of local values is very important in order to reduce the number of unknowns involved in beach evolution simulation.

On the other hand, two new expressions for equilibrium beach profiles have been tested, one of exponential type and the other one with a rational form. Both expressions give an improved fit in most of the measured profiles on the Catalan Coast with respect to other state of the art expressions.

Finally, a shoreline evolution model has been calibrated for different areas of the Catalan Coast, employing local values for the variables involved in the process. The calibration was carried out adjusting the free parameters of a longshore transport formula and finding their most suitable values.

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