CHAPTER 368

BEACH NOURISHMENT IN ALTAFULLA, SPAIN: VERIFICATION OF THEORETICAL MODELS

J. Galofré [1], F. J. Montoya [2] and R. Medina [3]

ABSTRACT

This paper describes the comparison between results from theoretical methods and field data measurements on a beach nourishment project, in Altafulla beach, Spain. A brief review of the processes involved in the behaviour of beach nourishment projects are made in order to analyse beach evolution after filling it. Theoretical results can be obtained applying theoretical methods. A monitoring program was carried out after nourishment works and field data measurements were taken in order to verify theoretical models. Capability, application and validity of models to the prediction of a project performance are discussed comparing with field data results.

The conclusion of the comparison is made for the Altafulla case study and a discussion of the results is included in order to understand beach evolution method by field data results.

1.- INTRODUCTION

Beach nourishment works, as an integrated coastal zone management plan, are used as a coastal engineering tool in order to guarantee the functions of a beach. The most important functions of a beach are: - Energy dissipation mechanism an Useful free space for every one.

Theoretical, technical-empirical and numerical methods are needed in order to design the solution and optimize nourishment efficiency. They must be calibrated in order to know the right beach parameters and analyze their behaviour.

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1) Coastal Civil Engineer. Tarragona Coastal Service. Environment Ministry. Pl.Imperial Tarraco 4-4ª. 43005 Tarragona, Spain.
2) Coastal Civil Engineer. Head of Tarragona Coastal Service. Environment Ministry. Pl. Imperial Tarraco 4-4ª. 43005 Tarragona, Spain.
3) Associated professor. Ocean & Coastal Research Group. Universidad de Cantabria. Avda. de los Castros s/n. Santander 39005. Spain.

Analysis of beach behaviour has received considerable attention during the last decades. Although the sediment processes involved in the changes of a beach are non linear and have great variability both in space and time, the comparative analysis of beach evolution with theoretical models and field data is necessary in order to know how powerful the predictive models are. These models can be used to assist in the determination of project design and/or beach evolution. Furthermore, models describing the response of beaches to different coastal forcings have become increasingly numerous and sophisticated in recent years (see Work and Dean 1995, as a general reference). At present, however, there is no model that can be used to solve all the spatial and temporal scales of variability involved in beach nourishment evolution and, consequently, different models must be used. Monitoring field data are needed in order to calibrate and verify the models. It is necessary to know how well every model works and when it can be used.

The goal of this paper is to analyse the theoretical and real behaviour of Altafulla beach, comparing monitoring field data to technical-empirical and numerical model results. Various types of models are used, they are classified by their spatial and temporal domains of applicability.

2.- ANALYSIS METHOD

The analysis of processes, scales and tools is necessary in order to advance the knowledge of beach behaviour.

In order to understand beach performance it is necessary to analyse the beach forcings that are acting on the beach, these are the cause of all the processes.

The beach responses are the consequence of the beach forcings, they are the phenomena that appear along the coast. Beach behaviour analysis implies many methods working with the forcings and responses give a comprehension of beach performance.

Erosion, accretion and beach change in offshore bottom topography are controlled by beach forcings described in table 1. They are divided into three time scales of variability: Short term (less than 15 days), middle term (15 days to 6 months) and long term (years). The space scale considered is the meso scale that has a range from 100 m to 10 km shoreline. There are others spatial scales like microscale, less than 100 m shoreline, and macroscale, more than 10 km shoreline. This case study involves the mesoscale. The responses of beaches to these perturbations and variable forcings can be found in a wide range of time scales, see table 2.

Besides the wide range of temporal and spatial scales of variability, coastal evolution processes are often three-dimensional. In spite of this, important aspects of the coastal behaviour can be understood and prediction on the bases of lower-

PROCESS – FORCINGS		
SHORT TERM	MIDDLE TERM	LONG TERM
• Waves • Tides • Wave currents • Wind • Atmospheric pressure • Sediment budget	• Platform–Currents • Fortnight–Tides • Storms • Sediment budget	• Winter–Summer waves • Platform–Currents • M.S.L. Variation • Sediment budget

TABLE 1 FORCINGS INVOLVED IN BEACHES

RESPONSES		
SMALL SCALE	MESO SCALE	LARGE SCALE

• Bed forms:
  • Beach cusps
  • Bars
• Morphological changes
• Sediment transportation and distribution
	• Profile changes
	• Planform changes
	• Shoreline changes
	• Crescentic bars
	• Morphodynamic states variation
	• Sediment distribution
		• Coastline acretion–erosion
		• Beach equilibrium planform
		• Beach equilibrium profile
		• Sediment distribution
		• Eustatic reponse

TABLE 2 RESPONSES INVOLVED BEACHES

	MODELS		
	SHORT TERM SMALL SCALE	MIDDLE TERM MESO SCALE	LONG TERM LARGE SCALE
FORCINGS	• Wave propagation • Tide propagation • Wave – currents	• Wave propagation • Tide propagation • Wave – currents	• Wave propagation • Tide propagation • Waves – currents
RESPONSES	• Profile models • Local sediment transport	• Profile models • N–Lines models • Sediment transport	• Parametric Models (plan, profile and granuiometric) • N–Lines models • Sediment transport • Statistic models

TABLE 3 MODELS USEFULS IN BEACH BEHAVIOUR ANALYSIS

dimensional models. These models take advantatge of the circumstance that the response of a beach often exhibits a different behaviour with essentially different length scales in three mutually orthogonal space directions (vertical, cross-shore and longshore), De Vriend, (1992).

The next point is to define the models that it is possible to use for the analysis of the forcings and responses. Table 3 shows a wide range of different models.

To improve predictive models for beach responses, an accurate description of the forcings is necessary. From table 3, it can be seen that existing hydrodynamic models (wave, tide propagation and wave induced currents) can be used for solving the forcings at almost all spatial scales of interest. The choice of a particular model should be made in relation to the response model to be used.

When selecting a response model, several physical facts must be taken into account. Cross-shore transport is very important just after the fill. A nourishment beach reaches its equilibrium profile within the first year after the fill (Kamphuis and Moir 1977). Several existing models can describe the post-fill evolution of the profile (usually neglecting longshore transport). However, cross-shore transport at greater time scales (months to years) remains a challenging problem that has not received a great deal of attention (Work and Dean 1995).

Longshore sediment transport is found to be important near the shoulders of the fill in the beginning. The effects of the longshore gradients propagate afterwards into the nourished region. N-line models can represent these coastline changes in the mid-long term. The one-line approach imposes limitations by neglecting the influence of cross-shore transport. However, this can be overcome if the model is calibrated adequately (Hanson and Kraus 1977). Technical empirical models can be useful in order to know beach equilibrium planform (Hsu et al, 1989) and profile equilibrium form (Dean, 1995). For the long term evolution prediction, parametric models (e.g. equilibrium profile-coast line models) and statistical models (e.g. P.C.A. models) can help N-line models.

The next step is to analyse this wide range of models and select the most interesting in order to know the beach behavior. In beach analysis from input data with the analysis method, must be obtained the output data. In table 4 an analysis model is proposed for it.

The case study will compare the models propounded in table 4 with the field data obtained from the monitoring program.

INPUT DATA

Historical analysis
Maritime climate data
Topobatimetry
Granulometric data

ANALYSIS			
	SHORT TERM	MIDDLE TERM	LONG TERM
TECNICAL–EMPIRICAL METHODS		Morphodynamics state distribution	Shoreline equilibrium model Profile equilibrium model Grain size distribution study Empirical evolution methods
NUMERICAL METHODS	Waves propagation Breaking current system Sediment transport		Numerical evolution shoreline methods (One line) Stadistical model (3PCA)

OUTPUT DATA

Beach Evolution Behaviour:

- Beach planform
- Beach profile form
- Grain size

TABLE 4 ANALYSIS METHOD IN BEACH BEHAVIOUR

3.- FIELD SITE AND DATA COLLECTION

The site of the field study is Altafulla (Fig.1), a sandy beach located 10 km north of Tarragona and 80 km south of Barcelona, in Catalonia, on the Mediterranean Coast of Spain. Altafulla is a half-opened beach 2.3 km long located between two capes, “Els Munts” to the east and “Tamarit” to the west. A small river flows during storms in the middle of the beach.

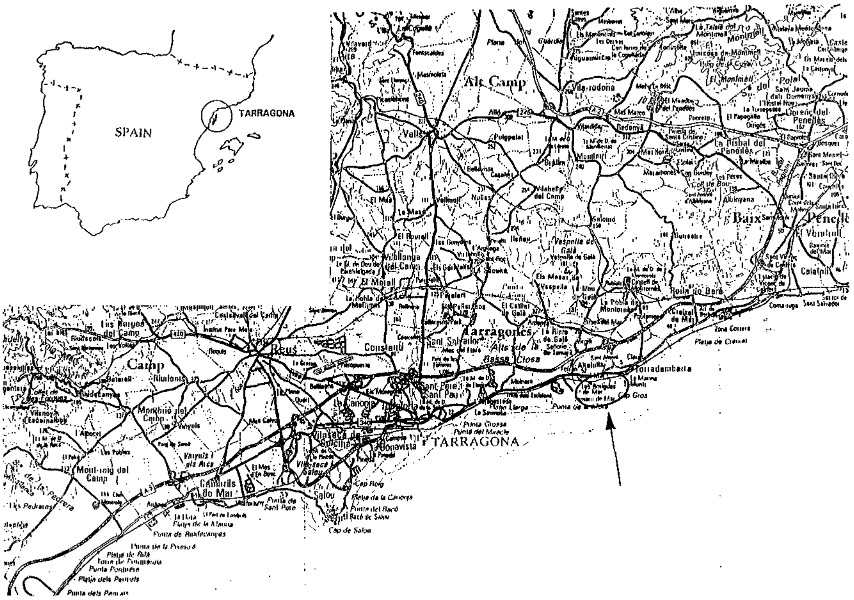

FIGURE 1 SITE LOCATION MAP

There are two predominant directions of wave aproach: SW and E. More than three quarters of deep water waves approach Altafulla 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 meters. Tides at Altafulla are negligible. In figure 3 a visual wave distribution is made and the affected area is shown, sea and swell limits are defined.

The native beach sand had a mean diameter between D_{50} = 0.12 to 0.2 mm and the beach profile slope changed from 1.2 % to 2.0 % from shoreline to bathymetric -5 meters. This value contour is considered the profile closure depth at Altafulla. The bottom of the sea is sandy up to the 10 m bathymetric contour line.

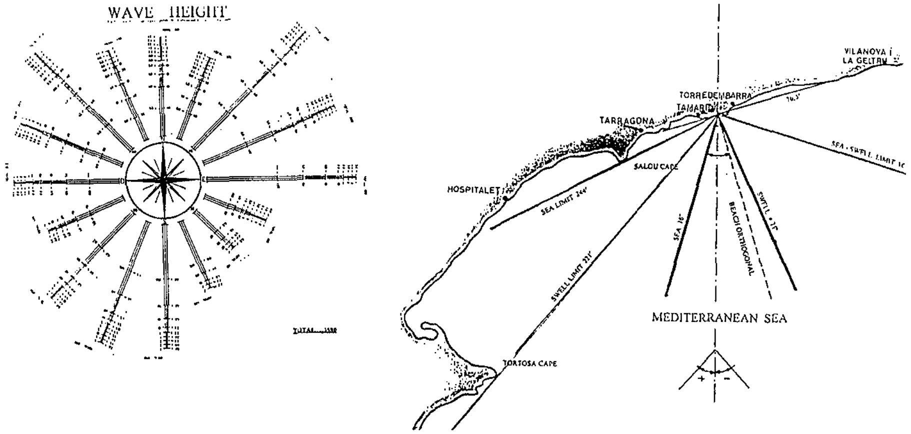

FIGURE 2) WAVE CLIMATE. SEA AND SWELL LIMITS

4.- BEACH NOURISHMENT AND MONITORING PROGRAM

In figure 3, a bathymetric map is shown in order to present beach problems and their solution.

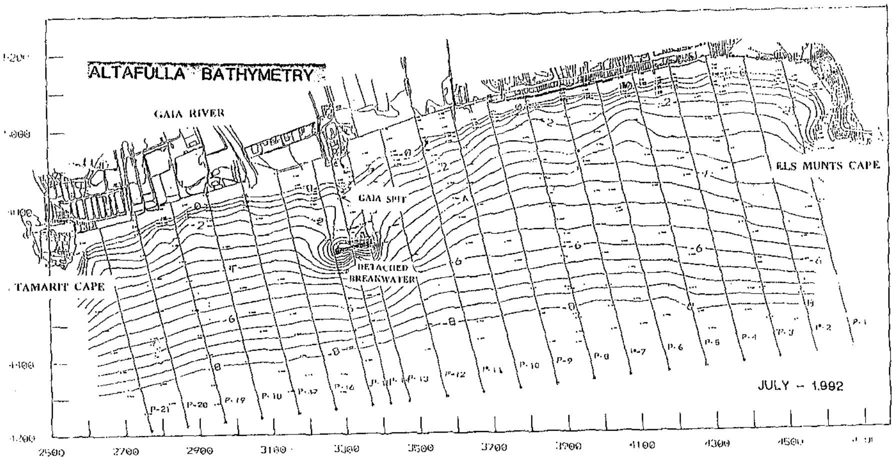

FIGURE 3 MORPHOLOGICAL AND BATHYMETRIC MAP

Several erosion problems occured in the northern part of the beach. A seawall was built to prevent backshore building damage. Southward littoral drift reduction of sediment appeared because of the construction of a dam 8 km up to the Gaià river and sand extraction during the 50's and 60's for construction works and filling the surrounding marsh. These have been theorized as major factors in the erosion that has been witnessed in Altafulla. A beach nourishment project was undertaken in 1989. Beach nourishment started in late 1990 and was completed in 1991. The beach nourishment works consisted of 160.000 m^3 of borrowed sand volume. The borrowed sand had a mediam diameter averaging $D_{50} = 0.6$ mm. A detached breakwater was also built in the middle of the beach, see figure 3. The breakwater was 110 m long and was placed at the -5 m bathymetric contour line.

A monitoring project was carried out to evaluate the evolution of the fill. The monitoring program started in July 1991, at the conclusion of the fill, and finished in December 1993, before renourishment works. The field program includes bathymetric beach profile every survey and sediment samples on some surveys. Six profile surveys were taken in this period. Each profile was surveyed from permanent monuments landward to a depth of approximately 10 meters. Sediment samples were taken in the last survey and samples were collected along three profiles simultaneous with beach equilibrium planform and profile survey.

Historical aerial pictures and visual maritime climate data are used with monitoring data in the comparison with the models.

5.- MODEL VERIFICATION

In table 3 a wide range of models which affect forcings and responses have been described. In table 4, a selection of these models have been chosen in order to define the analysis method to study beach nourishment evolution. Beach planform, beach profile form and grain size distribution can be obtained from historical analysis, maritime climate data, topobatymetric and granulometric data using the analysis methods.

The field data are needed in order to validate the models, some data are input, some are used to calibrate the models and others are output data. A planform and profile form are analysed in order to know their equilibrium. Grain size distribution is evaluated.

Qualitative and quantitative verification have been made. Qualitative results have been obtained studying beach dynamics and comparing with aerial pictures and topobatymetrics. Beach dynamics were computed by means of the numerical models.

Computations were carried out for conditions before and after the fill and construction of the detached breakwater. Different wave heights, wave periods and wave approach directions were used applying the REFDIF program, from Kirby and Dalrymple (1983-1986) computed by the parabolic wave propagation model.

Different wave heights were composed, the refraction and difraction phenomena were combined. By analysing aerial pictures, the protected areas behaviour, predicted by the models, can be observed. Figure 4 shows the wave induced currents determined from the wave field, as shown in the last figure. It can be seen that the breaking waves currents direction, induced by different wave height, change near the capes and the breakwater by difracting phenomena. Aerial pictures

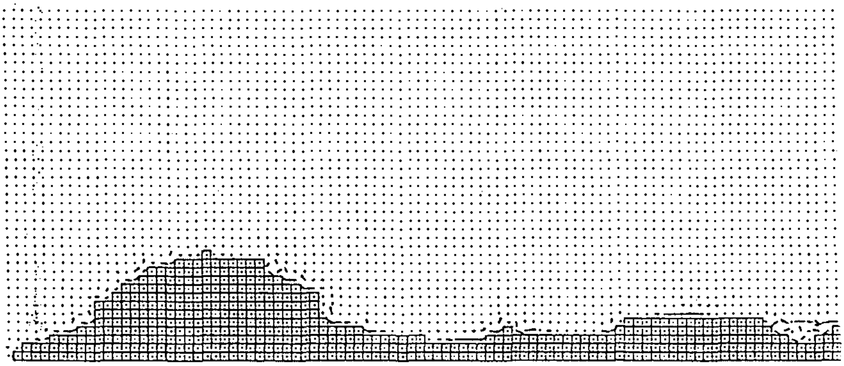

FIGURE 4.a) WAVE INDICED CURRENTS H= 0.5 m; $\alpha = +45°$; T = 10s.

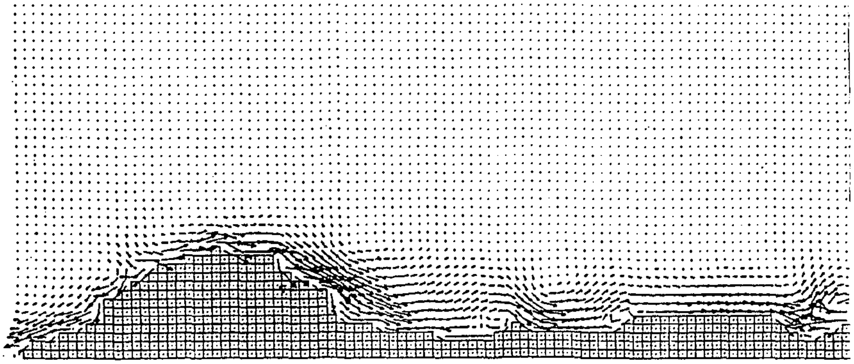

FIGURE 4.b) WAVE INDUCED CURRENTS H= 3.0 m; $\alpha = +45°$; T = 10s.

confirm these results showing sand accumulation in the calm areas. The spit formation landward of the breakwater can be explained with these results as is shown in the monitoring batymetry.

Quantitative verification can be made in order to analyse beach behaviour. Beach profile, planform and prediction methods are verified.

Beach field data profiles were compared with theoretical profiles before and after nourishment works. The Dean profile was used and compared with field data. The beach profile before nourishment can be approached by $y = A. X^{2/3}$, with the corresponding A according with $D_{50} = 0.16$ mm., the average of D_{50} in the native beach. After nourishment the beach profile can be approached by the same formula with A corresponding with $D_{50} = 0.35$ mm., the average of D_{50} in the nourished beach in the last topobatymetry field data.

Closure depth profile is calculated by the Birkermeier formula and compared with monitoring field data. Bathymetric -5 m. contour is considered the closure depth at Altafulla. This value was determined from the monitoring profiles and by technical-empirical model.

Planform was analysed by technical-empirical and numerical models and the results have been compared with monitoring field data results. The technical-empirical Hsu and Silvester method was used for analysing planform on the east part of the beach. Figure 5 shows the results with a great similarity with theoretical and field data results. The spit formed landward of the detached breakwater built in the middle of the beach is analysed using the method proposed by Gonzalez (1995), to calculate spits and tombolos. Figure 6 shows the application of this method and the conclusion is compared with the results of the monitoring field data results.

Numerical models can be used in order to understand beach performance and beach evolution. The basic procedures followed in this case study to analyse the beach nourishment evolution were the one-line model and statistical model. Field data are needed in order to calibrate and verify the one-line model and as input data for statistical models that can show theoretical tendencies from field data.

The one-line model used was GENESIS, (Hanson and Krauss, 1991). The model was calibrated with the profile evolution data following the procedure by Hanson and Krauss (1989). The climate waves were taken from visual data and calibrated from Tarragona harbour buoy data . Figure 7 shows the results of the shoreline position obtained from the model. The field data used for the calibration was 92 - 02 - 28 to 93 - 10 - 17.

The one-line model is a powerful tool that must be used carefully. To model the reality means to simplify the problem in order to reach some logical results that represent because two capes exist at the ends of the beach. These capes are not very long but it is not know if sand bypassed them.

In the model the capes are represented by two diffracting groings 550 m long. This hypothesis works well in a small and mesotime scale. It was calibrated and verified using two years monitoring field data and the results were quite reasonable. But if we apply long-term scales, more than 10 years, the results must be discussed more accurately. The boundary conditions are critical, especially for the evaluation of the sand beach losing outside the study stretch. Extra data are needed in order to calibrate the program better. Length, sand bypassing and sand transmission must be discussed in order to aplly long term.

Wave climate is another data that must be chosen carefully. In this case visual data, calibrated with Tarragona harbour buoy data, were used. During the monitoring period not many storms occured. This means that the medium wave climate that visual data represent was not absolutley according to real wave climate.

Sand granulometry is another aspect to consider. In the GENESIS model and program homogeneous sand is used, in this case it was supposed that all the sand had D_{50} = 0,35 mm. Before restoration D_{50} = 0,2 mm and in the mouth os the Gaià river a lot of rocks and gravel existed. This phenomena was not considered in the GENESIS program. In the places where gravel exists erosion problems are less than in sandy areas. In long term analysis these aspects have importance and the results must be taken carefully.

Combined phenomena, boundary conditions, wave climate and sand granulometry have incidences in the prediction results in long term scale and it is difficult to plan long term future by this kind of program in this case.

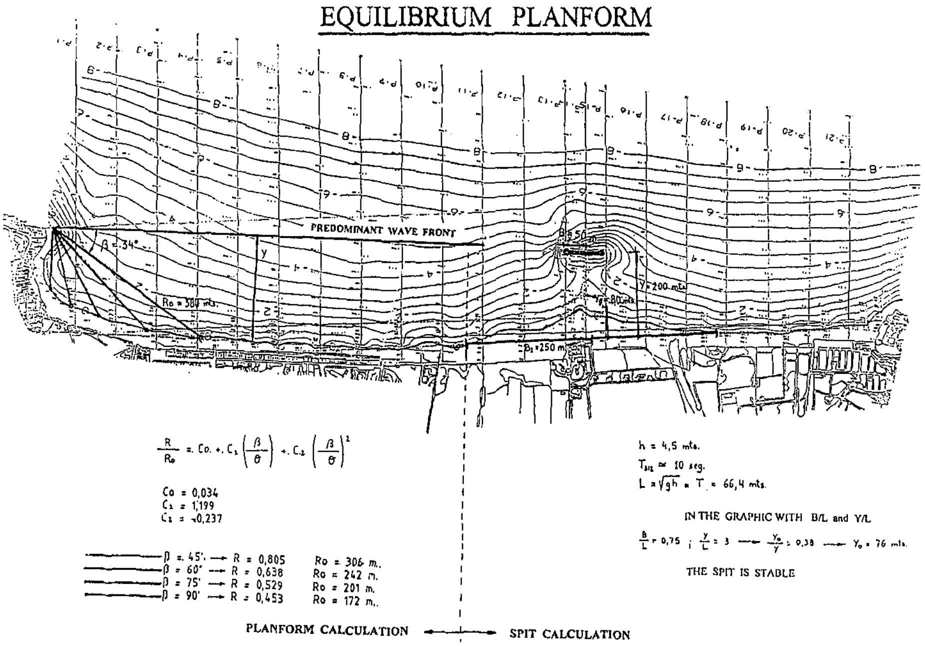

FIGURE 5 THECNICAL-EMPIRICAL METHODS INPLANFORM EVALUATION

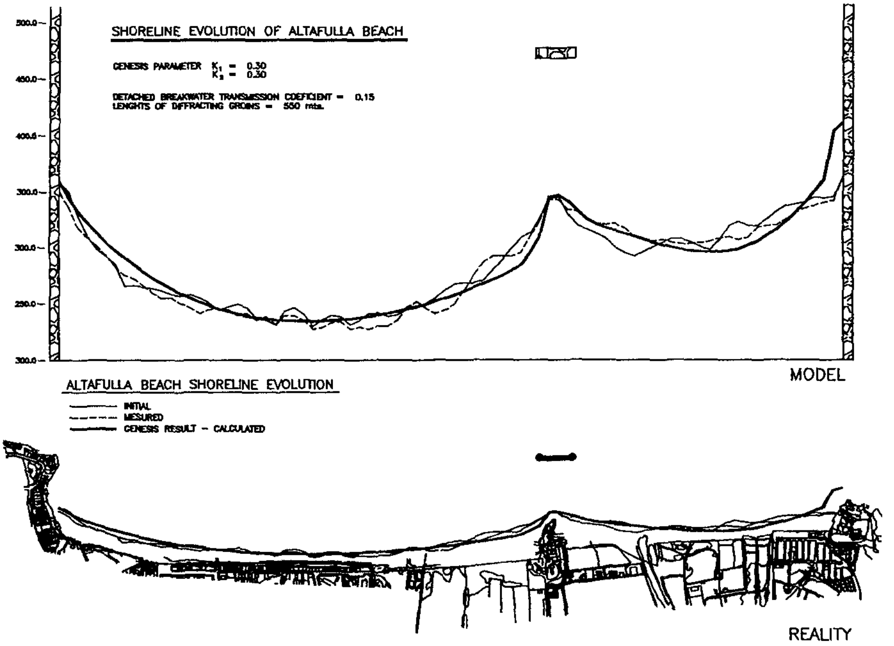

FIGURE 6 NUMERICAL METHOD, GENESIS, FOR SHORELINE EVOLUTION ANALYSIS

In order to understand beach behaviour, after the analysis of beach profiles and planform, a brief study of longshore transport was made. Theoretical formulas can be used, some of them only considere oblique wave incidence: CERC, KOMAR, etc. In this case heigth wave gradient, because of difraction phenomena, are also important. That is why it is necessary to use models that consider both phenomena. The GENESIS program also calculates longshore transport ratios along the shoreline and the average transport ratio considering obliquity wave incidence and height wave gradient. In this calculation initial and final shoreline data were used to calibrate the model. The average of long shore transport is about 5.000-9.000 m^3/year, this result agrees with some theoretical studies made near this area.

A statistical model was used computing the monitoring topobathymetry field data in order to find the tendencies of beach behaviour. The statistical model used was Principal Component Analysis (three way PCA). The method was used to objectively separate the spatial and temporal variability of the beach profile, planform and the sediment grain size data, as described by Medina et al 1994. The results show a seasonal variability in the beach profile data and a long-term trend. The bases of these statistical methods are the concentration of all topobathymetric information and to find some intrinsical information that can explain the trend of the beach evolution.

Three-way PCA is a statistical tool that can be used in the knowledge of beach behaviour. In Figure 7 the first, second and third cross-shore components, eigenvector are shown. The firts one defines the mean of the variable, in this case representing the medium average profile. The second cross-shore eigenvector is very important in the upper part of the profile and it will play an important role in determining the upper profile slope. The third cross-shore eigenvector shows a berm-bar variability. In our case the second and third eigenvectors have influence on the detached breakwater comparing COMPL ∅ and COMPL 1. A similar analysis can be made for long-shore eigenvectors.

The shows temporal eigenvectors, have been calculated the first one represents medium average temporal variation. The second one represents a seasonal dependence. Both of these are constant, and in the case of a two-year monitoring program, the temporal variability is not important. This means that the beach is in a quite equilibrium position with this wave climate. The combination of these eigenvectors explains most of the variability of the evolution of the beach. In order to combine them we will use the corresponding Bartussek core matrix values and the percentatge of variation explained. This matrix shows how to combine eigenvectors. In order to better interpret the variability they account for, it is useful to examine the profile or the bathymetry that is obtained by the product or one alongshore eigenvector with one cross-shore eigenvector, and use the corresponding temporal function to determine how the obtained profile or bathymetry evolves in time.

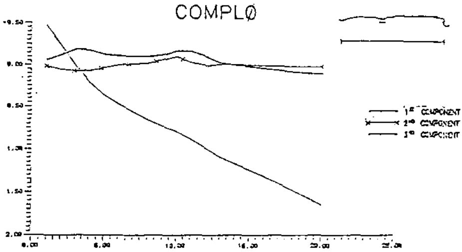

FIGURE 7 a) CROSS-SHORE EIGENVECTOR AFTER NOURISHMENT WORKS

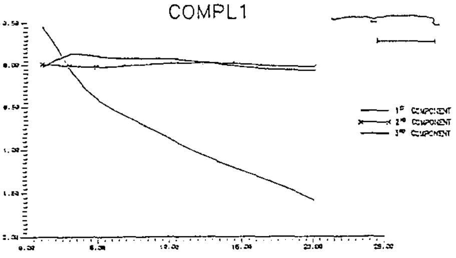

FIGURE 7 b) CROSS-SHORE EIGENVECTORS BEFORE NOURISHMENT WORKS

6.- CONCLUSION AND DISCUSSION

1.- Good data is needed in order to know the beach behaviour. It is the most important aspect for Coastal Engineers.

1.1 Wave climate must be obtained from:, Directional buoy, Non directional bouy with the direction data, Non directional bouy, Visual climate data.

This is the classification from the most valuable data to the least. Also, it depends on the range of information that it is possible to use. It is necessary to check different data information, if possible, and analyse it carefully before choosing the calculation data.

1.2 Topobathymetry data are the physical suport of Coastal Engineers. Accurate data is necessary for all king of model. It is necessary to control: Study are limits, Profile distance,Profile length, Points per profile, Position system and errors, Bathymetric and althymetric measurement system and errors,Working weather conditions, Technical and worker personnel,Data analysis and computation,Topobathymetry frequency.

1.3 Sand sampling is needed as a basic component of beach performance. It is necessary to control: Study area limits, Sampling points, Sampling system, Sampling analysis and computation, Sampling frequency.

2.- Technical empirical models are easy to use and give important qualitative and some quantitative results. Data errors can be detected.

3.- Numerical models are more complicated to use than technical-empirical and sometimes can take data errors obtaining results with more errors.

4.- No model, technical-empirical or numerical, gives good results with bad data.

5.- Numerical models need a lot of data, a calibration step and a verification step. The whole process requires a lot of time and money. For this reason, it is necessary to be rigorous choosing them on quantity and quality.

6.- Statistical models must be studied in depth in order to find the beach trends.

7.- Altafulla beach has been studied comparing monitoring fiel data and theoretical models. It is a quite stable beach with a sand drift of 5.000 m^3/year, from east to west. Sand is accumulated in calm areas and eroded in open areas.

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