CHAPTER 157

A Field Experiment on a Nourished Beach

A.J. Fernández*
G. Gómez Pina *
G. Cuena*
J.L. Ramírez*

Abstract

The performance of a beach nourishment at "Playa de Castilla" (Huelva, Spain) is evaluated by means of accurate beach profile surveys, visual breaking wave information, buoy-measured wave data and sediment samples. The shoreline recession at the nourished beach due to "profile equilibration" and "spreading out" losses is discussed. The modified equilibrium profile curve proposed by Larson (1991) is shown to accurately describe the profiles with a grain size varying across-shore. The "spreading out" losses measured at "Playa de Castilla" are found to be less than predicted by spreading out formulations. The utilization of borrowed material substantially coarser than the native material is suggested as an explanation.

1 INTRODUCTION

Fernández et al. (1990) presented a case study of a sand bypass project at "Playa de Castilla" (Huelva, Spain) and the corresponding monitoring project, that was going to be undertaken. The Beach Nourishment Monitoring Project at the "Playa de Castilla" was begun over two years ago. The project is being

*Dirección General de Costas. M.O.P.T, Madrid (Spain)

carried out to evaluate the performance of a beach fill and to establish effective strategies of coastal management and represents one of the most comprehensive monitoring projects that has been undertaken in Spain. This paper summarizes and discusses the data set for wave climate, beach profiles and sediment samples.

2 STUDY SITE & MONITORING PROGRAM

Playa de Castilla, Fig. 1, is a sandy beach located on the South-West coast of Spain between the Guadiana and Gualdalquivir rivers. The beach extends over $25km$ between Mazagón and Matalascañas, and has experienced a long-term trend of erosion. The shoreline at Playa de Castilla has been receeding at a rate of $1.5m/year$ during the last 30 years (Fernández et al., 1990). The main causes of this shoreline recession are the net litoral drift from West to East, that has been evaluated in $390.000m^3/year$ (CEDEX, 1979), and the civil works in the nearby rivers that have reduced the volume of sand carried to the coastline.

In 1989, an artificial nourishment of the beach was carried out. The fill project was conducted by the Ministry of Public Works of Spain and consisted of a sand bypass from the updrift side of the Tinto-Odiel Estuary to Playa de Castilla. The volume of sand moved was $1.690.000m^3$. The sand was dredged by a trailing suction hopper dredger and transported $2km$ down drift. The total volume of sand was placed in the updrift extreme of "Playa de Castilla", forming a protruding area about $2km$ long and $115m$ wide, Fig. 1. The borrowed sand was coarser than the native sand being $D_{50} = 0.63mm$ and $D_{50} = 0.3mm$ for the borrowed and native sand respectively.

A monitoring program was established to evaluate the performance of the nourishment. The field program includes wave measurements, beach profiles and sand samples (Fig. 2).

The wave climate measurements cover daily visual observations of wave direction in shallow water, surf zone width, wave period and wave height within the surf zone (two measurements per day). In addition, waves are recorded by a buoy gauge located in intermediate depths (18 m).

Beach profile data are acquired bimonthly from 42 shore-normal profiles located between Mazagón and Matalascañas. Alongshore spacing of the profiles is approximately $500m$. Each profile is surveyed from the beach dune up to a depth of about $10m$.

Sediment samples are collected from each beach profile during each bi-

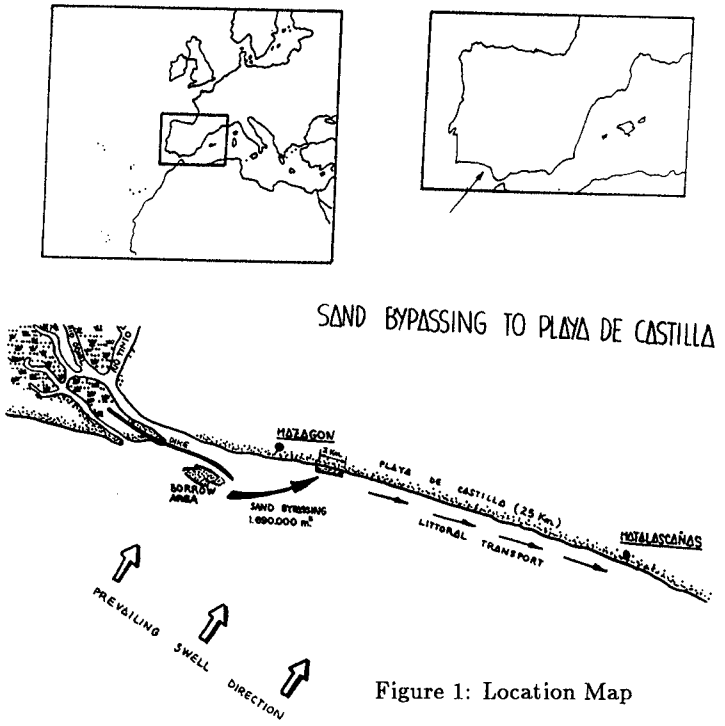

Figure 1: Location Map

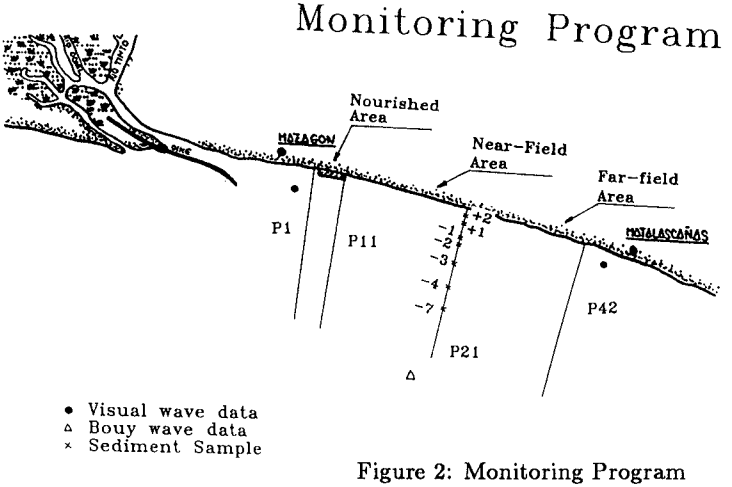

Figure 2: Monitoring Program

Table 1: Measured Wave Parameters

Variable	Max.	Mean	Min.
H_s	3.80 m	0.65 m	-
H_{max}	5.90 m	1.00 m	-
T_z	9.40 s	4.10 s	2.40 s
T_s	15.60 s	5.00 s	2.80 s

monthly survey from the dune to offshore. Samples are collected at the following locations: swash zone, surf zone (-1 m, -2 m), and offshore (-3 m, -4 m, -7 m). Each sample is processed in the laboratory for grain size parameters.

3 RESULTS

3.1 Wave Climate

Since waves are the primary agent for nearshore changes at Playa Castilla, several wave parameters are collected. Daily, visual observations are taken at Mazagón and at Matalascañas $25km$ downdrift. Morning and afternoon measurements of the following parameters are recorded: wave direction, breaking width, wave period and breaking wave height.

Average breaking wave height is of the order of $0.4m$. Wave heights during the strongest storms are on the order of $2.0m$. Most of these storms are locally generated with wave periods in the range of $6-8sec$. The breaking zone width varies between $5m$ and $200m$ with $10m$ as an average value. The predominant approach direction is from the SW/SSW sector, with more than 60the data corresponds to calm periods.

In order to obtain a more complete description of the wave climate, a permanent station for wave height recording was installed. The station was located in intermediate depths, (18 m) between Mazagón and Matalascañas. The buoy gauge consists of a Data Well Buoy model Waverider 6000, a recording unit and a power source. The data are recorded on cassettes and is computer analyzed to yield significant wave heights and periods. Table I presents the range of values for the different wave parameters.

where H_s is the significant wave height, H_{max} is the maximum wave height, T_z is the upcrossing period and T_s is the significant period.

3.2 Beach Profiles

The beach profile data are acquired bimonthly from 42 shore normal profiles across the nourished beach (profiles 2-6) and adjacent beaches (profile 1 is updrift and profiles 7.42 are downdrift). The transect spacing was designed to monitor the whole beach (nourished and unnourished) and to resolve the long term "spreading out" losses of the nourishment though it might not be adequate to resolve the spacing of rythmic topography, which can be closely spaced. In the first survey, the alongshore spacing in the nourished beach was 250 meters. These additional profiles were included to determine information about the profile readjustment that occurs from the linear project profile until finally arriving at the natural equilibrium profile.

3.3 Unnourished Section, Far Field

The Eastermost profiles are (far apart) from the nourishment and give information from the natural changes of the beach profiles. The storm season profiles (Sep./90 and Jun./91, Fig. 3) show a dissipative profile with a steep beach face, a marked break point bar and a very mild offshore slope beyond the 3 m contour. The bar can be observed in almost all the campaigns with minor changes in its offshore position and seasonal changes in its elevation. During calm periods (Feb./91 and Feb./92), the bar trough is filled and the bar becomes a step which separates the steeper beach face and the milder offshore profile.

The dune erosion process is clearly shown in the measured profiles. During storm conditions, the landward part of the profile retreats and the dune is eroded. The dune material is transported to the offshore part of the profile, beyond the bar (Sep./90 and Jun./91). This excess of sediment in the offshore profile is lost during calm periods (Feb./91 and Feb./92) but the foreshore does not recover the pre-storm position and, consequently, the erosion process is completed.

3.4 Unnourished Section, Near Field

The morphology of the profiles which are adjacent to the nourished beach are qualitatively quite similar to those at the far field, with a steep beach face, a marked bar during the storm season and a mild offshore slope beyond the 3 m contour (Fig. 4). However, the magnitude of the bar is not generally as important as in the far field. During calm periods, the bar becomes a step as in the far field. It can be observed from Figure 5, that the foreshore part of

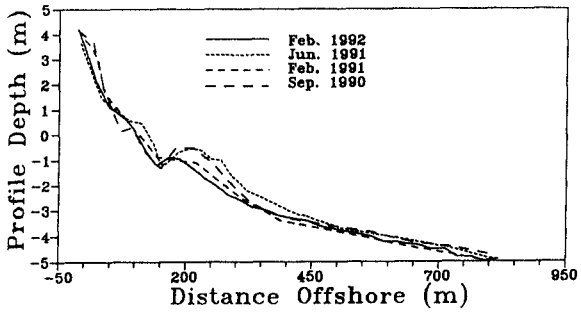

Figure 3: Beach Profile. Far Field

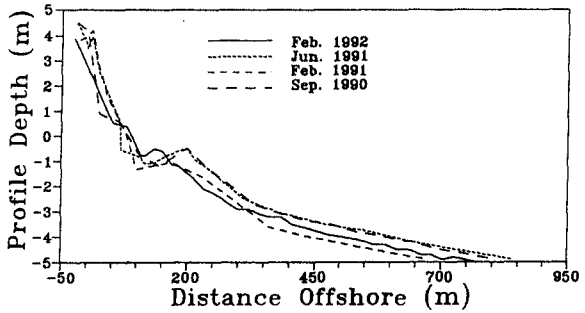

Figure 4: Beach Profile. Near Field

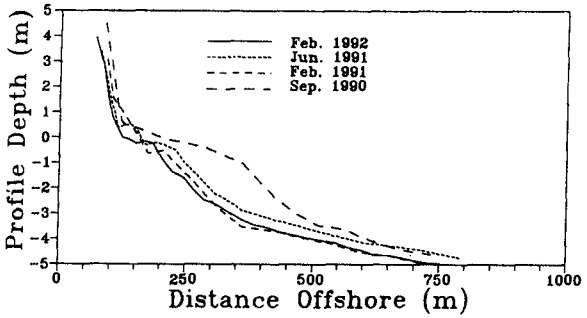

Figure 5: Beach Profile. Nourished Area

the profile benefited from the project, at the beginning, (Sep./90 to Jun./91), with a net accumulation of sediment, mainly above low tide level. However, the offshore part of the profile, retreated afterwards during the period (Feb./91 to Feb./92). This part of the profile, beyond the bar, shows the seasonality above mentioned with a significant accretion during storm conditions and a gradual lowering of the offshore beach during calm periods.

3.5 Nourished Section

In the nourished beach there is no bar but a permanent step or a transition between the very steep beach face and the more gently sloping offshore profile (Fig. 5). The offshore changes of the profiles are as important as those encountered at the near field and far field profiles. The foreshore part of most of the profiles displays a loss of material. Nearly all of this loss is located in the swash zone of the intertidal beach.

3.6 Sediments

Sediment samples are collected from each beach profile each bimonthly survey. The samples are adquired by hand-operated grab samplers, and represent approximately the upper 10 cm of sediment at each location. The samples are analyzed in the laboratory and grain sizes are computed by sieving according to the ASTM standards. Samples are taken for each profile at the swash zone, surf zone (-1 m, -2 m) and offshore (-3 m, -4 m, - 7 m).

3.7 Swash Zone

The grain size at the swash zone (Fig. 6) is the most stable in time of all the locations, with minor changes at the unnourished beach and more important fluctuations at the nourished part. The temporal variations of the mean size exhibit a similar variability in the alongshore direction, being coarser or finer at all the profiles depending on the survey. Spatially, the nourished beach represents a discontinuity in the distribution of grain size.

The unnourished backbeach is characterized by a very uniform grain size in the alongshore direction with an average $D_{50} = 0.32mm$, while the nourished beach shows a less uniform alongshore distribution with an average $D_{50} = 0.51mm$. There is, however, a slight tendency for decreasing grain size variability both temporally and spatially in the nourished beach throughout the campaigns.

3.8 Surf Zone

Grain size temporal variability is much more important in the surf zone than in the backbeach (Fig. 7). The average D_{50} in the surf zone is $0.25mm$ with a range of values from $0.4mm$ to $0.2mm$. As in the backbeach, there is a clear trend in the grain size to be coarser or finer in all the profiles depending on the campaign. Unlike the landward location, there is almost no discontinuity in the alongshore direction due to the nourished beach. The nourished beach was coarser during the first campaign but afterwards achieved a grain size similar to the rest of the beach.

3.9 Offshore Zone

The offshore part of the beach shows different characteristics depending on the depth. At the $3m$ and $4m$ contour, the beach shows a fine sand, with slight temporal and spatial variations (Fig. 8). The average D_{50} is $0.14mm$ with values in the range of $0.2mm$ and $0.12mm$. No discontinuity is found at the nourished beach. At the $7m$ contour, the mean grain size shows great temporal and spatial variation. Samples range from fine sand, $D_{50} = 0.12mm$ to coarse sand $D_{50} = 0.9mm$. Most of the coarse samples are obtained at fixed locations throughout the program.

4 DISCUSSION

In addition to the seasonal changes that may occur in a natural beach, it is well known that the nourished beaches suffer modifications both in the cross-shore and alongshore directions, due to the profile equilibration and the "spreading out" losses. The performance of a beach nourishment project may be evaluated by the magnitude of these changes compared to the initial configuration of the designed beach fill.

4.1 Profile Equilibration

Beach fills are constructed using a broad range of designs, but generally the material is placed using profiles which are steeper than the natural profile for the size of sediment that is used in the beach nourishment project. Thus, the profile will tend to equilibrate to its natural shape. Profile equilibration occurs gradually, depending on the specific project characteristics (sand volume, average grain diameter...) and the wave and water level conditions, and usually

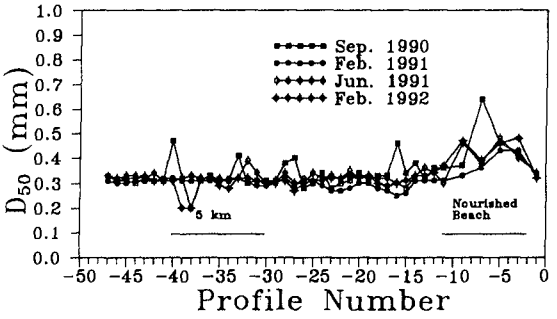

Figure 6: Grain Size. Swash Zone

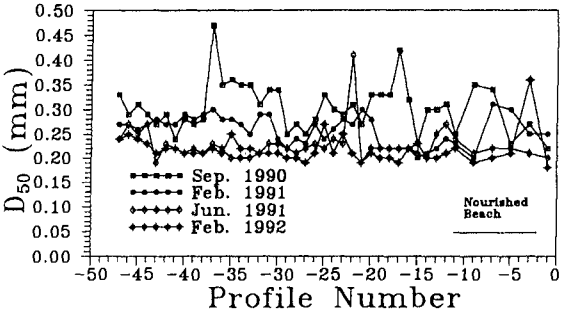

Figure 7: Grain Size. Surf Zone

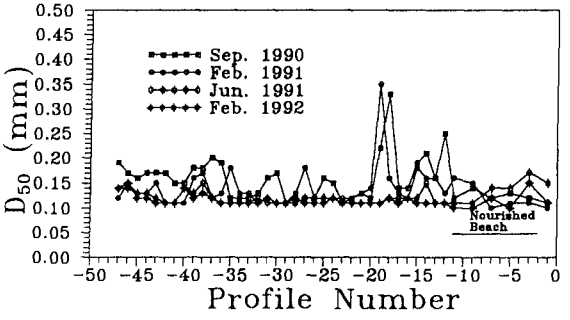

Figure 8 : Grain Size. Offshore Zone (-4)

last for a few years, Dean and Grant (1989). In considering the last profile equilibration, these are the most important questions to be answered: What will be the final equilibrium profile and when will this equilibrium profile be achieved?

Equilibrium beach profiles have been found by Bruun (1954) and Dean (1977) to be reasonably well represented by:

$$h(y) = Ay^{\frac{2}{3}} \tag{4.1}$$

in which h is the depth at a distance, y seaward of the shoreline and A is a scale parameter primarily dependent on sediment size (assumed to be constant along the profile), Moore (1982). If the grain size varies markedly along the profile, as (it occurs) at Playa Castilla, significant deviations may be encountered. Different approaches have been made to take into account the cross-shore distribution of sediment grain sizes.

Larson (1991) modified the equilibrium profile equation to better represent the grain size variation along the profile as:

$$h = A[y + (\frac{D_o}{D_\infty} - 1)(1 - e^{-\lambda y})]^{2/3} \tag{4.2}$$

where D_0 and D_∞ are the equilibrium energy dissipation for the material at the shoreline and in the offshore respectively ($D_0 \geq D_\infty$) and λ is an empirical coefficient. Eqs. (4.1) and (4.2) are assumed to represent the equilibrium profile up to a "closure depth", h_*. Usually, Hallermeier (1981), littoral zone limit ($H_* = 2.28H_{s0.137} - 68.5(H^2_{s0.137}/gT^2_s)$) or Birkemeier (1985), ($H_* = 1.75H_{s0.137} - 57.9(H^2_{s0.137}/gT^2_s)$) are adopted.

From the buoy data, the values of the closure depth are found to be 7.74 m and 7.87 m for Hallermeier and Birkemeier formulations, respectively.

Figure 9 displays a comparison between the measured beach profile at Playa Castilla and the least-squared fit of eq. (4.2) and eq.(4.1) for a beach profile located at the nourished beach (Figure 9a) and a beach profile located at the unnourished beach (Figure 9b). As seen from the figures, the agreement between the measured and calculated profile improves considerably if eq. (4.2) is used in comparison to eq.(4.1). The improvement is even more evident at the nourished beach, where there is a strong variation of the sediment size in the cross-shore direction.

From the 378 profiles analyzed, it was found that the best fit, when applying the classical $2/3 - power$ curve, eq.(4.1), was obtained using a value of the A-

parameter that corresponds roughly with the grain size located at the surf-zone, in accordance with Moore's curve. It is remarkable that the offshore part of the profile beyond the bar (or step), where the sediment size is almost constant, can be well-represented by a simple $2/3-power$ curve (see Figures 9a and 9b). The modified equilibrium equation provides an improved description of the profiles with decreasing grain size with distance offshore, however, at present, the parameters involved in the equation must be estimated by a best-fit procedure. Additional work is being carried out to establish the dependence of the parameters on the grain and wave characteristics.

From the analysis of the temporal evolution of the constructed profile to the natural equilibrium profile (not shown), it can be concluded, that the equilibrium profile was well achieved in less than one year, as suggested by Kamphuis and Moir (1977).

4.2 "Spreading out" Losses

The placement of a beach nourishment project usually results in a planform that interacts with the waves to result in a spreading out of the sediment, with the consequent loss of material from the region in which it was placed. In addition to the erosion due to the anomalous plan form of the nourishment project, there is usually a background erosion which was present prior to the placement of the beach nourishment project (and which made it necessary) that is superposed to the spreading out. The superposition of these two components yields the shoreline recession at the nourished beach.

The equations available to represent the planform evolution are a sediment transport equation and a sand continuity equation.

Using Komar's and Inman (1970) sediment transport equation and combining it with the sand conservation equation, an equation governing the evolution of a beach system can be obtained, Dean and Grant (1989),

$$\frac{\partial y}{\partial t} = G\frac{\partial^2 y}{\partial x^2} \tag{4.3}$$

in which the parameter G can be interpreted as the alongshore diffusivity, and primarily depends on the wave height and on the sediment transport coefficient, K, which depends on the sediment size. The wave direction is relatively unimportant on a long uninterrupted shoreline as "Playa de Castilla", Dean and Grant (1989).

The solution of equation (3) can be obtained once an initial condition is established. Using equation (3) with the designed beach nourishment project

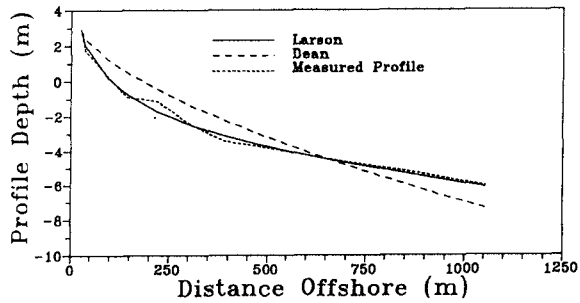

Figure 9a: Measured Profile vs Calculated Profile. Far Field

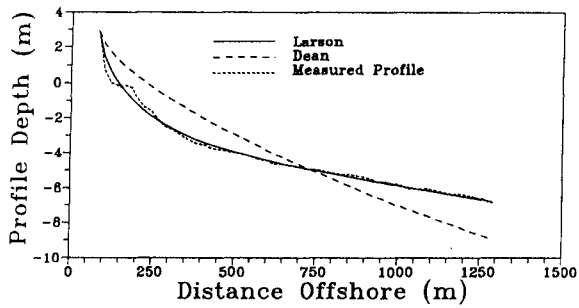

Figure 9b: Measured Profile vs Calculated Profile. Nourished Area

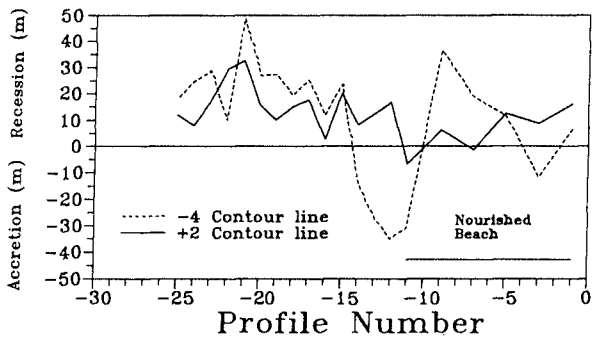

Figure 10: Shoreline Evolution

characteristics at Playa Castilla (borrowed sand diameter $D_{50} = 0.63$ and background erosion $1.5m/year$), about 20 % of the material should have been spread out in two years; however, except for the initial profile equilibration, no significant loss has been measured at the nourished beach. Furthermore, if we compute the losses with the actual grain size measured during the campaigns and take into account the cross-shore distribution of grain size as in Moutzouris (1988), more than 40 % should have been transported down drift.

It seems that the utilization of a material substantially coarser than the native sand has armor the beach in the nourishment area thereby resulting in less transport from the nourished area. The similarity of the changes of the offshore part of the profiles at the nourished beach and the unnourished beach, and the alongshore uniformity of grain size in the submerged part of the profiles indicate that the natural littoral drift is being re-established and that the nourishment area has been passed, as if it were a jetty.

In Figure 10, the shoreline evolution during the period Feb-91/Feb-92 for the contour lines +2 and -4 is presented. It can be observed from figure 10 that: the shoreline in the unnourished section has retreated with the similar rate of erosion in the far-field and in the near-field. The shoreline in the nourished are shows a tilting motion with recession in the updrift area and accretion in the downdrift area.

5 SUMMARY

The "Playa de Castilla" beach nourishment monitoring data set has been presented. The data include beach profiles surveys, wave measurements and sand samples. Availability of accurate levellings and soundings, sea conditions information and sediment distribution has provided the opportunity to evaluate the performance of the beach fill at "Playa de Castilla". The performance has been described in terms of beach "profile equilibrium" and "spreading out" losses. It has been shown that the equilibrium profile was achieved in less than one year, as suggested by Kamphuis and Moir (1977). The classical $2/3 - power$ curve proposed by Bruun (1954) and Dean (1977) to represent the equilibrium beach profile has been found to be inadequate to describe the strong grain size varying across-shore beach profiles existing at "Playa de Castilla". The modified $2/3 - power$ curve proposed by Larson (1991) has been shown to accurately represent the profiles with the cross-shore distribution of sediment size of "Playa de Castilla". The "spreading out" losses evaluated by profile measurements were less than those determined by spreading out formulations. It has been suggested that the utilization of a substantially coarser material for the beach fill has armor the beach in the nourished area, resulting in a

decreased transport from the nourished area.

ACKNOWLEDGEMENTS

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