CHAPTER 105

DESIGN OF POCKET BEACHES. THE SPANISH CASE

José Mª Berenguer *
Javier Enríquez **

Pocket beach is a usual method to restore an eroded or regressive coast without natural sand supply. Nowadays, there are more than 40 of these beaches on the Spanish coasts and a lot of them all over the world.

This paper deals with the design parameters of pocket beaches, based on the analysis of data collected from 24 existing beaches on the Mediterranean coast of Spain. Fourteen of these beaches have been studied in detail; nine of them located on the Alboran Sea and the other five on the coast of Cataluña. Data from 10 additional beaches have also been considered.

Different parameters such as structural design, location of breakwaters, beach planform, beach profile, wave conditions at the site and sedimentary conditions have been analyzed. A mathematical model has been used for the study of the shoreline equilibrium planform.

Practical coastal criteria design considerations have been drawn from the observed behaviour of the aforementioned beaches.

1.- INTRODUCTION

The term "pocket beach" is going to be used for all those beaches which have been artificially created using constructions that limit them laterally, and also in certain cases frontally, either totally or partially. By definition, the term suggests that the dimensions are limited and generally reduced.

* Civil Engineer, Deputy Director of the Harbour Division at the "Centro de Estudios de Puertos y Costas"(CEDEX)
Antonio López, 81, 28026 Madrid, SPAIN
** Civil Engineer, Head of the Coastal Defence Division at the "Centro de Estudios de Puertos y Costas"(CEDEX)

This work is concerned with those pocket beaches protected by works parallel to the coast. Beaches which are bounded by groynes that are straight and perpendicular to the coast are thus excluded. On the other hand, constructions that are of the detached breakwater kind, L-shaped or T-shaped or curved groynes and platform islands are those which will be studied.

The main purpose of these constructions is to obtain a stable and safe beach. Pocket beaches undoubtedly have their advantages and drawbacks. Each and every coastal problem has its own specific characteristics, (purpose, wave climate, environment, etc.), and this makes the indiscriminate use of theoretical plans and the extrapolation of practical solutions unadvisable even if they have been successful in other cases.

The methods that have been developed in coastal engineering for the control of sedimentary processes which are of an erosive nature, are basically three.

1. To protect the coast with works that prevent or limit the direct action of the waves on sedimentary deposits.

2. To reduce or alter the rate of littoral transport.

3. To supply new sediment to the beaches in order to replace the losses or to increase size.

The pocket beaches are a compendium of all these systems and as such can act in any of these three capacities. Their projection parallel to the coast reduces the average energy that reaches the shoreline. The differential way in which this effect is brought about, causes a considerable change in the littoral transport of sand. Finally the reduced dimensions of the physiographical micro-unity created make it possible to gain stable and economical beach by artificial nourishment or natural trapping of new sand.

In recent years, the increase of pocket beaches has been remarkable. In Mediterranean countries where tidal effects are insignificant, especially in Spain, Italy, France and Israel, this system of beach regeneration has been widely used because of its rapid results and its economical nature. Japan also has a lot of experience in this kind of work.

In Spain, there are over 40 beaches of this kind. They are usually situated on stretches of coastline where there is a lot of tourism and in which there is also a fairly rapid erosional process as a consequence of either causes exogenous to coastal use (dams, wells), or endogenous causes (marinas, coastal works, dredging, etc.).

2.- PREVIOUS RESEARCH

The influence of detached breakwaters on the coast and the formation of tombolos has been studied by several researchers. Sawaragi (1957), using movable-bed model, analyzed the variation induced on the longshore current by this kind of coastal structures. Shinohara and Tsubaki (1966) developed a new physical model for the analysis of the role of detached breakwaters in the formation of tombolos. Toyoshima (1974) carried out a statistical survey of 308 detached breakwaters constructed in Japan, looking for a series of relationsships between the lengths of the works, their distance from the coast and the accumulations caused in the sheltered area.

The planform of tombolos in the lee of breakwaters has been studied by Perlin (1979) through the use of a numerical model. One of the conclusions points to the considerable influence that the parameter L_0 (wave length) has in the shape of the resulting tombolo. Noble (1978) carried out an analysis of the behaviour of diverse coastal protection structures and their effects on the beaches, reaching the conclusion that an off-shore breakwater has virtually no influence on the coast when its distance from the coast is over six times its length. Berenguer (1986) presents graphs which are similar to Toyoshima's; these are drawn up from different artificial beaches on the Spanish Mediterranean Coast.

The study of the planform of the beaches formed behind offshore structures, whether these be natural or artificial has been the subject of considerable Coastal Engineering work. Sauvage (1954) was one of the first authors to analyze the equilibrium of these coastal formations, showing that the shape of the planform was markedly elliptical. Yasso (1965) checked, by analyzing real cases, of adjustment of the planforms of the beaches to logarithmic spirals of equation $r = e^{\theta ctg \alpha}$, where r is the radius from the pole of the spiral, θ is the horizontal angle from the origen and angle α is the constant angle of the radii to the tangents of the curve.

Silvester et al. (1970), (1972), using prototype data, concludes that the beach planforms between headlands consist of three distinct zones:

- an arc behind the headland which is located upstream in the direction of littoral transport.

- a stretch which is logarithmic spiral in shape.

- a straight stretch which extends downstream towards the next headland.

Applying these conclusions, Silvester and Ho (1972) have used the logarithmic spiral for the stabilization of artificial reclamations through the concept of headland control.

Garau (1973), using observations made at various beaches of the Spanish Mediterranean Coast, defines the planforms of the diffraction beaches through their sediment filling and emptying processes. His most important conclusions are that the maximum emptying curve would be a logarithmic spiral whose centre is in the diffraction pole and that the characteristic angle of the family of spirals depends basically on the friction angle of the sand in the trough of water, and which can be generalized for a value of $\alpha = 60^{o}$.

Rea and Komar (1975) developed a numerical model of evolution of spiral beaches behind a rocky headland. Font, Sanabria and Silva (1976) include the effects of the gradient at the height of the breaking wave and the associated current. The longitudinal current is estimated as a consequence of the obliqueness of the incident wave and of the set-up gradient caused by this. Dean (1978) presents a method for calculating the equilibrium shape of pocket beaches. In this method the bathymetry is considered stable when the wave front is tangent everywhere to the local bottom contours. The calculation is carried out for relatively narrow openings with normal and oblique waves. For high wave-periods the planform obtained is markedly semi-circular.

Another of the aspects dealt with in the question of beaches situated in diffraction zones, is the hydrodynamic conditions required in the sheltered area for the systems to be equilibrium in the face of a specific wave condition. This question has caused different authors to try and clarify the processes associated with the propagation of waves in the diffraction zone (currents, set-up, etc.). The works of O'Rourke and Le Blond (1972), and Gourlay (1974) (1976), are to be found in this section. The presence of longshore currents in the sheltered zone when the beach is stable, phenomenon confirmed in tests by Gourlay, contrasts with the assumptions made by other authors with regard to the stability situation on a protected beach.

Walton (1977), after analyzing the planform of spiral beaches, concludes that their position is at all points perpendicular to the energy vector of the incident waves. Rosen and Vajda (1982) deduce that the stability of a tombolo is achieved when the bathymetric lines are such that the diffracted waves have a component of movement quantity opposite to the gradient of average level induced by the radiation stress.

3.- METHODOLOGY

The basis of the present study is the experience achieved in cases where constructions are already present on the Spanish Coast. This is why a detailed study of formal and sedimentological characteristics of 14 "pocket beaches" on the Mediterranean Coast have been carried out. Nine of these beaches are to be found in a limited marine area, which is the Alborân Sea, that reaches the coast of the province of Mâlaga. The other five are in Catalonia: two in the province of Gerona and three in Tarragona. In addition to these beaches, some geometrical parametres of another ten beaches are analyzed, all of these also on the Mediterranean Coast.

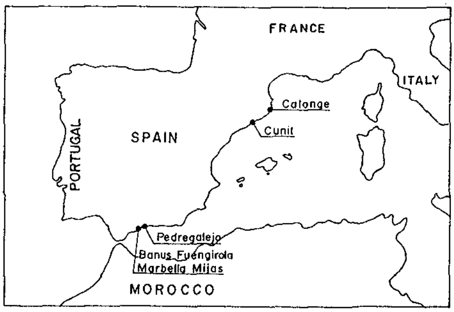

Fig. 1.- Site Location.

4.- DATA COLLECTION

Table 1 shows the main information collected from each of the beaches studied. In 10 of these, the information has been obtained through special field studies whereas in the rest, the data has been got from plans and aerial photography.

The information includes the following aspects:

- Geometrical characteristics: The measurements have been carried out using topographical techniques. The criterion used for the determining of distances between points of contact between water and land has been to adjusted to situations of mean sea level.

- Bathymetry: The survey has been extended to the inside of the cell, the gap and the outer area in front of the gap. The depth of the bottom within each cell has been determined at base, with at least 5 profiles.

- Slope: The slope measurements refer to those carried out at different points throughout the length of the beach face.

- Granulometric distribution: On 12 beaches, sediment samples have been collected on both the subaerial and submerged parts of the beach. These samples have been dried, weighed and sifted by the ASTM series.

The parameters used for defining the characteristics of pocket beaches are sef out in fig. 2.

5.- WAVE CLIMATE

Tidal and wave conditions on the Spanish Mediterranean Coast are fairly uniform. The maximum range of astronomical tides varies between 0.30 m. (Catalonia) and 0.85 m. (Málaga). Wave energy in the whole area is moderate. The significant wave height of the one year return period storm, is in Málaga about 3.0 metres, and slightly higher in Catalonia. For calculation purposes, the characteristic value of the parameter "wave length", L, has been estimated from data obtained by wave buoys located in these two areas. The average of the zero-crossing significant period, $T_{z,s}$, of all the wave records in which $H_s \geqslant 1.0$ m. during a complete year, has been calculated:

Catalonia: $H_s \geqslant 1.0$ m. (percentage of exceedence: 8'9%)
$T_{z,s} = 8.62$ sec.

Málaga: $H_s \geqslant 1.0$ m. (percentage of exceedence: 3'8%)
$T_{z,s} = 7.37$ sec.

6.- RESULTS AND DISCUSSIONS

6.1.- Beach planform

From the analysis of the principle geometrical parameters, it is found that the planform of pocket beaches follows a pattern which is very similar in all the cases examined. In fig. 3, values of A_o and A_1 have been drawn for each beach. It can be observed how the points obtained generally adjust to the following straight line:

$$A_o = 2\ A_1 \qquad (1)$$

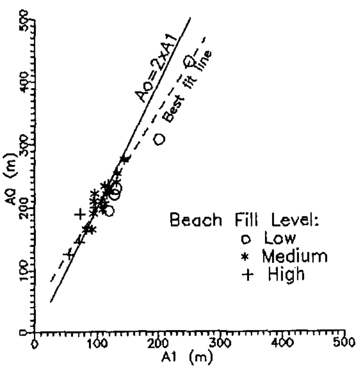

Figure 3.- Relation between Ao and A1

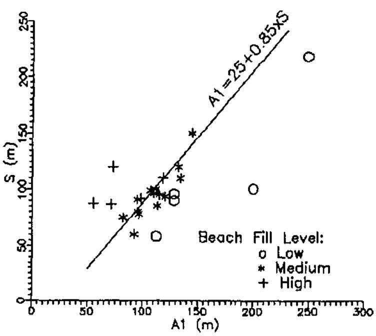

Figure 4.- Relation between A1 and S

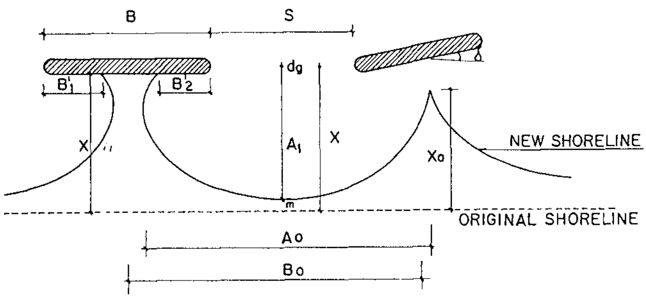

Figure 2.- Definition of pocket beach parameters.

Beach	X(m)	S(m)	A1(m)	Ao(m)	Dg(m)	Bo(m)	Dm(mm)
BANUS 1	150	90	128	230	3.40	247	0.29
BANUS 2	150	94	120	224	-	250	-
BANUS 3	156	95	115	220	4.10	222	0.84
BANUS 4	144	91	95	210	-	190	-
DON PEPE	108	78	96	222	-	192	-
MARBELLA-1	130	110	134	254	-	260	-
MARBELLA-2	-	99	107	210	2.70	-	0.25
MARBELLA-3	-	75	82	165	2.80	-	0.25
MARBELLA-4	160	150	144	276	-	-	-
MARBELLA-5	-	88	55	125	1.50	-	0.25
MARBELLA-6	-	87	71	145	2.50	-	0.25
MARBELLA-7	-	120	73	190	-	-	-
FUENGIROLA	120	60	92	165	2.10	210	0.31
MIJAS	108	120	132	240	-	-	-
PEDREGALEJO-1	110	80	95	190	3.50	220	1.86
PEDREGALEJO-2	122	92	98	200	3.70	225	1.12
PEDREGALEJO-3	124	110	118	235	3.50	268	1.86
PEDREGALEJO-4	148	58	112	195	3.50	202	1.86
CUNIT 1	120	96	110	196	-	230	-
CUNIT 2	150	96	128	220	2.70	249	0.15
CUNIT 3	210	101	200	308	3.50	313	0.14
CUNIT 4	270	218	248	430	3.55	520	0.13
CALONGE-1	125	85	113	205	5.70	247	1.89
CALONGE-2	128	100	112	234	6.40	255	1.42

Table 1.- Summary of Basic Data.

The points that correspond to beaches with a high or low fill level move away from this general tendency. It should be observed in fig. 3 that the best fit line does not correspond exactly to the relationship mentioned. However, with a view to facilitating engineering design and to take into consideration the beach fill level, this relationship has been taken as the line of approximate adjustment.

In addition, an analysis of the planform has been carried out using a computer program that brings about the optimum adjustment of a logarithmic spiral to a given shoreline, in accordance with Yasso's method. Previous studies that have taken place at the CEPYC (J.M.Berenguer (1981), J.Almenar (1983), J.Enríquez (1984)) showed how, considering the two halves of the cell separately, the planform of these stretches adjusted reasonably well to the logarithmic spirals with a pole at the head of the detached breakwaters, that in each case caused diffraction, and characteristic angles (α) of around 60° - 65°. Taking the pocket beach as a whole, the optimum adjustment is obtained using the logarithmic spiral, whose characteristic angle (α) is situated between 80° and 90°, the pole of the curve being close to the average point of the gap. With a view to design, a theoretical central circumference at the centre point of the gap adjusts very closely to the aforementioned beach line. When there is a low-fill level the beach line will lag behind with respect to the circumference mentioned, and when this level of filling is high, the shore line will stand out with respect to this theoretical curve.

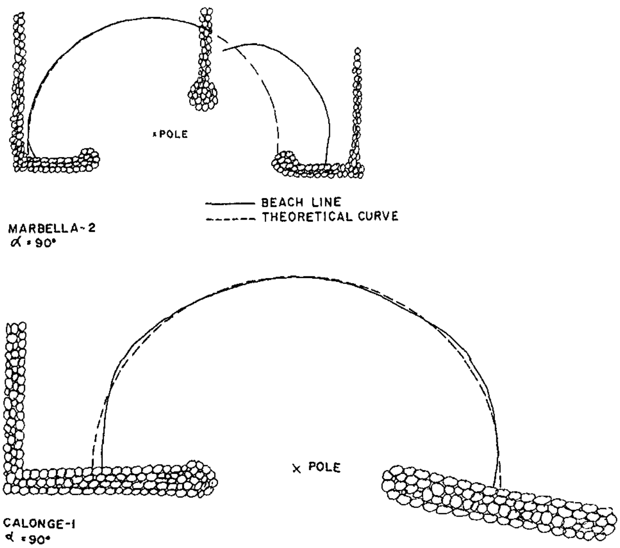

Figure 5.- Examples of adjust of beach planform.

The determining of the radius of the theoretical circumference that defines the shoreline of the cell in each case, can be found by using fig. 4. This figure represents the relationship between the opening of the gap (S) and the distance from the shore (A_1). A good adjustment of these points is obtained with line of equation.

$$A_1 = 25 + 0.85xS \qquad (2)$$

The points corresponding to cells with a high or low level of filling deviate considerably from this straight line.

Another interesting result obtained in the analysis is the one shown in fig. 6. The product (XB_o) represents the surface area of water in the lee of the new works, while$A_1{}^2$ is proportional to the surface of water that will remain after the filling of the cell with sand, given that this surface area is assumed to be a semicircle with an area ($\pi A_1{}^2/2$). The relationship obtained is that expressed by the equation

$$XB_o = 2.5A_1{}^2 \qquad (3)$$

Using this relationship as a basis, the maximum surface area (S_p) of beach that could be stable can be obtained

$$S_p = XB_o - (\pi A_1{}^2/2) \qquad (4)$$

Thus: $$S_p = 0.37\ X.B_o \qquad (5)$$

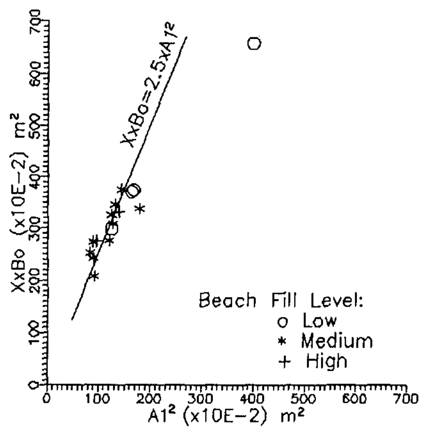

Figure 6.- Relation between $A1^2$ and XxBo

6.2.- Beach profiles.

The general bottom configuration of a pocket beach presents a characteristic that makes it different from the typical pattern of an open beach. The groynes or breakwaters that make up the pocket beach, act as wave filters to a greater or lesser extent. At any point on the beach, the range of variation of the wave height is considerably reduced and as a consequence, so is its wave steepness. The direction of the wave as it propagates towards the shallower zones of the beach becomes more independent with respect to the deep-water direction, when the breakwater gap is narrower. Restrictions of both energy and direction, cause marked differences to the profiles of the submerged beach as regards its position along the shoreline, but with great annual stability.

In most of the theoretical studies carried out up to the present on pocket beaches, the simplification of assuming a symmetry of actions and responses along a central axis, has been adopted.

This hypothesis is only borne out in two cases:

a) When the directional distribution of the wave energy is more or less constant in time and has an incidence near to the normal direction of the gap.

b) When the relationship between the width of the gap (S) and length of wave (L) is small enough, in such a way that the action of the filter caused by the breakwaters through diffraction is considerable.

In all other cases, the assymetry shows itself clearly in the form of the profiles of the different zones of the beach, and also, but in a less clear way, in the planform of the shoreline.

The homologous profiles have been compared by grouping homogeneous beaches together according to their climatic and sedimentary characteristics. The most significant conclusions obtained in this analysis are summarized in the following line (see fig. 7).

- Within one single beach the diverse profiles take on characteristic forms in accordance with their position.

- In the areas exposed to greater wave energy, (profile num. 3, central), the profiles take on a parabolic shape similar to that of an open beach without bar.

- The end profiles (num. 1 and num. 5) of the cells present two clearly differentiated zones. The upper part of the profile where the residual energy of the wave after diffraction, is capable of moving the sediment by drag and suspension, and the lower part with a gentle slope, where the wave acts dragging the material along the bottom. A marked step is produced as a transition of the two, and its slope depends on the angle of internal friction of the sediment and its height from the depth of the gap. The lower limit of the highest zone is a function of the height of the residual wave of the most severe storms that reach the cell every year.

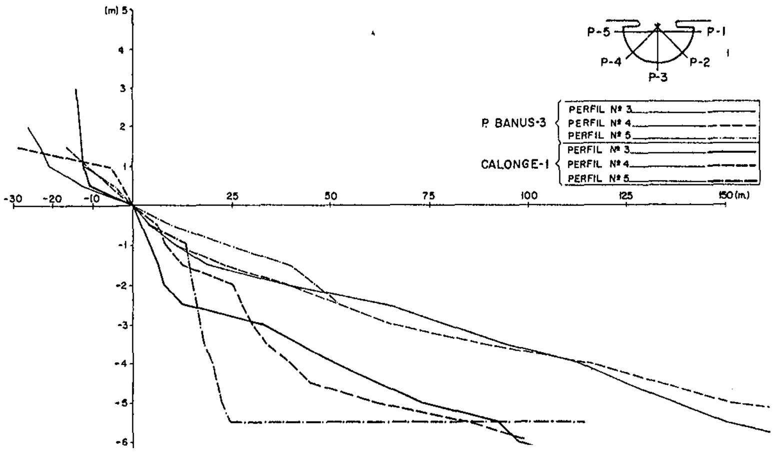

Figure 7. Beach profiles from two selected pocket beaches

Within one cell the transition between the central profile and the ends (profiles num. 2 and num. 4) takes place gradually and in accordance with the spatial variation of the resulting energy from the process of double diffraction. The progressive reduction of wave height as the sheltering increases, implies a change in the steepness of the wave, and with this a different response on the beach profile.

6.3.- Sediment-size distribution

This analysis has been carried out on 12 beaches from which over 25 samples were taken from each.

With a view to design, it is considered essential to carry out a survey of two relationships: the distribution of the average grain-size according to depth and the relationship between the average grain-size and the slope of the bottom.

In fig. 8 the relationship between the relative diameter (D_i/D_m) and the relative depth (d_i/d_g) of the samples corresponding to profiles num. 2, 3 and 4 of three beaches is represented. D_i is the mean size of each sample, D_m is the average of the mean sizeof all the samples in the cell, d_i is the depth where the sample is collected and d_g is the depth at the centre of the gap.

As can be observed, in beaches with fine and medium sand, (Cunit-4 and Banús-1) the dispersion of the relative diametre becomes progressively smaller with the relative depth. In beaches with coarse sand, (Calonge-2) a considerable discontinuity is caused, together with a greater dispersion in the samples situated near the shore.

As regards the relationship between the slope of the bottom at a point (m) and the size of the sediment (D_5) at this very point, fig. 9 shows a general increase of (D_{50}) as (m) increases. All the samples taken on the 12 beaches have been included in this figure. The high dispersion in the results does not make it possible to draw exact conclusions from this analysis. It is possible that the reduced wave energy that reaches the inside of the cells contributes to the irregular size distribution observed in the sediment that makes up this kind of beach.

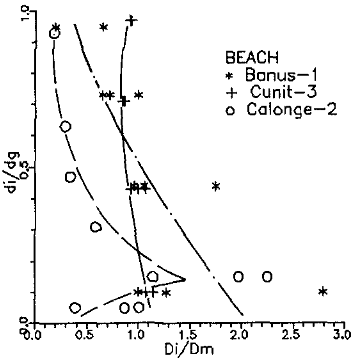

Figure 8.- Relation between Di/Dm and di/dg

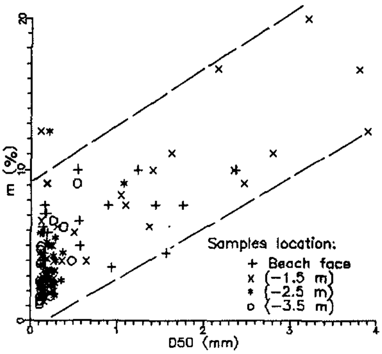

Figure 9.- Relation between D50 and m

6.4.- Other factors

In addition to the relationship between the various pocket beach parametres previously studied, others have been sought that help to define relationships between them that are useful in designing. In particular, an attempt has been made to relate the surface of the gap (Sd_g) and the dimensions of the resulting beach ($A_1{}^2D_m$). As a consequence of the relationship that exists between the mean size of the sediment (D_m) and the general slope of the submerged beach, this parameter can be adopted as a measure of the volume of water contained in the cell.

The results are presented in fig. 10, in which it can be seen just as expected that the greater the gap surface, the larger the cell. For values of (Sd_g) situated at the interval $1.5\ 10^2 < Sd_g < 5.10^2$ the fitting to a straight line such as that shown is reasonably good, this being a very useful tool for the evaluation of the balance between the different parameters, both geometrical and granulometrical, that define a pocket beach. Below a value of $1.5\ 10^2$, it is logical that the adjustment line undergoes inflection and shows a tendency towards the origin of coordinates as the size of the cell becomes smaller. For the adjustment of the upper zone of the graph it will be necessary to rely on additional data in the future, that will make it possible to increase it for values of (Sd_g) above 5.10^2.

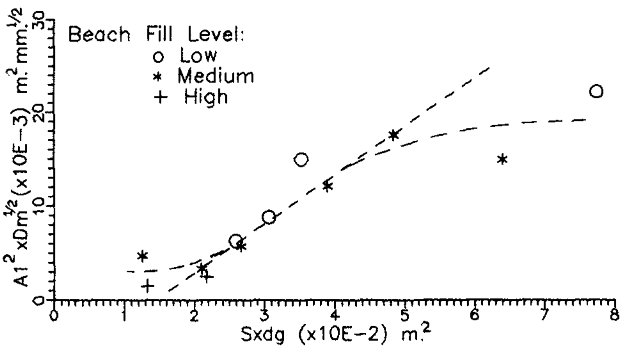

Figure 10.- Relation between Sxdg and $A1^2 xDm^{1/2}$

7.- CONCLUSIONS

A rigurous analysis of a high percentage of pocket beaches on the Spanish Mediterranean Coast has been carried out. A total of 24 of these beaches have been studied from geometry, bathimetry, and granulometric characteristics of sediment perspectives.

The limited amount of wave energy that reaches the inside of the cell, causes specific areas of the beach to show profiles that are hardly shaped by the waves, with slopes close to the natural slope of the sediment. This phenomenon is clearly visible at the end profiles of virtually all the cells that have been studied, where swift changes in the profile occur as a result of the lack of there being sufficient energy to form normal beach profiles.

Another consequence of the low and irregular exposure to the wave energy that occurs on these beaches is the great irregularity observed in the granulometric distribution of the sediments that it is made up of.

It has been demonstrated that the planform of the shoreline can be predicted with sufficient accuracy, by means of different kinds of theoretical curves. In beaches where the variables S,A_1 an L are within the range of those analyzed (1 S/L 5 and 1.5 A_1/L 5, being L the wave length at the gap) it has been possible to get a good adjustment using arcs of circumference whose centre is in the middle of the gap of the cell. The radius of the theoretical circunference that defines the shoreline can be estimated by the equation that relates the parameter (S) (to be defined in the design) with (A_1).

Knowing the characteristics of the sand that is going to form the new beach, fig. 10 provides a quick method of assuring that the diverse design parameters established adjust to a balanced relationship between them.

It should be observed that given the similarity of characteristics (wave climate, dimensions, sand size, etc), of most of the beaches analyzed in this survey, the range of validity of application of the partial conclusions is, to a certain extent, limited. Its application to other markedly different types must take place with caution and by engineering experience.

REFERENCES

- Berenguer, J.M., (1986) "Caracteristicas de los diques exentos en España", Curso de Ingeniería de Costas, CEPYC.

- Dean, R.G., (1978) "Diffraction Calculation of Shoreline Planforms", Proc 15th Conf.Coastal Eng. 2, 1903-1917.

- Font, J.B.,P. Sanabria and A.Silva, (1974) "Geometria des Playas Protegidas en Equilibrio", Proc., VI Congreso Latino Americano de Hidráulica, p. C3-1 to C3-12, July.

- Garau Sacrista, C (1973), "El rozamiento y la estabilidad de las playas", Revista de Obras Públicas Num. 3099 y 3100, Julio, Agosto.

- Gourlay, M.R. (1974), "Wave Set-up and Wave Generated Currents in the Lee of a Breakwater or Headland". Proc. 14th Conf. on Coastal Eng.

- Gourlay, M.R. (1976), "Non Uniform Alongshore Currents" 15th Conference on Coastal Engineering. ch. 40, pp. 701-720.

- Noble, R.M. (1978), "Coastal Structures' Effects on Shorelines" Proc. 16 Conf. on Coastal Eng. Vol. III, ch. 125, pp. 2069-2085.

- O'Rourke, J.G. and P.H. LeBlond, (1972) "Longshore Currents in a Semi-Circular Bay", J.Geophy. Res. Vol. 77, p. 444-452.

- Perlin, M., (1979), "Predicting Beach Planforms in the Lee of Breakwater" Symp. on Coastal Structures 79, ASCE, vol. 2, pp. 792-808.

- Rea, C.C. and Kohar, P.D., (1975) "Computer Simulation Models of a Hooked Beach Shoreline Configuration" Jour. Sed. Petrology vol. 45, nº 4, p. 866-872.

- Rosen D.S. and Vajda. M., (1982) "Sedimentological Influences of Detached Breakwaters". Proc. Conference on Coastal Engineering. ASCE.

- Sauvage de St. Marc M.G., and Vincent, M.G., (1954), "Transport littoral, formation de fleches et de tombolo", Proc. of 5th Conf. on Coastal Eng.

- Sawaragi, T., (1957), "Effects of Shore Structures on Coastal Sand Drift (Report Nº. 1), "4th Conf. on Coastal Engineering in Japan.

- Shinohara, K. and Tsubaki, T., (1966), "Model Study on the Cange of Shoreline of Sandy Beach by the Offshore Breakwater", Proc. 10th Conf. on Coastal Engineering, pp. 550-563.

- Silvester, R., (1970), "Growth of Crenulate-Shaped Bays to Equilibrium", Journal of the Waterway and Harbours Division, May 1970, WW2, pp. 275-287.

- Silvester, R. and HO, S.K., (1972), "Use of Crenulate Shaped Bays to Stabilize Coasts", Proc. 13th Conf. on Coastal Eng., Vol w, pp. 1347-1366.

- Toyoshima. O. (1974), "Design of a Detached Breakwater System". Proc. Conference on Coastal Engineering. ASCE.

- Toyoshima. O. (1976), "Changes of Sea Bed Due to Detached Breakwaters". Proc. Conference on Coastal Engineering. ASCE.

- Toyoshima. O., (1982), "Variation of Foreshore Due to Detached Breakwaters". Proc. Conference on Coastal Engineering. ASCE.

- Walton, T.L. (1977), "Equilibrium Shores and Coastal Design", Proc., ASCE Speciality Conference on Coastal Structures, p. 1-16, Nov.

- Yasso, W.E. (1965), "Plan Geometry of headland bay beaches" Jour. Geology: v. 73, p. 702-714