

CHAPTER 145

LONGSHORE SEDIMENT TRANSPORT RATE vs. CROSS - SHORE

DISTRIBUTION OF SEDIMENT GRAIN SIZES

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ABSTRACT

Existing models for longshore sediment transport rate computations assume the sediment grain size and grain size-related parameters to be uniform in both the cross-shore and longshore directions. Field results from tideless beaches, which are briefly described in the paper, show that the latter change in both directions due to changing wave energy-levels. The sensitivity analysis described in the paper shows that both longshore current and transport rate computations are sensitive to the cross-shore changes in grain size. Finally, a modified linearity coefficient for the wave power equation is proposed based upon the cross-shore distributions of grain size as found in nature.

1. INTRODUCTION

It is now widely believed that sediment grain size is an important parameter in wave-induced sediment transport processes in the surf zone. As a result, attempts are increasingly being made to incorporate the grain size in models of longshore sediment transport rate computations. Some examples are as follows. Dean et al.(1983) plotted results from various previous studies and found that the linearity coefficient K of the empirical wave power equation increases with decreasing sediment size D . Theoretical predictions by Deigaard et al.(1986) indicate a similar decrease in K with increasing D . Detailed predictor models, such as the Bijker (1971) formula, have already incorporated the grain size and a number of other grain-related parameters.

In all existing models, however, grain size and grain size-related parameters are assumed to be uniform in both the cross- and longshore directions in the surf zone. Recent results from field measurements on tideless beaches along the Greek coast conducted by the team of the Civil Engineering Department, National Technical University of Athens, show clearly that grain size and grain size-related parameters

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change in both directions, due to changing wave energy-levels. Changes are more predominant in the cross-shore direction. Maximum grain size is observed in zones of maximum energy, such as the breaker zone and zones of wave convergence. Changes are in most cases so drastic that selecting the values to be introduced into the models is a difficult task.

It therefore becomes clear that grain size and grain size-related parameters can no longer be considered to be uniform across the surf zone. Realistic models should not only introduce the influence of grain size but also the cross-shore changes.

In the present paper, a synopsis of the above-mentioned field results is presented and a sensitivity analysis of longshore sediment transport computations on the cross-shore changes of grain size is made. Finally, a modified linearity coefficient for the wave power equation is proposed, which is based on the cross-shore distribution of grain sizes, as found in nature.

2. CROSS-SHORE DISTRIBUTION OF GRAIN-RELATED PARAMETERS

Field measurements have been/are being made along various Greek beaches: Kokkino Limanaki, Marathonas, Linoperamata, Platanias, Plakias and Rio. Each beach has its own specific characteristics: Kokkino Limanaki is a small-scale pocket beach with a strongly arcuate coastline 310m long. It is exposed to medium wave energy from two dominant directions. Marathonas has a straight coastline and is exposed to medium wave energy from one direction only. Linoperamata is also a straight beach but receives high wave energy. Longshore transport occurs to the left and to the right. Platanias has a slightly arcuate coastline with medium to high wave energy. The equilibrium of the latter beach was recently disturbed by the construction of a small fishing harbour, which caused local erosion and accretion. Plakias is a large-scale pocket beach exposed to high wave energy. Finally, Rio is a shingle beach along a protruding headland which receives medium wave energy from both directions. Characteristics which are common include microtidal environments (maximum range: 25 to 30 cm) and locally generated sea states. Therefore, sediment distributions on the sea bed are almost exclusively wave-induced, which is considered to be highly advantageous.

Cross-shore distributions of grain size and grain size-related parameters are obtained from spot sediment samples collected with hand-operated grab samplers. Samples are limited to the upper 5cm of bed material so as to collect the sediment deposited during only the previous sea state. Samples are analysed in the laboratory. Grain sizes are computed by sieving according to the ASTM standards.

In the following paragraphs, a synoptical overview of the main results is presented. They concern wave-induced cross-shore distributions of grain size-related parameters, which reflect the hydrodynamic conditions prevailing across-shore.

A typical grain size distribution is shown in Fig.1, as found on the Marathonas beach. Noticeable differences in the

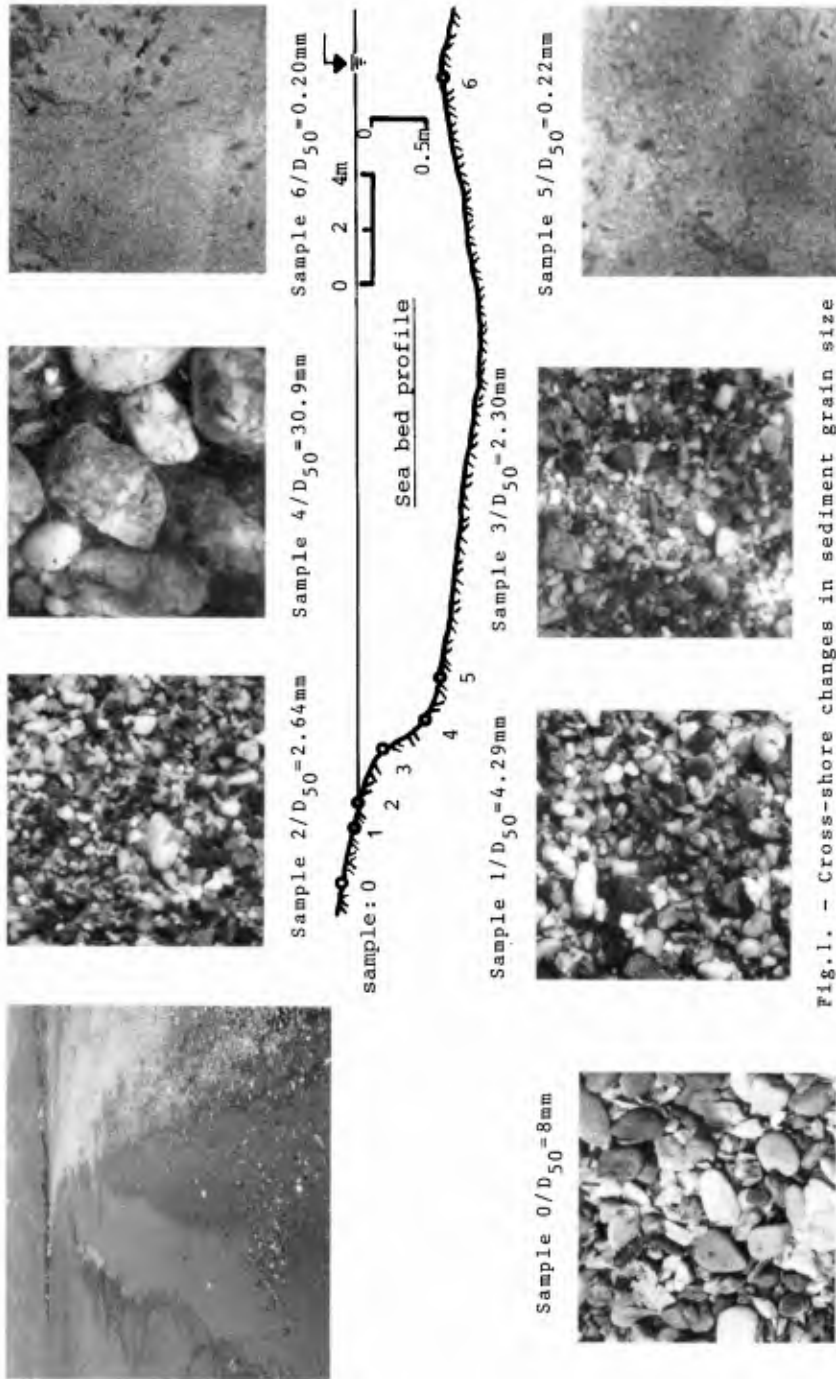


Fig.1. - Cross-shore changes in sediment grain size (Marathonas beach)

cross-shore sediment size distribution are observed throughout the beaches and under all wave conditions. A regular sediment sorting is detected in the cross-shore direction due to differing hydrodynamic loading. Grains are found to be coarser and worse sorted in zones of increased wave energy than in zones with lower energy levels, where grains are finer and better sorted.

Fig.2 shows a number of cross-shore distributions of statistical mean diameters for various types of beaches. D_{50} is the sediment grain diameter exceeded in size by 50% by weight in the sample population. M_z is the graphic mean diameter, as defined by Folk and Ward, 1957. The plunge step, where wave breaking occurs, is always found to be composed of the coarsest and worst sorted material, due to the increased action of breaking waves (Moutzouris and Kypraios, 1987). Grains are coarser and worse sorted at the toe of the step than at the crest. Therefore, the toe of the plunge step and the zone immediately seawards are composed of the coarsest material across the beach. From the plunge step shorewards, a regular decrease in grain size is observed. Sediment on the beach face is normally found to decrease in size and improve in sorting. Exceptions to this rule are due to the occasional presence of beach cusps, the terrigenous supply of coarser material, and the berm formation. In these cases, coarser material is found than normally. The offshore zone is covered with fine and rather well sorted material due to the decreased wave action.

Our field data indicate that all statistical diameters D_n (sediment grain diameter exceeded in size by 1-n% by weight) have a qualitatively similar distribution in the cross-shore direction as D_{50} (see Fig.3).

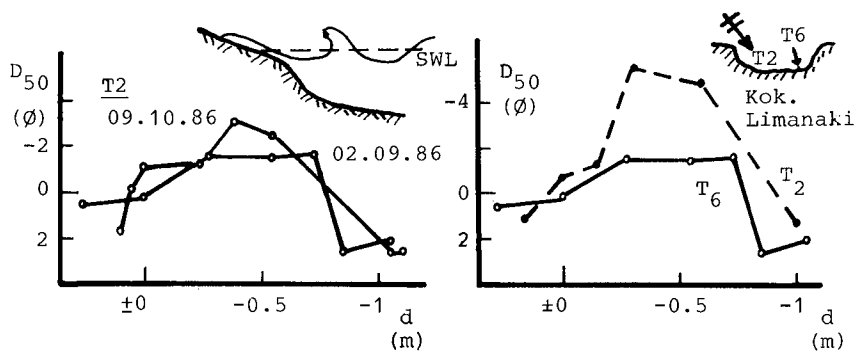
The settling velocity w of grains in water depends mainly upon the physical characteristics of the particles (such as the diameter, density, shape and roundness). Water temperature has a minor influence in beaches. As density is more or less constant across a beach, the most characteristic is grain size. It is, therefore, no wonder that the settling velocity of grains with median diameter D_{50} shows a qualitatively similar distribution across-shore as D_{50} (see Fig.3).

The porosity p is found to depend mainly upon the mode of flow. In the breaker zone, wave impacts on the bed cause compaction of the sediment and porosity decreases. At the beach face, water flow is mostly parallel to the sediment layer and porosity decreases. As a result, porosity is found to change across-shore. The maximum values observed were of the order of 0.40, which is the most common value of p in models (see Fig.3).

The distribution of the mean density ρ_s of the bed material across-shore is almost uniform (see Fig.3), which means that grain size and mean density do not appear to be inversely proportional to one another. Therefore, ρ_s is not influenced by the wave-energy changes across-shore.

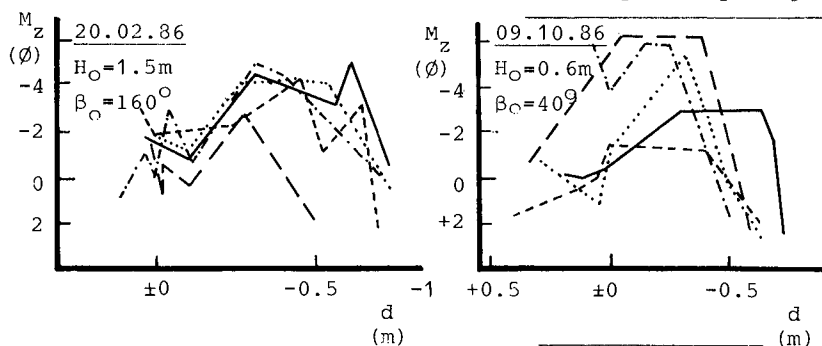
3. SENSITIVITY OF LONGSHORE TRANSPORT RATES ON CROSS-SHORE CHANGES OF GRAIN-RELATED PARAMETERS

In the third part of the paper, the sensitivity of two



d : water depth

D_{50} : grain diameter
exceeded in size
by 50% by weight



M_z : grain graphic
mean diameter

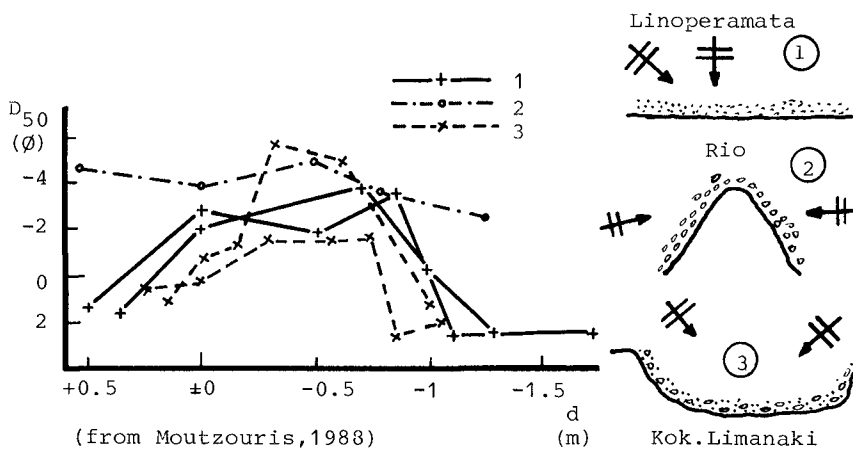


Fig.2.- Cross-shore distribution of characteristic statistical mean grain diameters

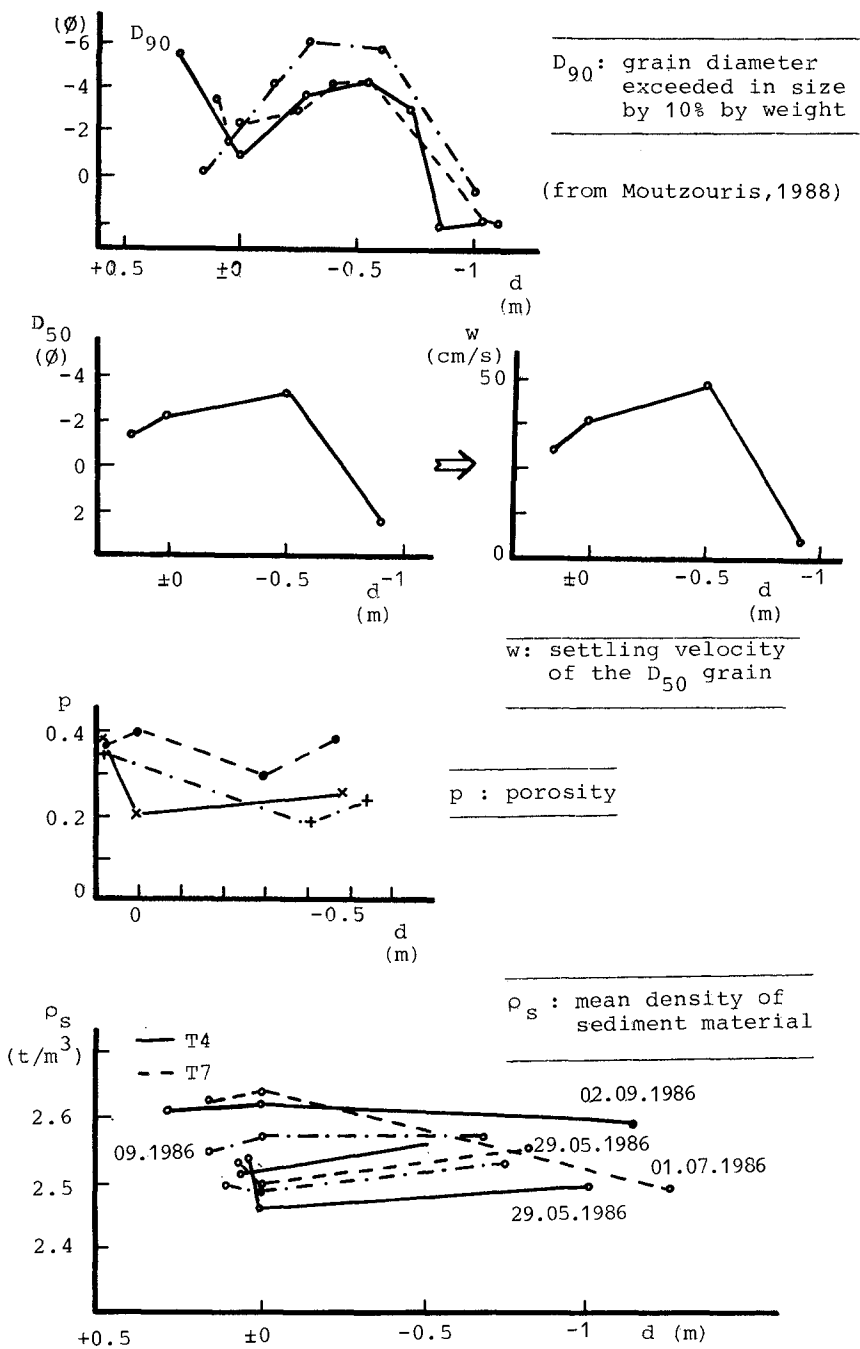


Fig.3.-Cross-shore distribution of various grain size-related parameters (Kok.Limanaki beach)

commonly used longshore sediment transport predictors on the cross-shore distribution of grain size and grain-related parameters is analysed. The predictors examined are the wave power equation and the Bijker formula.

The empirical wave power equation for the total longshore sediment transport rate S_t gives the spatially integrated immersed weight rate as a linear function of the total wave power available for transporting sediments. The best known and most widely used value of the non-dimensional linearity coefficient K is reported by Komar and Inman (1970) and is independent of the sediment characteristics. Their value was derived for sand size within the range of 0.18 and 0.6mm.

It has been increasingly argued recently that K could not be a constant but should depend upon some other parameters and most probably upon the sediment size. Dean et al (1983) plotted the values of K from various studies (Watts, Galdwell, Bruno and Gable, Komar and Inman, Johnson and Galvin, Moore and Cole, and Dean et al.) and found that K increases with decreasing sediment size D . Theoretical predictions by Deigaard et al. (1986) also indicate a decrease of K with increasing D . Komar (1988) does not seem to agree with such a dependency.

Fig.4 shows the cross-shore distribution of D_{50} , as found on one of our tideless beaches and the corresponding values of K , as computed from Dean et al (1983). x denotes the distance offshore, measured from the still water line. It can be seen that the longshore rate decreases by a factor of almost 3 if the largest diameter (0.75mm) is taken into account instead of the smallest one (0.37mm). The smallest diameter on the beach (0.37mm) gives almost 3 times higher transport rates than the largest diameter (0.75mm). It is therefore concluded that longshore transport rates computed with the wave power equation are very sensitive to the cross-shore changes in sediment grain size, if the linearity coefficient K is taken to be grain size-dependent. The Komar and Inman (1970) model would give a constant transport rate independent of the grain size distribution across-shore.

The Bijker formula computes the total longshore sediment rate as the sum of the bed and the suspended loads. Numerous grain size-related parameters are introduced in the formula.

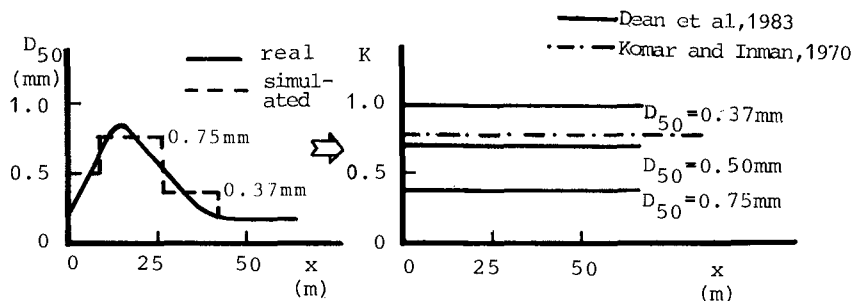


Fig.4. - Cross-shore distribution of the linearity coefficient

Among others are the D_{50} and D_{90} diameters, the Chezy roughness and wave friction coefficients (or factors), the grain settling velocity, the longshore current velocity, etc.

The sensitivity of the Bijker formula on the cross-shore distribution of grain size-related parameters is shown in Fig. 5, where S_t is the volumetric transport rate. These rates were computed with (a) a uniform grain size across the surf zone, as is common practice in transport rate computations, and (b) changing distributions, as found in the beaches of our field measurements. The results show that the Bijker formula is very sensitive to the cross-shore changes in size-related parameters. Of major influence upon the results is the sensitivity of the longshore current model introduced in the Bijker formula on the cross-shore changes in the grain size-related parameters. Fig. 6 shows the longshore current velocity according to the Longuet-Higgins (1970) and Komar (1975) models, as computed with grain size distributions observed in the field.

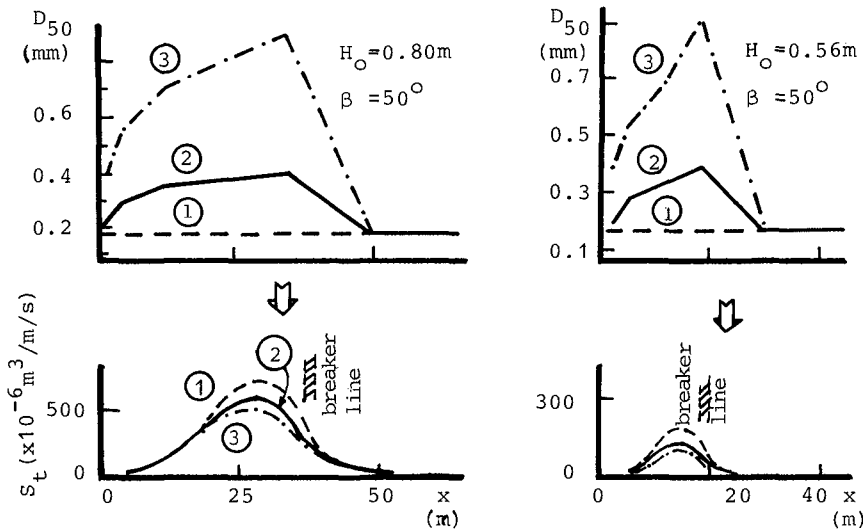


Fig. 5. - Sensitivity of the Bijker formula on the cross-shore changes in grain size-related parameters

It is finally concluded that neglecting the sediment size on a beach might be a first source of considerable errors in longshore transport rate computations. Assuming the grain size-related parameters to be uniform across-shore is a second source of equally important errors. The Bijker formula can take into account the cross-shore changes. The linearity coefficient of the wave power equation needs to be modified if the cross-shore changes are to be incorporated.

4. MODIFIED LINEARITY COEFFICIENT

In this part of the paper, a modified linearity coefficient K_m is proposed for use in the computations with the wave power equation. The modification seems necessary in view of

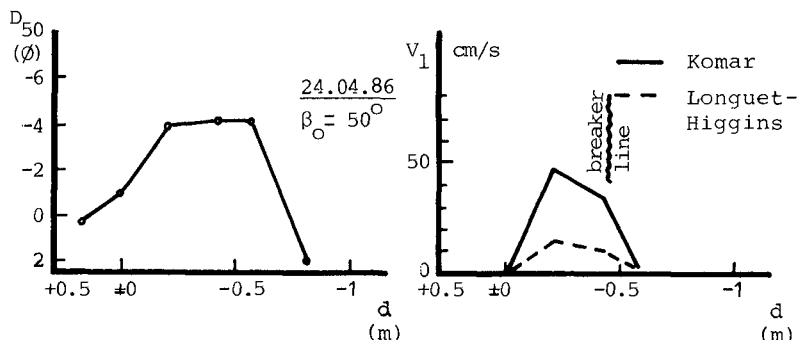


Fig.6.- Sensitivity of longshore current on the cross-shore changes in grain size

the results presented above.

The active zone of a beach is divided into a number of n successive sub-zones, with almost uniform grain size in each one. K_m is defined as the sum of the ponderated coefficients K , as proposed by Dean et al. (1983). In the general case of n sub-zones, the resulting $K_{m,n}$ is defined as:

$$K_{m,n} = \sum_{i=1}^n C_{n,i} K_{n,i}$$

with: $\sum_{i=1}^n C_{n,i} = 1$ and $C_{n,i} = \frac{l_{n,i}}{l_a}$

$l_{n,i}$ is the width of sub-zone i and l_a is the length of the active zone (see Fig.7).

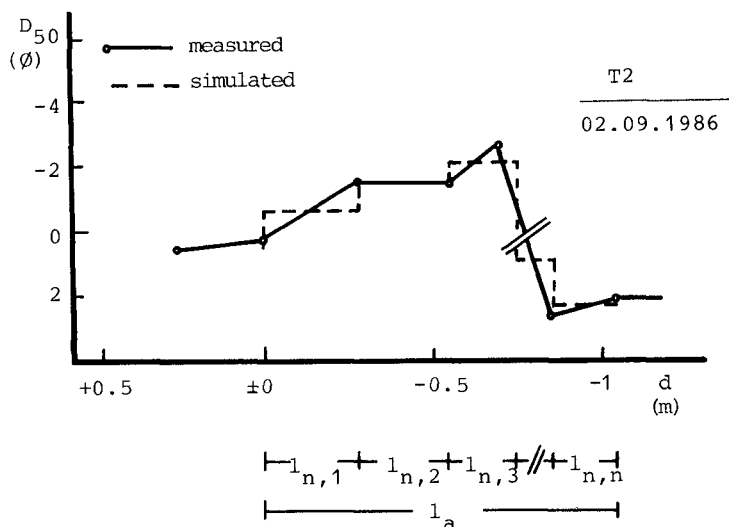


Fig.7.- Definition sketch

The coefficients $C_{n,i}$ can only be determined from field measurements. In the following paragraphs, data from our field measurements are presented for the cases of $n=3$ and $n=2$. In the case of $n=1$, the unique sub-zone has a width $l_{1,1}$ ($=l_a$) and $K_{m,1}$ coincides with the classical linearity coefficient, as defined by Komar and Inman and proposed by Dean et al. (1983).

In the case of $n=3$, the active zone is divided into the pre-breaker, breaker and after-breaker zones (see Fig.8) and $K_{m,3}$ is defined as:

$$K_{m,3} = C_{3,1} K_{3,1} + C_{3,2} K_{3,2} + C_{3,3} K_{3,3}$$

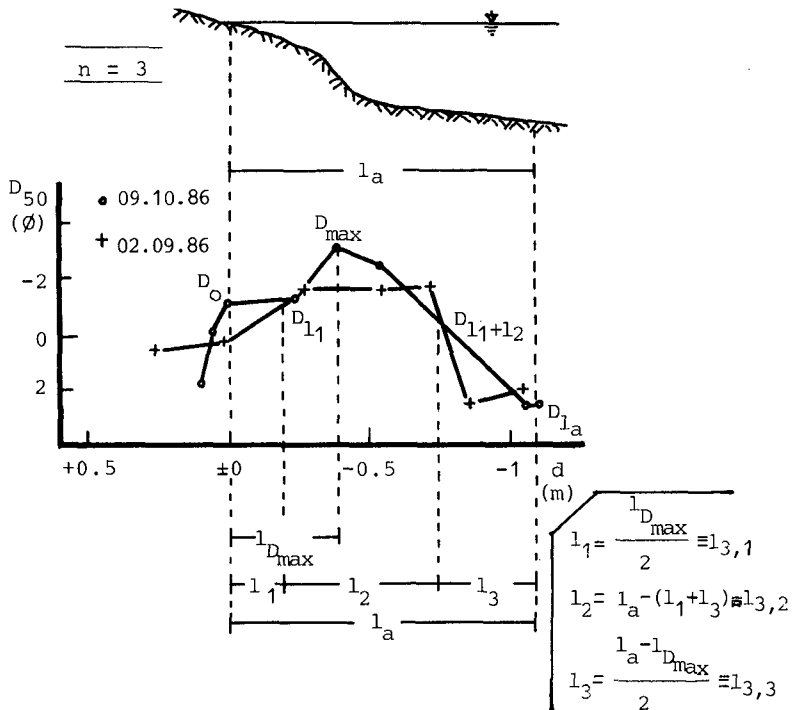


Fig.8.- Sub-zones for $n=3$

Data from our field measurements on the Kokkino Limanaki beach concerning coefficients $C_{3,1}$, $C_{3,2}$ and $C_{3,3}$ are plotted in Fig.9. It is found that:

$$C_{3,1} = 0.07 \quad \text{to} \quad 0.47 \quad \text{with} \quad \bar{C}_{3,1} = 0.21$$

$$C_{3,2} = 0.50 \quad (\text{by definition})$$

$$C_{3,3} = 0.16 \quad \text{to} \quad 0.38 \quad \text{with} \quad \bar{C}_{3,3} = 0.28$$

The following modified linearity coefficient could be proposed for the cases presented in Fig.9:

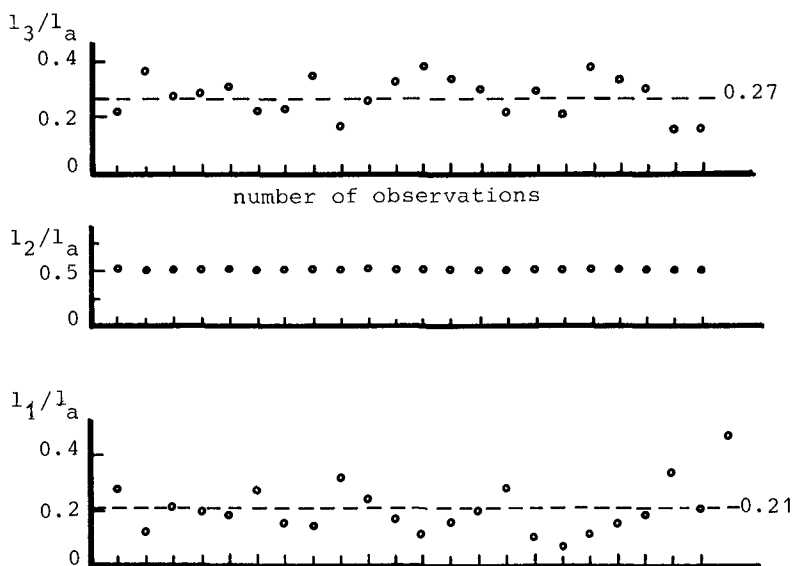


Fig.9. - Lengths of the sub-zones (n=3)
(Kokkino Limanaki beach)

$$K_{m,3} = 0.2K_{3,1} + 0.5K_{3,2} + 0.3K_{3,3}$$

$K_{3,1}$, $K_{3,2}$ and $K_{3,3}$ are linearity coefficients in sub-zones with almost uniform grain size. By adopting the results of Dean et al (1983), $K_{3,1}$, $K_{3,2}$ and $K_{3,3}$ are obtained as functions of the uniform grain size.

An estimation of $K_{m,3}$ is now made for the same beach considered above. The field measurements show the following range of values (see Fig.10):

$$\frac{D_{3,1}}{D_{3,2}} = 0.11 \quad \text{to} \quad 0.33 \quad \text{with} \quad \overline{\left(\frac{D_{3,1}}{D_{3,2}}\right)} = 0.23$$

$$\frac{D_{3,3}}{D_{3,2}} = 0.04 \quad \text{to} \quad 0.20 \quad \text{with} \quad \overline{\left(\frac{D_{3,3}}{D_{3,2}}\right)} = 0.10$$

It is repeated that these values reflect conditions, which prevailed along the beach during the period of field measurements. Therefore, it is necessary to examine the sensitivity of $K_{m,3}$ on the changes in $D_{3,1}$. Fig.11 shows the changes in $K_{m,3}$. It is found that $K_{m,3}$ decreases with increasing grain diameters and/or cross-shore size sorting. The value proposed by Komar and Inman, 1970, for the linearity coefficient is found to be rather higher than $K_{m,3}$. The values proposed by Dean et al, 1983, coincide with $K_{m,3}$ in the special case of $D_{3,1} = D_{3,2} = D_{3,3}$.

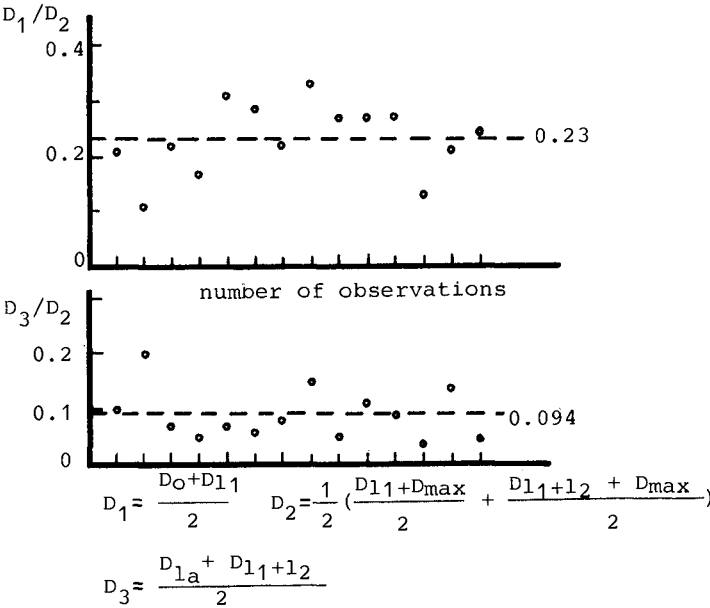


Fig.10. - Grain diameters in the sub-zones (n=3)

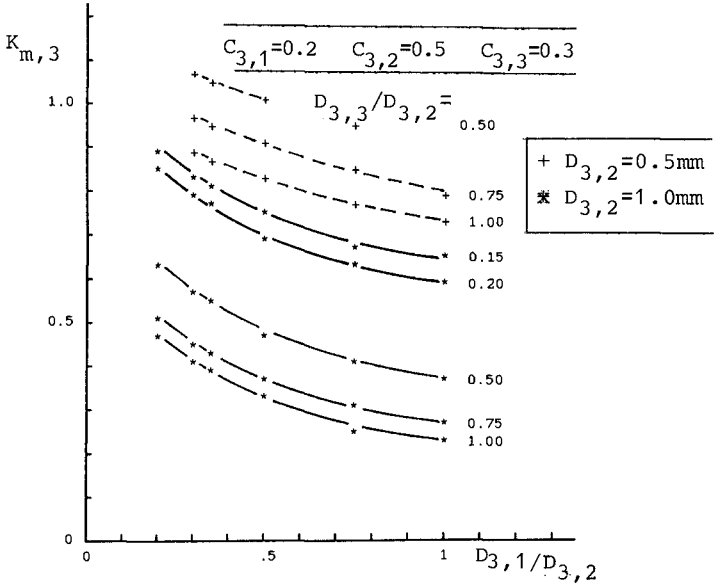


Fig.11. - Modified linearity coefficient (n=3)

In the case of $n=2$, it is proposed to divide the active zone into a pre-breaker zone and an after-breaker zone. The limit between the two zones is situated in the transition zone at the toe of the plunge step (see Fig.12). $K_{m,2}$ is now defined as:

$$K_{m,2} = C_{2,1} K_{2,1} + C_{2,2} K_{2,2}$$

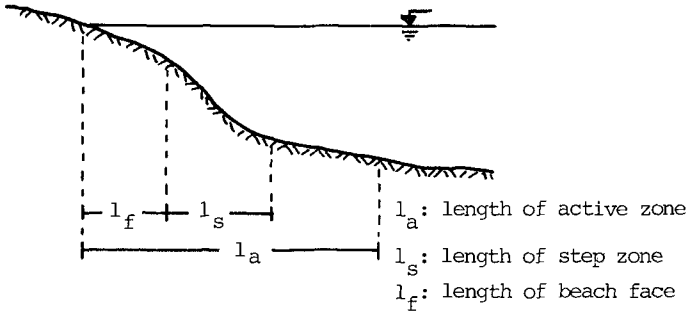


Fig.12. - Sub-zones for $n=2$

The after-breaker zone is comprised of the plunge step and the beach face with widths l_s and l_f , respectively. Data from the Kokkino Limanaki beach show that (see Fig.13):

$$\frac{l_s}{l_a} = 0.02 \text{ to } 0.14, \quad \frac{l_f}{l_a} = 0.04 \text{ to } 0.41$$

and

$$\frac{l_s + l_f}{l_a} = 0.08 \text{ to } 0.48$$

Therefore:

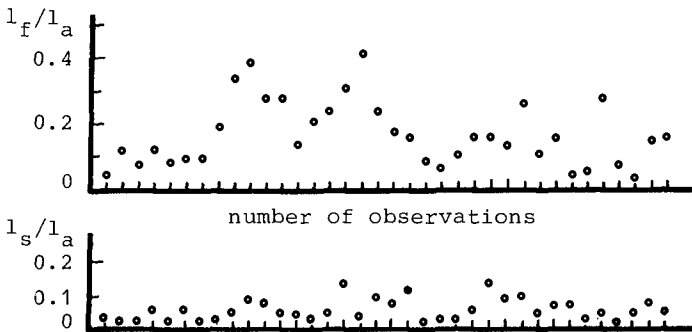


Fig.13. - Lengths of sub-zones ($n=2$)

$$C_{2,1} = 0.1 \text{ to } 0.5 \quad \text{and} \quad C_{2,2} = 0.9 \text{ to } 0.5$$

The sensitivity of $K_{m,2}$ on $D_{2,1}/D_{2,2}$, $C_{2,1}$ and $C_{2,2}$ is examined in Fig.14.

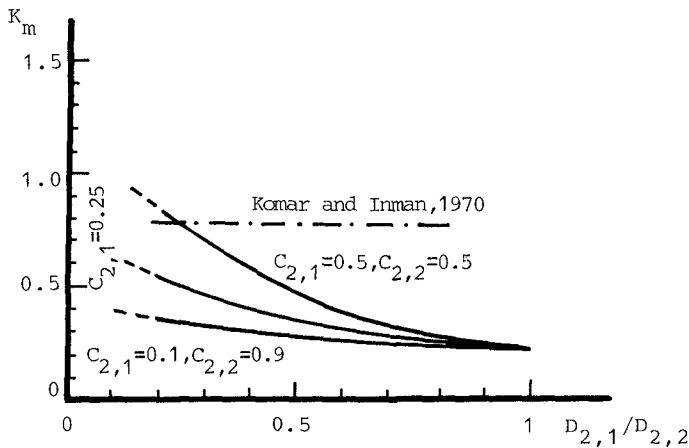


Fig.14. - Modified linearity coefficient ($n=2$)

5. DISCUSSION

The field results briefly presented in the paper are from tideless beaches with mixed sedimentary environments. Although beaches in most parts of the world are of this type, the research effort devoted to them has been too small compared to the extensive work carried out for beaches covered with fine sand. Special interest seems to have been given recently from researchers around the world (f.i. Komar, 1988, Moutzouris, 1988, Nicholls and Webber, 1988, van der Meer, 1988, etc) to beaches which are not exclusively sandy.

The results clearly show that the distribution of sediment grain size is non-uniform on the bed of natural beaches. Grain size and grain size-related parameters change considerably, especially in the cross-shore direction of beaches. The main reason for this is the changing wave-energy levels across-shore.

The cross-shore distributions are expected to be more uniform on tidal beaches due to the dispersion of sediment caused by tidal action. The degree of cross-shore grain uniformity on a beach is also dependent upon the range of sizes met on the beach. Sediment distribution is more uniform for beaches with narrow size ranges than for beaches with broad ranges.

Hydrodynamic conditions prevailing in the active zone of a beach is the main driving mechanism for longshore sediment

transport. Transport rates are also believed to depend upon the beach slope. Sediment size distribution found on a seabed immediately after a sea state reflects the hydrodynamic conditions during the sea state. Introducing the cross-shore distribution into a model for sediment transport computations is in a way equivalent to introducing the cross-shore hydrodynamic conditions and the beach slope because slopes are sediment size-dependent.

The sensitivity of longshore sediment transport models described in this paper is a consequence of the above statements. It is believed that no model can give realistic results for beaches with mixed sedimentary environments unless the cross-shore changes in grain size and grain size-related parameters are taken into account. Further research is necessary in relation to the latter considerations, as has been attempted in the present paper.

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