CHAPTER 194

Experimental Results on the Sediment Grain Threshold under Short-Wave Action

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Abstract

Results on the conditions of initiation of first sediment movement on a flat bed under the action of monochromatic short waves are presented in this paper from a laboratory study. The results indicate the existence of a correlation between the Ursell number and the parameter a. The correlation is of the $a=\lambda\ U^{n}$ type. The values of n and λ, as defined from the experiments, were not unique and were different from the values found in an earlier study by Sunamura. Therefore it was considered necessary to cross-check the values of n using data from real-world beaches.

Introduction

The Laboratory of Harbour Works, National Technical University of Athens, is conducting a research programme on the sediment distribution on the bed of real-world beaches under the action of waves. The beaches from which field data are collected are located along the coastline of Greece, which is an almost tideless environment. This means that the collected data are free of tidal effects, which may influence the results considerably. Other specific features of the beaches are as follows: slopes are, generally speaking, steeper than in many other parts of the world, and sedimentary environments are of the mixed type as far as grain size is concerned.

A rather important conclusion derived from the programme is that grain size changes considerably in the cross-shore direction of beaches. Grain size distribution is found to be related to the wave energy level. Consequently, grain size-related parameters, which are known to influence nearshore processes significantly, are found to change in the cross-shore direction. Results from the

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programme have been reported in a series of past papers (Moutzouris,1989,Moutzouris and Kypraios 1987,etc.).

In almost all cases, it was found that cross-shore changes mainly occur in a zone extending from the line of maximum wave run-up to a critical depth d_c. In the zone seawards of d_c, changes become almost insignificant (see Fig.1). d_c is believed to depend upon the previous sea state, the prevailing sediment size and the bed topography. From one point of view, d_c could be equivalent to the "closure depth" of van de Graaff, in which the profile of a beach becomes insensitive to changes. From another point of view, d_c could be related to the critical depth of initiation of grain movement under wave action.

In the present paper, an attempt is made to investigate whether a correlation exists between d_c and the critical depth of initiation of grain movement. Results from the laboratory are presented on the sediment grain threshold and field data are also used.

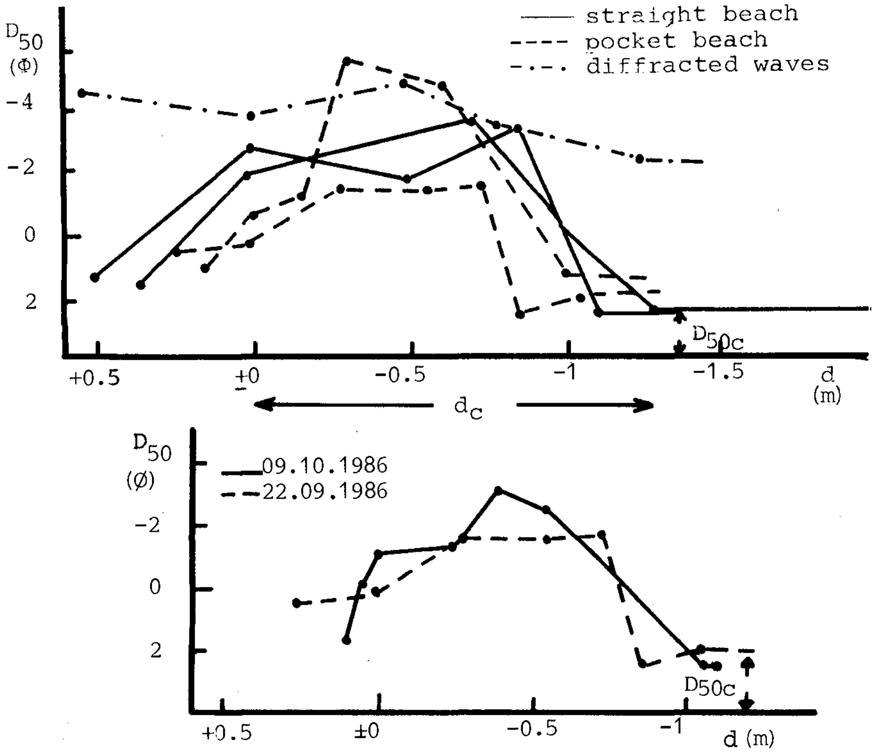


Fig.1.-Cross-shore distribution of sediment grain size (D_{50} is the median grain diameter)

Methodology and Experimental Apparatus

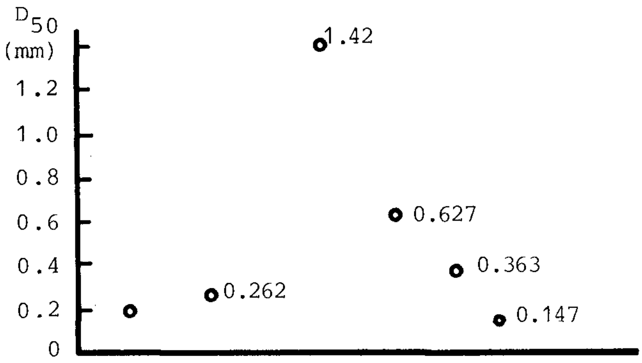
A number of beaches were selected along the coastline of eastern Attica, Greece. The beaches were surveyed four times a year, namely in spring, summer, autumn and winter. Sediment samples from the sea bed were collected along transect lines on each beach. The cross-shore distributions of grain size on these beaches were computed. The critical depth d_c in each case and the corresponding median diameter D_{50c} of grains were then evaluated. d_c and D_{50c} are defined in Fig.1.

A first attempt to compare the above values of d_c found on the beaches to the depth of initiation of sediment movements d_s, as computed from various existing empirical formulae, did not lead to any decisive conclusion. One major reason for this is believed to be the lack of adequate knowledge of the wave disturbance, which had caused the sediment distributions found on the beaches.

It was thus considered necessary to define precisely the critical values of wave height, wave period and the water depth at which initiation of the first movement of grains of diameter D_{50c} occurs on the sea bed. For this purpose, experiments were conducted in a concrete wave flume with a glass sidewall, 27m long, 1.50m deep, and 60cm wide. At one end of the flume, a piston wavemaker created monochromatic waves and at the other end, an absorbing mildly sloping beach was installed. An aluminium tray 1.00m long and 60cm wide was placed on the bottom of the flume. The bed material used consisted of natural sediment grains obtained from a single sieve fraction, in order to obtain the same diameter as the median diameter D_{50c} in nature. A sediment layer consisting of beach material several millimeters thick was placed on the tray. The surface of the sediment was smoothed and waves were then allowed to act on the sediment grains. In each experiment, the grain diameter was kept constant and the wave-induced bed shear stress τ was progressively increased. Starting at a value of $\tau=0$ and increasing τ, the layer initially stayed at rest. After τ reached a critical value τ_c, the first grain movement was observed and then bed load transport started occurring. Five kinds of well-sorted sediment of a constant density (2.6) but different diameter were used in the experiments. All diameters tested had been found in nature to be D_{50c} and are presented in Fig.2. Numerous water depths were tested. The experiments are described by Loisidou (1989).

Experimental results

Various dimensionless parameters were computed using the data obtained from the experiments. Among others, the Hallermeier parameter F, which indicates the intensity



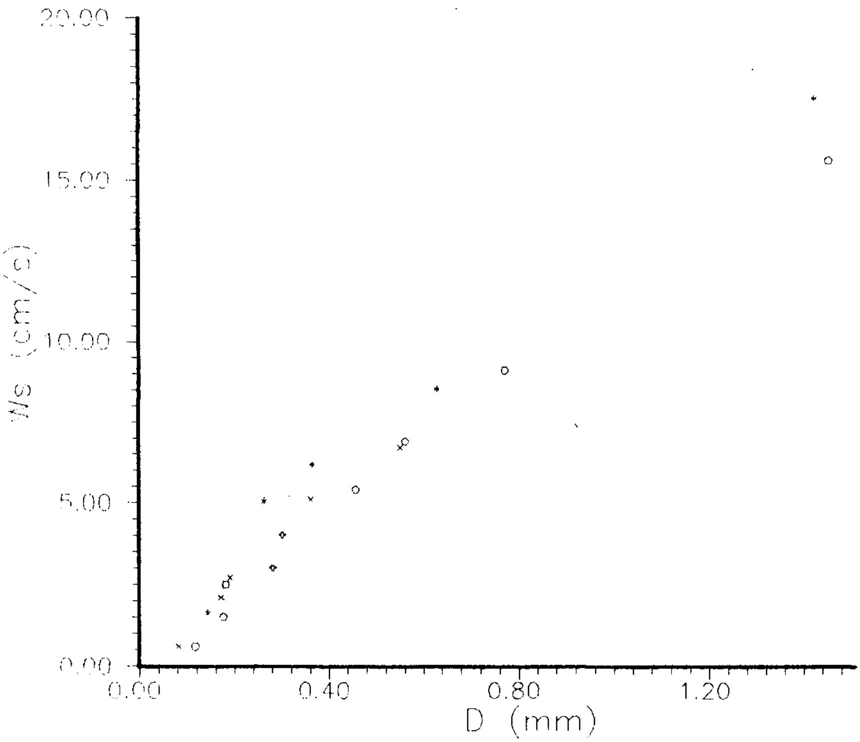


Fig.2.- Sediment grains used in the experiments
(w_s is the settling velocity)

of sediment movement, the Shields parameter Ψ, the Ursell number U, which represents the skewness of the water particle velocity profile, the Reynolds number R, the Dean number and finally the parameter a, which is defined by equation(2). It was found that the best correlation existed between the Ursell number and the parameter a, defined as follows:

$$U = \frac{HL^2}{d^3} \tag{1}$$

$$a = \frac{u_m^2}{\gamma_s' \, g \, (D_{50} \, A_o)^{1/2}} \tag{2}$$

$$\gamma_s' = \frac{\rho_s - \rho_w}{\rho_w}$$

where H and L the wave height and length, respectively, d is the corresponding water depth, g is the gravitational acceleration, D_{50} is the diameter of the grains tested, γ_s' is the specific gravity of immersed sediment, and ρ_s and ρ_w are the densities of sediment and water, respectively. A_o and u_m are respectively the near-bottom orbital diameter and velocity of water particles, as computed using the Airy theory. All wave-related parameters in equations (1) and (2), namely H, L, u_m and A_o, represent values at the moment of occurrence of initiation of first grain movement.

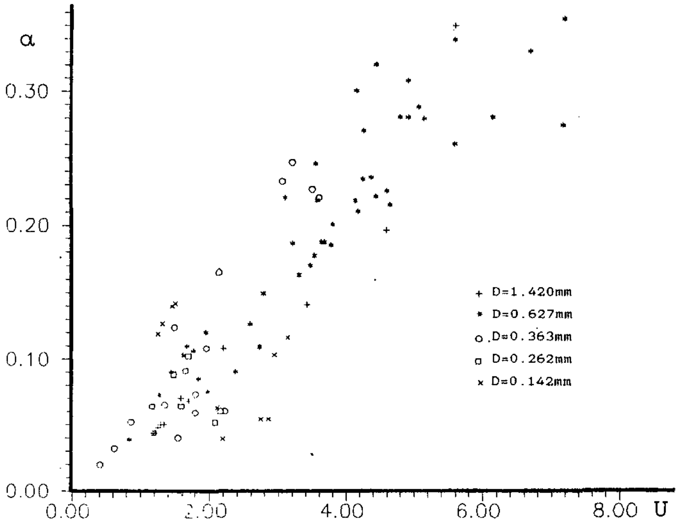


Fig.3.-Dimensionless parameter a versus U (from laboratory measurements)

A plot of the correlation obtained is shown in Fig.3. The correlation is of the following type:

$$a = \lambda\, U^{n} \tag{3}$$

where λ and n are constant. The lefthand of equation (3) is similar to Shield's relative stress. The correlation obtained shows a scatter, which does not allow a unique set of (λ, n) values to be defined from the experiments. The following ranges of values emerge instead, as is also shown in Fig.4:

$$\begin{aligned} \lambda &= 0.04 \quad \text{to} \quad 0.075 \\ n &= 0.6 \quad \text{to} \quad 1 \end{aligned} \tag{4'}$$

The best fitting curve is the one with:

$$\lambda = 0.05 \quad \text{and} \quad n = 1 \tag{4}$$

The above correlation between a and U is not surprising. In a previous similar experimental study by Sunamura (1980), a qualitatively similar relationship was derived for a flat bed with:

$$\lambda = 0.1 \quad \text{to} \quad 0.2 \quad \text{and} \quad n = 0.25 \tag{5}$$

The considerable quantitative differences between equations (4′) and (5) may partly be attributed to the different initial conditions in the two studies. The conditions examined by Sunamura were as follows

$$2 < U < 300$$

which were different to the ones in the present study, namely:

$$0.5 < U < 8$$

The ranges of values tested in the two studies are shown in Fig.5. The relationship derived by Sunamura is compared to the present one in Fig.4.

According to the Komar and Miller (1975) laboratory results for sediment threshold on a flat bed with monochromatic waves:

$$\lambda = 0.21 \quad \text{and} \quad n = 0 \qquad (D<0.5\text{mm})$$

which means that initial sediment movement is independent of the skewness of the water particle velocity profile. These values were derived from the best fit to their data. It is believed (Drake et al.,1985) that lower values of λ should be expected, when the characteristics of the largest waves in a spectrum are used.

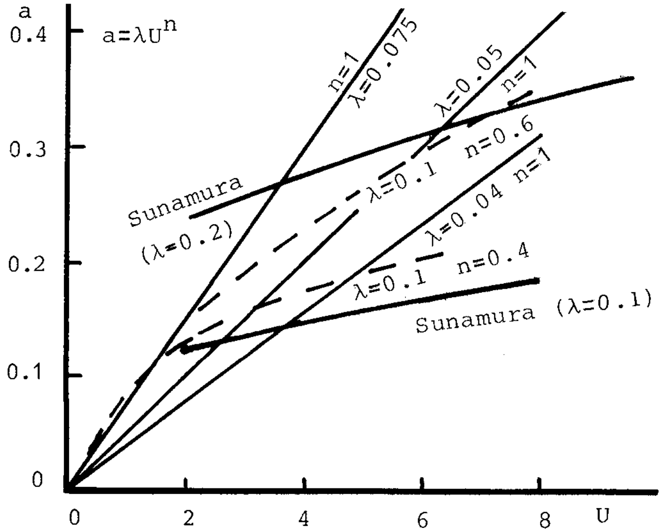


Fig.4.-Equation (4′) compared to experimental results

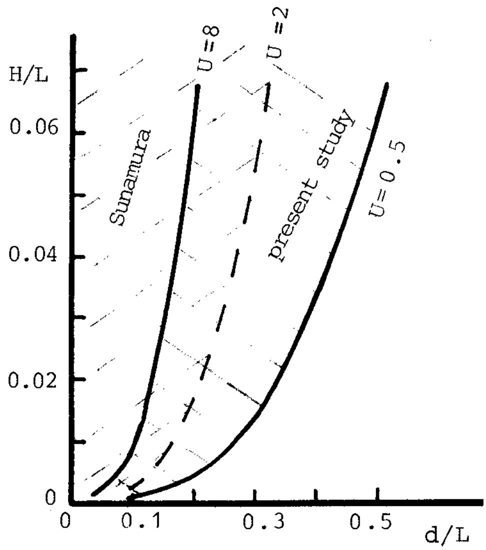


Fig.5.-Range of conditions tested in the present study and in the study of Sunamura

As a result of the above uncertainties and contradicting values of λ and n, it appeared useful to verify the values of λ and n using data from field measurements.

Field Results

Combining equations (1),(2) and (3) and rearranging leads to the following equation:

$$(6) \qquad F_w = \frac{1}{\lambda} F_b$$

with

$$(7) \qquad F_b = \frac{\pi}{2} \frac{\rho_w}{\rho_s - \rho_w} \left(\frac{d}{D_{50}}\right)^{0.5}$$

$$(8) \qquad F_w = \left(\frac{H}{L}\right)^{n-1.5} \left(\frac{d}{L}\right)^{0.5-3n} f$$

with

$$f = \cosh kd \, (\sinh kd)^{0.5}$$

where k is the wave number. F_b is a function of the sediment parameters and the bed morphology whereas F_w is function of the local wave parameters only. Both F_b and F_w change in the cross-shore direction of a beach. Equation (6) indicates that grain movement occurs when a certain number of wave, bed and sediment-related parameters combine in a way to satisfy the criterion indicated by this equation. Initiation of grain movement occurs when F_b/λ becomes larger than F_w.

It now seems appropriate to look closer at both functions F_b and F_w and how they change in the cross-shore direction. Equation (7) may be wrotem as:

$$(9) \qquad F_b = C\left(\frac{d}{D_{50}}\right)^{0.5}$$

with

$$C = \frac{\pi}{2} \frac{\rho_w}{\rho_s - \rho_w}$$

Sediments usually found on beaches have a value of ρ_s=2.4 to 2.6. In a previous paper (Moutzouris,1988), it was reported that ρ_s does not seem to change considerably across-shore (see Fig.6).

It therefore seems reasonable to assume that for the beaches examined, C is almost constant in the cross-shore direction with values in the following range:

$$(10) \qquad C = 1.02 \text{ to } 1.15$$

The cross-shore distribution of $(d/D_{50})^{0.5}$ is now examined using field data. Typical cross-shore profiles of d and D_{50} are shown in Fig.7. The local depth normalized by the corresponding median diameter for a number of cases is shown in Fig.8.

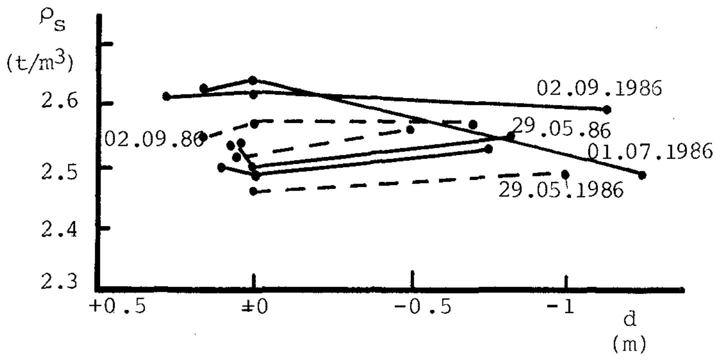


Fig.6.-Cross-shore distribution of ρ_s

The envelope of all cross-shore distributions found on the beaches studied is shown in Fig.9, which is also the envelope of F_b if a multiplication factor of 1.02 to 1.05 is applied. It is seen that F_b was never found to be larger than, say,110 (see equations 9 and 10). In most cases F_b was smaller than, say, 80. A rather important conclusion is that F_b is very much dependent on the cross-shore distribution of D_{50}.

The cross-shore chenge of F_w is now computed using the Airy theory. Values of n intoduced in equation (8) range from 0.25 to 1. F_w is computed for wave steepnesses γ_o (=H_o/L_o) in deep water ranging from 1 to 4%. The energy flux conservation principle is applied. The results are shown in Fig.10.

From the analysis it was found that F_b and F_w change in the cross-shore direction of a beach. In deeper water F_w is always larger than F_b/λ , which means that no sediment movement occurs. The criterion of sediment movement is satisfied in the zone of shallow water. The depth of first grain movement depends upon the bed form, the cross-shore distribution of sediment grain sizes and the wave characteristics. The data from the beaches did not lead to any clear conclusion concerning the values of n. It seems that n depends upon the conditions prevailing on each beach.

It was then decided to adopt the values of n and λ from the best fitting curve to the laboratory results. Equations(3) and (4) were used to compute the depths of initiation of sediment movement d_s for the beaches where depths d_s had been defined, as mentioned earlier. Depths d_s were then compared to d_s. This second attempt again did not lead to any conclusion, which means that d_c was not found related to d_s.

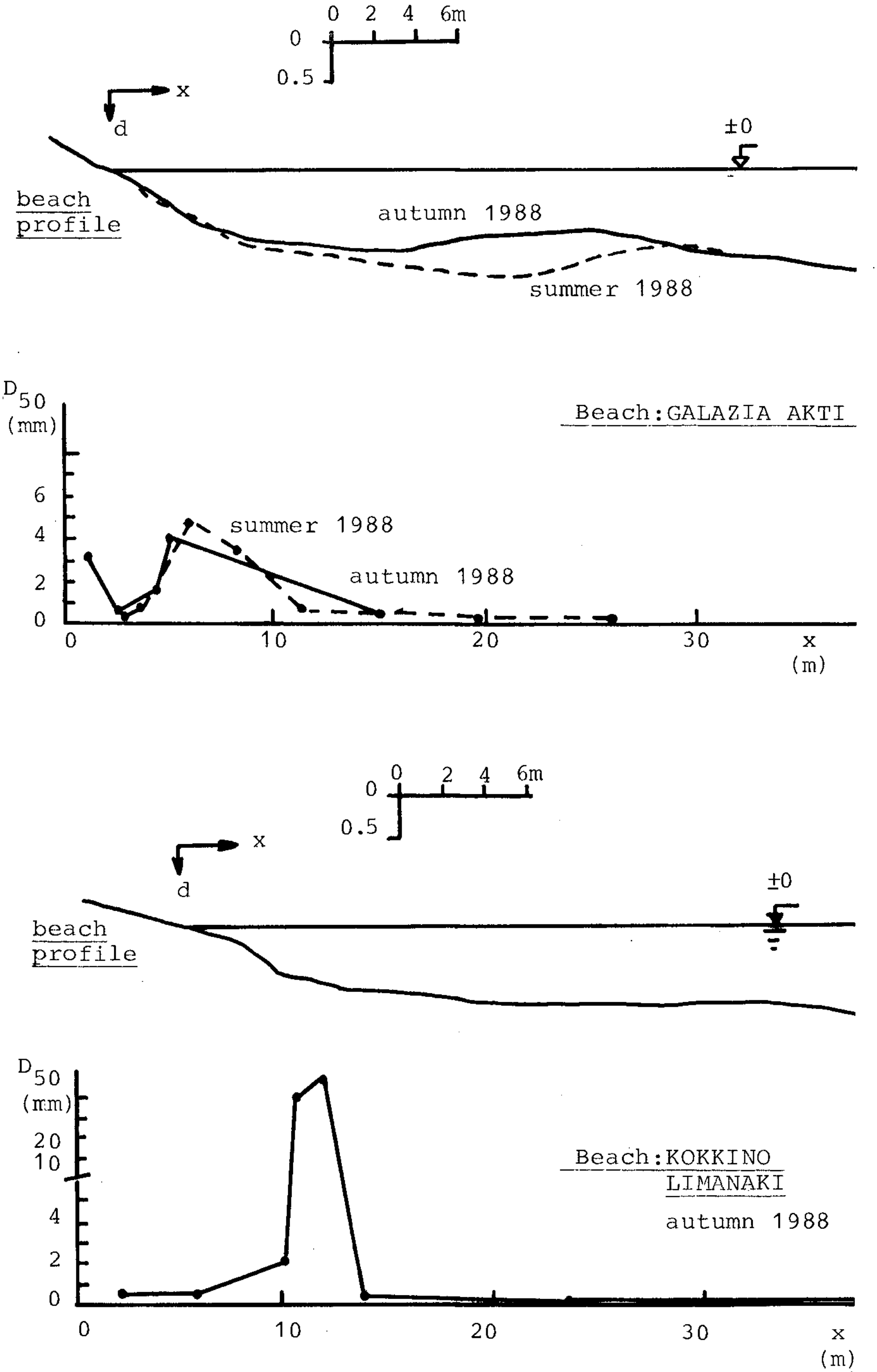
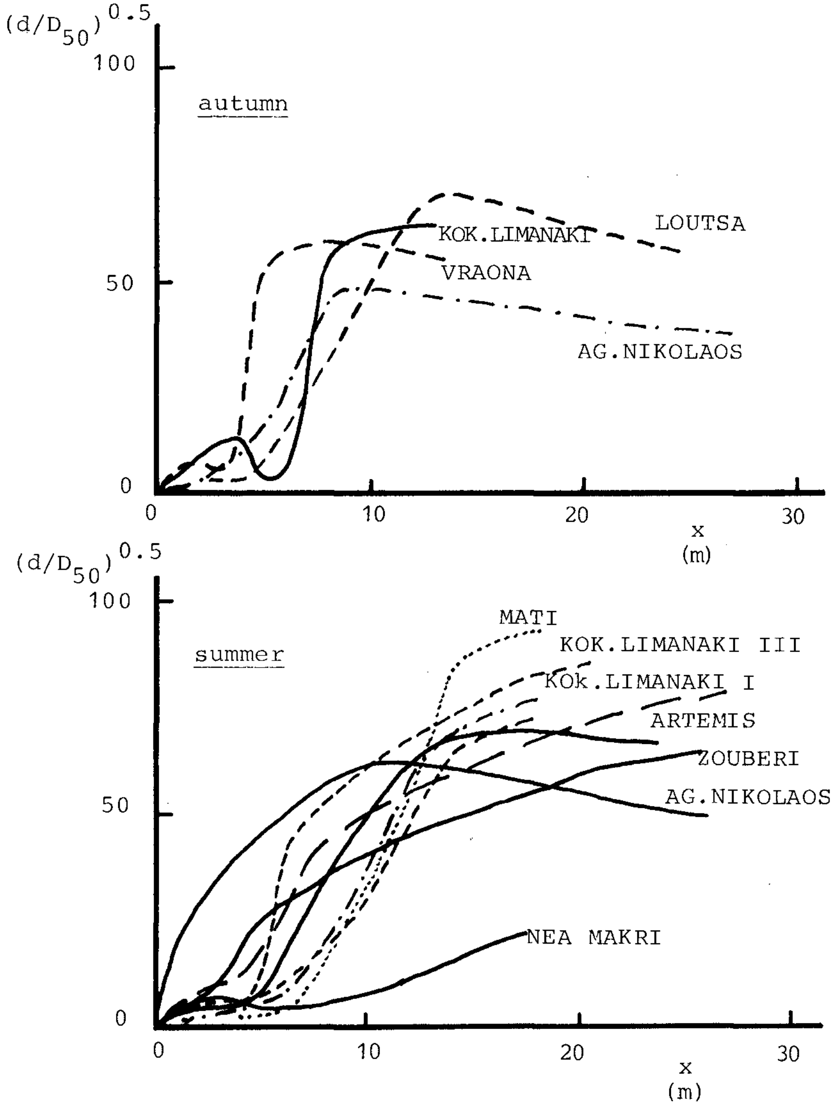


Fig.7.-Typical cross-shore distributions of water depth and grain median diameter on Greek beaches



(d/D50) 0.5
100
autumn
LOUTSA
KOK.LIMANAKI
VRAONA
50
AG.NIKOLAOS
0
0
10
20
30
x
(m)
(d/D50) 0.5
100
MATI
KOK.LIMANAKI III
summer
KOk.LIMANAKI I
ARTEMIS
ZOUBERI
AG.NIKOLAOS
50
NEA MAKRI
0
0
10
20
30
x
(m)

(continued)

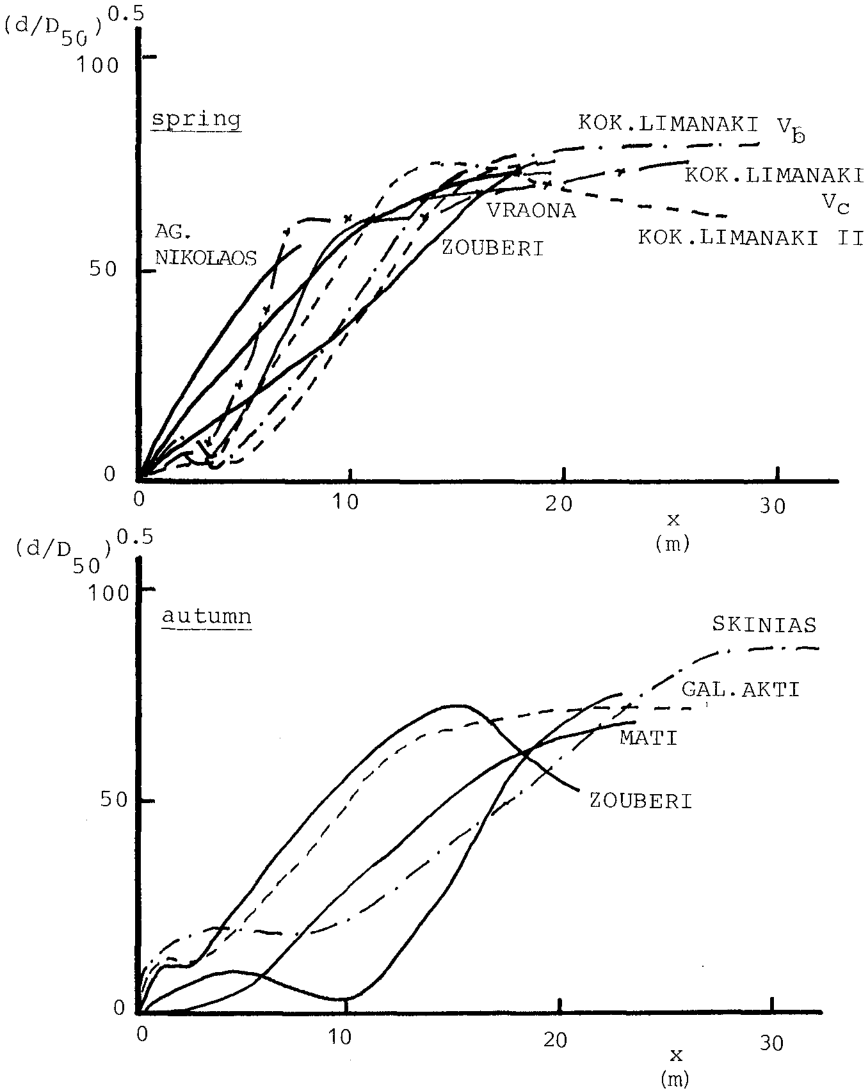


Fig.8.-Typical cross-shore distributions of the paremeter $(d/D_{50})^{0.5}$

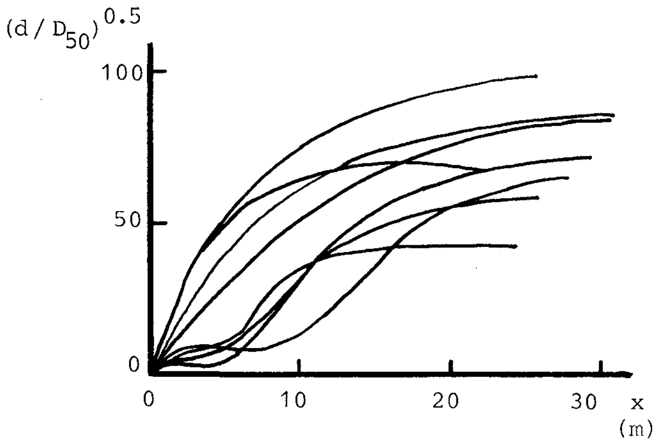


Fig.9.-Envelope of cross-shore distributions of $(d/D_{50})^{0.5}$

Discussion

The results from laboratory measurements on the conditions of initiation of sediment movement under the action of monochromatic short waves confirm the existence of a correlation between the Ursell number U and the parameter a, as defined by equation (2). The coefficients of the correlation n and λ were not found to be unique and are different from the values found in an earlier study. A first explanation could be that the values of U tested in the two studies were different. The use of data from various beaches did not help to a better definition of the correlation coefficients.

The depth of initiation of sediment movement was not found to be correlated to the depth of stabilisation of grain size on a beach.

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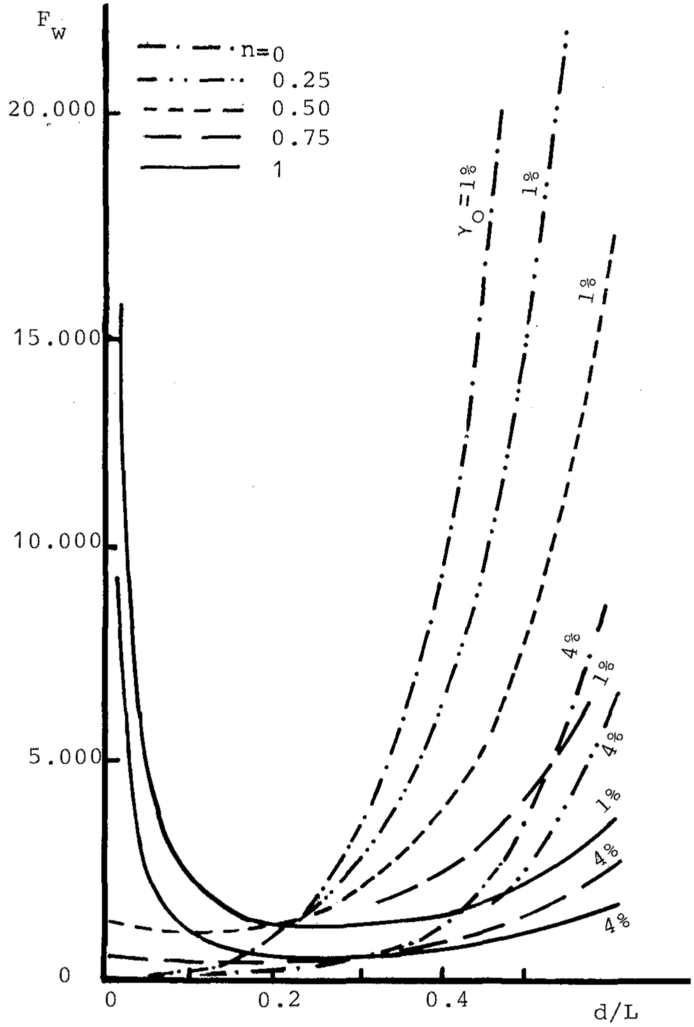

Fig.10.-Cross-shore distribution of the function F_b

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