An Investigation of Breaking Criteria For Shoaling Oscillatory Waves

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SUMMARY

An experimental study is made to show the applicability of the two breaking criteria, geometrical and kinematical, to shoaling oscillatory waves.

It is found that the ratio of wave crest elevation to water depth at the breaking point, η_b/d_b, remains reasonably constant at a value of 0,78 over the range of beach slopes between 1/4,45 and 1/15,00. In this slope range, the maximum value of the ratio of the crest particle velocity, u_{bc}, to the local wave celerity, C_b, is found to be 0,91. Thus, the common assumption that u_{bc} equals C_b during the production of plunging breakers is not substantiated by the results of these experiments.

Consequently, it may be stated that the definition of the plunging breakers can only be made using a geometrical criterion.

ÖZET

SIĞLAŞAN SUDAKİ SALINIM DALGALARININ KIRILMA KRİTERLERİ ÜZERİNE BİR ARAŞTIRMA

Bu çalışmada, geometrik ve kinematik kırılma kriterlerinin sığlaşan sudaki salınım dalgalarına uygulanabilirliği deneysel olarak incelenmektedir.

Kırılma noktasındaki dalga tepesi yüksekliğinin su derinliğine ora-

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nı, η_b/d_b, 1/4,45 ve 1/15,00 taban eğimleri arasında 0,78 sabit değerine yaklaşmaktadır. Gene bu taban eğimleri arasında dalga tepesindeki noktasal hızın, u_{bc}, yerel dalga yayılma hızına, C_b, oranının maksimum değeri 0,91 olarak bulunmuştur. Böylece, bu çalışmadaki bulgulardan u_{bc} nin C_b ye eşitliği, sıçrayarak kırılan dalgalar için, görülememiştir.

Sonuç olarak denebilir ki, sıçrayarak kırılan salınım dalgalarının kırılma tarifi sadece geometrik bir kriterle yapılabilir.

NOTATION

C_1	wave speed in the experimental tank
C_b	wave crest velocity at the breaking point
d_1	still - water depth in the experimental tank
d_b	still - water depth at the breaking point
g	acceleration due to gravity
H_0	deep - water wave height
H_1	wave height in the experimental tank
H_b	wave height at the breaking point
L_0	deep - water wavelength
L_1	wavelength in the experimental tank
S	beach slope
T	wave period
u_b	horizontal particle velocity at the breaking point
u_{bc}	horizontal crest particle velocity at the breaking point
η_b	wave crest elevation at the breaking point

1 — INTRODUCTION

Many different criteria have been proposed for predicting wave breaking. However, none is universally accepted as correct for waves in shoaling water.

Rankine (1864) was one of the first to write on wave breaking in a paper entitled «Summary of the Properties of Certain Stream - Lines». He came to the following conclusions :

(1) A wave begins to break as soon as its crest ceases to be rounded and becomes angular. At such a point the horizontal water particle velocity at the crest is equal to the wave celerity.

(2) At every sharp or breaking crest of a wave in which there is no molecular rotation (i.e., irrotational flow), the two surface slopes meet each other at right angles.

The first of these conclusions has been taken as a basic assumption in many subsequent analytical studies of wave breaking. The second conclusion was later shown by Stokes (1880) to be 120°. It should be noted that Rankine assumed his work to apply for any depth of water.

McCowan's (1894) well-known expression $H_b/d_b=0{,}78$ (H_b is wave height; and d_b is still-water depth at the breaking point) for the limiting height of a solitary wave moving over a horizontal bed, has frequently been used in design for predicting the heights of breaking oscillatory waves on sloping beds.

In recent years plenty of laboratory and field data have been collected to determine the geometrical properties of breakers. The results for some oscillatory waves, in shoaling water, are summarised in Table 1.

The following assumptions are commonly made in deriving breaking criteria :

(a) Geometrical condition: a breaking wave is the heighest possible wave for the specified conditions,

(b) Kinematical condition: breaking occurs if the maximum horizontal water-particle velocity, at the wave crest, exceeds the wave celerity. In this experimental study it is intended to show how these two criteria apply to the breaking (by plunging) of shoaling oscillatory waves.

2 — EXPERIMENTAL EQUIPMENT AND PROCEDURE

2.1 — Experimental Equipment

Experiments were performed in a glass-walled laboratory channel which was 12,5 m long, 0,3 m deep. At one end of the channel there was an adjustable beach made of perspex and plywood (Fig. 1). Four beach gradients were used: 1/4,45, 1/7,12, 1/9,80 and 1/15,00. Waves were generated at the other end of the tank by means of a paddle-type wave generator.

Water surface variations were measured using capacitance-type wave gauge equipment. The output signal was recorded on ultra-violet sensitive paper. Two fixed gauges, 2 m apart, were used for measuring the wave characteristics in the constant-depth portion of the channel, the second gauge being at least 1 m in front of the beach toe. A movable gauge was employed to measure the water - surface variations on the beach (i.e., at the breaking point). A typical wave profile at the breaking point, with some definitions, is given in Fig. 2. The wave celerity at the breaking point was measured with the aid of two capacitance gauges, 10 cm apart, which were fixed to a movable carriage (Fig. 1). Outputs from the two gauges were recorded simultaneously.

Table 1. A Summary of Experimental Investigations On Oscillatory Wave Breaking

Author	Year	Beach Slope	Number of Experiments	H_b/d_b		η_b/d_b
				min - max	mean %	mean
MUNK (Summary)	1949	1/ 6,3	13	0,621 – 0,980	0,754	
		1/11,1	5	0,676 – 0,741	,0694	
		1/13,9	6	0,787 – 1,149	0,995	
		1/18,5	5	0,685 – 1,111	0,921	
		1/20,4	15	0,699 – 1,190	0,834	
		1/33,3	9	0,641 – 0,719	0,684	
			717[1]	0,549 – 1,282	0,768	
SUQUET	1950[2]	1/ 5,7 1/11 1/15,5 1/25		0,746 – 0,826	0,766	
IVERSEN	1952	1/10	16	0.787 – 1,233	1.034	
		1/20	19	0,648 – 1,000	0,840	
		1/30	15	0,673 – 0,833	0.765	
		1/50	13	0.981 – 0,937	0,818	
LARRAS	1952	1/ 3,7	160	0,870 – 1,111	1,000	
		1/11,1		0,570 – 1,050	0,862	
		1/50		0,570 – 0,870	0,746	
		1/100		0,570 – 0.830	0,684	
WIEGEL and BEEBE	1956	1/10	16	0,781 – 1,235	0,990	0,780
		1/20	19	0,649 – 1,000	0,826	0,630
		1/50	13	0,667 – 0,952	0,794	0,660
GALVIN	1969	1/ 5	6	1,000 – 1,640	1,180	
		1/10	14	0,819 – 1,754	1,233	
		1/20	7	0,768 1,121	1,019	
WEGGEL	1972	1/19,6	9	0,867 - 1,016	0,968	
BATTJES	1974	1/ 3,3 1/ 5 1/ 6,7 1/10			1,100	

[1] Field Experimenst

[2] Only upper parts beaches had constant gradients

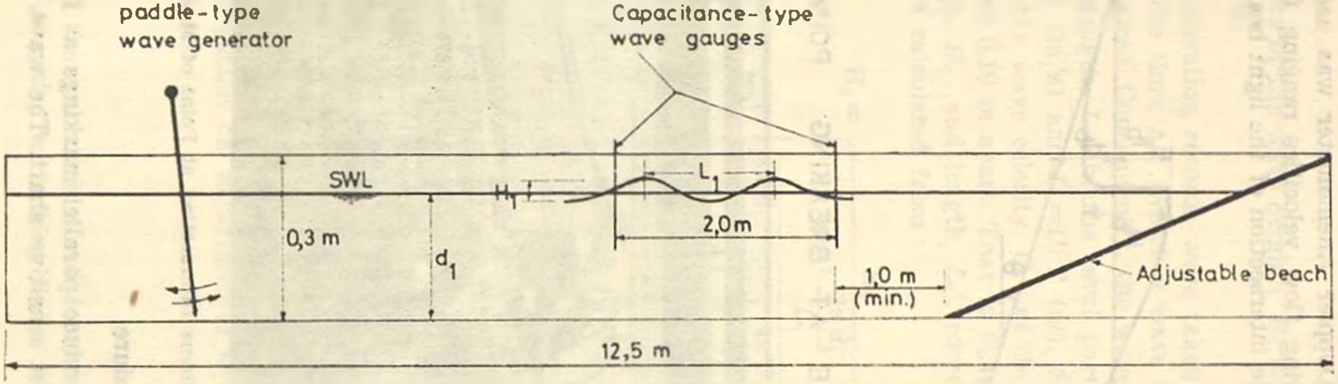

FIG. 1 WAVE TANK (not to scale)

In the measurement of water-particle velocities, at the breaking point, a DISA 55L Laser Doppler Anemometer was used. This instrument is capable of measuring flow velocities ranging from 0,003 m/s to 300 m/s. Fig. 3 shows the intersection of the light beams at the point of measurement.

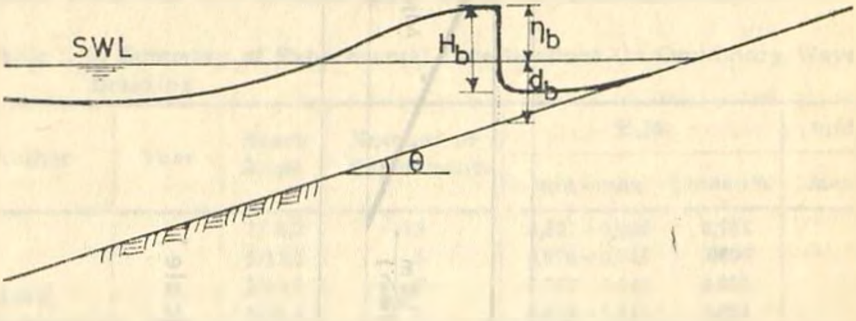

FIG. 2 WAVE PROFILE AT BREAKING POINT

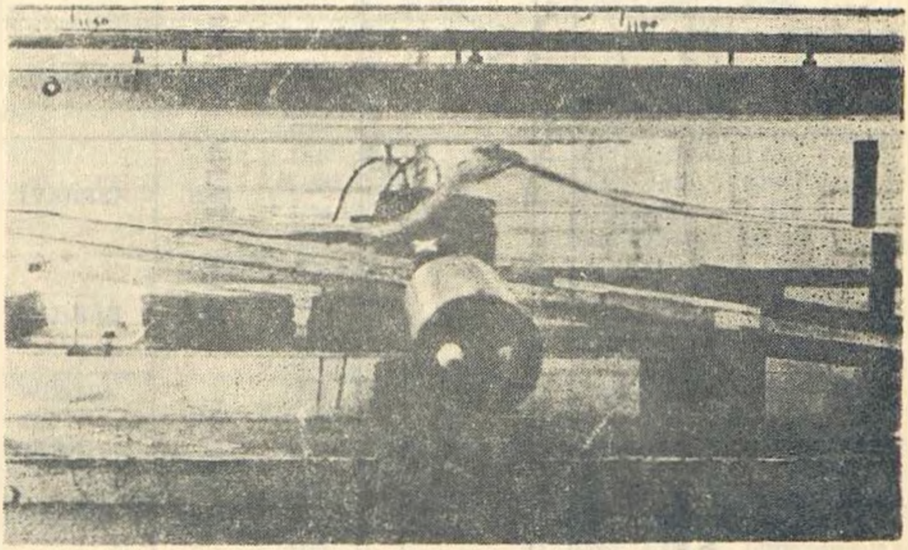

Figure. 3. — Laser Beams Intersecting at Point of Measurement.

2.2 — Experimental Procedure

The recorder could produce parallel markings at fixed time intervals across the ultra-violet sensitive shart. The wave period, *T*, could then be found simply by dividing the total time, t_{tot}, for n wave periods by n: $T=t_{tot}/n$.

Measurements of the wave heights, H_1 and H_b, were found through calibration curves.

As surface elevation records were taken at two points 2 m apart in the channel, the time, Δt_1, which a wave took to travel that distance could be measured. Consequently, the wave celerity, C_1, and the corresponding wavelength, L_1, in the level part of the channel, could be found: $C_1=2/\Delta t_1$ (m/s) and $L_1=C_1 T$ (m). Similar procedure was applied to measure the wave celerity, C_b, at the breaking point where the wave gauges were 0,10 m apart. That is $C_b=0{,}10/\Delta t_b$ (m/s). The deep-water wave heigh, H_0, and length, L_0, corresponding to the values in the channel were calculated from :

$$H_0 = \frac{H_1}{\left[\dfrac{2\cosh^2 \dfrac{2\pi d_1}{L_1}}{\dfrac{4\pi d_1}{L_1} + \sinh \dfrac{4\pi d_1}{L_1}}\right]^{1/2}} \qquad (1)$$

$$L_0 = \frac{g\,T^2}{2\pi} \qquad (2)$$

in which d_1 is the still-water depth in the channel.

In the measurement of particle velocities, two laser beams which arrive from the optical unit of the laser Anemometer intersect at the point where measurements are to be made. The component of the flow which is measured lies in the plane of the two laser beams and perpendicular to the instrument axis. Since this study was concerned with the horizontal velosity components beneath the waves, the anemometer was set perpendicular to the channel with the laser beams in a horizontal plane. In this way, measurements were taken at several points vertically beneath the crest at the breaking point.

Further information on experimental equipment and procedure is given in reference 4.

3 — RESULTS

Fig. 4 gives the variation of dimensionless crest elevation from still-water-level, η_b/d_b, with deep water wave steepness, H_0/L_0, at

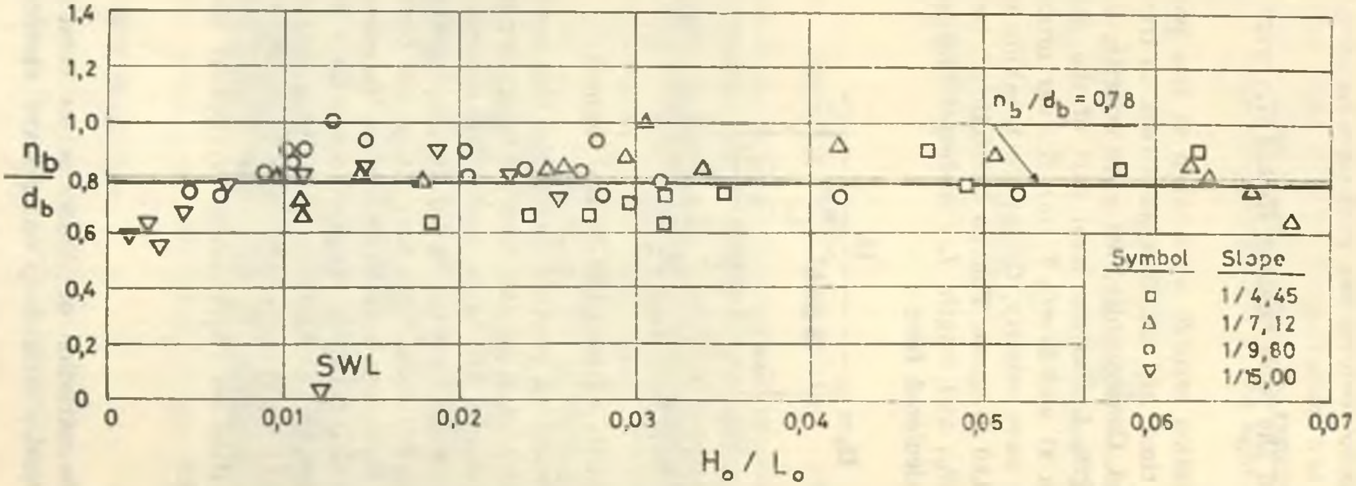

FIG. 4 DIMENSIONLESS CREST ELEVATION AT BREAKING POINT

the breaking point. It is seen from the figure that this ratio remains reasonably constant at a value of 0,78 over the range of beach slopes tested in the present experiments.

Fig. 5 shows the ratio H_b/d_b plotted against deep water wave steepness. The average value of H_b/d_b is 1,14 which is substantially greater than McCowan's value of 0,78 for solitary waves. The values of H_b/d_b and η_b/d_b are given in Table 2.

Table. 2. — The ratios H_b/d_b and η_b/d_b.

Beach Slope	Number of Experiments	H_b/d_b		η_b/d_b
		min - max	mean	mean
1/4,45	11	1,015 – 1,383	1,189	0,736
1/7,12	13	0,896 – 1,350	1,161	0,793
1/9,80	18	1,006 – 1,360	1,169	0,847
1/15,00	10	0,979 – 1,121	1,047	0,722

Typical examples of the measured vertical distribution of onshore particle velocities beneath crest, at the breaking point, are given in Fig. 6. Measurement of velocities very close to the wave crests was impossible owing to the inability of the apparatus to respond within the very short tim interval between the laser beam entering and leaving the water. Consequently, the upper parts of the velocity distributions (i.e., for crest particle velocity, u_c) have been extrapolated from the lower parts. This procedure is unlikely to have produced errors in predicted crest velocities of more than 5 %. Fig. 7 shows the ratio of particle velocity at the crest to wave celerity at the breaking point, u_{bc}/C_b, for different wave and beach conditions.

4 — DISCUSSION

Figs. 4, 5 and 7 are given to show the geometrical and kinematical features of plunging breakers. In the literature, a special Interest is given to the ratios, η_b/d_b and H_b/d_b, in deriving a breaking criterion. As may be seen from Figs. 4 and 5 these ratios are reasonably constant over the experimental range. It should be noted, however, that the ratio H_b/d_b equals 1,14 which is quite similar to the values found by Galvin and Battjes (see Table 1) for about the same slope range. Therefore, it should be noted that the McCowan's value of $H_b/d_b = 0,78$ for solitary waves does not apply to breaking oscillatory waves. On the

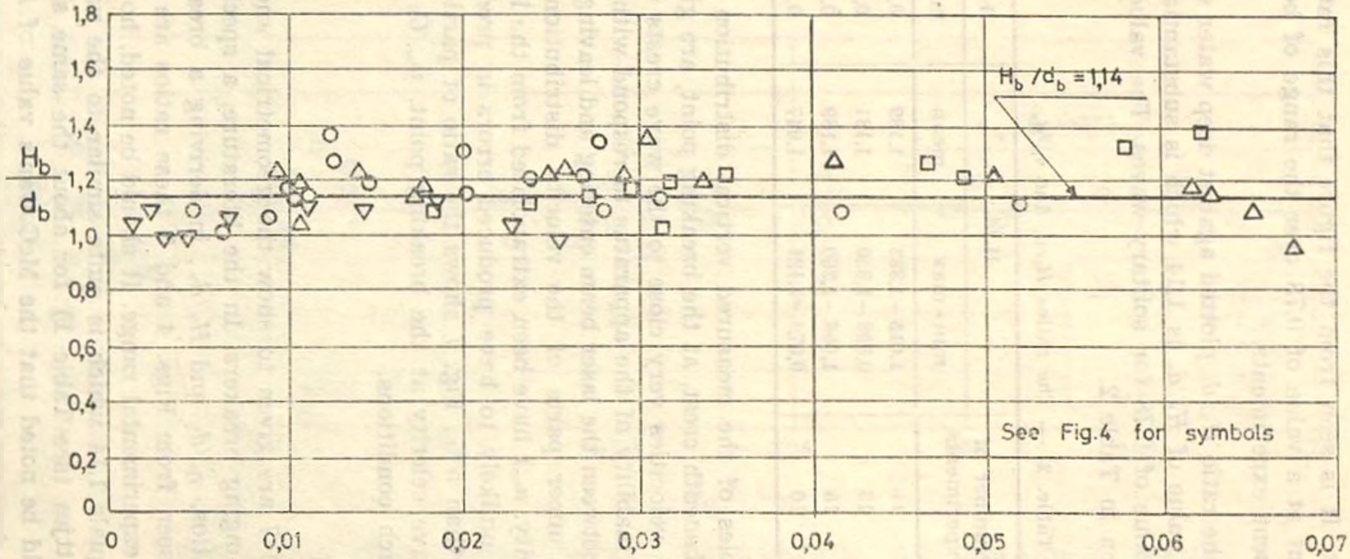

FIG. 5 DIMENSONLESS WAVE HEIGHT AT BREAKING POINT

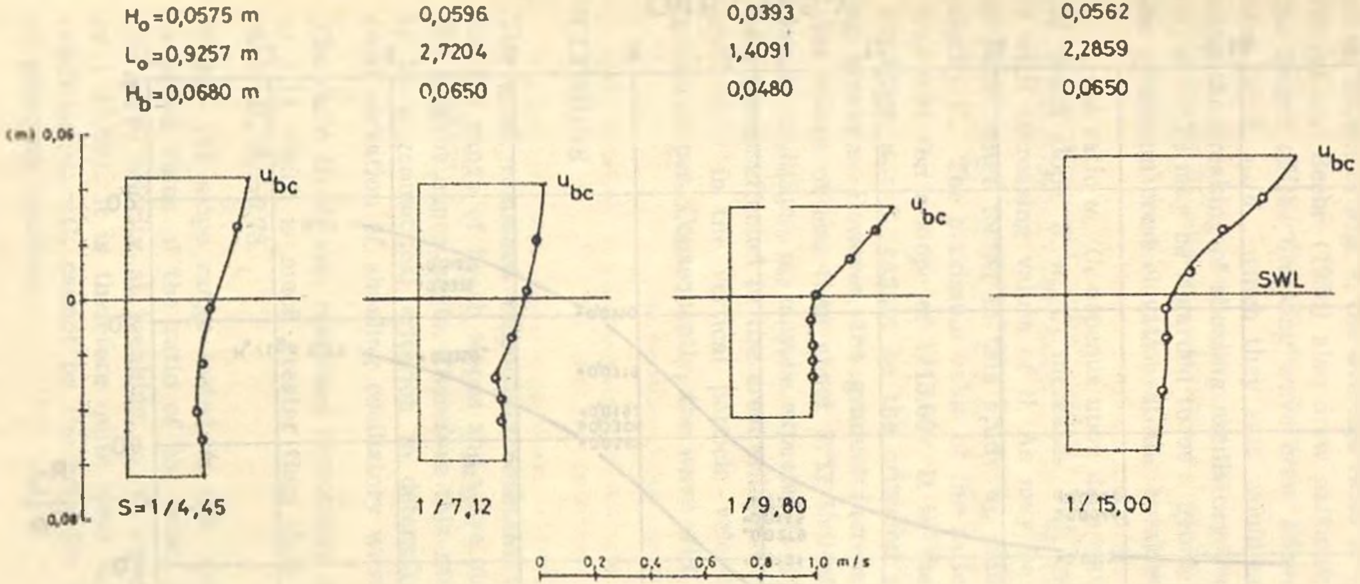

FIG. 6 TYPICAL EXAMPLES OF THE VERTICAL DISTRIBUTION OF ONSHORE PARTICLE VELOCITIES AT BREAKING POINT

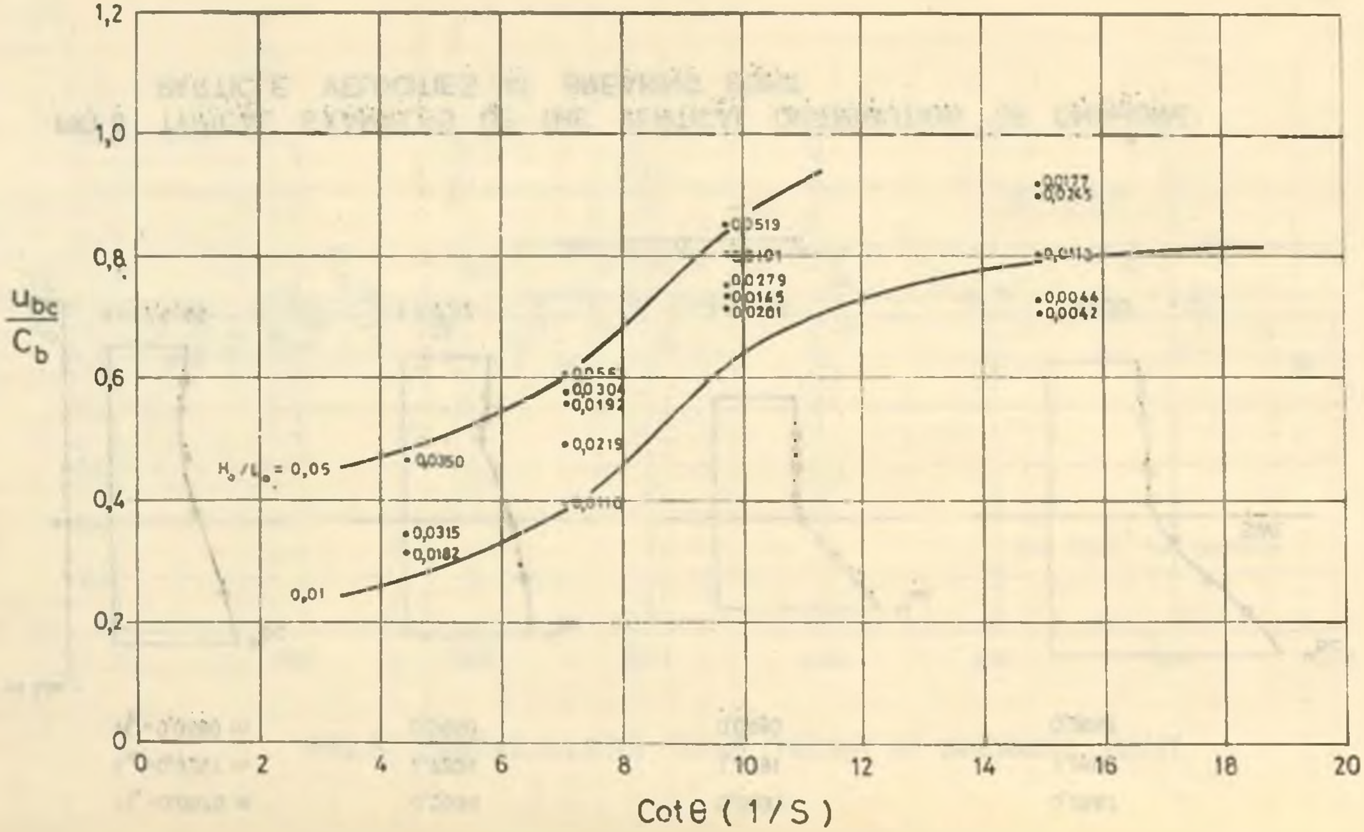

FIG. 7 RATIO OF CREST PARTICLE VELOCITY TO WAVE CELERITY AT BREAKING POINT

other hand, as shown in Fig. 4, the average ratio of η_b/d_b takes a value of 0,78. Wiegel and Beebe (1956) also drew particular attention to the ratio of the height of the breaking wave crest above still-water-level to the water depth, η_b/d_b, which they said would be a good criterion for predicting the breaking of shoaling oscillatory waves. Consequently, the ratio $\eta_b/d_b=0{,}78$ may be regarded to be a geometrical criterion governing the maximum crest elevation at the breaking point.

In Fig. 7, the ratio u_{bc}/C_b depends upon deep water wave steepness, H_0/L_0, and beach slope, S. u_{bc}/C_b increases with increasing values of H_0/L_0 and with decreasing values of S. As may be seen from Fig. 7, within the slope range tested in this study u_{bc} was always less than breaker celerity C_b. The maximum value of the ratio u_{bc}/C_b which was recorded was 0,91 (on a slope of 1/15,00). It is, therefore quite clear that the condition $u_{bc}=C_b$ cannot be the criterion for the production of plunging breakers. However, the gradual increase in u_{bc}/C_b shown in Fig. 7 for slopes of less than about 1/11 indicates that in certain wave and beach conditions, u_{bc} may be expected to equal C_b. When this happens the regions affected in the crest will be quite small owing to the non-uniformity in the vertical particle-velocity distribution for waves on gentle slopes. Consequently, the wave will probably break by spilling.

5 — CONCLUSIONS

(a) The η_b/d_b remained reasonably constant at a value of 0,78 for the range of beach slopes and wave steepnesses tested in the present experiments. Therefore this ratio can be assumed to be a geometrical criterion in determining the maximum crest elevation of shoaling oscillatory waves.

(b) The ratio H_b/d_b also remained reasonably constant at a value of 1.14 which is much greater than that of solitary wave's ratio $H_b/d_b=0{,}78$.

(c) Within the slope range tested in this study, the maximum recorded value of the ratio of the crest particle velocity to the wave celerity at breaking, u_{bc}/C_b, was 0,91 (on a slope of 1/15,00). It is therefore quite clear that the kinematical condition $u_{bc}=C_b$ cannot be the criterion for the production of plunging breakers.

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