CHAPTER 31

EXPERIMENTS OF WAVE REFLEXION ON IMPERMEABLE SLOPES

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ABSTRACT

Results from experiments on the reflective power of smooth and rough impermeable slopes are presented The importance of relative depth to the regular scatter diagram of the function R=R (δ_o) and the need for an adequate computational wave theory through which no significant alterations are introduced in the determination of reflective power is pointed out Stokes 2nd order corrections are introduced These help find a superior value for the reflexion coefficient and destroy the mentioned regularity of the scatter diagram A regular scattering of experimental points, also of function R=R (δ_o), where, however, for constant steepness, reflexion decreases when relative depth increases, is found in rough slope tests In this case, the more inclined is the slope, the greater is the influence of roughness

1 - INTRODUCTION

Some of the approaches used for determining the reflexion coefficient of a given parameter are based on direct recording of incident and reflected wave trains (these are the "wave tail" and "subtraction" methods described in [1] by Goda and Abe), others on the recording of clapotis Calculation procedures using maxima and minima of these clapotis range from the simplest — immediate application of the small amplitude assumption through the well-known formula

$$R = (Max-min)/(Max+min) \qquad (1)$$

to more elaborate cases in which approximations of different orders are used Stokes II (as developed by Carry [2], Stokes III (as proposed by Goda and Abe [1]), cnoidal theory, etc More sophisticated methods exist as, for instance, Santon's and Marcou's method developed in Grenoble, which applies harmonic analysis to the clapotis profile as recorded at three points [3], [4], [5]

The present paper concerns results of tests where the reflective power of smooth and rough impermeable slopes was studied

Use was made of the method of recording maxima and minima of clapotis The aim was above all to study the validity range of the linear theory small amplitude assumption and acquire an idea of errors introduced by its application

2 - RANGES OF PARAMETER VARIATION IN TESTS

Systematic tests were performed in a 20 m long and 0 80 m wide flume with a total depth of 0 55 m This flume is equipped with a monochromatic translation actuator Results of the tests are studied in the following

Absolute water depth (d) was kept constant and equal to 0 35 m since the slope concerned a semi-indefinite plane Local or offshore relative depth, d/L or d/Lo, respectively varied then only owing to L_o variation, that is, owing to T, which took values between 0 8 and 2 2 s

In most cases concerning the presentation of results, periods 1 0, 1 6 and 2 2 s were selected corresponding the following relative depths

T (s)	d/L	d/Lo
1 0	0 25	0 22
1 6	0 13	0 09
2 2	0 09	0 05

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Going along the decreasing order of relative depths, the first of those three cases presents waves satisfying Miche's condition for non-appearance of secondary crests ($d/L > 0\ 15$) These waves are best suited for elementary computations, according to the linear theory small amplitude assumption The second case (which occupies an intermediate position in the set of tests) includes waves corresponding to finite amplitude wave theories To them the different Stokes approximations may be applied, according to the rigour demanded The case of the least relative depth comprises waves calculation of which enters the domain of cnoidal wave theory*

As for steepness, its off-shore value (δ_o) varies approximately between 0 3 and 3% These are the most common limits for sea waves It was endeavoured to secure a great range of values corresponding to unbroken waves Also, tests were carried further whenever breaking occured for increasing steepness However, beyond a certain point it was impossible to get acceptable clapotis from the point of view of regularity

The plane slope inclination varied, for the set of tests, from the minimum 10% value to vertical inclination

Roughness, which was introduced in the second part of the tests made, consisted of sand glued to the slope Of course, the greater the intended roughness, the greater the used sand grain size The sift hole diameter r was used to characterize absolute roughness This factor was made non-dimensional by means of the wave length The resulting parameter r/L_o, a measure of relative roughness, took values between $1\ 3 \times 10^{-4}$ and 240×10^{-4}

3 - TEST RESULTS

3 1 - Smooth slopes

In Fig 1, a graphic diagram of $R=R\ (\delta_o)$, points corresponding to 10%, 15%, 20% and 30% slope tests are plotted

Fig 2 comprises four R (δ_o) plots corresponding to 40%, 50%, 100% and vertical slopes

In the first set of tests (Fig 1) points corresponding each one of the four inclinations cluster around similar curves In each inclination only an experimental scattering of points occurs, with no period separation

On the other hand, in the second set of tests a regular scattering of periods occurs For constant δ_o values a decrease of R is apparent when T increases The same phenomenon is noted for run-up experiments (Fig 5)

3 2 - Rough slopes

In Fig 4 four diagrams relating to rough slope tests are selected, absolute roughness being in each case a constant

It is seen that in every case two type of point scattering are present, according to slope variation for 20% and 30% a regular scattering of periods is observed, now, however, in the opposite sense for constant δ_o values, R and T values increase or decrease together For vertical inclination (and also for 100% inclinations, though no diagrams are presented) again a regular scattering of periods is observed as in the case of smooth slopes

4 - INTERPRETATION OF RESULTS

4 1 - Introduction

With a view to simplifying the language used, the following designations are adop

* - However, according to Ursell's parameter

$$U = \frac{H}{d} \left(\frac{L}{d}\right)^2 \qquad (2)$$

cnoidal theory should be applied only for $U > 100$ Taking into account the highest wave of the tests (6 75 cm) and the local wave length ($L=3\ 9$ m) corresponding to the off-shore wave length $L_o=7\ 55$ m ($T=2\ 2$ s) we get $U=24$

ted for characterization of the three mentioned scattering types

- experimental scattering
- smooth type regular scattering
- rough type regular scattering

An attempt shall be made to interpret occurrence of regular scattering in the high of an explanation relative to computations in a case and of physical order in another That is physical causes are perhaps related to energy dissipation phenomena which in turn are the reason for the decrease in the slope reflective power Changes undergone by the wave in its orbital velocity field, when it is propagating in decreasing relative depths, with an increasing turbulence and finally reaching breaking point or energy dissipation due to slope roughness are cases in which the physical factor is indisputable The decrease in reflective power may however be fictitious, that is, it may merely result from a inefficient computation method

4 2 - Smooth slopes

4 2 1 - Influence of relative depth on reflexion computations

It is known that the best suited wave theory for computations of the relevant parameters is determined by relative depth It should be noted, however, that the parameter t/L (where t is the horizontal distance measured from still water level to the slope base projection on the surface and L is the local wave length) may be of great importance

					SLOPE								
					10%	15%	20%	30%	40%	50%	100%	200%	vert
					t (m)								
d = 0 35 m					3 50	2 33	1 75	1 17	0 88	0 70	0 35	0 18	0 00
T(s)	L_o(m)	L(m)	d/L_o	d/L	t/L								
0 8	1 00	0 97	0 3506	0 3584	3 58	2 39	1 79	1 19	0 90	0 72	0 36	0 18	0 00
1 0	1 56	1 42	0 2244	0 2458	2 46	1 64	1 23	0 82	0 61	0 49	0 25	0 12	0 00
1 2	2 25	1 86	0 1558	0 1881	1 88	1 25	0 94	0 63	0 47	0 38	0 19	0 09	0 00
1 4	3 06	2 28	0 1145	0 1535	1 54	1 02	0 77	0 51	0 38	0 31	0 15	0 08	0 00
1 6	3 99	2 69	0 0876	0 1301	1 30	0 87	0 65	0 43	0 33	0 26	0 13	0 06	0 00
1 8	5 05	3 09	0 0692	0 1132	1 13	0 75	0 57	0 38	0 28	0 23	0 11	0 06	0 00
2 0	6 24	3 49	0 0561	0 1004	1 00	0 67	0 50	0 33	0 25	0 20	0 10	0 05	0 00
2 2	7 55	3 88	0 0464	0 0903	0 90	0 60	0 45	0 30	0 23	0 18	0 09	0 04	0 00

Schoemaker and Thijsse have pointed out [6] that that parameter is the main cause of energy dissipation and indicated that for an almost total reflexion we must have $t/L \leq 0\ 25$, and for a very small reflexion then $t/L \geq 0\ 5$

In a small inclination slope (15%, for instance) two waves of different lengths, which propagate, before reaching it, in different relative depths, will in the end have traveled over zones with same relative depth (of course one lagging behind the other) Thus period does not exert a selective action This is the type of tests corresponding to "experimental scattering" which was found for 10%, 15%, 20% and 30% slopes

For strong inclinations (greater than 40%), the fact that t/L is small makes the two waves propagate in different relative depths when they bear on the slope Thus, a proper wave theory for computations is essential For the shorter wave a deep water wave theory seems best suited while for the longer one a shallow water theory is indicated This seems to be the evident explanation for the occurence of the "smooth type regular scattering"

In fig 3 is shown the influence of inclination on R for constant values of T and cen be easily noted the different espect of the phenomenon in inclinations up to 40% and from this value up to vertical in what concerns the shorter period (1 0s) and the longer ones (1 6s and 2 2s)

4 2 2 - Miche's theory

The steepness maximum value, δ_{max}, of a wave theoretically capable of totel reflexion on a slope which is at an angle α with the horizontal has been defined by Miche [7] as

$$\delta_{max} = \sqrt{\frac{2\alpha}{\pi}} \quad \frac{\sin^2\alpha}{\pi} \tag{2}$$

the theoretical reflexion coefficient being

$$R' = \frac{\delta\, max}{\delta_o} \tag{3}$$

for $\delta_{mex} < \delta_o$ If $\delta_{max} \geq \delta_o$ then $R' = 1$

The ectuel reflexion coefficient is

$$R = \rho\, R' \tag{4}$$

where ρ is the so-called slope intrinsic reflexion coefficient

The diagram $R' = R'(\delta_o)$, Fig 6, shows thet up to an 40% inclination and within the steepness range of the tests, R' values present a first constant 100% "landing" The smaller the inclination, the smaller is this landing For slopes of inclination greater than 40% and about (but not quite) 3% steepness, theoretical reflexion is always total for steepness values up to 3%

Greater δ_o values are more and more unlikely in nature For instance, for a 100% slope it is $\delta_{max} = 11\ 26\%$

This 40% inclination value (for results corresponding to the steepness range of the tests, as said before) separetes in fact the two domains of experimentel results: experimental scattering end regular scattering

4 2 3 - Stokes' 2nd order corrections

According to

$$1/\alpha = \frac{2\pi}{th\frac{2\pi d}{L}} \left(1 + \frac{3}{2\ sh^2 \frac{2\pi d}{L}}\right) \tag{5}$$

α values were computed as e function of d/L

T(s)	d/L	α	T(s)	d/L	α
0 8	0 3584	0 1458	1 6	0 1301	0 0382
1 0	0 2458	0 1118	1 8	0 1132	0 0277
1 2	0 1881	0 0782	2 0	0 1004	0 0206
1 4	0 1535	0 0541	2 2	0 0903	0 0157

following Carry's procedure [2] These α values were used to compute

$$D = \frac{M}{2\alpha L} + \frac{m}{2\alpha L} \tag{6}$$

where M and m are maximum end minimum of the recorded clapotis

Fig 7 shows a diagram taken from [2] where the corrective value μ is determined which will allow the calculation of the new reflexion coefficient β (value corrected according to Stokes' 2nd order theory)

$$\beta = \mu R \tag{7}$$

where R is computed from (1)

In Fig 2, the corrected experimental points (black simbols) and the uncorrected points (white simbols) are presented linked by line segments which provide a measure of the amplitude of the introduced correction

In Fig 8, the percentage of introduced correction ($\frac{\beta - R}{R}$) is plotted as a function of δ_o, inclination and $\underline{T}$

The following points are noted

- Using a higher order wave theory will decrease the regular scattering of periods $\underline{R}$ being corrected for values close or equal to 100% Proximity to this value seems to depend on the approximation order of the used wave theory

- Correction increases with period, i e , decreases with relative depth (see Fig 8), which agrees with what was said above about the wave characteristics relating to depth

- Correction increases when either inclination or steepness increase

4 3 - Rough slopes

4 3 1 - Influence of relative roughness

In rough slopes, the regular scattering of periods is due, as said above, to two reasons

- "rough type regular scattering" for low inclinations (20% and 30% in the case of the tests performed) in which the greater the relative roughness (i e the smaller is L_o relative to $\underline{r}$) the greater the energy dissipation This explains that, for the same slope, longer period waves dissipate less energy

- "Smooth type regular scattering" for higher inclinations, in which, for the same absolute roughness, energy dissipation is smaller than in low inclination slopes The effect of the separation of the experimental points due to insufficient approximation of the used wave theory overrules the physical effect of energy dissipation through roughness

Fig 9 shows experimental results obtained for equal values of relative roughness. They confirm the given explanation for small inclinations, the "rough type regular scattering" disappears For vertical inclination the smooth type regular scattering remains

2nd order corrections for rough slopes are not presented in this paper

4 3 2 - Variation of the slope intrinsic reflexion coefficient

According to formula (4) and to Fig 10 diagrams, the intrinsic reflexion coefficient decreases with steepness until a minimum value is reached corresponding to $\delta_o = \delta_{max}$, afterwards it increases to values greater than δ_o

When a slope's actual reflexion coefficient is estimated from the theoretical reflexion coefficient R' one should not take a constant ρ value, taking the steepness into account

4 3 3 - Roughness influence on inclination from the point of view of energy dissipation

It is known that in a flume the maximum bottom orbital velocity for a wave which is propagating with height $\underline{H}$ and length $\underline{L}$ is given by

$$v_{max} = \frac{H\,\pi}{\sin\alpha} \sqrt{\frac{g}{L}}$$

and that this velocity value is concerned with energy dissipation by roughness

This v_{max} value increases very rapidly when inclination decreases, energy dissipation also increases as a consequence of roughness

Fig 11 shows, for a 30% slope, the decrease of reflective power due to the roughness increase The same strong effect is not present for the case in which the inclination is greater than 100%

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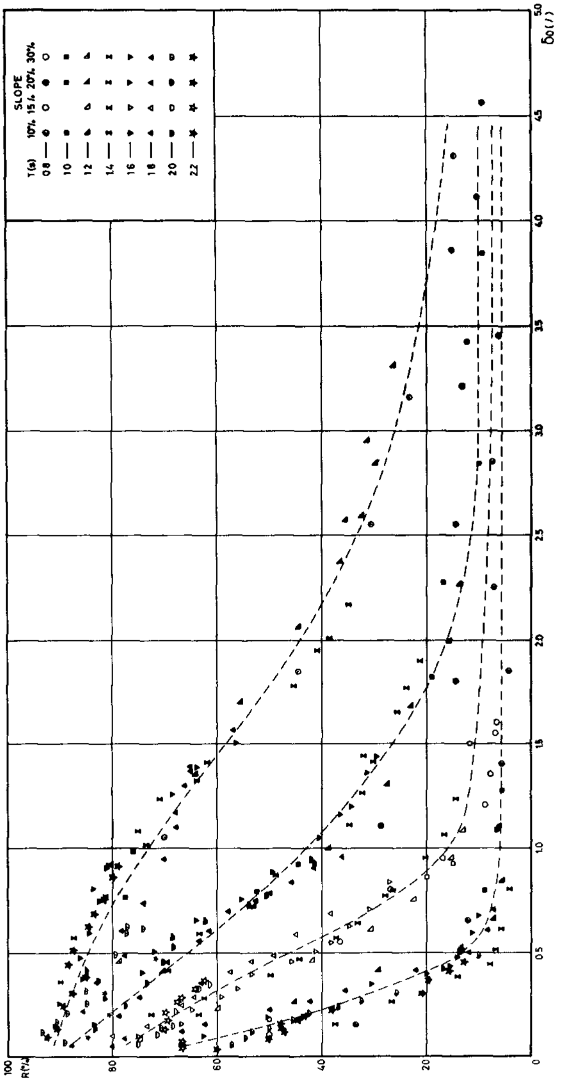


Fig 1 - Tests with smooth slopes of 10% 15%, 20% and 30%

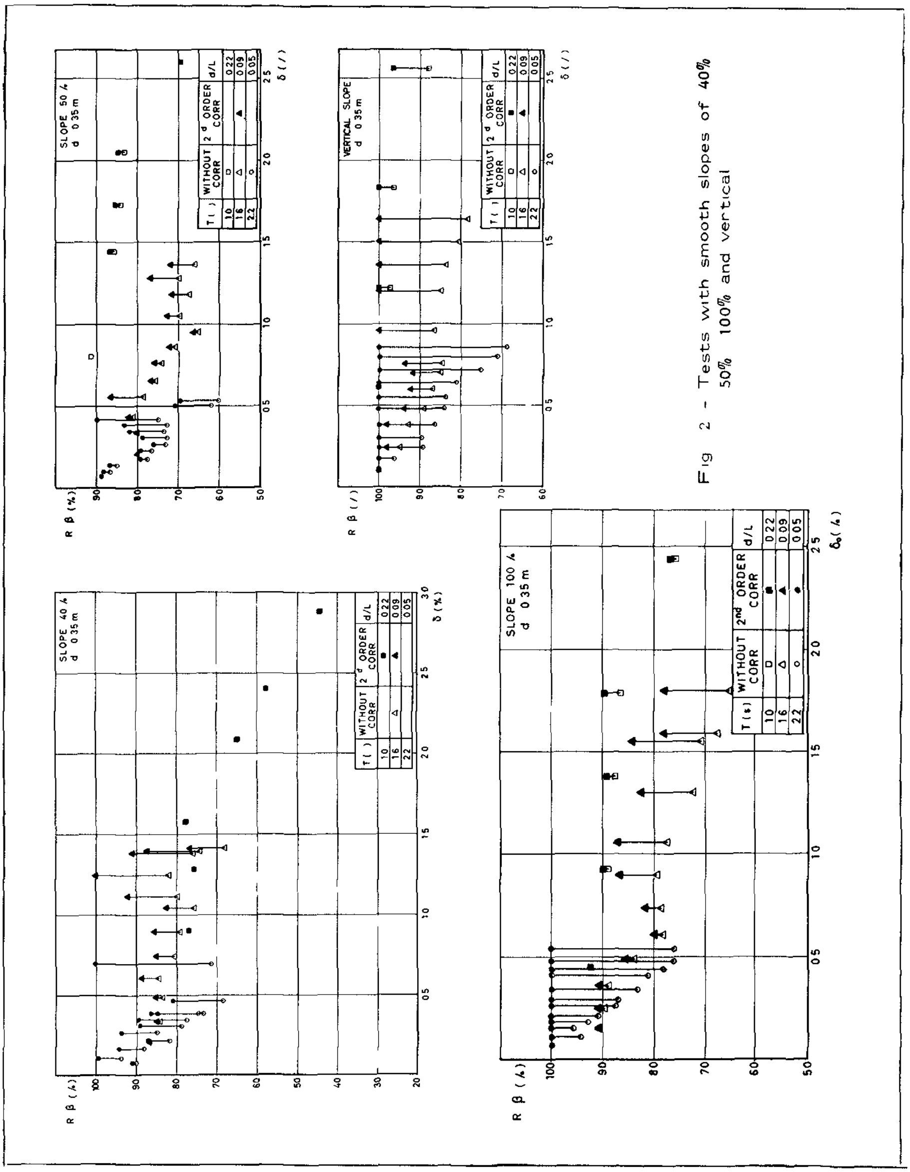


Fig 2 - Tests with smooth slopes of 40% 50% 100% and vertical

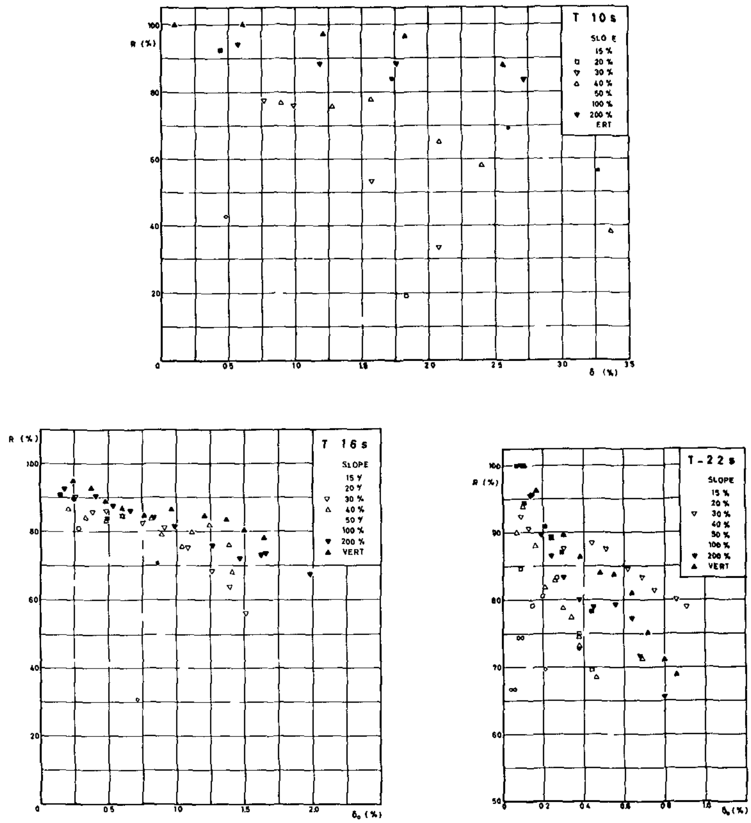


Fig 3 - Influence of inclination on R
for constant values of T

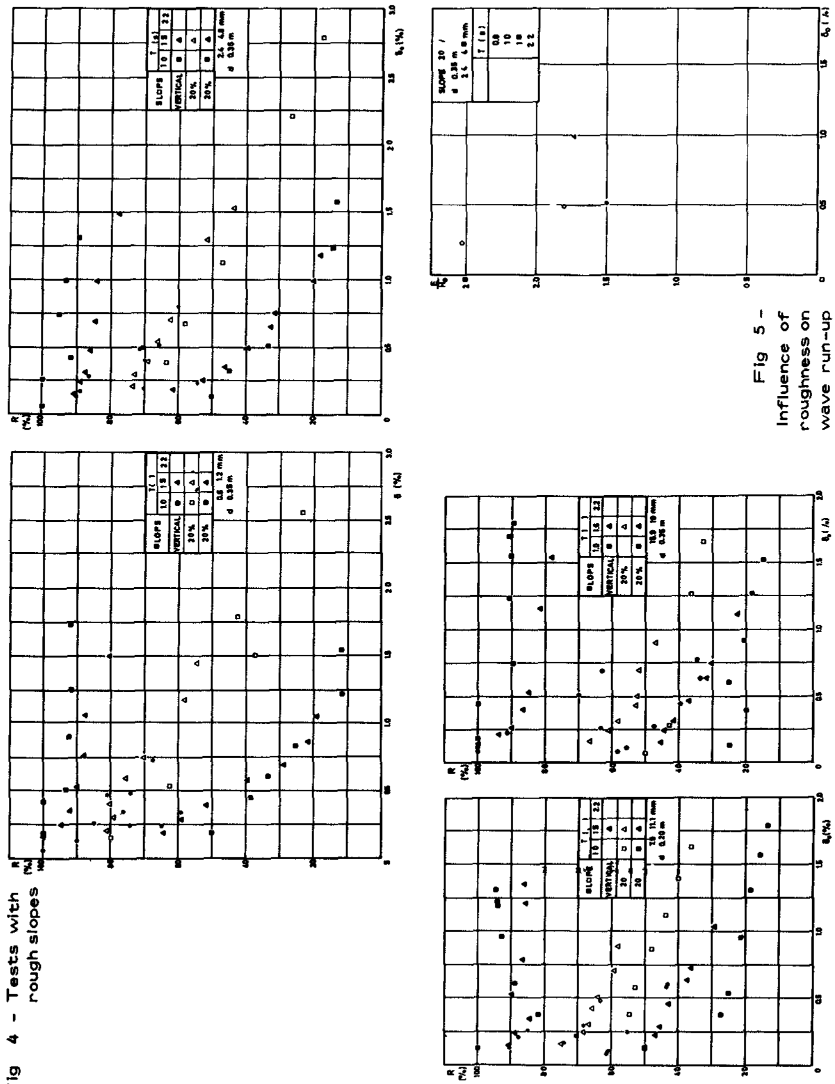


Fig 4 - Tests with rough slopes

Fig 5 - Influence of roughness on wave run-up

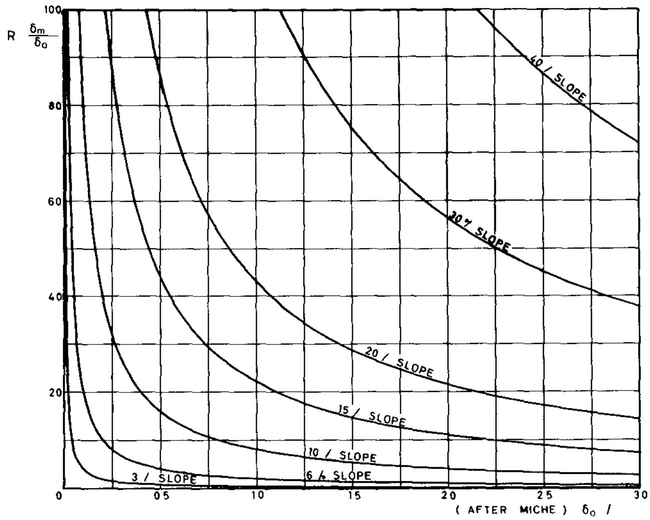


Fig 6 - Miche's theoretical reflexion coefficient

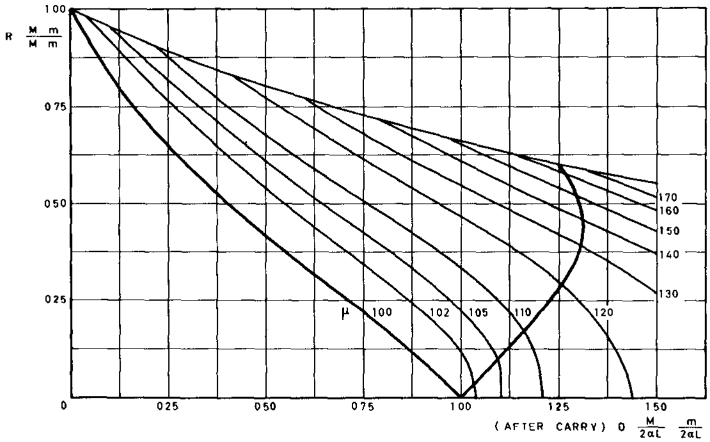


Fig 7 - Graph for the 2nd order corrections

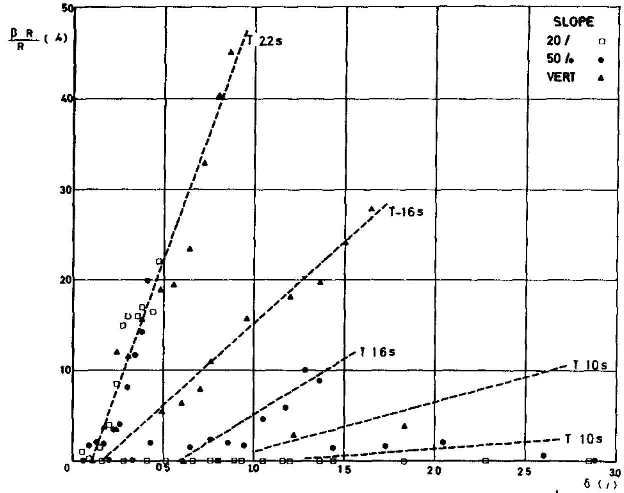
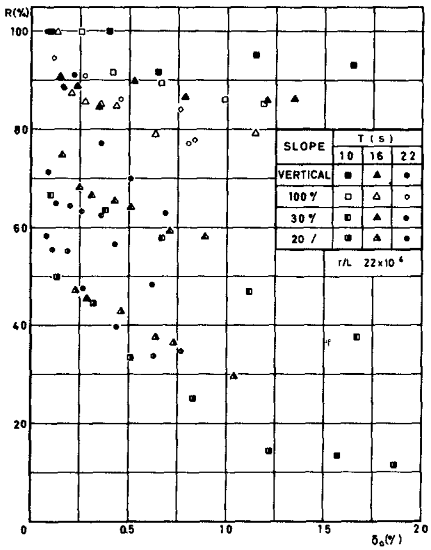
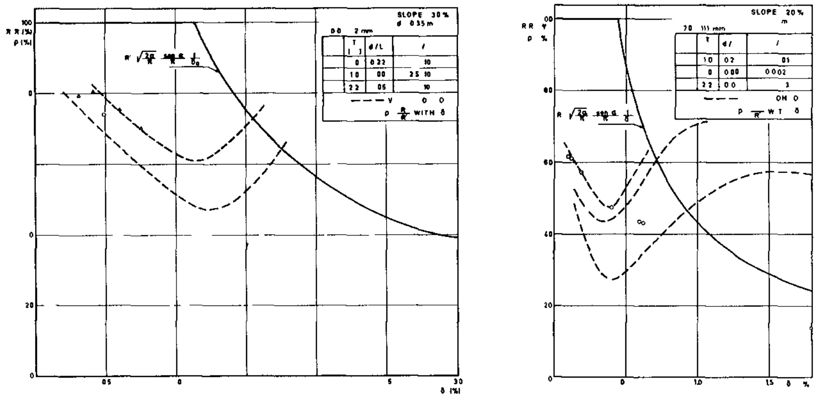


Fig 8 - 2nd order corrections for the reflexion coefficient according to the period and slope



SLOPE	T (s) 10	16	22
VERTICAL	■	▲	●
100 %	□	△	○
30 %	■	▲	●
20 %	■	▲	●

Fig 9 - Reflexion coefficient for the same relative roughness



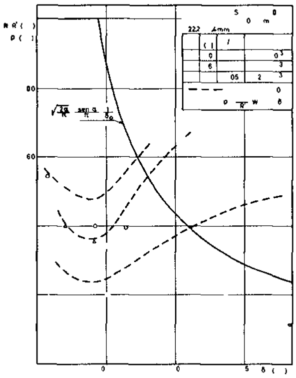


Fig 10 - Variation of ρ with off-shore steepness

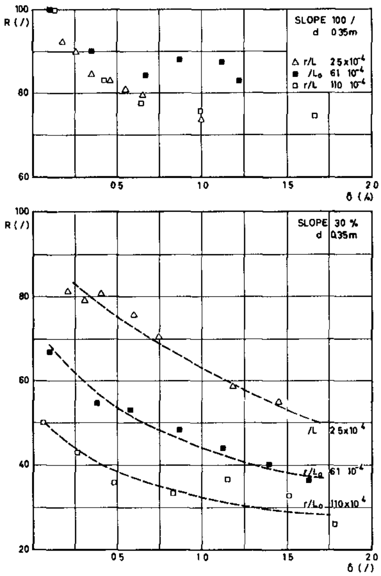


Fig 11 - Influence of roughness on R for different slopes