CHAPTER 96

DAMAGE FUNCTIONS FOR A RUBBLE-MOUND BREAKWATER UNDER THE EFFECT OF SWELLS

Juan B Font
Assistant Professor
College of Engineering, Central University
Caracas, Venezuela

ABSTRACT

In this paper experimental data are given to aid in the design of a rubble-mound breakwater The use of armor damage functions is supported rather than the use of the wave height for the no damage condition Damage curves defined experimentally are proposed, for both rocks and tetrapods, for different wave storm durations and for different placing techniques

A determinant influence of storm duration is found for advanced damage of the armor layers

The experiments with different placing techniques showed that stability coefficients based upon the no damage criteria, do not give a reliable picture of the ultimate strength of a rubble-mound breakwater

INTRODUCTION

The experiments on which this paper is based have been made in a series of research works Hernández, Pastor and Suárez (1968), Loreto (1969), Ibarra and Blumentals (1969) Neri and Santeliz (1970) These researches were accomplished in the Hydraulic Laboratory of the Central University of Venezuela, in partial fullfillment of their Civil Engineer Degree, under the writer's direction

A preliminary paper on the influence of wave storm duration was submitted by the writer to the Eleventh Conference on Coastal Engineering (1968) In that paper were given damage functions por different storm durations with the number of waves as the only parameter A strong dispersion of the experimental data showed the importance of the ratio $H_{1\%} / H_{1/3}$, $H_{1\%}$ being the wave height that caused one percent damage and $H_{1/3}$ the so called significant wave height or mean of the larger one third In this paper new data on wave storm duration is submitted, in which this ratio is also taken as a parameter, thus obtaining a better fitting of the experimental points

The Hudson's design wave height

Since the no damage criteria for rubble-mound breakwater design were defined (Hudson, 1959), most research work on this subject has focused its attention on the initial damage However, it is generally accepted that rubble-mound breakwaters are expected to withstand the design storm with some damage, either reaching equilibrium or being repaired before next storm hits

The deffinition of the design condition for the one percent damage has the advantage of being equivalent to the no damage situation and thus numerically well defined However, the stability of the one percent of the armor rocks that are first displaced, depends largely on random placing and geometrical factors, rather than on the armor capacity as a whole to resist waves Rogan (1968) points out the fact, also observed by the writer, that the filter layers uncovering is simpler to observe and more significant than the number of displaced rocks, specially at the incipient stages of damage In this sense, also the late Iribarren (1965) defined the design criteria based on the total failure of the breakwater Iribarren proposed his most recent formula considering that the failure of the armour depended largely on the slope stability of about six rows of that could slide at the same time Nevertheless, although this type of failure is often present at the final stages of failure, it has been largely induced by the continuous weakening of the armor in the maner considered by Hudson, it est rocks rolling or being lifted one by one

The design using the damage functions

The damage functions, rather than the no damage or total failure conditions alone, should be given to the design engineer, summarizing the afore discussion in the following reasons

1 Economic considerations in one hand and safety factor in the other, usually lead to a design damage different from either the no damage or total failure conditions

2 Neither the no damage or total failure conditions are solely determinant of the safety factor for a given design damage

Both Hudson and Iribarren, in the writings above mentioned, have presented experimental data in the form of damage functions in which the percentage of damage is related to parameters defined by themselves The writer (1968) has proposed to relate the percentage of damage $\Delta\%$ to the ratio $H/H_{1\%}$, H being the wave height that causes the $\Delta\%$ damage, since technical literature is plenty of data for the $H_{1\%}$ selection. This representation also simplifies visual comparison of damage functions for different armor blocks and placing techniques

The experimental data and curves given in this paper are believed to apply specially to the case of decayed swells, since the waves used in the laboratory are periodic waves of intermediate steepness To the writer knowledge, the first reference given to the frecuency spectrum shape influence apeared in a paper by Carstens et Al (1966) It could be said that the shape of the frecuency spectrum is related to the tendency of higher waves to break in front of the breakwater, therefore it is suggested that in future experimentation, related with the non-uniform waves effect on breakwaters, the relation between the significant wave height and the breaker height for the mean wave period at the depth of the structure be considered as a significant parameter In the present experiments this relation was

$$0\,3 < \frac{H_{1/3}}{H_b} < 0\,4$$

H_b being the breaker height corresponding to the wave period and water depth of the tests as computed after the experiments of Danel (1952)

The influence of duration of locally wind generated waves was studied in the laboratory by Rogan (1968) The main conclusion of the latter is that the effect of a local wave storm is similar to that of periodic waves with height equal to the storm significant wave height

INFLUENCE OF SWELL DURATION

Fig 1 Shows the damage functions for rocks and tetrapods in which $\Delta\%$, the percentage of displaced elements, has been related to $H/H_{1\%}$, H being the height of the wave that causes the damage and $H_{1\%}$ the heinght of the wave for the 1% damage, usually defined as the limit of the no damage condition The symbol n refers to the number of waves of the swell The simbol $H_{1/3}$ refers to the significant wave height of swell

Fig 2 Shows the total damage caused by swells of different durations with $H_{1\%}$ / $H_{1/3}$ as parameter H_{max}. reffers to the maximum vave height expected during the storm For storms with more than 3 000 waves the $n = \infty$ curve could be used

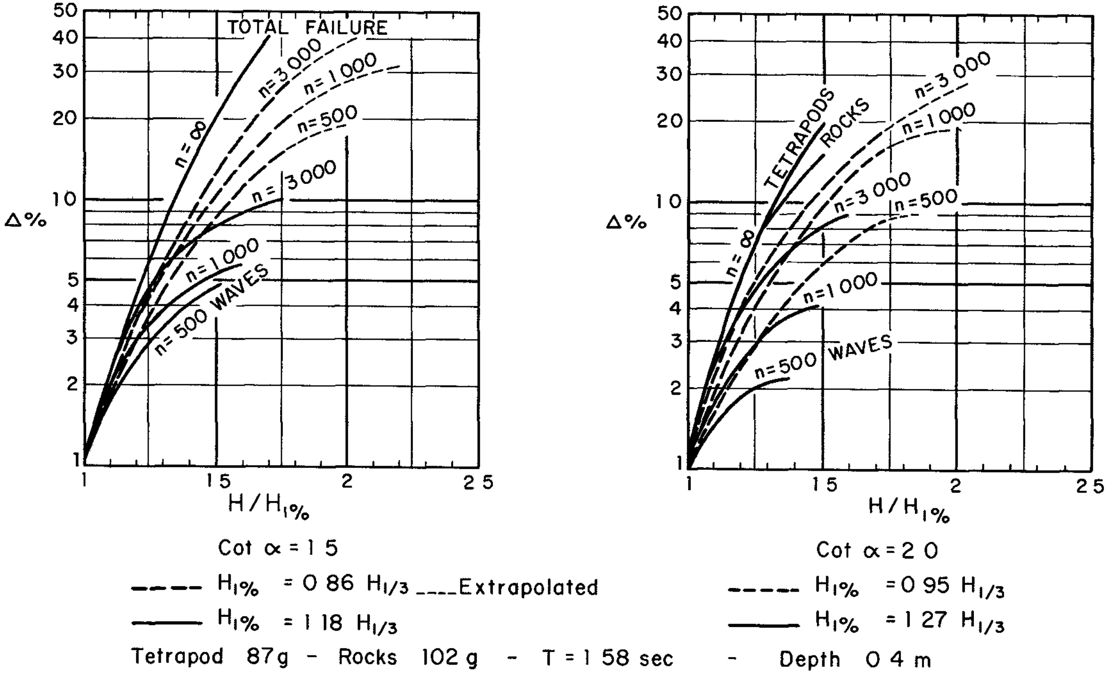
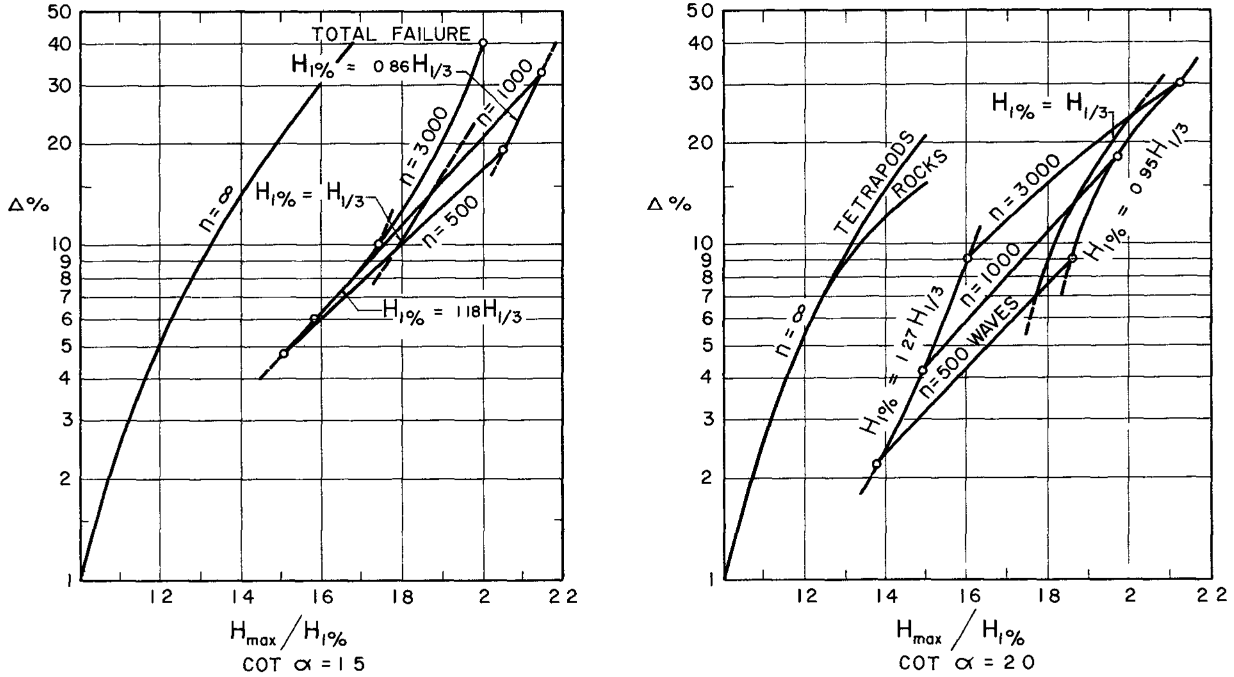


FIG 1 DAMAGE FUNCTIONS FOR ROCKS AND TETRAPODS
INFLUENCE OF SWELL DURATION



TETRAPODS 87 g ROCKS 102 g T = 1 58 sec Depth 0 4 m

FIG 2 TOTAL DAMAGE FOR DIFFERENT DURATION SWELLS

Although a subject for future research, it is believed that design in shallow water, where the largest waves break far from the structure, could be carried using the curves in Fig 1 with H being the maximum active wave height Galvin (1969) has made experiments that may help in the selection of the maximum active wave height

INFLUENCE OF PLACING TECHNIQUES OF ARMOR ELEMENTS

Fig 3 shows the damage functions for rocks and tetrapods using different placing techniques Dashed curves correspond to careless random placing Full curves stand for careful placing, interlocking elements as much as possible

As it is shown by the experimental results, placing makes a big difference for the initial damage, but is less relevant for advanced damage, when the armor porosity and " dynamic" stability are essential

DAMAGE DISTRIBUTION ALONG BREAKWATER SLOPE

Fig 4 Shows the average damage distribution curve of four sets of experiments, with the 1 1 5 slope for both rocks and tetrapods It is seen that while at the beginning the the damage mostly occurs below the still surface level, for larger waves the portion inmediately above that level is also strongly affected As a matter of fact it is in this region where uncovered filter first appears

THE ARMOR DENSITY COEFFICIENT

Usually the kind of armor block to be used in a breakwater (rock, tetrapod, tribar, tetrahedron, dolos, stabit, etc), as well as the constructive method (dumping, placed by crane, placed with special techniques, etc), are selected taking into account economic and functional considerations It is sometimes difficult, however, to make economic comparisons since authors do not give enough data, restricting it usually to the Hudson's Coefficien K_d, which is only indicative of the block weight and not of the volume required to cover a given breakwater slope area

In order to adopt a standard terminology and to simplify the economic design, the following coefficients and expresions are proposed

If we call A_t the area of the breakwater slope tributary to one block, then

$$A_t = \frac{\text{Area}}{\text{Number of blocks}}$$

In order to give this area in a dimensionless manner,

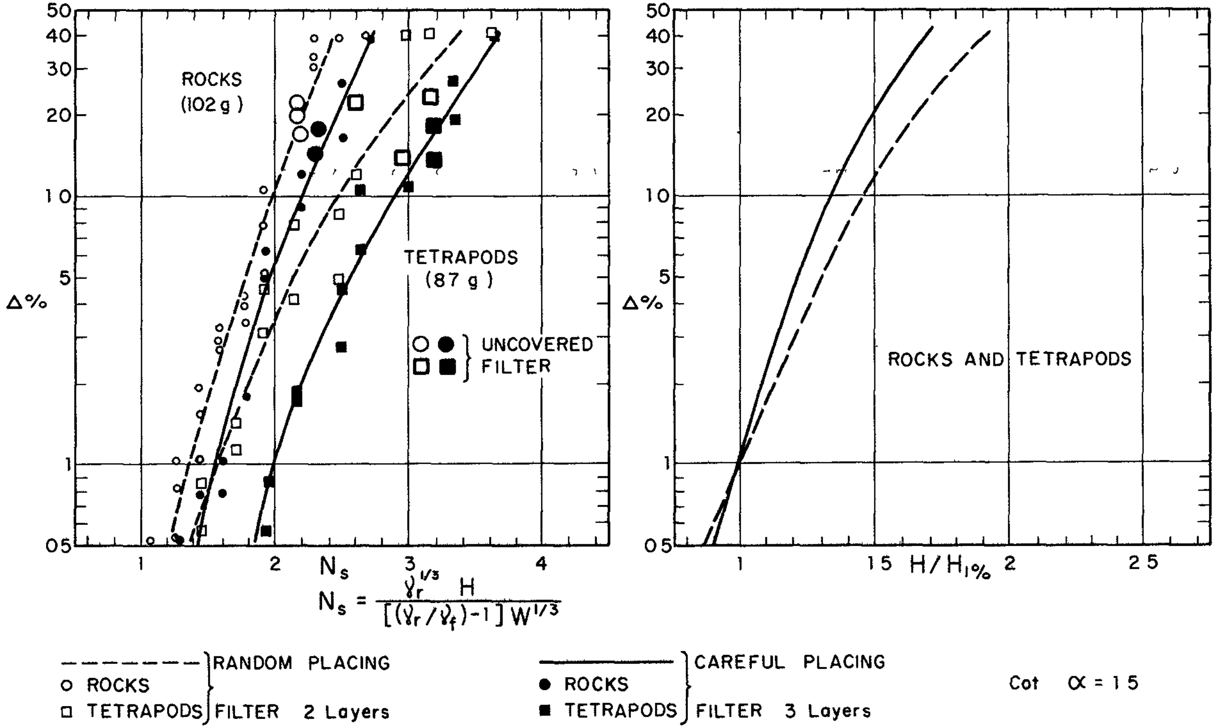


FIG 3 DAMAGE FUNCTIONS FOR DIFFERENT PLACING TECHNIQUES

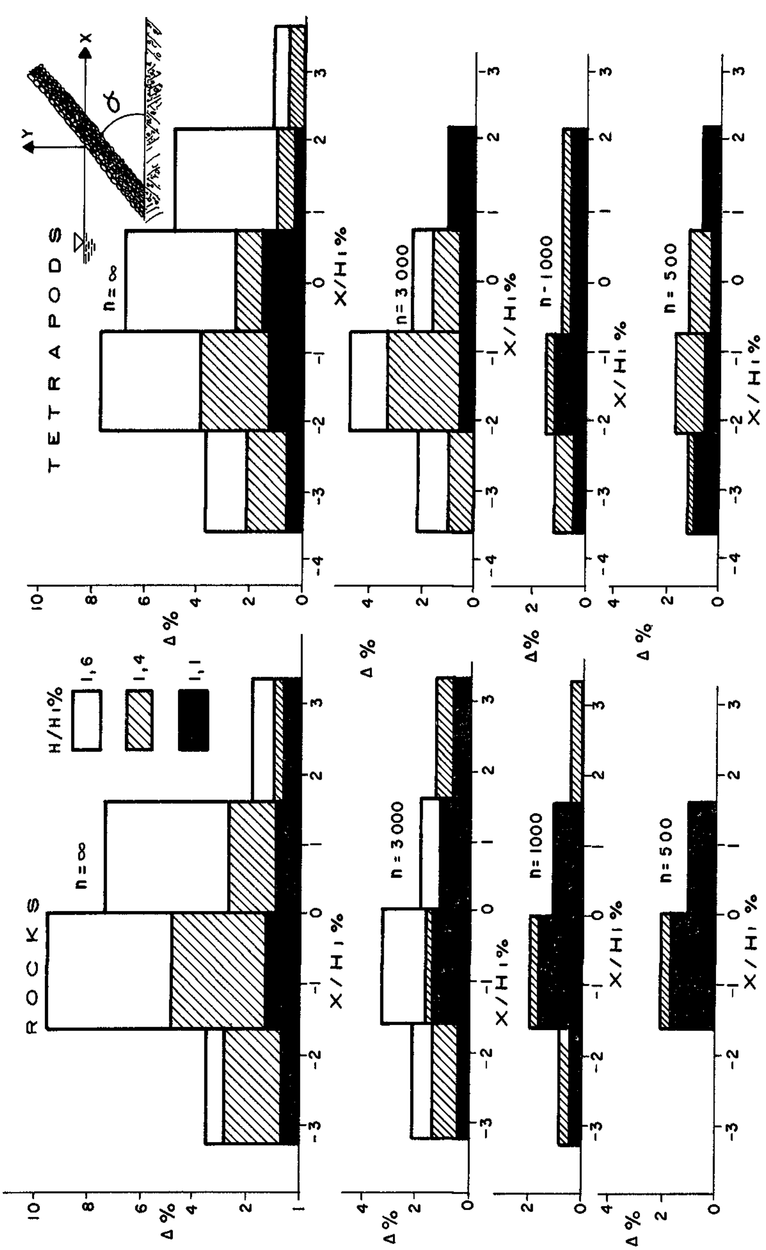


FIG 4 DAMAGE DISTRIBUTION ALONG BREAKWATER SLOPE COT α = 1 5 (MEAN OF TWO TESTS)

it may be defined the " revetment unit " U_r such that

$$U_r = \frac{A_t}{V^{2/3}} = \frac{A_t}{(W/\gamma_r)^{2/3}}$$

Where V is the solid volume of one block, W its weight and γ_r its specific weight

In the experiments reported in this paper, corresponding to the carefull placing technique, the mean values for U_r were

Tetrapods 1,00 Rocks 0 95

Since the specific gravity of rocks is usually 2 7 and that of concrete 2 2 , it may be defined a coefficient K_s such that

$$\frac{W}{A_t} = \frac{1}{K_s} \frac{\gamma_t H}{\cot g \alpha}$$

Where γ_t is the water specific weight In this manner the required weight per unit area would be inversely proportional to K_s for a given breakwater slope and wave height

If K_s is related with Hudson's formula

$$W = \frac{\gamma_r H^3}{K_D \left[(\gamma_r / \gamma_t) - 1 \right]^3 \cot g \alpha}$$

Then the following expressions result

$$K_s = \frac{\gamma_t H U_r}{\gamma_r^{2/3} W^{2/3} \cot g \alpha} = \frac{K_D \gamma_t \left[(\gamma_r/\gamma_t) - 1 \right]}{\gamma_r^{5/3}} \frac{U_r W^{2/3}}{H^2}$$

K_s could be named " Armor density coefficient "

In Fig 5 the " armor density coefficient " has been plotted against the damage percentage Δ % for both rocks and Tetrapods It is also shown a sample of economic comparison of both kinds of blocks for a 10% damage design It is readily seen that a price per unit weight of tetrapods 1 26 times the price per unit weight of rocks will make both blocks economically equivalent for that condition.

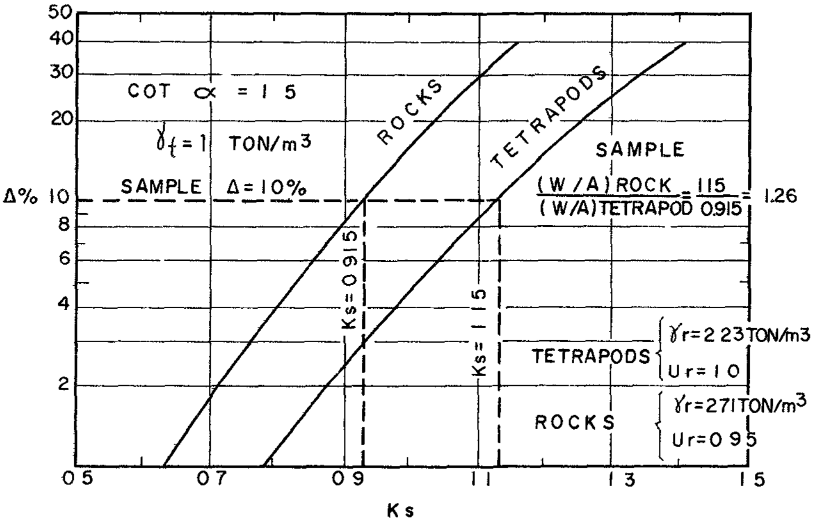


FIG 5 STABLE DENSITY COEFFICIENT (CAREFUL PLACING)

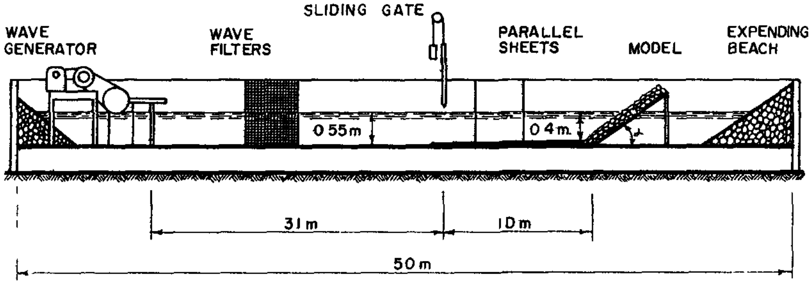


FIG 6 WAVE CHANNEL AND EXPERIMENTAL SET-UP

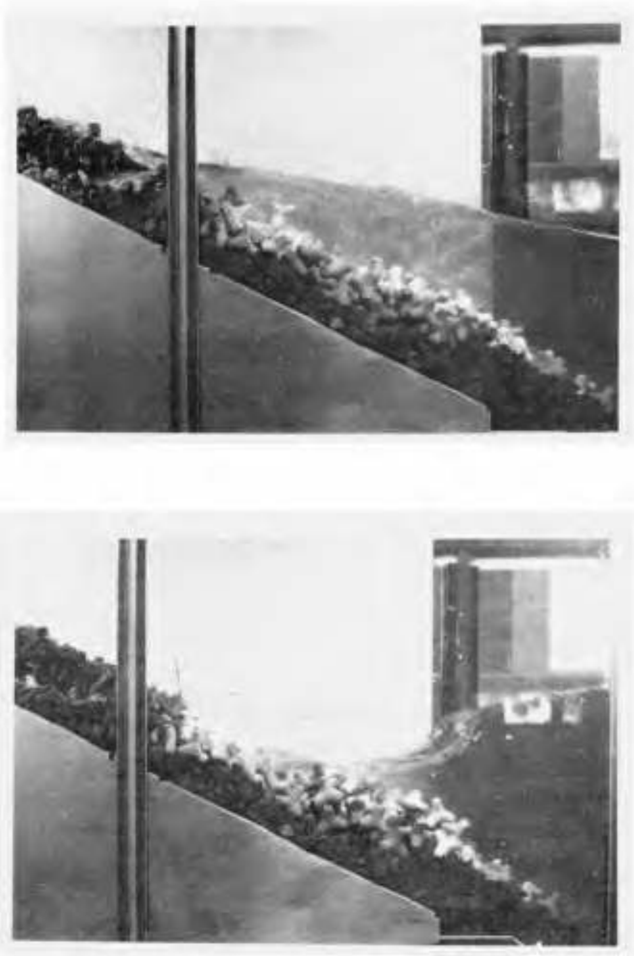


FIG. 7 WAVE ACTION ON THE MODEL BREAKWATER

DESCRIPTION OF THE EXPERIMENTAL WORK

The tests

For the limited duration storms the model breakwater was subjected to the attack of periodic waves of height and in number according with the known statistical distribution for actual swells (Putz, 1954) See in Fig 13 the wave height histograph actually used in the experiments In Fig 12 are shown records of a typical uniform wave train and a train of " three waves ", it est a train with three larger waves of mean height 2 7 times the mean wave height, as specified in the 1000 waves histograph

For the infinite duration swells, waves of a given height attacked the breakwater until equilibrium was reached Then the displaced blocks were counted and, without rebuilding the slope, the experiment followed increasing the wave height in steps of about one centimeter The test were conducted in bursts such that reflection from the breakwater would not interfere with wave generation; furthermore, a slide gate, close to the model, was used to interrupt the " last wave " of the train that is up to 20% larger than the preceeding waves In terms of Hudson's formula, a 10% difference in wave height means 33% difference in the stability coefficient Kd

The core of the breakwater was considered to be impervious and, as such, a board with stripes was used Completely different results are expected if a core with significant porosity were used

It was observed (See Fig 7) that all waves that caused some damage broke on the breakwater slope in the manner of a collapsing breaker as defined by Galvin (1969)

The Experimental Set - up

See fig 6 for a description of the experimental Set - up

CONCLUSIONS

1 For the initial movement of rocks and tetrapods it seems that the duration of the swell is not important The duration becomes relevant for advanced damage (See Figs N° 1 and 2)

2 Economic considerations in one hand and safety factor in the other, usually lead to a design damage different from either the no damage or total failure conditions Therefore the damage functions, rather than those criteria, should be given to the design engineer.

3 The experiments show that placing techniques of the armor blocks make a big difference for the initial damage, but are less relevant for advanced damage, when the armor porosity and " dynamic" stability are essential (See Fig 3.)

4 Uncovering of the filter layers in holes of diameter equal to two pieces ocured for armor damage percentages between 10% and 20% Usually, in the next wave height step, total failure would follow for damage between 30% and 40% (See Fig 3)

5 It was observed in the experiments that while at the beginning the damage mostly occurs below the still surface level, for larger waves the portion inmediately above that level is also strongly affected (See Fig 4)

ACKNOLEDGMENTS

Financial support for this research was provided by the "Consejo de Desarrollo Científico y Humanístico" of the Central University of Venezuela through the research project N° 273 The author is also grateful for the assistance given by the Ministry of Public Works, Ports and Airports Division, in the preparation of this report

REFERENCES

Carstens, T , A Torum and A Traetteberg, "The stability of rubble mound breakwaters against irregular waves", Proc Tenth Conference on Coastal Engineering, A S C E , 1966, Volume II,pp 958-971

Danel,Pierre, "On the limiting clapotis", Gravity Waves, National Bureau of Standards Circular N° 521 (November, 1952), 35-38

Font, Juan B. "The effect of storm duration on rubble-mound breakwater stability", Proc 11 th Conference on Coastal Engineering, A S C E., 1968, pp 779-786

Galvin, Cyril J "Breaker Travel and Choice of design wave height", proceedings, Journal of the Waterways and Harbors Division, ASCE, Vol 95, N° WW 2, May, 1969, pp 175-200

Hernández, Pastor and Suárez " Estabilidad de rompeolas de roca," Graduation Research, Hydraulic Laboratory, Universidad Central de Venezuela, Aug, 1968

Hudson, Robert Y , "Laboratory investigation of rubble-mound breakwaters", J Waterways Harbors Div ASCE, 85, WW 3, paper N° 2171 (September, 1959) 93-121

Iribarren, R , "Formule pour le calcul des diques en enrochements Naturels ou elements artificiels" XXIst International Navigation Congress - Stokholm, 1965, P I A.N C,

Ibarra E and T Blumentals, " Estabilidad de Rompeolas ", Graduation Research, Hydraulic Laboratory, Universidad Central de Venezuela, Dec , 1969.

Loreto R., Alberto " Estabilidad del Talud de un Rompeolas de Roca,"Graduation Research, Hydraulic Laboratory, Universidad Central de Venezuela, May, 1969

Neri, Lucila and Yandira Santeliz " Estabilidad de la Coraza de Rompeolas de Roca y Elementos de Concreto ", Graduation Research Hydraulic Laboratory, Universidad Central de Venezuela, July, 1970

Putz, R R , "Statistical analysis of wave records" Proc Conference on Coastal Engineering, Berkeley, Calif , The Eng Foundation Council on wave Res, 1954 pp 13-24

Rogan, Adelkis J " Destruction Criteria for rubble-mound breakwaters " Proc. 11th Conference on Coastal Engineering, ASCE, 1968, pp 761-778

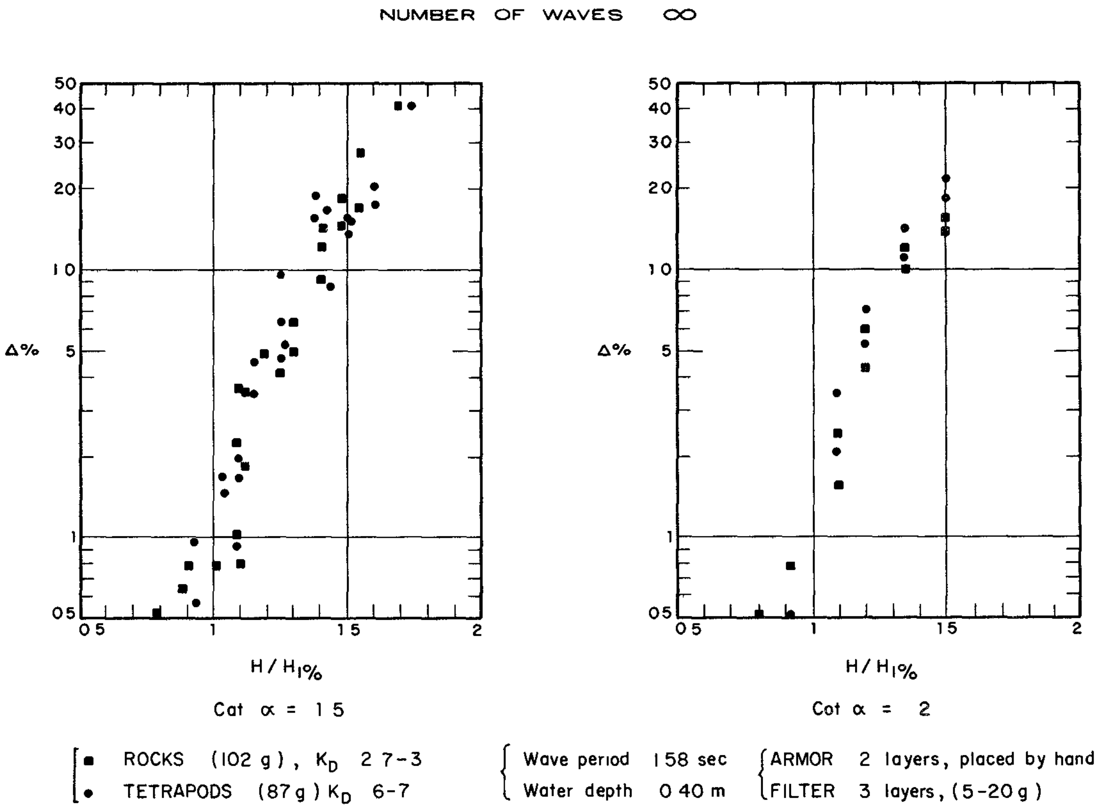
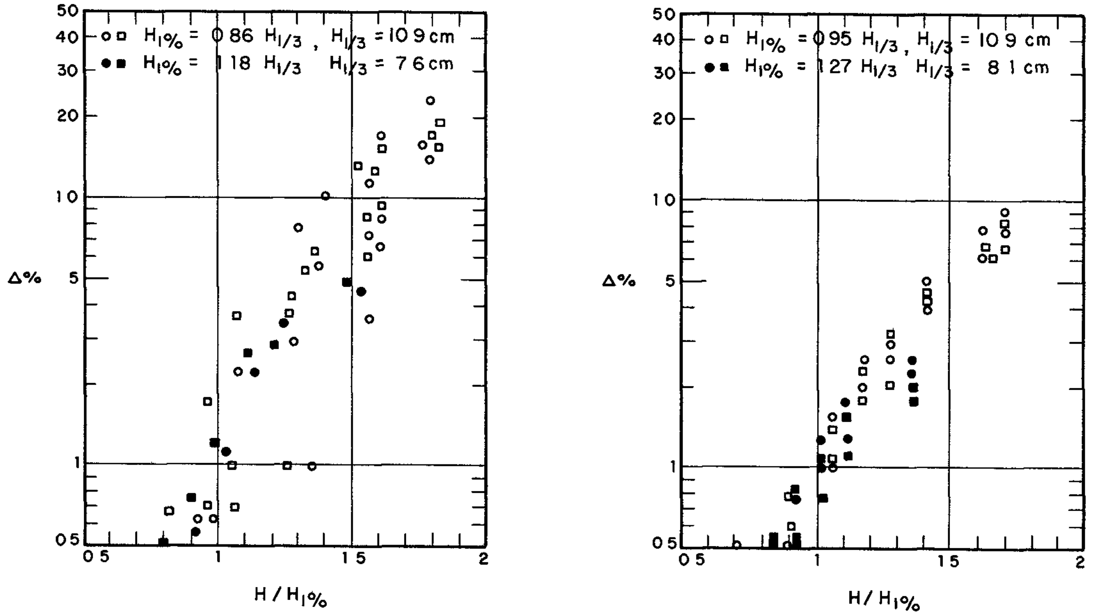


FIG 8 EXPERIMENTAL DATA

NUMBER OF WAVES 500



Cat α = 1 5

Cat α = 2

[■ □ ROCKS (102 g) , K_D 2 7 - 3
● ○ TETRAPODS (87 g) K_D 6 - 7

Wave period 1 58 sec
Water depth 0 40 m

ARMOR 2 layers, placed by hand
FILTER 3 layers, (5-20 g)

FIG 9 EXPERIMENTAL DATA

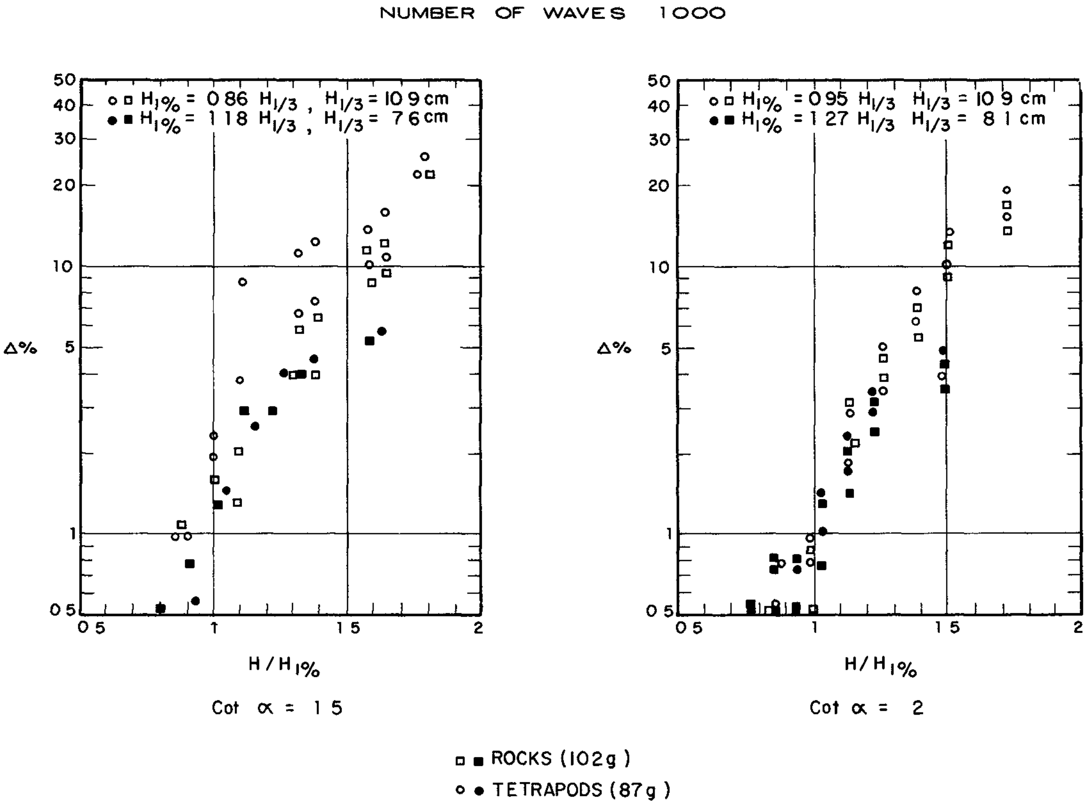


FIG 10 EXPERIMENTAL DATA

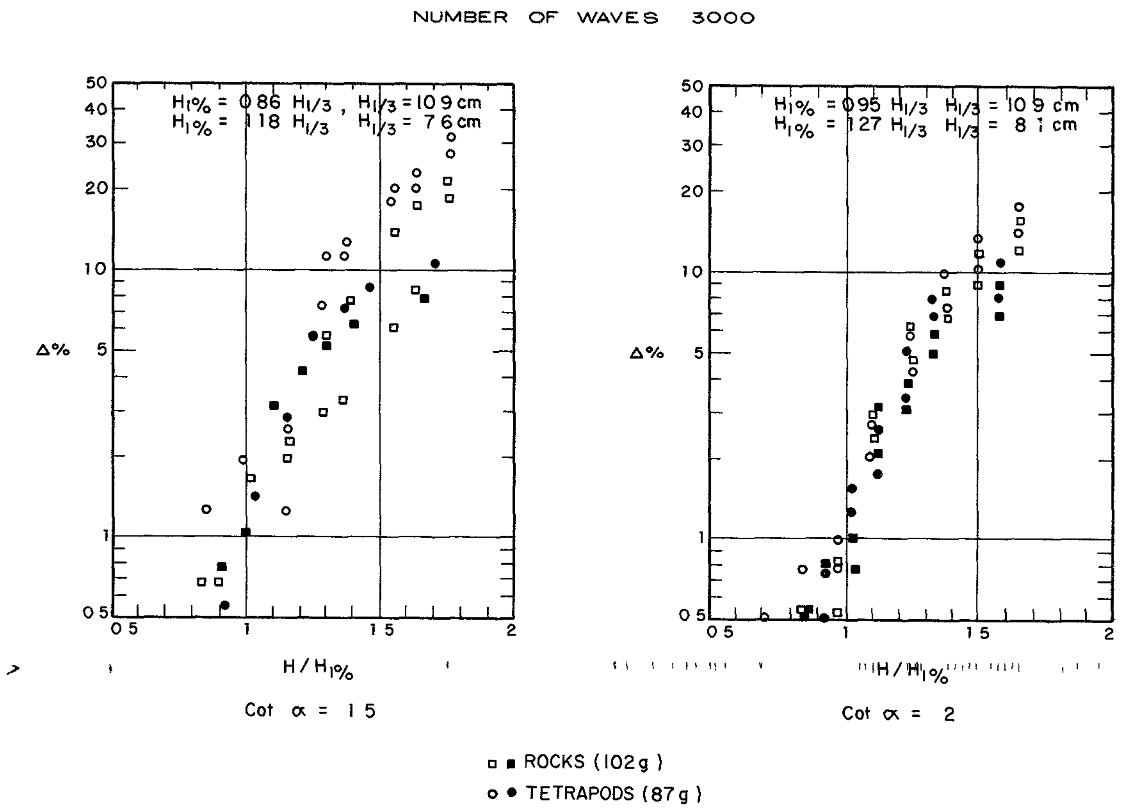


FIG 11 EXPERIMENTAL DATA

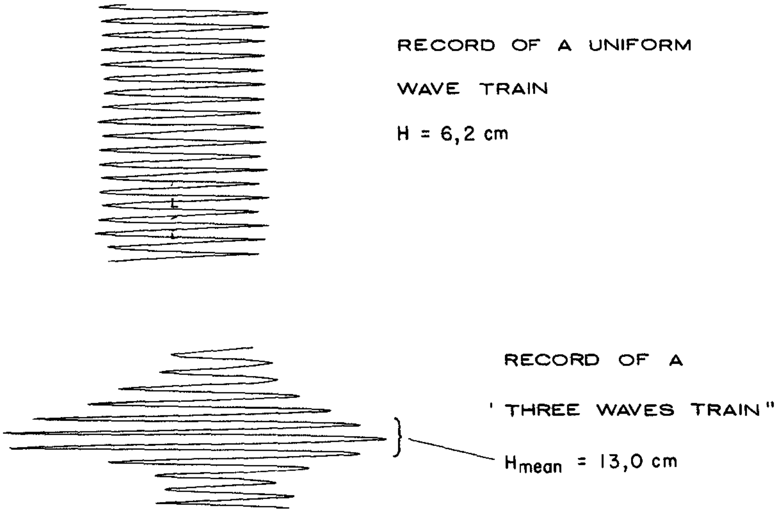


FIG 12 SAMPLE WAVE RECORDS

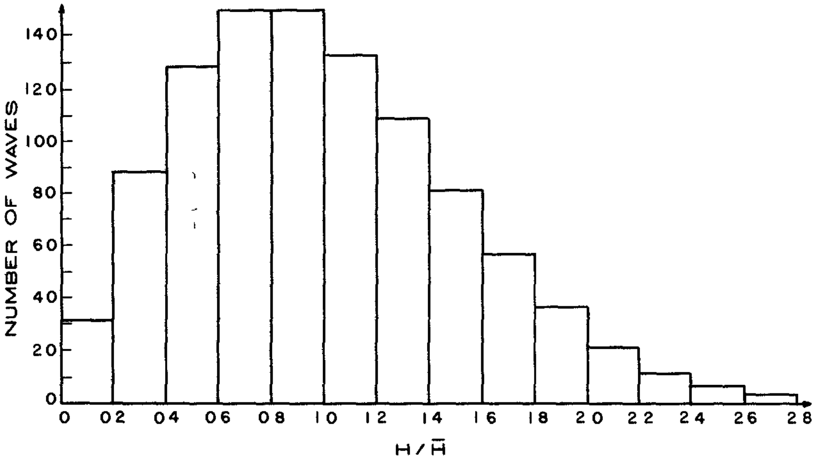


FIG 13 WAVE HEIGHT HISTOGRAM FOR 1000 WAVES