CHAPTER 49

DESTRUCTION CRITERIA FOR RUBBLE-MOUND BREAKWATERS

By Adelkis J. Rogan, Docteur Ingénieur
Laboratoire National d'Hydraulique, Chatou, FRANCE.

ABSTRACT

The general purpose of the author's research undertaken in the "Laboratoire National d'Hydraulique" was to study wave action on rubble-mound breakwaters with regular (periodic) waves on the one hand and irregular (random) wind generated waves on the other, and to compare the effects of these two types of waves by use of the storm duration t. With a first series of periodic waves experiments we have obtained the destruction of the breakwater's cover-layer for different storm durations t, by varying H and T. The mass of armor units remained constant. The angle of the slope, according to the seaward equilibrium profile could be considered as constant.

For the destruction cases we obtained a risk criterion:

$$\frac{t}{T} = - A.\log\left(\frac{H^2}{\nu T}\right) + B$$

which provides the storm duration t, knowing H, T and ν.

Then for a second series of random wind generated waves experiments we eliminated t and found that the constant periodic wave height ($H_{dest.}$) is equal to the "significant wave height" ($H_{1/3}$) for the random waves. This is an experimental demonstration of the justifiable use of $H_{1/3}$ as "project wave height".

1. INTRODUCTION

1.1. Analysis of Classical stability formulas.

First of all an analysis of classical empirical and semi-empirical stability formulas was necessary to show the importance of some variables and the absence of others. Thus formulas of CASTRO, IRIBARREN, MATHEWS, EPSTEIN and TYRELL, IRIBARREN and NOGALES, RODOLF, LARRAS, IRIBARREN (modified by HUDSON), HEDAR, HENNES and LEONOFF, BEAUDEVIN, HUDSON (or W.E.S. formula) have been analysed and were adapted to "L.N.H." commonly used notation. Afterwards, they were transformed to show common parameters and to verify their dimensional homogeneity (1). Only two of them are homogeneous: IRIBARREN's (modified by HUDSON) and HUDSON's formulas. Stability formulas have the following general aspect:

$$M = H^3.F$$

where $F = k.f_1\ (\delta).\ f_2\ (\alpha)\ ....$

Two of them (the formulas of MATHEWS and RODOLF) have the aspect $M = H^2.T.F$, but they are not used in practice.

The stochastic character of waves and the time of action, or otherwise storm duration, do not appear in the previous formulas. On the other hand, engineers use more and more the "significant wave height" $H_{1/3}$ as "project wave height" for maritime structures.

1.2. Main purpose.

The main purpose was to introduce the "time of action" t (or storm duration) into the consideration of rubble-mound breakwater's stability and to verify experimentally the empirical and theoretical (2,3) assumption that $H_{1/3}$ is really the representative and afterwards destructive mean wave height value of a random sea.

The reasoning below was followed prior to laboratory experimentation on multi-layered breakwaters:

(a) Cover-layer's profile can be modified till stabilization. When second layer is reached then destruction is imminent. Smaller armor units of the second cover-layer can no longer resist wave attack.

(b) It is easier to observe the complete destruction of the cover-layer than to measure the number of displaced armor units.

(c) Wave height or period of random waves are not known a priori. Duration of wave action on the breakwater is the only parameter for comparison between periodic and random waves.

Therefore we have chosen as a criterion of comparison the complete destruction of the cover-layer in the same time, obtained one time from periodic waves (H and T constant) and another time from random waves (H_i and T_i random values). Thus, eliminating the parameter t, H and H_i can be compared as well as T and T_i.

Figure 1 shows the general configuation of "L.N.H." research facilities as well as pertinent dimensions in meters.

1.3. Similitude.

The assumption was made that the inertia forces are very much larger than viscous forces. In general, similitude of the two flows with free surface requires two conditions:

$$F_1 = F_2$$

$$R_1 = R_2 \text{ (or in default of: } R_1 \gg R_c \text{ and } R_2 \gg R_c).$$

For our investigation we used the FROUDE-REECH condition, which is essential for model studies in open channels with strongly turbulent flows. Nevertheless, we did not throw aside the assumption of the importance of the condition of REYNOLDS. The dimensions of the model were sufficiently small that infiltration or percolation flows accompany the wave attack on armor units.

The scale 1:40, has been chosen according to the dimensions of "L.N.H." research facilities. Specific gravity of water used during experimentation was assumed to be equal to 1.00. Difference of specific gravity between model water (1.00) and sea water (1.026 - 1.029, according to salinity) is big enough to be important if model investigation is related to field construction (4). Our study was theoretical; therefore we did not take the difference into account. The mass per unit-volume of armor units was

$$\rho_s = 2.6 \text{ t/m}^3$$

2. PERIODIC WAVES

2.1. Introduction.

The variables H and T were constant during each experiment and the following values were chosen for these variables:

H = 0.05, 0.075, 0.10, 0.125 m. (i.e. 2, 3, 4, 5 m. in nature) approximately.

T = 0.948, 1.265, 1.581, 1.897 sec. (i.e. 6, 8, 10, 12 sec. in nature).

It was easy to set the wave generator at the period desired with the channel empty. Afterwards, the model was constructed, the channel filled with water to the level 0.35 m. (corresponding to 14 m. in nature), the resistance type wave gauges calibrated and, then the generator started. The wave height was increased from zero to the desired value and then remained constant during the whole experiment.

2.2. Model.

Figure 2 shows one of the breakwater profiles studied. It is a type commonly employed with three cover-layers. The same armor units of specific gravity 2.6, weighed one by one and arranged always in the same way, have been used throughout all experiments.

Particle size distributions used for each layer were:

A = 50 - 80 g. (i.e. 3 - 5 t in nature) with $A_m \simeq 63$ g. (i.e. 4t).

B = 20 - 50 g. (i.e. 1.5 - 3 t in nature) with $B_m \simeq 37$ g. (i.e. 2.36 t).

C = 5 - 25 g. (i.e. 0.32 - 1.6 t in nature) with $C_m \simeq 11$ g. (i.e. 0.7 t).

Where A_m is the median of A, B_m of B and C_m of C.

The middle-layer armor units were coloured blue. The colouring made it easier to know the moment at which the middle-layer was reached in the process of destruction.

Water depth on the sea side was always constant and equal to 0.35 m. (i.e. 14 m. in nature). The angle of breakwater slope varied from 30 to 36 degrees in steps of 2 degrees.

2.3. Experiments with periodic waves.

Every experiment lasted, as a rule, 3 hours 45 minutes (i.e. 24 hrs. in nature) if the cover-layer was stabilised. If the destruction of the cover-layer was achieved before 3 hrs. 45 min., we stopped the experiment. If the destruction was imminent around 3 hrs. 45 min., we prolonged the experiment until complete destruction was obtained. Sixteen experiments were made for every angle of breakwater slope: 4 for every wave period (0.948, 1.265, 1.581, 1.897 sec.) for each wave height,(0.05, 0.075, 0.10, 0.125 m. approximately).

Some experiments were omitted when no influence of the breakwater slope was obtained (for instance for H = 0.05 m. and T = 0.948 sec.). At the end of the experiment we drew the new profile on the glass-wall and we photographed it. The destruction of the cover-layer was obtained in 13 cases.

Ten minutes after the waves were fully developed, a record of the clapotis between the model and the wave generator was made. From this record we obtained the value of H, which we will later compare with the destructive mean value of the irregular wave height.

2.4. Seaward equilibrium profile.

During the first minutes of every experiment we observed the tendency of attacking waves to move armor units from the upper portion of the slope to the lower portion. After some minutes a new profile was "carried" on the seaward face of the breakwater (Figure 3, profile DA BC). The new discontinuous slope was composed of three different slopes, one of which (the slope AB) was flatter than the initial one.

From this moment onwards, the destruction of cover-layer progressed, with a good approximation, parallel to the new slopes. Comparison between corresponding slopes for various tests (1, section 4.33) shows no big differences between them. Their mean values were:

$$\tan\alpha_1 = 1/1.059, \quad \tan\alpha_2 = 1/2.627, \quad \tan\alpha_4 = 1/1.278$$

$$\alpha_1 \simeq 43 \qquad \alpha_2 \simeq 21 \qquad \alpha_4 \simeq 38$$

Therefore profiles with different slopes of 30, 32, 34, and 36 degrees were transformed, after a few minutes, to an identical discontinuous seaward profile; i.e. to an identical reflection slope for incident waves. Thus, values measured during all these experiments have been used together for calculations.

2.5. Characterization of the risk of cover-layer destruction.

a) Study of parameters: $Y = \log\left(\frac{H^2}{\nu T}\right)$ and $X = \frac{t}{T}.10^{-3}$

We first specify r as the sample coefficient of correlation and as the value for the true bivariate distribution of Y and X.

We obtained destruction of the cover-layer in 13 cases (n = 13). Thus we have studied the coefficient r for the bivariate distribution of dimensionless functions Y and X, of parameters measured during the above experiments (5). Pursuing the calculation of Table 1, we obtained:

$$\sigma_x^2 = \frac{D_x}{n^2} = 7.297 \qquad \sigma_x = 2.701$$

$$\sigma_y^2 = \frac{D_y}{n^2} \qquad \sigma_y = 0.063$$

$$C = n\cdot\Sigma XY - \Sigma X\cdot\Sigma Y = -23.008$$

$$\text{and} \quad r = \frac{C}{\sqrt{D_x D_y}} = -0.796 \qquad = -0.796$$

We will now test its significance with the Z - Transformation of FISHER:

$$Z = {}^1/_2 \log\left(\frac{1 + r}{1 - r}\right)$$

which is distributed approximately according to a GAUSS law of expectation:

$$\xi = {}^1/_2 \log\left(\frac{1 + \rho}{1 - \rho}\right)$$

and standard deviation:

$$\sigma = \frac{1}{\sqrt{n-3}}$$

For r = - 0.796 we obtained Z = - 1.088 and for n = 13 : $1/\sqrt{n-3} = 0.3164$

If no real correlation exists for the true bivariate distribution of Y, X (i.e. $\rho = 0$), the variable $u = Z/\sigma$ is distributed according to a unit normal distribution, then u = - 3.44.

The probability of findin a value less than or equal to u = - 3.44, if $\rho = 0$, is equal to 0.0003, i.e. $\Pr(u \leqslant -3.44 \,/\, \rho = 0) = 0.0003$. Thus the correlation observed in our sample corresponds to a strong one for the true bivariate distribution of Y and X.

TABLE 1

	T (sec.)	H (m)	H^2	$\frac{H^2}{\nu T}$	t (sec.)	$X = \frac{t}{T}.10^{-3}$	$Y = \log \frac{H^2}{\nu T}$	X^2	Y^2	X.Y
F510	10	4,37	19,0969	$1,90969.10^6$	$86,4.10^3$	8,64	6,280942	74,649589	39,450233	54,267333
F412	12	4,58	20,9764	$1,7480.10^6$	$86,4.10^3$	7,2	6,242541	51,840003	38,969314	44,946296
F512	12	5,095	25 9590	$2,1632.10^6$	$7,2.10^3$	0,6	6,335096	0,36	40,133438	3,801057
G510	10	5,365	28,7832	$2,87832.10^6$	$14,4.10^3$	1,44	6,459136	2,073599	41,720436	9,301155
G412	12	4,60	21,1600	$1,7633.10^6$	$50,4.10^3$	4,2	6,246326	17,640003	39,016586	26,234571
G512	12	5,05	25,5025	$2,1252.10^6$	$10,8.10^3$	0,9	6,327399	0,81	40,035976	5,694659
H58	8	4,31	18,5761	$2,3220.10^6$	$64,8.10^3$	8,1	6,365862	65,610008	40,524196	51,563484
H510	10	4,315	18,6192	$1,86192.10^6$	$10,8.10^3$	1,08	6,269956	1,166399	39,312351	6,771552
H412	12	5,095	25,9590	$2,1632.10^6$	$43,2.10^3$	3,6	6,335096	12,960000	40,133438	22,806346
H512	12	5,025	25,2506	$2,1042.10^6$	$25,2.10^3$	2,1	6,323086	4,410000	39,981414	13,278481
158	8	4,55	20,7025	$2,5878.10^6$	$21,6.10^3$	2,7	6,412930	7,29000	41,125671	60,602188
1510	10	4,53	20,5209	$2,05209.10^6$	$54,0.10^3$	5,4	6,312177	29,16000	39,843582	34,085758
1512	12	4,585	21,0222	$1,7518.10^6$	$19,8.10^3$	1,65	6,243484	2,722499	38,981094	10,301748
$\nu = 10^{-6}\ m^2/sec.$		n = 13		$n^2 = 169$		$\Sigma X =$ 47,81	$\Sigma Y =$ 82,154031	$\Sigma X^2 =$ 270,6921	$\Sigma Y^2 =$ 519,227729	$\Sigma X.Y =$ 300.367350

$\overline{X} = \frac{\Sigma X}{n} = 3,677692$ $\quad (\Sigma X)^2 = 2285,795898$ $\quad n\Sigma X^2 = 3518,997313$ $\quad n \cdot \Sigma XY = 3904,775590$

$\overline{Y} = \frac{\Sigma Y}{n} = 6,319540$ $\quad (\Sigma Y)^2 = 519,227729$ $\quad n\Sigma Y^2 = 6749,960449$ $\quad \Sigma X \cdot \Sigma Y = 3927,783691$

$D_x = n\Sigma X^2 - (\Sigma X)^2 = 1233,201415;$ $\quad D_y = n\Sigma Y^2 - (\Sigma Y)^2 = 0,677246;$ $\quad D_x D_y = 835,180725;$ $\sqrt{D_x D_y} = 28,899494$

The linear regression of X on Y is:

$$X = b.Y + a$$

with approximately : $b = \frac{C}{D_y} = -34$

and $a = \bar{X} - b\bar{Y} = 218$

so that (Fig. 4) : $\frac{t}{T} = -34.10^{-3} \log\left(\frac{H^2}{\nu T}\right) + 218.10^3$ (1)

Equation (1) allows the theoretical prediction of a mean value of X for a given value of Y. But this value depends on the particular sample to which the regression curve was fitted. The values of the sample are subject to random fluctuations, so that we must estimate the variance of random fluctuation resulting for X, in order to ultimately estimate its confidence interval (6):

$$s_x^2 = \left[\frac{1}{n} + \frac{(Y-\bar{Y})^2}{\Sigma(Y_i-\bar{Y})}\right] S_2^2$$

where n is the number of variables of our sample and

$s_2^2 = \frac{1-r^2}{n-2}\sum(X_i-\bar{X})^2$ is the estimate of the conditional variance.

But if we are willing to consider X, not as a mean value for Y, but as a forecast of the particular value which X obtains, we have to add the proper variance of X (conditional variance S_2^2) to this variance of the linear regression curve:

$$s_x^2 = \frac{1-r^2}{n-2}\sum(X_i-\bar{X})\left[\frac{1}{n} + \frac{(Y-\bar{Y})^2}{\Sigma(Y_i-\bar{Y})^2} + 1\right]$$

or: $$s_x^2 = (1-r^2)\frac{n-1}{n-2}\,\sigma_x^2\left[\frac{1}{n} + \frac{(Y-\bar{Y})^2}{(n-1)\sigma_y^2} - 1\right]$$

The predicted value of X for a given Y is approximately distributed according to a GAUSS law; its standard deviation we have given above. The tables of the GAUSS law give the reduced limits of intervals, which cover the true value with a given probability. Limits of a confidence interval for a probability P = 0.95 are: $\pm 1.96\, S_x$. It is easy to plot the two curves of limits:

$$F(Y) = \pm 1.96.\ \sigma_x\sqrt{(1-r^2)\frac{n-1}{n-2}\left[\frac{1}{n} + \frac{(Y-\bar{Y})^2}{(n-1)\sigma_y^2} + 1\right]}$$

$$= \pm 3.35\sqrt{1.077 + \frac{(Y-6.319)^2}{0.048}}$$

b) <u>Study of parameters</u>: $Y = \log\left(\frac{H}{gT^2}\right)$, $X = \frac{t}{T}\cdot 10^{-3}$

According to the same argument we obtained:

$$r = 0.336$$

r is too small, therefore we cannot have any conclusion about the real coefficient of correlation of the true bivariate distribution of Y and X.

c) Conclusion

The equation: $\frac{t}{T} = - A.\log \frac{H^2}{\nu T} + B$ permits us to determine the time t needed for the destruction of the cover-layer, knowing H, T and ν. The parameter t/T can also be considered as an index of fatigue of the structure: period T is constant for periodic waves, therefore t/T represents the number of shocks received by the structure till its destruction. We ascertained also that the parameter $H^2/\nu T$ is strongly correlated with t/T, whereas H/gT^2 is not.

Further analysis of the strong correlation between $H^2/\nu T$ and t/T, recalling at the same time that H^2 is an energy factor, we conclude from this equation that we can relate wave energy to wave period and storm duration.

3. RANDOM WIND GENERATED WAVES

3.1. Production of wind waves.

Random waves were induced by an air flow over a fetch of 30 m - maximal length. Water depth was, as for the periodic waves, 0.35 m. and wind speeds up to 9.4 m/sec. were obtained. We observed during the first tests, that a constant wind flow over the water surface generated quite periodic waves. After some investigations (1, section 5.31) we connected to the blower's motor an electro-mechanical system, which produced different cycles of start-off and stops. With this system and the variation of wind velocity and fetch we obtained a sufficient variety of wave heights and periods. Surface elevations were measured, with the help of a sonar, every 0.1 sec. and punched on a paper tape. A resistance type wave gauge placed at the same location gave an immediate picture of the waves.

3.2. Experiments with wind generated waves.

The purpose of this series of experiments was to destroy the total thickness of the cover-layer along the model in approximately the same time as in experiments with periodic waves. Several experiments, with variations of wind velocity, fetch and motor cycles, were necessary to obtain this.

Every experiment involved the following operations:

(a) Construction of the model and the filling of the channel with water to a depth of 0.35 m.

(b) Choice of a motor-cycle, a fetch and a wind velocity.

(c) Calibration of the resistance wave gauge.

(d) Regulating of wind deflector.

(e) Starting of blower.

(f) Ten minutes afterwards (time necessary to obtain fully developed waves) the first record with the sonar and at the same time with the resistance wave gauge. Duration of records: 4 minutes.

(g) Continuous observation of the profile's transformation, especially approaching any time in which we obtained the destruction with periodic waves. If the maximal time of periodic waves destruction was exceeded we stopped the experiment. If we observed that we were near to a "same time destruction" a second wave record was obtained.

(h) At the end of the experiment we drew the new profile on the glass-wall and photographed the profile.

3.3. Seaward equilibrium profile.

During the random waves experiment series we observed the same evolution of the equilibrium profile as in the periodic waves experiment series. We generally distinguished 3 new slopes with mean values:

$$\tan \alpha_1 = 1/0.96 \;,\; \tan \alpha_2 = 1/2.78 \;,\; \tan \alpha_4 = 1/1.37$$

$$\alpha_1 \simeq 46 \qquad \alpha_2 \simeq 19 \qquad \alpha_4 \simeq 36$$

The comparison with the values obtained from the periodic waves series shows no big difference between corresponding slopes.

4. - COMPUTER ANALYSIS OF THE RECORDS

Every tape record contained 2,400 values. It was converted in an I.B.M. 47 machine to punched cards. The "Service E.R.C.A." of "Electricité de France" is equipped with a C.D.C. 6600 digital computer. Another facility, the System D.D. 280 made graphical output possible.

The process of surface elevation was assumed stationary and ergodic, the frequency distribution similar to a GAUSSIAN process.

4.1. Autocorrelation function, Spectral density and relative width E.

The purpose of this computer calculation was to investigate the randomness of the wind waves produced in our channel. Our records have been discreetized into observations $X_i(t)$. We have obtained the autocorrariance function from the following equation (7):

$$W(J) = \frac{1}{N-J} \sum_{I=1}^{N-J} X(I) \cdot X(I+J)$$

and then the autocorrelation function:

$$R(J) = \frac{W(J)}{\frac{1}{N-J} \sum_{I=1}^{N-J} X(I)^2}$$

Thus the first approximation of the spectral density was:

$$LP(J) = W(0) + 2 \sum_{K=1}^{199} W(K) \cdot \cos\left(\frac{K \cdot J \pi}{200}\right) + W(200) \cos(J \cdot \pi)$$

and finally after smoothing by HAMMING:

$$SP(J) = 0.23.LP(J) + 0.54\, LP(J+1) + 0.23\, LP(J+2).$$

An example of graphical presentation is given on Figure 5. Values of ε have varied from 0,70 to 0,97.

4.2. Joint distributions of H and T (Fig. 6).

With the help of zero up-crossings of the sea level we have obtained the wave heights and periods for every sample. The principal difficulty was the determination of the mean level.

The different cycles of start-off and stops of the blower provoked seiches. As the waves were random this was not of importance from an energy point of view, but was very important for the definition of wave heights and periods; nevertheless the method utilized was the zero-up-crossings one. Therefore we have eliminated the seiches with the help of a moving-mean over 75 points. H and T values have been classed in increasing order, to evaluate the mean values $H_{n/m}$, $T_{n/m}$ (where n = 1,2,3 and m = 1,2,.....,10).

Recalling that $H_{dest.}$ has been defined as the constant periodic wave height for the experiments during which we obtained the destruction of the cover-layer, we have calculated the ratios:

$$H_{dest.} / H_{1/3} \quad \text{and} \quad H_{1/3} / \bar{H}$$

a) for $H_{dest}/H_{1/3}$ we have obtained values going from 0.87 to 1.10, with a mean of 1.00 (Ex. Fig. 6). This is an experimental demonstration of the empirical and theoretical assumption that $H_{1/3}$ is the representative wave height and thus good to be used as a project wave height.

b) for $H_{1/3}/\bar{H}$ we have obtained values going from 1.33 to 1.48. Through the use of LONGUET-HIGGIN'S formula, we can obtain the value of 1.598 for the same parameter.

Ocean observations (8) have given values going from 1.37 to 1.85.

c) The comparison between constant periods of periodic waves and random periods of wind generated waves did not give a significant relationship between them because of the different ranges; i.e. periodic waves period varied from 0.948 to 1.897 sec., but the random wind generated wave period varied from 0.7 to 1.5 sec. Nevertheless in some cases, where constant and random periods belonged to the same range, we obtained $T_{dest.} = T_{1/3}$, though from a statistical point of view it is impossible to correlate $H_{1/3}$ and $T_{1/3}$. Definite results do not exist in this domain, we would suggest correlating $\overline{T}$ with $H_{1/3}$.

4.3. Conclusion.

With a first series of periodic waves experiments we have obtained the destruction of the breakwater's cover-layer for different storm duration t, by varying H and T. The mass of armor units remained constant. The angle of the slope, according to the seaward equilibrium profile could be considered as constant. For the destruction cases we obtained a risk criterion:

$$\frac{t}{T} = - A.\log \left(\frac{H^2}{\nu T}\right) + B$$

which provides the storm duration t, knowing H, T and ν.

Then for a second series of random wind generated waves experiments we eliminated t and obtained that the constant periodic wave height ($H_{dest.}$) is equal to the significant wave height $H_{1/3}$ of random waves. This is an experimental demonstration of the justifiable use of $H_{1/3}$ as "project wave height".

5. SUGGESTIONS FOR FURTHER RESEARCH

The restricted research time as well as some problems with laboratory facilities did not permit us to study every aspect of the regular and wind generated action on rubble-mound breakwaters. The flow is two-dimensional. Our investigation has been strictly limited to the effects of these two types of wave action on the structure. It was technically impossible to study the production of waves by the wind, at the same time.

There is certainly more to do, and we would suggest the following:

(a) The seaward face of rubble-mound breakwaters, as we have seen in sections 2.4 and 3.3., is "carved" by wave attack, during the first minutes of the experiment. Therefore variations of the angle of slope every two degrees do not influence the results. Figure 7 illustrates this point. The experimental destruction border line is nearly horizontal for varying from 30 to 36 (every 2). Thus, there are two, more efficient, ways to experiment with breakwaters: either to retain a constant slope during all experiments, or to vary the angle every 5 or 6 degrees.

(b) We have to choose random values for H and T during experiments with periodic waves. The statistical study could be then generalised.

(c) It would be also desirable to measure exactly the stabilization time for the cover-layer, when wave attack did not destroy it.

(d) A relationship between $H/H_{1/3}$ and other characteristics of the power spectrum would permit a reduction in the scatter of the results concerning the comparison between periodic and random waves.

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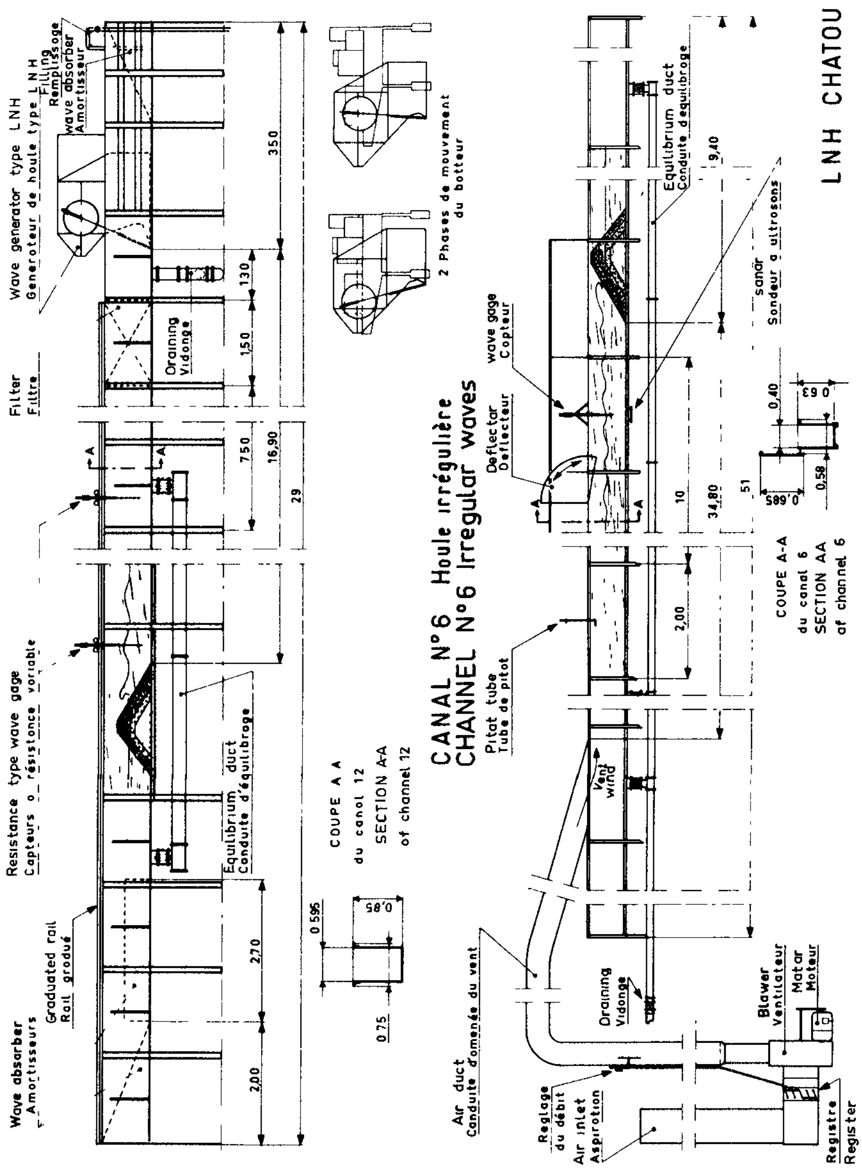
CANAL N° 12 Houle monochromatique
CHANNEL N°12 Regular waves
Wave generator type LNH
Generateur de houle type LNH
Filling
Remplissage
wave absorber
Amortisseur
Filter
Filtre
Draining
Vidange
Resistance type wave gage
Capteurs a résistance variable
Equilibrium duct
Conduite d'équilibrage
Graduated rail
Rail gradué
Wave absorber
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CHANNEL N°6 Irregular waves
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Deflector
Deflecteur
Pitot tube
Tube de pitot
Vent
wind
Equilibrium duct
Conduite d'equilibrage
sonar
Sondeur a ultrasons
Air duct
Conduite d'amenée du vent
Reglage
du débit
Air inlet
Aspiration
Draining
Vidange
Blower
Ventilateur
Motor
Moteur
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du canal 6
SECTION AA
of channel 6

Figure 1

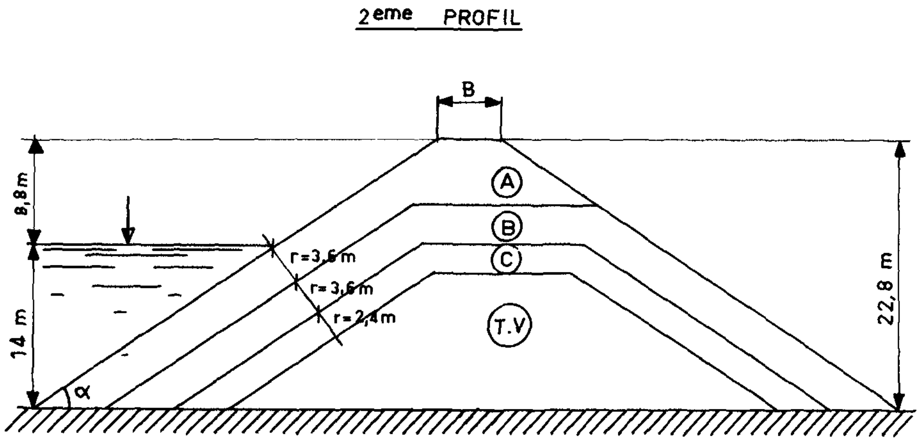


Figure 2

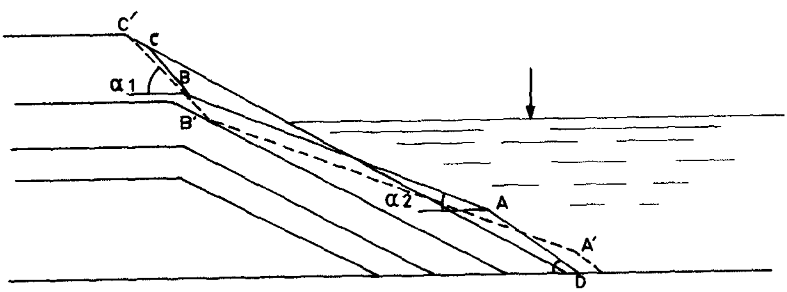


Figure 3

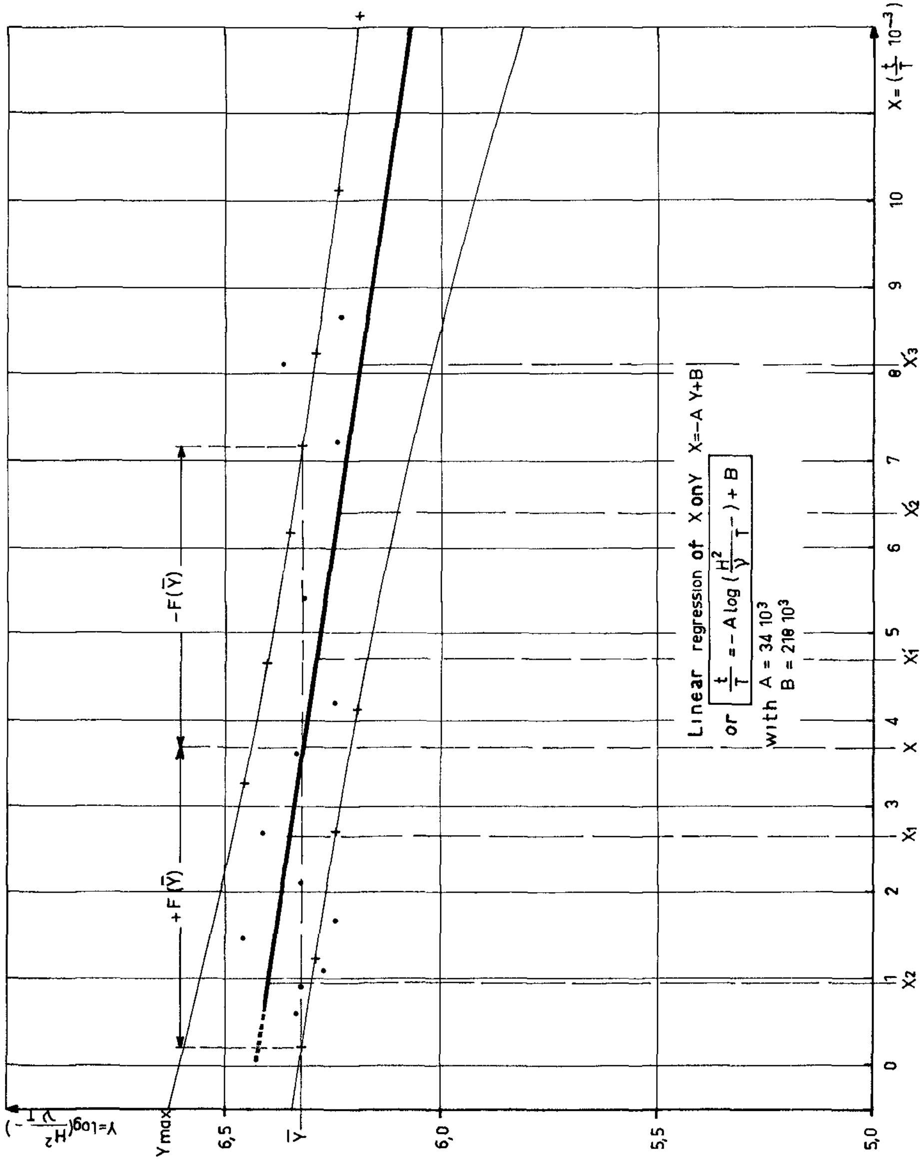
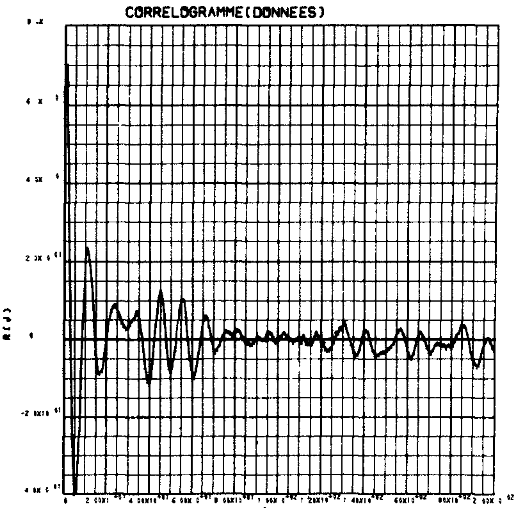

Linear regression of X on Y X=−A Y+B
or $\frac{t}{T} = -A\log\left(\frac{H^2}{\gamma\,T}\right) + B$
with A = 34 10^3
B = 218 10^3
$X = \left(\frac{t}{T}\,10^{-3}\right)$
$Y = \log\left(\frac{H^2}{\gamma\,T}\right)$
Y max
$\bar{Y}$
$-F(\bar{Y})$
$+F(\bar{Y})$
X_1
X_1'
X_2
X_2'
X_3'
X
6,5
6,0
5,5
5,0
0
1
2
3
4
5
6
7
8
9
10

Figure 4



H-1 (E81)

Spectral Density

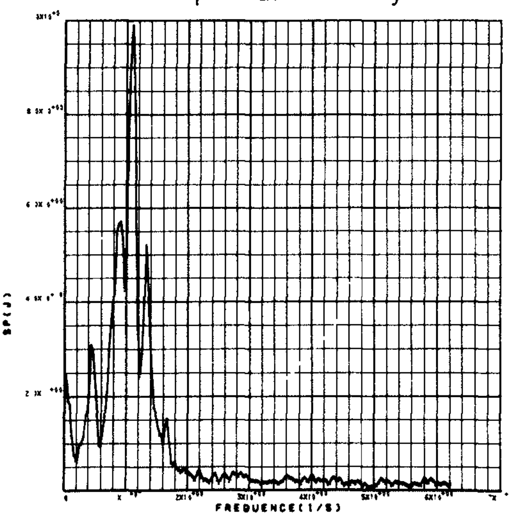


Figure 5

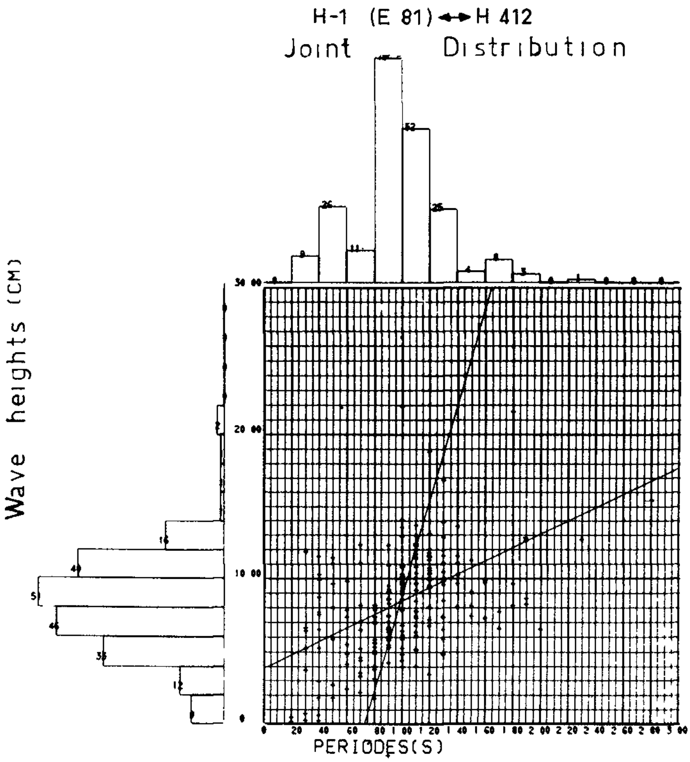
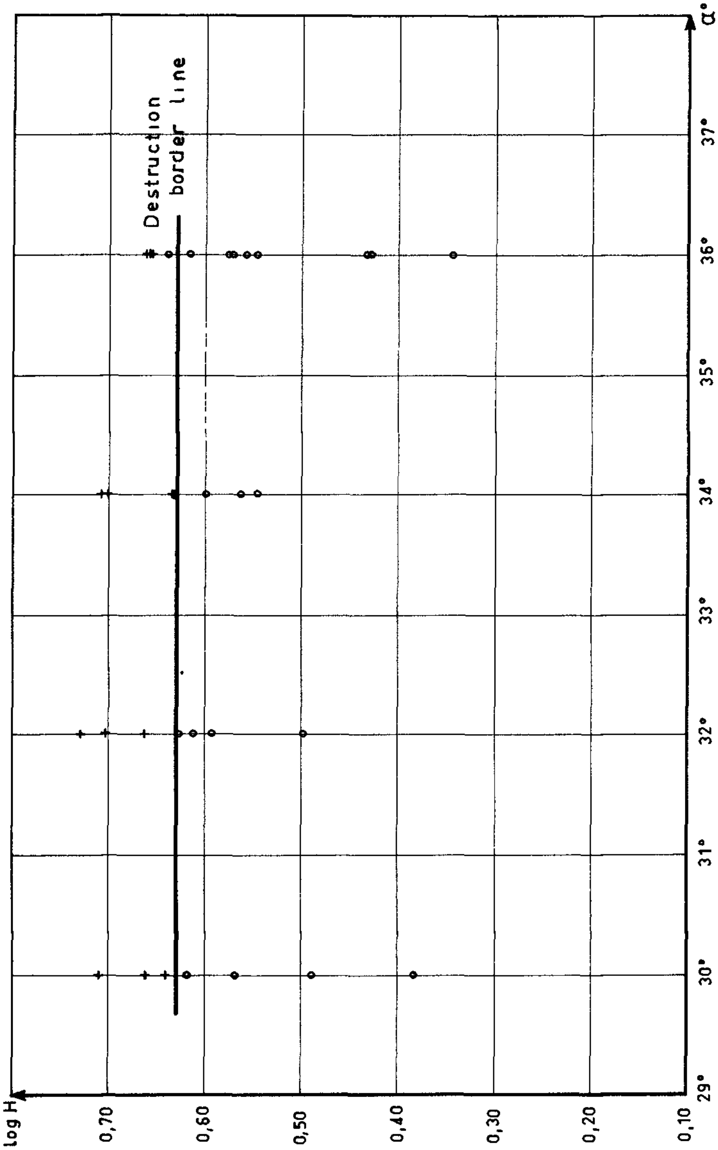


Figure 6

$\bar{H}$	= 8,47 cm	t =	$43{,}210^3$ s	$\bar{T}$	= 0,99 s
H_{dest}	= 12,74 "	r =	0,37	T_{dest}	= 1,90 s
$H_{\frac{1}{10}}$	= 16,577 "	$H_{dest}/H_{\frac{1}{3}}$	= 1,02	$T_{\frac{1}{10}}$	= 1,652 s
$H_{\frac{1}{3}}$	= 12,536 "	$H_{dest}/\bar{H}$	= 1,50	$T_{\frac{1}{3}}$	= 1,356 s
$H_{\frac{1}{2}}$	= 11,374 "	$H_{\frac{1}{3}}/\bar{H}$	= 1,48	$T_{\frac{1}{2}}$	= 1,257 s


Destruction border line
log H
0,70
0,60
0,50
0,40
0,30
0,20
0,10
α°
29°
30°
31°
32°
33°
34°
35°
36°
37°

Fi

Figure 7