CHAPTER 98

IRREGULAR WAVE ATTACK ON A DOLOS BREAKWATER

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ABSTRACT

The paper deals with two-dimensional tests on a scale model of a dolos breakwater. It is related with the construction of a large harbour at Sines for tankers with up to 1 million dwt, ore ships with up to 300,000 dwt, general cargo, etc. The main breakwater is designed with 40 t dolos, in order to withstand waves with up to 11 m significant wave height (100 years return period).

Considerations on wave data and on modelling the spectrum (Pierson-Moskowitz) precede the presentation of three sets of tests on LNEC's irregular wave flume. Main results are compared with those from regular wave tests.

The most important conclusions are stressed: influence of placement on dolos damages, irrelevance of maintenance, importance of the singular zone of the dolos support base, disadjustment of Hudson's formula for calculation of dolos weight using H as significant wave height, and importance of individual movements for the risk of breaking of individual blocks.

1. INTRODUCTION

The use of dolos in the construction of breakwaters is in permanent expansion. After its presentation by Merrifield and Zwamborn [1], [2], a few studies on the subject appeared [3], but we can say that the principal reason for its use is the heigh damage coefficient presented and the consequent low weight of the block compared with others when the same design wave is considered. But the high interlocking power of every block gives to that kind of breakwaters some characteristics not identical to classical ones: return period of waves must be larger, individual movements risk to provoke breaking damages, placement of dolos is a complexe job, etc.

Hydraulic model studies using irregular waves and connected with the present construction of a large oil harbour in Sines are the subject of this paper.

2 - SINES PROJECT

The location of Sines is on the portuguese western coast, south of Lisbon (fig. 1). The future port, under construction, will be built in a zone limited by a cape and a bay (fig. 2) with no important littoral mouvements. Before the construction of the new harbour only a small fishing harbour (fig. 3)and a recreational beach (fig. 4) existed there.

The project embodies the construction of a new town, for a population expected to be near 100,000 people during the early eighties, and a lot of new industries, usually related with port areas: oil refineries, steel mills, shipyards, petrochemicals, oil and ore transhipment, etc [4] . So the port has to deliver sheltered conditions for super-tankers and ore ships. Main features and dates of the maritime undertaking are as follows:

- Oil refinary for 10-12 million tons/year of crude
- Sheltered berthing for tankers up to 1 million dwt and ore carriers up to 350,000 dwt
- Physical characteristics of the harbour:
  Max. depth of water (head of main break.): -50 m
  Total length of main breakwater: 2 km
  Max. height " " "
  (from bottom to crest) : 70 m
  Crest level of curtain wall : +19 m
  Total vol. of concrete : 860,000 m^3
  Total vol. of rock : 8,500,000 m^3
  Weight of dolos : 40 t
- Beginning of project : ~ March 72
- Work contract : August 73
- Installation of contractor yard : August 73/June 74
- Expected dates of completion :
  for the small construction harbour: June 74
  Berth nº 3 (100,000 dwt) : April 75
  Berth nº 2 (250 to 350,000 dwt) : August 75
  Berth nº 1 (500 to 100,000 dwt) : August 76
  Final conclusion : April 77

Fig. 5 shows the lay-out of the harbour scheme with the main breakwater reaching, at the head, 50 m deep water and sheltering the three berths: for up to 100,000 dwt tankers, for up to 350,000 dwt tankers and for up to 1,000,000 dwt tankers.

The study, from the maritime hydraulic point of view, of the cross section of this main breakwater, was the subject of several studies at LNEC. Fig.s 6, 7 and 8 show the three cross sections consecutively considered on LNEC's studies: the one formerly considered, the variant presented by the contractor when he won the public competition and the cross section under study at present.

3 - LABORATORY STUDY OF MARITIME HYDRAULIC PROBLEMS FOR SINES

Besides tests on wave agitation, long period waves and wave data computation, hydraulic tests using the cross section were done.

Fig. 9 summarises the most important problems studied. From those, the more important results related with the stability of dolos are presented in this paper.

4 - WAVE DATA, SPECTRUM MODELLING AND IRREGULAR WAVE SIMULATION

4.1 - Wave data

Data used for the Sines study are based on six years visual observations (with optical device) that were made at Figueira da Foz [5] and on a two years set of records made by a Datawell wave-rider buoy (accelerometer) off Sines. Figueira da Foz data were extrapolated to Sines after reciprocal comparison and thus a valid wave climate was defined for the Sines Harbour design.

Using the exponential, log-normal, Weibull and Weibull- Battjes distributions extreme values were computed, appearing the most probable values for significant wave heights:

Once in	1 year :	H_s^Z	= 6.5 m
" "	10 years:		= 8.5 m
" "	30 years:		= 9.5 m
" "	100 years:		= 11.0 m

4.2 - Modelling the spectre

In order to simulate adequate spectra for use in model tests the Pierson-Moskowitz expression was used as follows:

$$W(\omega) = \frac{\alpha g^2}{\omega^5} e^{-\beta(\omega_0/\omega)^4}$$

or

$$P(f) = \pi \frac{\alpha g^2}{\omega^5} e^{-\beta(\omega_0/\omega)^4} \quad \text{as} \quad W(\omega) = \frac{1}{\pi} P(f)$$

f : frequency ; ω : angular frequency

P(f) : spectral density

$\alpha = 8.1 \times 10^{-3}$

$\beta = 0.74$

$g = 9.8 \text{ m s}^{-2}$

<u>Note:</u> $\omega_0 = \frac{g}{U}$

$$U = \sqrt{\frac{H_s \times 10^2}{2.12}}$$

U : wind force, measured 19.5 m above sea level, necessary for the generation of a F.A.S. with H_s

Fig. 10 shows a sequence of different theoretical P-M.spectra corresponding each one to a given H_s.

Fig. 11 shows actual spectra as an example of the growth of a storm, recorded on the 16th - 17th December 1973 by the Sines Datawell buoy.

4.3 - Irregular wave simulation

LNEC's irregular wave flume has been described in several previous papers [6] , [7]. It is 50 m long, 1.6 m wide and 0.80 m maximum depth of water (fig. 12). The system of signal generator is through filtering white noise, feeding a servo-controlled hydraulic-actuator. The data acquisition system is based in a Hewlett Packard analog-to-digital converter (fig. 13).

5 - TESTS WITH IRREGULAR WAVES

The duration of each test was 90 minutes and tide was reprodueed (+0.20 to +3,80 m). Thirty ton dolos were used.

Three series of tests with irregular waves are presented. In the first two series (Nº 2000 and 4000) cross section from fig. 6 was tested. In the third one conditions were similar but the dolos layer did not lay on the toe rock and was rather indefinitely extended until it lied on the flume floor.

Fig.s 14, 15 and 16 show simulated spectra for each test.

Cumulative damage curves are shown for 2nd series (fig. 17) and 3rd series (fig. 18)

It should be noted:

- The scatter of results, although the experimental conditions were the same

- The way damages grow is practically uniform. During the first part of the test (low water) damages grow rather steeply and thein settle (with the exception of test nº 4011, in which damages would still grow if the test were extended in time)

In the following table individual results for tests nº 4000 are presented, together with correspondent values of H_s, H_{max} and percentage of damages (total values and values for the upper, middle and lower zone of dolos layer)

Test nº	H_s(m)	H_{max}(m)	% damages			
			total	upper	middle	lower
4004	8.8	21	22	12	40	48
4005	8.8	21	35	1	40	59
4006	8.8	20	9	8	39	53
4007	8.9	18.5	9	0	63	37
4008	7.8	18.5	10	10	50	40
4009	8.8	18	11	14	53	33
4010	8.6	18	5	0	38	62
4011	8.5	19	18	0	32	68
4012	8.5	18	5	0	63	37
4013	7.9	16.5	19	10	39	51
4014	8.0	17	9	3	18	79

In the 2000 series, with 3 tests, damages were between 6 and 7.5 %.

6 - JOINT COMPARISON OF RESULTS USING REGULAR AND IRREGULAR WAVES

The most important results of tests with regular waves [8], on the same cross section, are summarised in fig. 19.

Let us see, in the following table, a joint comparison of results, using regular and irregular waves.

JOINT COMPARISON OF RESULTS				
IRREGULAR WAVES	H_s (m)	H_s^Z (m)	H_{max} (m)	% damages (*)
1) Tests nº 2000	8.8	10-11	16	6-7.5
2) Tests nº 4000	8.9	10-11	18-20	5-35
3) Indefinite dolos layer		(9.5)	18-20	4-6
REGULAR WAVES	H(m)			% damages (**)
Criterium of damages: (*) blocks displaced from original position	10.5			1
	12.5			5
(**) blocks displaced from dolos layer	13			10

The main conclusion is that the significant wave heigth should not be used as equivalent parameter for regular and irregular waves. Results are not enough to allow the definition of another parameter, which however should be an exceedance quantile greater than $H_{1/3}$ ($H_{13.3\%}$) but lower than $H_{1/100}$ ($H_{1\%}$).

In the evaluation of results there are three important details that should be taken into account because they contribute to make it difficult to interpret them:

- The large scatter of experimental results
- The different criteria of considering damages in tests with regular and irregular waves (blocks displaced from dolos layer or blocks displaced from original position)
- Rather important variations in the density of the concrete used in the models of dolos:

2.53 t/m^3 (prototype)

2.47 (correct value on model, using 1.03 t/m^3 to sea water)

2.24 (actual value on LNEC model tests)

7 - FINAL DESIGN OF DOLOS WEIGHT

The criterion used by the designer for establishing the design wave is mentioned [9]:

1 - Only oscillations for a storm with 10 years of return period (H_s^Z = 8.5 m)

2 - Beginning of dolos displacements for a storm with 30 years of return period (H_s^Z = 9.5 m)

3 - Damages up to 1% for a storm with 100 years of return period (H_s^Z = 11 m)

As the test results did not obey the design wave criterion it was decided to use 40 t instead of 30 t dolos. Later tests with 40 t have shown that this weight produced results in agreement with the adopted design wave criterion.

According to recently published results by HUDSON, 1974 [10], the weight theoretically compatible with the utilized parameters should be 33 t for K_D = 22. The excess weight will minimize individual block movement and thus breaking risks will be smaller.

8 - FINAL REMARKS

Taking into account these results and results published by other authors some final remarks will be made on the use of dolos in rubble-mound breakwaters:

1 - One of the most important aspects in the investigation of model and prototype behaviour of dolos is the large dependance of the amount and growth of damages upon the way the blocks are placed. This is shown by the scatter in the experimental results and it is feared that the behaviour of a structure will depend on the way it was built

2 - Owing to the interlocking capacity of the dolos, such breakwaters do not allow recharges, and so, to avoid maintenance, it is necessary to design them for large return periods in order that the percentage of damages is low

3 - The singular zone of the dolos support base, either in what concerns its depth, is intimately linked with the regular or the irregular characteristics of the simulated waves, and when they are irregular, with the respective extreme values distribution, as is readily understood.

4 - As previously mentioned the significant wave height parameter does not seem to be suitable for the design of breakwaters through the use of Hudson-type formula.

5 - The individual movements of the blocks which, if large, may determine unwanted breaks, can only be minimized if an increase in the dolos weight is used, above the value that from the hydraulic stand point is considered satisfactory. Other people prefer to use reinforced blocks as it was the case at Humboldt Bay Harbour [11] .

9 - MAIN PARTICIPANTS IN THE PROJECT OF SINES MARITIME UNDERTAKING

Gabinete da Area de Sines (GAS) - Direct overall responsability (Governamental Department).

Bertlin/Consulmar/Lusotecna - Designers of maritime project.

Mrs Castanho, R. Carvalho, Vera-Cruz - Sea wave basic data study.

Societá Italiana per Condotte d'Acqua - Contractor.

Laboratório Nacional de Engenharia Civil (LNEC) - model test studies (tests with regular waves by Mr. Vera-Cruz).

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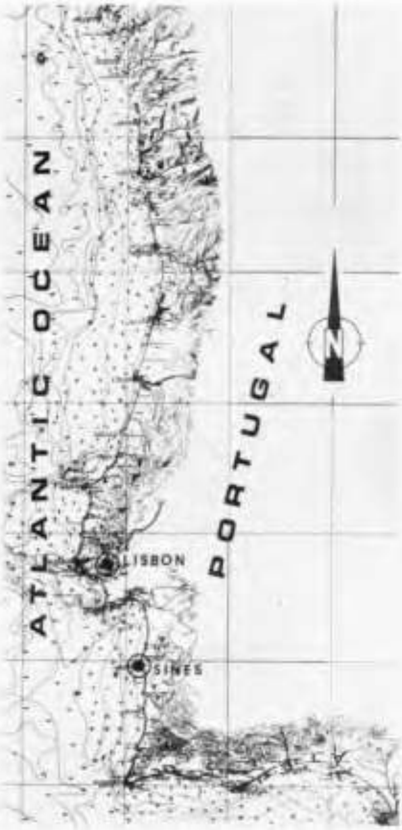

Fig. 1 - Location of Sines

Fig. 2 - Sines surroundings

Fig. 3 - Old small fishing harbour

Fig. 4 - Bay and beach

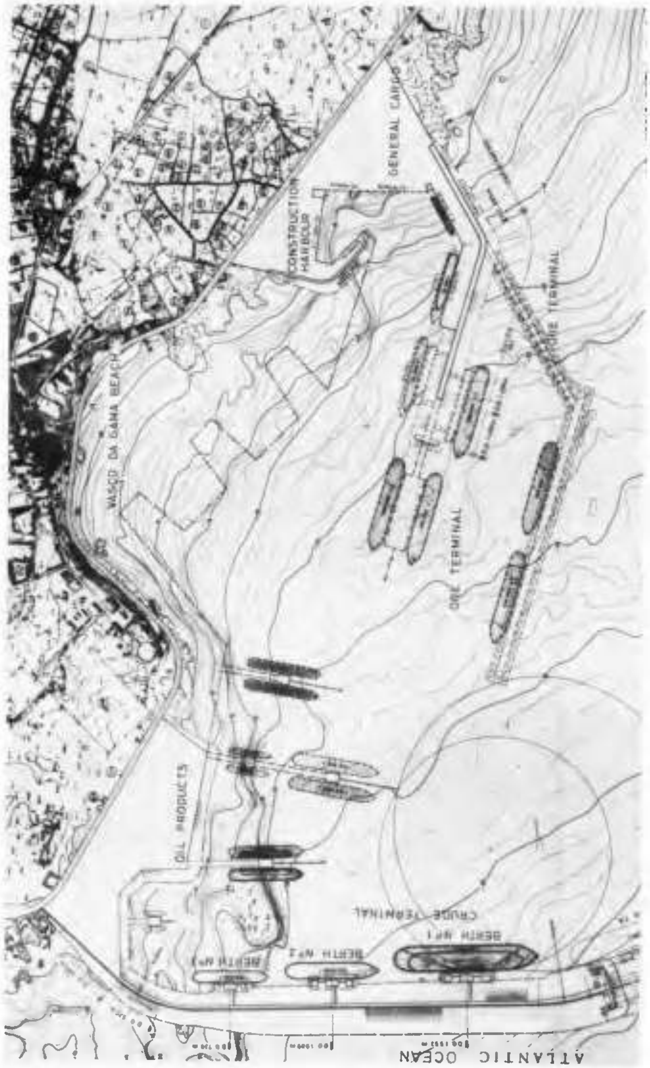

Fig. 5 - Lay out of the harbour

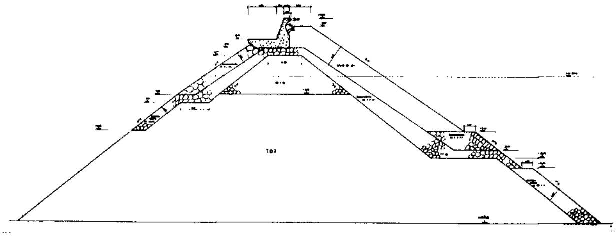

Fig. 6 - Cross section formerly considered

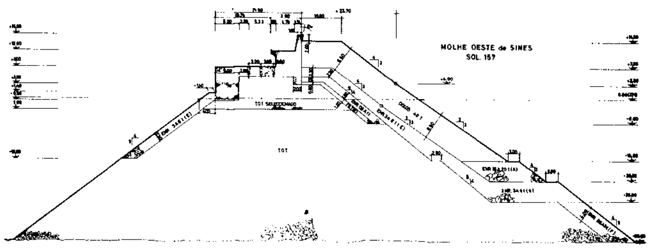

Fig. 7 - Variant presented by the contractor

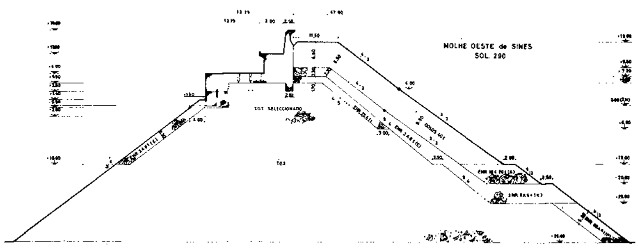

Fig. 8 - Cross section under study

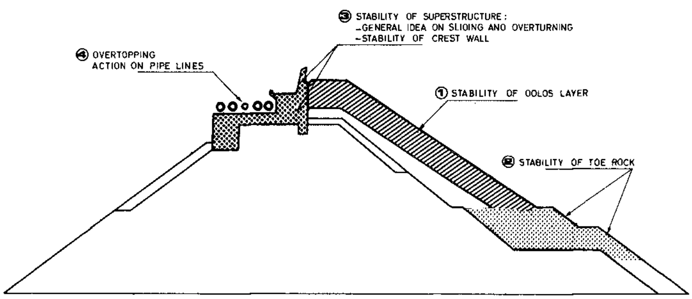

Fig. 9 - Problems under study

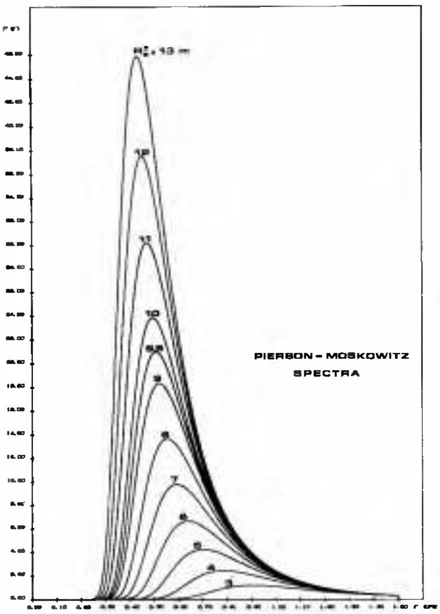

Fig. 10 - Theoretical Pierson-
-Moskowitz spectra

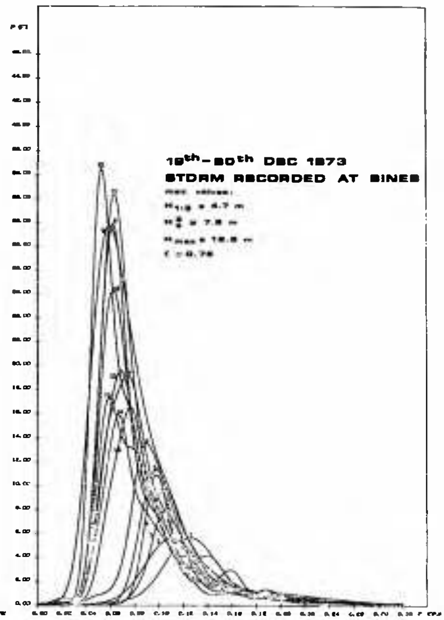

Fig. 11 - Spectra from a storm

Fig. 12 - LNEC irregular wave flume

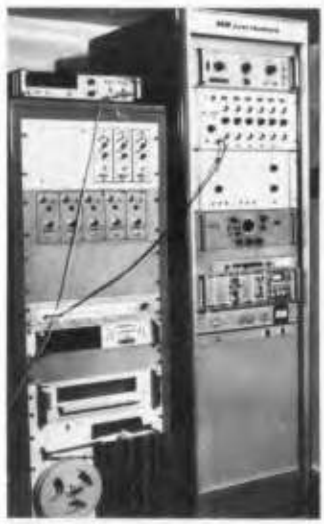

Fig. 13 - Instrumentation

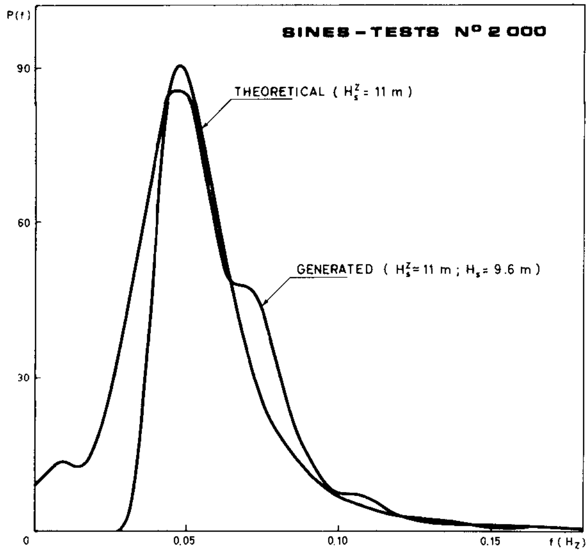

Fig. 14 - Theoretical and simulated spectra (tests nº 2000 - 1st serie)

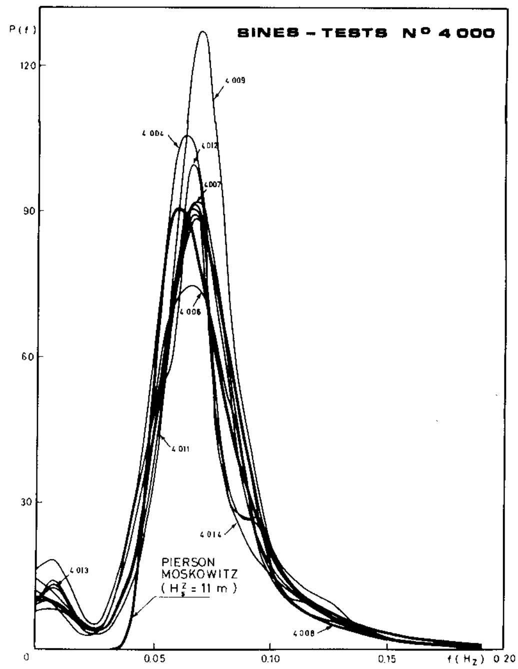

Fig. 15 - Theoretical and simulated spectra (tests nº 4000 - 2nd serie)

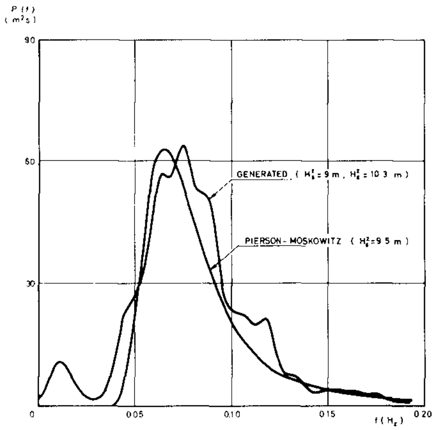

Fig. 16 - Theoretical and simulated spectra (3rd serie)

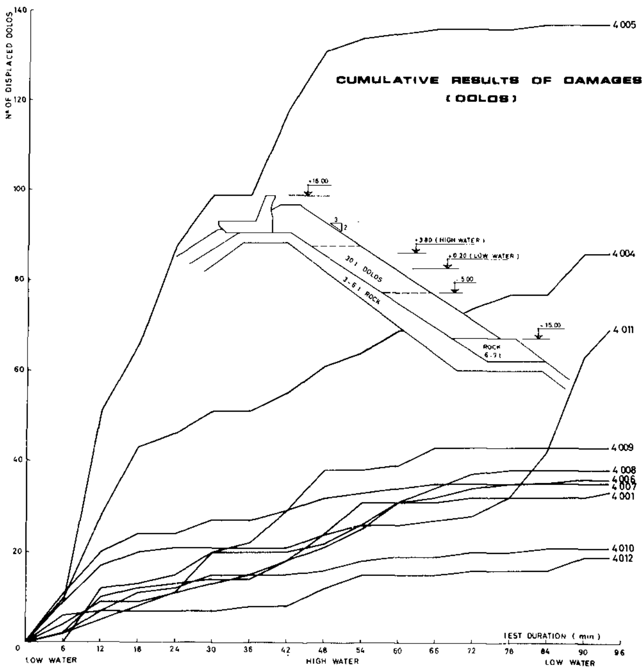

Fig. 17 - Cumulative results of damages (2nd serie)

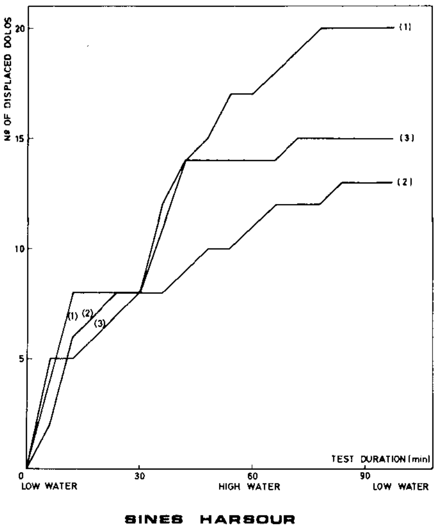

Fig. 18 - Cumulative results of damages (3rd serie)

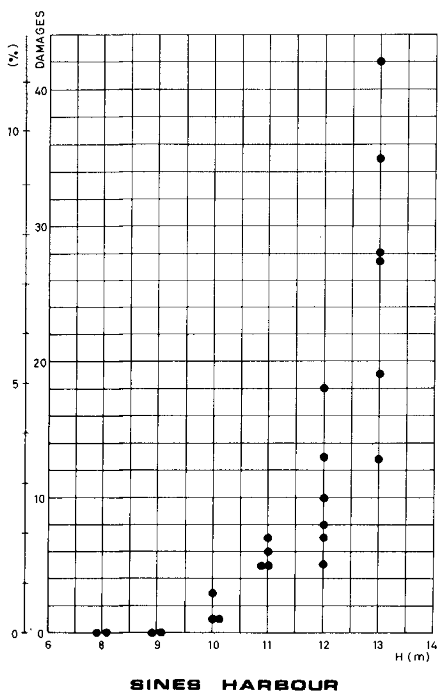

Fig. 19 - Regular wave test results