## ANALYSIS OF WAVE DATA AT SINES

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#### Abstract

The aim of this paper is to summarise the main results obtained from wave data collected in the Portuguese west coast near Sines Harbour. In spite of special attention given to wave characteristics during storm occurrences, some considerations about mean wave regimen will be done.

#### Introduction

Sines Harbour is located in the South part of Portuguese west coast (fig. 1).



Acquisition of wave data is made in a regular basis at Sines since 1973, with some interruptions for maintenance of recorder devices or caused by buoys mooring problems. Unfortunately only after 1981 data processing is carried out systematically. So, at this moment, available data cover a period of 18 years, period of time still insufficient for a good definition of extreme values, but interesting to provide information about the tendencies of these extreme values, specially when compared with design conditions.

Two Datawell directional wave buoys are installed at depths of -100 m CD and -50 m CD. In spite of some small variations in the positions of these buoys, after their removal for maintenance needs, it may be assumed (taking into account mathematical model results) that, for wave regimen characterisation, data from each depth may be considered as recorded at the same point.

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## Wave Data

Wave data is nowadays obtained in a continuous form. Records are segmented in parts with a duration of about 20 minutes, which are subjected to an on-line computation at Administração do Porto de Sines (APS) facilities. This analysis allows the computation, for each record, of maximum individual wave height, Hmax, significant wave height, Hs, mean period, Tz and main direction.

These 20 minutes records are also digitally registered. In a subsequent treatment, done by the portuguese hydrographic service, Instituto Hidrográfico (IH), parameters like peak period or wave height and wave period distributions are also computed.

In present paper most of used results where obtained from APS on-line computations, complemented in some cases by the evaluation of wave parameters done at IH. The results of some studies performed by Laboratório Nacional de Engenharia Civil (LNEC) and by IH are also used.

# Storm Waves

It was assumed by the Portuguese coastal engineers, taking into account their experience about wave conditions in the Portuguese west coast, that a "storm" occurs when there is one exceedance of a significant wave height of 5.0 meters. In the case of Sines there is a "storm" if the significant wave height of 5.0 meters is exceeded at least in one of the two wave buoys.

Considering this definition, a total of 57 storms happened since the beginning of 1981 until February 1998.

In table I the main characteristics of these storms, namely maximum values of Hs, Hmax and associated main direction are presented for the two wave buoys. The total time of exceedance of Hs = 5.0 meters is also presented, with a maximum error in each storm of +1 hour.

According to this table, since 1981 storm total duration is around 1.000 hours (aprox. 42 days) with maximum yearly duration in 1989 (about 200 hours) and 1996 (222 hours) - fig. 2.

Wave conditions are in general more severe at the depth of -100 m CD than at -50 m CD (as it was expected) - figures 3 and 4, with maximum values of:

•Depth -100 m CD: Hs = 9.6 m

•Depth -50 m CD: Hs = 9.0 m

Anyway, largest Hmax had occurred at buoy at -50 m CD, with a value of 16.1 m, against a value of Hmax = 14.7 m at -100 m CD.

				Buoy	at -100	n CD	Buoy at -50 m CD		Storm	
Nr.	Year	Month	Dav	Maximu	n Values	Main	Maximu	n Values	Main	Duration
				Hmax	Hs	Direction	Hmax	Hs	Direction	(hrs.)
1	1981	March	28-31	8.3	5.5	-	6,7	4.5	-	< 12
2		December	28-30	13.6	8.7	-	16.1	9.0	_	< 67
3	1982	January	11-12	8.9	5.6	-	8.0	4.9	-	< 12
4	1		19	8.3	6.0	-	9.0	4.9	-	< 6
5	1	February	15-16	8.6	5.4	-	9.1	5.0	-	< 6
6	[	October	16-17			·	-	4.5(1)	-	-
7		November	7-8		No		15.8	7.9	-	< 31
8	1		14		Data		7.7	5.0	-	< 6
9	1983	April	22				7.6	4.1(1)	-	-
10	1	December	15-23	12.3	6.0	_		·		< 19
11	1984	January	26-27	9.6	5.5	-				< 3
12	1	October	5	8.2	5.1	-	ĺ	No		< 3
13	1985	February	8-9	8.5	5.2	-				< 6
14	1	December	23-26	9.1	5.9	-		Data		< 18
15	1986	January	2-3	8.8	5.4	-	1			< 21
16	]	February	17 (2)	14.7	9.6	-	1			< 27
17	[	November	14	8.2	5.0	-	7.7	5.0	-	< 6
18	1987	January	13	11.0	7.4	-	10.8	7.2	-	< 15
19	1	February	2-3	8,0	5.2	-	8.3	5.3	-	< 12
20	1	-	11	10.0	7.2	-	11.4	5.8	-	< 15
21	1	October	15-16	10.7	5.9	-	7.4	4.4	-	< 6
22	1988	January	6	9.0	5.3	-				< 1
23		February	6-7	10.3	5.9	-				< 9.5
24	1989	February	26	11.0	5.4	311	]	No		< 25
25		April	9	10.2	5.4	280	]	Data		< 9
26		November	19-20	12.3	7.3	288	]			< 33
27			22	9.7	6.3	277				< 9
28	]	December	16-19	11.7	7.4	286	10.3	6.6	281	< 73
29	]		21-22	9.4	6.0	284	10.3	5.7	283	<17
30			25-27	11.7	6.8	300	10.3	6.2	290	< 32
31	1990	Jan./Feb.	30-1	12.7	7.7	302	10.0	6.6	281	<42.5
32		October	22	10.6	6.3	309	9.3	5.7	291	<8.5
33	1991	Feb./March	28-1	11.1	6.7	311	8.6	5.2	295	<10
34	1	March	6-7	10.6	5.7	298	8.8	5.1	288	<15
35	1992	February	13	8.8	5.6	306	5.8	3.5	286	<9
36	]	March	30-31	10.3	5.6	308	7.3	3.9	294	<20
37	]	May	25-26	7.8	5.0	315	6.0	3.4	286	<6
38	[	December	8	8.0	5.1	304		No		<6
39			16	12.5	6.0	304		Data		<6
40	1993	October	16	11.3	6.7	289	10.2	5.8	286	<7
41		November	6	7.5	5.0	314	7.4	3.9	294	<3
42	1994	February	3 - 5	10,7	5.8	313				<32
43	1995/6	Dec./Jan.	31-1	-	6,8	293				<20

TABLE ISINES WAVE STORMS (1981-98)

(Cont.)

				Buoy	Buoy at -100 m CD Buoy at -50 m CD		1 CD	Storm		
Nr.	Year	Month	Day	Maximu	m Values	Main	Maximum	Values	Main	Duration
				Hmax	Hs	Direction	Hmax	Hs	Direction	(hrs.)
44	1996	January	6-15	-	8.8	293				<188
45	]		19	-	5.0	293				<2
46	]		23	-	5.6	225				<4
47		April	1 - 2	-	6.8	325				<17
48		November	11-12	-	6,8	315		No		< 8
49		December	11-13	-	5,2	225				< 3
50	1997	February	_16-19	-	6,6	315				< 6
51			19-20	1	6,6	315		Data		< 11
52		November	24-26	-	7,8	290				< 56
53	1998	January	1	-	5,4	315				< 2
54			5	I	6,1	315				< 3
55	]		7-8	-	6,1	315				< 4
56	]		12-13	-	5,6	225				< 4
57	]	February	2-3	_	6,6	270				< 11

**TABLE I - Cont.** 

Notes:

(1) - Identified as a "storm" due to the occurrence of Hs > 5.0 meters in other points of portuguese coast. As there is no data from the buoy positioned at -100 m CD, it was impossible to confirm deep water conditions.

(2) - Due to a problem with the measurement devices, records do not cover all the storm. Storm duration could not be properly evaluated.



More frequent values of Hmax and Hs are: •Depth -100 m CD: Hmax between 10.3 and 10.7 m Hs between 5.3 and 5.7 m •Depth -50 m CD: Hmax between 7.3 and 7.7 m Hs between 4.8 and 5.2 m





Wave directions during storms at a depth of -100 m CD are dominant in the sector  $270^{\circ} - 320^{\circ}$ , with a few occurrences from  $225^{\circ}$  (SW). At -50 m CD existing data are not enough to get good conclusions, but a concentration between  $280^{\circ}$  and  $300^{\circ}$  seems to occur, as it was expected, if refraction effects are taken into account (Fig. 5).

## Wave Parameters

# Wave Heights Distribution

Theoretically, assuming a Rayleigh distribution for individual wave heights during any record of each storm, the parameters  $H_{max}$  (maximum individual wave height of each record), H1 (average of 1% higher wave heights of the record), H10 (average of the



10% higher wave heights of the record) are related with Hs (average of 33,3% highest wave heights of the record) by the following relationships:

$$H_{\max}^{NA} = \sqrt{\frac{\ln NA}{2}} Hs$$
 (1)

in which NA is the number of waves of the record and  $H^{NA}_{max}$  is the average maximum wave height expected in a record with a number of waves Na and a significant wave height, Hs,

$$H1 = 1.668 Hs$$
(2)  
$$H10 = 1.273 Hs$$
(3)

To evaluate the validity of these relations, individual records from the buoy positioned at a depth of -100 m CD obtained during storm conditions were analysed. Results are presented at figures 6 to 8.

These results suggest the following comments and conclusions:

a) As each record contains less than 150 waves, the parameter H1 has no statistical meaning. The group of the 1% higher waves is composed by one single wave, and, in consequence, H1 = Hmax. No conclusion can be obtained about the correctness of the relation H1 = 1.668 Hs. Anyway, the tendency of the results is that values evaluated by theoretical relationship are higher than observed values - Fig. 6.



b) Average values of the relation H10/Hs are around 1.23 and 1.27, in the range of 0 to -2% around theoretical value. At the peak of the storm, these oscillations are larger, varying between +0,5% and -7.3%. Maximum and minimum values of this relation oscillate around +5% and -9% of theoretical value.

These oscillations are small enough to conclude that theoretical values are very close to the real ones and can be used to evaluate H10 in the absence of computed values - Fig. 7.



c) Relations between Hmax and Hs have average values of 1.5 to 1.6, as expected from theoretical results. Anyway, the results show a large scatter and, at the peak of the storm, these relations can oscillate  $\pm 20\%$  around theoretical value - Fig. 8.



Relationships between Wave Heights, Directions and Peak Periods

In figure 9 is done a presentation of the value of Tp associated to the maximum Hs in each storm. This presentation illustrates that parameter Tp has a large scatter in recorded wave storms at Sines. The same conclusion can be obtained considering maximum Tp at each storm and associated values of wave directions (fig. 10) and Hs at the same record (fig. 11).



Anyway, it must be noticed that large values of Tp can occur at Sines, as, during more than 50% of the storms, Tp values higher than 15 seconds were computed at both wave buoys (Table VI). It is also interesting to recognise that records done at the same hour in both wave buoys do not show the same value of Tp, with differences that can reach 2 seconds (Table VII). Anyway, in both positions most frequent values occur for Hs between 4 and 6 meters and Tp from 15 to 18 seconds (Table VI).





	Di Wa	istributions ave Buoy a	of (Tp)max t -100 m Cd	and association (Sample of 3	ated Hs 5 values)		
	]			Hs (m)			
		2 - 4	4 - 6	6 - 8	8 - 10	TOTAL	
	9 - 12	-	2.9%	-	_	2.9%	
	12 - 15	-	22.9%	5.7%	-	28.6%	
Tn (s)	15 - 18	-	39.9%	11.4%	2.9%	54.2%	
	18 - 21		8.6%	5.7%	-	14.3%	
	TOTAL	-	74.9%	22.8%	2.9%		
	W	ave Buoy at	-50 m CD (S	ample of 22 v	/alues)		
Hs (m)							
		2 - 4	4 - 6	6 - 8	8 - 10	TOTAL	

TABLE VI	
Distributions of (Tp)max and associated He	ŝ
Wave Buoy at -100 m Cd (Sample of 35 values	3)

		2 - 4	4 - 6	6 - 8	8 - 10	TOTAL
	9 - 12		4.5%	-	-	4.5%
	12 - 15	9.1%	22.7%	_	-	31.8%
Tn (s)	15 - 18	4.6%	31.8%	9.1%	-	45.5%
	18 - 21	4.6%	13.6%	-	-	18.2%
	TOTAL	18.3%	72.6%	9.1%	-	

-100 m CD	-50 m CD	-100 m CD	-50 m CD
12,5 s	12.0	16.5	14.5
13,5 s	14.5	16.5	16.5
13,55 s	14.5	16.6	16.6
14,5 s	13.5	16.5	18.0
15,0 s	18.0	17.5	16.0
15,2 s	17.0	18.0	18.0
15,2 s	16.0	18.1	18.1
16,0 s	16.0	19.0	18.5
16,0 s	14.5	20.0	18.0

 
 TABLE VII

 Examples of Values of Tp at the same hour in both depths (at the peak of the storms)

These conclusions were checked in a study conducted by IH and LNEC (ref. [1]), where it was stated that:

# a) Significant Wave Heights:

- A strong correlation between significant wave heights was found (91%). According to linear model and from a general way significant wave heights at -50 m CD are about 80 - 90% of significant wave heights at -100 m CD.
- b) Peak Periods

Correlation coefficient between records obtained at the two points is about 76 to 77%.

## Wave Propagation

The importance of previous results is due to a large discussion, which took place after west breakwater accident in 1978, about the possibility of occurrence of energy concentrations on the breakwater.

In fact, a lot of refraction studies were carried out at different institutions after 1978 accident at Sines west breakwater, with very different conclusions, some of them pointing out the possibility of occurrence of wave concentrations on the breakwater.

Mathematical studies or physical model tests with regular waves carried out either at LNEC (Portugal) and LCHF (France) concluded by the possibility of occurrence of refraction coefficients up to 1.5 or even higher.

On the other hand, tests in a physical model with irregular waves performed at DHL (Netherlands) lead to the conclusion that do not occur refraction coefficients higher than 1.1. Besides, the reaches of the breakwater in which the occurrence of energy concentrations could be expected were not the same in the different studies.

The differences in the conclusions of different studies can be explained by the use of different techniques (traditional refraction diagrams with different bottom digitalisation, model studies with regular waves or with random waves).

At figure 12 relations between existing wave data collected with directional wave buoys at depths of -100 m CD and -50 m CD are presented. In spite of an important dispersion, these results seem to show that:

- For wave directions at depth -100 m CD below 300 degrees, a relation between significant wave heights of 0.9 to 1.0 may be expected, with a variation of directions lower than 10° towards the perpendicular to the breakwater (the direction of which is 270°);
- For wave directions at deep water between 300 and 310°, relations between wave heights at depths of -50 m CD and -100 m CD of 0.6 to 0.9 can occur, with variations on the direction of 14 to 22°;
- For wave directions higher than 310°, relations lower than 0.8 between significant wave heights can be expected;
- No influence of peak period was found in these relations.
- Anyway in the referred study conducted by IH and LNEC, it was found for the Mean Direction of Peak Period a small correlation coefficient (0,88). The direction in the deeper water location shows a rotation of about 12° North with reference to lower water depths.



It must be stated that these results are preliminary, additional analysis and a physical explanation for them being required (for instance, to evaluate how much they were affected by local winds or by reflections in the breakwater).

#### Wave regimen - Extreme Values

During initial studies of Sines West Breakwater a wave climate was defined, conducting to the extreme values presented in Table VIII.

After 1978 accident, during the studies about the rehabilitation of the breakwater, PRC Harris defined, mainly based in hindcast studies performed by WES, a new deep water wave climate, supported in a Gumbel distribution. This climate was

used, taking into account refraction and diffraction effects, in the design of all the breakwaters existing at Sines harbour. Extreme values of this climate are also presented in Table VIII.

Return	Extreme Values of Hs				
Period	Initial Design (Bertlin, 1973)	Repair Works (Harris, 1981)			
10 years	8.5 m	10.0 m			
20 years	9.3 m	11.8 m			
50 years	10.3 m	13.0 m			
100 years	11.0 m	14.0 m			

Since 1981 a lot of additional storm data were collected, as indicated at Table I. In general, maximum waves occur during the winter, which in Portugal is, in what sea conditions is concerned, between October and March. It is the author's opinion that a "maritime year" is extended from October until October of next year (like the hydrologic year).

Yearly maximum individual and significant wave data according to the previous definition are the following in the period from 1980/1 until 1997/8:

 TABLE IX

 Yearly Maximum Values of Hmax and Hs

Year	Buoy at -	100 m CD	Buoy at	-50 m CD	Year	Buoy at -100 m CD		Buoy at -50 m CD	
	Hmax	Hs	Hmax	Hs		Hmax	Hs	Hmax	Hs
1980/1	13,6	8,7	16,1	9,0	1989/90	12,7	7,7	10,3	6,6
1981/2	8,9	5,6	9,1	5,0	1990/1	11,1	6,7	9,3	5,7
1982/3	-	-	15,8	7,9	1991/2	10,3	5,6	8,8	5,1
1983/4	12,6	6,0	-	-	1992/3	12,5	6,0	-	-
1984/5	8,5	5,2	-	-	1993/4	12,5	6,5	10,2	5,8
1985/6	14,7	9,6	-	-	1994/5	10,7	5,8	-	-
1986/7	11,0	7,4	11,4	7,2	1995/6	-	8,8	-	-
1987/8	10,7	7,2	7,4	4,4	1996/7	-	6,8	-	-
1988/9	11,0	5,4	-	-	1997/8	-	7,8		-

Using Gumbel and Log-Normal Distributions the Extreme Values of Hs and Hmax associated to different Return Periods were computed. They are presented at Table X.

Presented values for -50 m CD depth were computed using a very small time series (10 values) and should be considered with additional caution, specially because a sample of 17 values was available for the depth of -100 m CD.

Obtained values are between adopted design values after west breakwater accident and those established initially. In spite of, once again, the importance of being very careful about these conclusions, it is important to the owner of the harbour and to its users to be confident that wave action influence on the structures have a high probability of being from safe side.

A Maximum wave neights							
	-100 m CD (1	Deep Water)	-50 m CD (Deep Water)				
Return Period	Gumbel Distribution	Log-normal Distribution	Gumbel Distribution	Log-normal Distribution			
5 years	13,0	13,7	14,1	14,3			
10 years	14,1	15,0	16,4	16,9			
20 years	15,1	16,1	18,6	19,1			
25 years	15,5	16,6	19,5	19,9			
50 years	16,6	17,2	21,8	22,4			
100 years	17,8	19,1	24,0	24,8			
B Significant Wave Heights							

TABLE IX EVALUATION OF EXTREME VALUES A.- Maximum Waya Haighte

#### Gumbel Return Log-normal Gumbel Log-normal Period Distribution Distribution Distribution Distribution 7.9 5 years 8.0 8.2 7.8 10 years 8,9 9,0 9,1 8,1 20 years 98 97 10.2 98 25 years 10,1 10.0 10.6 10.0 50 years 11.0 10,7 11.8 11.0 100 years 11.9 11.4 13.0 11.9

# Wave regimen - Mean Values

Measured mean wave conditions are clearly in accordance with values defined by Frederick R. Harris in their studies. Main results are summarised in figure 13.

These results show that, as expected, predominant wave directions are in the reach WNW to W and that only in 10% of the time (38 days per year) Hs exceeds 3.0 meters.

## **Conclusions**

- A total of 57 wave storms occurred at Sines since 1981, with a total duration of about 1.000 hours with Hs  $\geq$  5.0 meters.

- Maximum recorded values of wave heights were:

٠	at a depth of -100 m CD:	Hs =	9.6 m
		Hmax =	14.7 m
•	at a depth of -50 m CD:	Hs =	9.0 m
		Hmax =	16.1 m



- Using existing data and assuming that statistical distributions of yearly maximum values of Hs and Hmax are Gumbel or Log-normal, the following extreme values of Hs and Hmax were obtained for a depth of -100 m CD:
  - •With a return period of 10 years:
    - Hs from 8.9 to 9.0 meters Hmax from 14.1 to 15.0 meters
  - •With a return period of 50 years:
    - Hs from 10.7 to 11.0 meters
    - Hmax from 16.6 to 17.2 meters
  - •With a return period of 100 years: Hs from 11.4 to 11.9 meters Hmax from 17.8 to 19.1 meters

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