CHAPTER 4

ON THE PORTUGUESE WAVE REGIMEN

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SYNOPSIS

Some general characteristics of the wave regimen along the Portuguese coast and the zones next to it are presented. The paper is of a chiefly informative nature and results from the analysis of values obtained during an initial stage of swell observation, applied to studies carried out at the Laboratõrio Nacional de Engenharia Civil (LNEC), Lisbon. Presently, a network of observation posts is being installed on the Portuguese coast. These posts will be duly equipped and will make it possible to gather systematic observation as regards swell as well as to make a much more accurate analysis of the wave regimen and of the wave trains.

1 - BASIC CONSIDERATIONS ABOUT WAVE OBSERVATION IN PORTUGAL

Proper knowledge of the waves along a coast will only be achieved through a network of posts for carrying out systematic observation, constantly updated information making it possible to study any changes in regimen. In an indirect way, the expense of installing these posts will no doubt prove compensating because of the economy they will originate in the works and in their use (not to mention problems connected with sea traffic and fishing safety, whose importance and seriousness cannot be estimated in numbers). Under the circumstances an undertaking of this type is an official charge to be borne by state organizations, and data regarding the wave regimen should be made public and immediatly available to the individuals in charge of the studies and projects (such as meteorology information).

Presently, the best model study techniques make use of the simulation of irregular waves and therefore a more accurate knowledge of the real wave train structures is necessary. Besides, this knowledge has many advantages for practical applications in general. Thus the present tendency is towards using highly accurate, automatic and autonomous recording instruments and to treat the recorded values so as to give special importance to spectral analysis and to the definition of the statistic parameters characteristic of the wave trains. There is also a tendency to use observation means that will give immediate information (accelerometer buoys), which is of great practical importance.

The absence of the abovementioned network of posts along the Portuguese coast made it necessary to make the best possible use, with the degree of approximation considered sufficient, of the data available on waves, and to analyse this data according to the practical needs met with, extrapolating whenever necessary.

The results of the study of Figueira da Foz wave regimen, on the west coast, were thus made known and first applied at the LNEC between 1964 and 1966, based on the observations made since 1954 by Figueira da Foz Harbour Authority with a tachymeter and signal buoy for determining wave heights, periods and directions, completed by the observation of the directions with the SIMATHA (a set of horizontal rods connec

Fig. 1 - SIMATHA (Sines) Equipment for wave observation (directions and periods).

ted to a vertical rotating axle, which allows to read angles and distances by adjusting the horizontal rods to the wave crests and also determine the values of the period by cronometer during the sightings – see figure 1).

A study of the wave regimen in the Portimão harbour zone was subsequently made based on the observations made since 1958 by the Maritime Services comprising only the observation of directions and periods by SIMATHA, in view of the model study of this harbour. Additional information on the south coast was supplied by the observations carried out since 1970 by the Portuguese Hydrographic Institute in the Huelva harbour zone (Spain), in view of the model study of this harbour's bar (using a pressure wave recorder and radar).

In 1965 an observation post equipped with a pressure wave recorder and radar was installed in Leixões harbour by Douro and Leixões Harbour Authority in order to collect data for the extensive work that was going to be carried out in this port, which is one of the most important harbours in the country (owing to deficient exploitation it has not yet supplied complete information). A pressure wave recorder and SIMATHA were also installed that year in Lagoa de Albufeira, south of the Tagus, by the Lisbon Harbour Authority, to gather data for the model study of Lisbon harbour.

In May 1971 a Symposium on wave data, SIDAM 71, was carried out in Lisbon, for promoting wave observation and studies on the Portuguese wave regimen under cooperation and coordination of the different official organizations (Harbour Department, Hydrographic Institute, National Meteorologic Department and LNEC).

In 1971 the Harbour Department installed posts in the north of Peniche (fishing harbour in the west coast, north zone) and Sines (future large sea harbour on the southern zone of the west coast). These posts were equipped with accelerometer buoys connected to reading stations with radio transmission and with SIMATHAS for observing the directions. In 1972 the Harbour Department installed a similar post in Baleeira (Sagres, western end of the Algarve coast) where a small fishing harbour

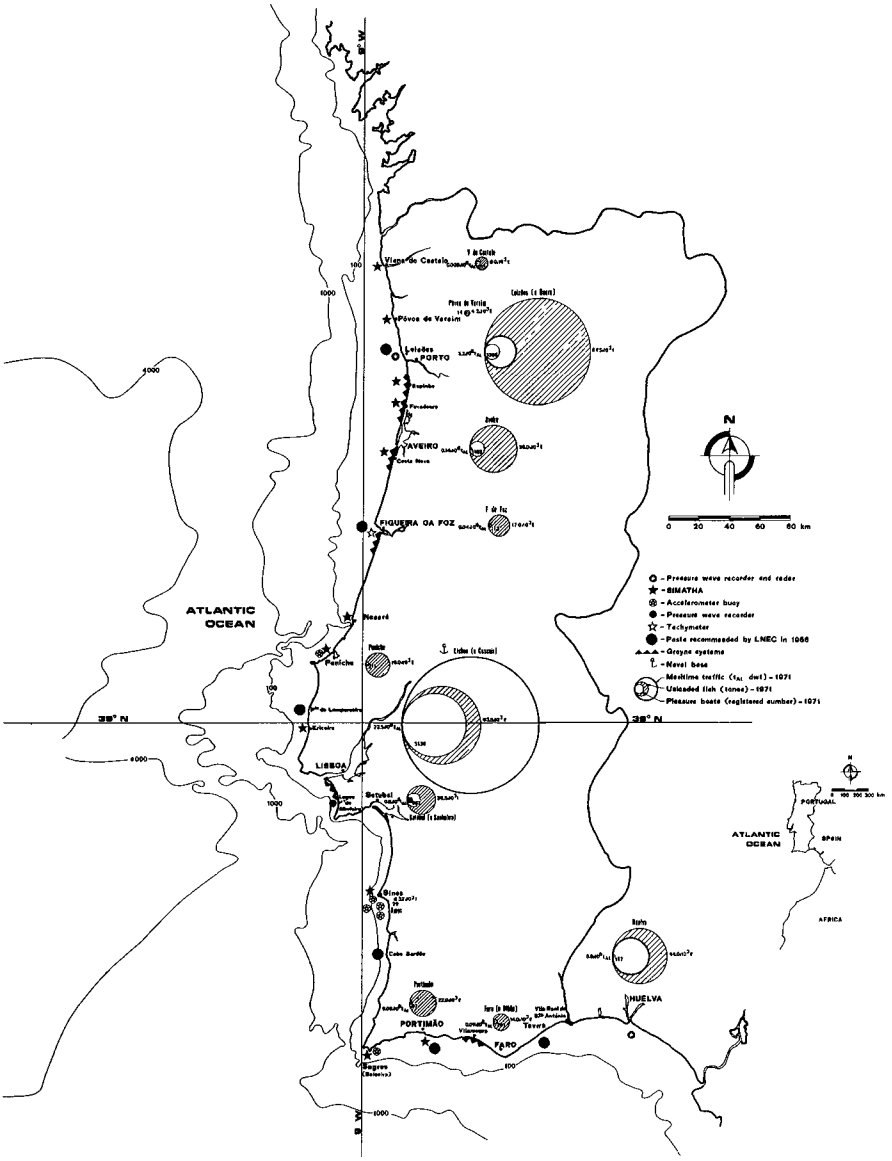


Fig.2 - Map of the Portuguese coast.

(and refuge for pleasure boats) is to be built. In 1973 three accelerometer buoys were installed in Sines by the official organization in charge of the construction of this port (Department of Sines Area).

In 1957 there had been an attempt to install in Portimão an American WH1 pressure cell with land transmission by cable but after some damages the connecting cable was cut off by a wrecked ship and the method abandoned A similar cell was available at Leixões in 1962, attempts to install it having failed; further attempts of installation during that year also proved unsuccessful.

Besides the posts referred to, there are also visual observations carried out at the lighthouses along the coast and some additional SIMATHA posts in the north coast. Other types of information that may be referred to are the American charts on the sea and swell conditions studies of the North Atlantic (based on the observation carried out at meteorologic ships) and the previsions of the National Meteorologic Department transmitted by television.

Figure 2 shows a map of the Iberian peninsula with the sites referred to. Besides, it also gives a general idea of the importance of the different harbours and coastal zones as far as sea traffic, fishing and pleasure sailing are concerned (based on 1971 official statistics). The groyne systems constructed or under construction, as for instance at Figueira da Foz, are also indicated. Note also that ships with up to 1 million dwt are envisaged in Sines. In Cascais (near Lisbon) a harbour with moorings for 800 pleasure boats, in the first stage, has been designed and in Vilamoura (south coast) another harbour with moorings for 500 pleasure boats, in the first stage, will be inaugurated.

2 - PRACTICAL CONSIDERATIONS ABOUT WAVE OBSERVATION EQUIPMENT

Some practical aspects have to be borne in mind with regard to the main types of automatic equipment (pressure wave recorders, accelerometer buoys and radar).

In addition to supplying immediate information, accelerometer buoys also present the advantage that routine operations are easier and do not require such elaborate means as pressure wave recorders. This is due to the fact that their weight is about 90 kg and their autonomy of 9 months. It cannot however be forgotten that these buoys must have a periodical inspection (which could be every fortnight) because of the danger of maritime deposits in the links of the chain and cable that connect a massive in the bottom, and which may cause, among other accidents, rupture and disappearance of the buoy (these considerations are based on recent facts at Baleeira – see figures 3, 4, 5, 6 and 7), adequate painting of the buoys is therefore indispensable.

The risk of disappearance of the buoys owing to other causes must also be taken into account (there have also been instances). A simple inspection routine has therefore to be followed, which will not be too difficult as the buoys transmit a radio signal which can be referenced. The accelorometer buoy of Baleeira was only operative from November

Fig.3 - DATAWELL type accelerometer buoy (Sines, 19th Sept. 1971).

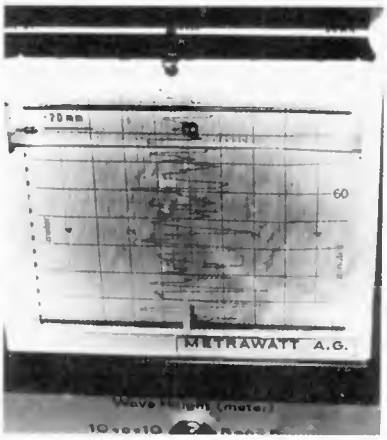


Fig.5 - Mainland recorder of an accelerometer buoy (Sines).

Fig.4 - An aspect of the installation operations of an accelerometer buoy. Cables and links (Sines, 19th September 1971).

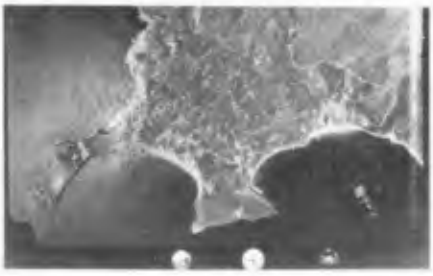


Fig.6 - Aerial view of Baleeira (12th April 1973).

Fig.7 - Hydrographic survey of Baleeira (1959).

1972 to December 1973. The accelerometer buoy of Sines was operative from September 1971 to September 1973. The accelerometer buoy of Peniche was operative from September 1971 to February 1973. All the buoys of the Harbour Department have disappeared and that of Sines was not found. It must be said that the Harbour Department does not possess the necessary means to keep this equipment in good conditions of assistance. The three buoys of Department of Sines Area, which have their own maintenance team, have been operating very efficiently.

Regarding pressure wave recorders placed on the bottom, although they may be dragged away in fishing areas (or even during the working of the assisting ship), the risk of disappearance is smaller. However, if they are damaged, a month of information may be lost (this is generally the time of their autonomy) without the possibility of intervening. Pressure wave recorders need more powerful means as well as larger and more higly qualified teams for the routine operations, not only because of their location at the bottom but also because of their weight which is about 600 kg. Besides, divers will be needed to carry out the monthly routine operations, whereas accelerometer buoys will only need this type of assistance during the initial location operation. Also, assistance operations in pressure wave recorders are difficult in sea zones where the sea is often rough, as for instance in the northwestern coast.

The operation of pressure wave recorders may also be affected by the obstruction of its membrane through sea deposits or sanding up, or there may even be excavations during storms that bury the equipment, with subsquent sanding up (as occurred in Leixões)

Accelerometer buoys, besides supplying immediate information, can also be connected to special reading units with immediate automatic treatment of the recorded information, thus simplifying reading operations, which are always necessary in the case of pressure wave recorders.

Taking into account the criterion adopted chiefly by the Dutch and Americans and now also by Portugal (in connexion with Sines and the posts of the Harbour Department) and bearing in mind what has just been said about pressure wave recorders and accelerometer buoys, it can be concluded that it is the buoys that offer the best conditions, from the practical point of view and with regard to treatment of information. Nevertheless considering the characteristics described, it is indispensable to the suitable exploitation of a network of posts to dispose of well equipped and qualified teams.

On the other hand a network of posts will only be complete if wave direction observation means are added to the accelerometer buoys, or else pressure wave recorders Radar will be the best method. It is pointed out however that powerful radar should be used, offering better possibilities of echo captation, in order not to limit its use. Also in this case the need arises for qualified personnel to operate the radar

The radar used in Huelva, with a peak power output of 5 kilowatts, a frequency band of about 9 375 MHz, and a range of 3 to 30 miles, showed deficiencies in the information concerning wave directions, as opposed to the radar of Leixões, with 20 kilowatts, 9 375 MHz and 0.75 to

Fig.8 - CHATOU type pressure wave recorder (experimental stage in January 1965 at the Tagus estuary).

Fig.9 - Adjustment of pressure wave recorder (Huelva).

Fig.10 - Typical record of pressure wave recorder (Lagoa de Albufeira, 5th October 1965 at 22.09h. T_C = 10.28s; H_S = 1.79m).

Fig.11 - Waves at Huelva in front of Prácticos observation post (25th June 1970).

Fig.12 - Aerial view of Huelva observation zone (13th October 1973 at 9.30h).

Fig.13 - Huelva radar (block and sighter).

Fig.14 - Huelva radar (block with camera).

Fig.15 - Hydrographic survey of Huelva bar (June 1970).

Fig.16 - Huelva radar (aerial).

Fig.17 - Typical image supplied by Huelva radar(26th Jan.1971 at 21.00h. T_C = 8.0s; H_S = 0.70m).

Fig.18 - Aerial view of Leixões harbour (5th April 1973 at 13.00h).

Fig.19 - Typical image of Leixões radar (non identified photograph).

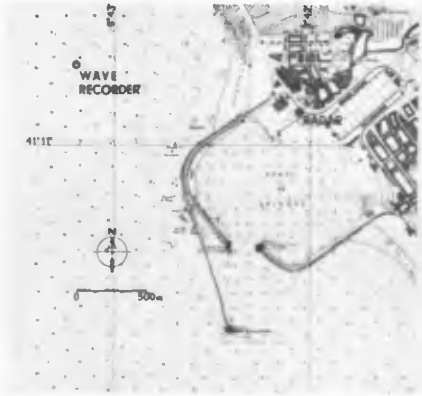


Fig.20 - Hydrographic survey of Leixões harbour (1950, updated).

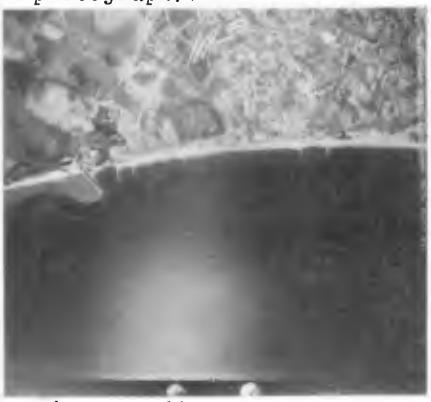


Fig.21 - Vilamoura groyne system. SW wave action (12th April 1973 at 13.00h). Construction phase of the marina.

Fig.22 - Aerial view of Peniche (2nd March 1973 at 13.00h).

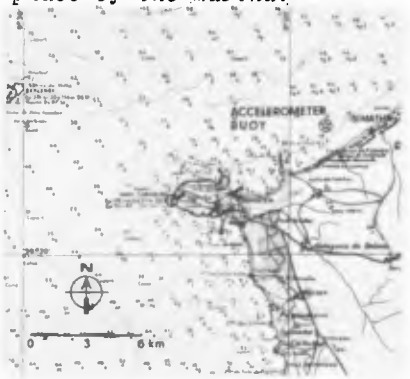


Fig.23 - Hydrographic survey of Peniche harbour (1915, updated).

Fig.24 - Aerial view of Lagoa de Albufeira(9th March 1973, 13.00h).

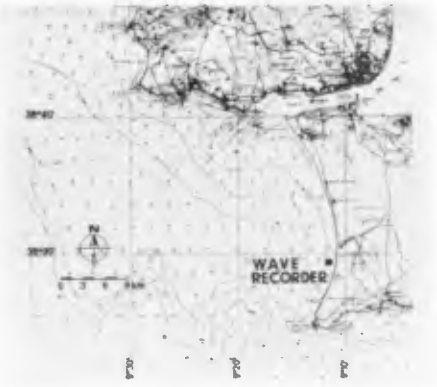


Fig.25 - Hydrographic survey of Lagoa de Albufeira(1961).

Fig.26 - Aerial view of Sines (16th March 1973,at 13.00h).

Fig.27 - Hydrographic survey of Sines (1972).

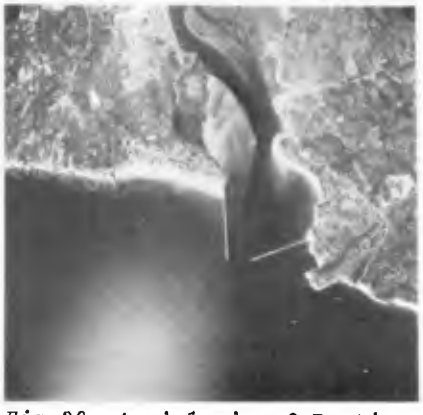


Fig.28 - Aerial view of Portimão(12th April 1973 at 13.00h).

Fig.29 - Hydrographic survey of Portimão (1961).

18 miles, which supplied images with greater contrast of the waves and is therefore considered to be more suitable.

The Tucker Draper method has been used by the Hydrographic Institute to analyse the recordings of the wave recorders in the cases of Huelva and Lagoa de Albufeira.

The cost of the accelerometer buoys is about 15 000 US dollars (DATAWELL, Dutch make, including land station equipment). The cost of the pressure wave recorder is about 12 000 US dollars (CHATOU, French origin). The cost of the radar used in Huelva was 3 200 US dollars (AR 305 B - ANRITSU ELECTRONIC WORKS, LTD).

Figures 8 to 29 illustrate some aspects regarding pressure wave recorders and the use of radar in the observation of wave directions, and show some air photographs and hydrographic surveys of the places referred to.

3 - GENERAL CHARACTERISTICS OF THE WAVE REGIMEN IN THE ZONES OF PORTIMÃO (Algarve coast) AND HUELVA (southeast coast of Spain)

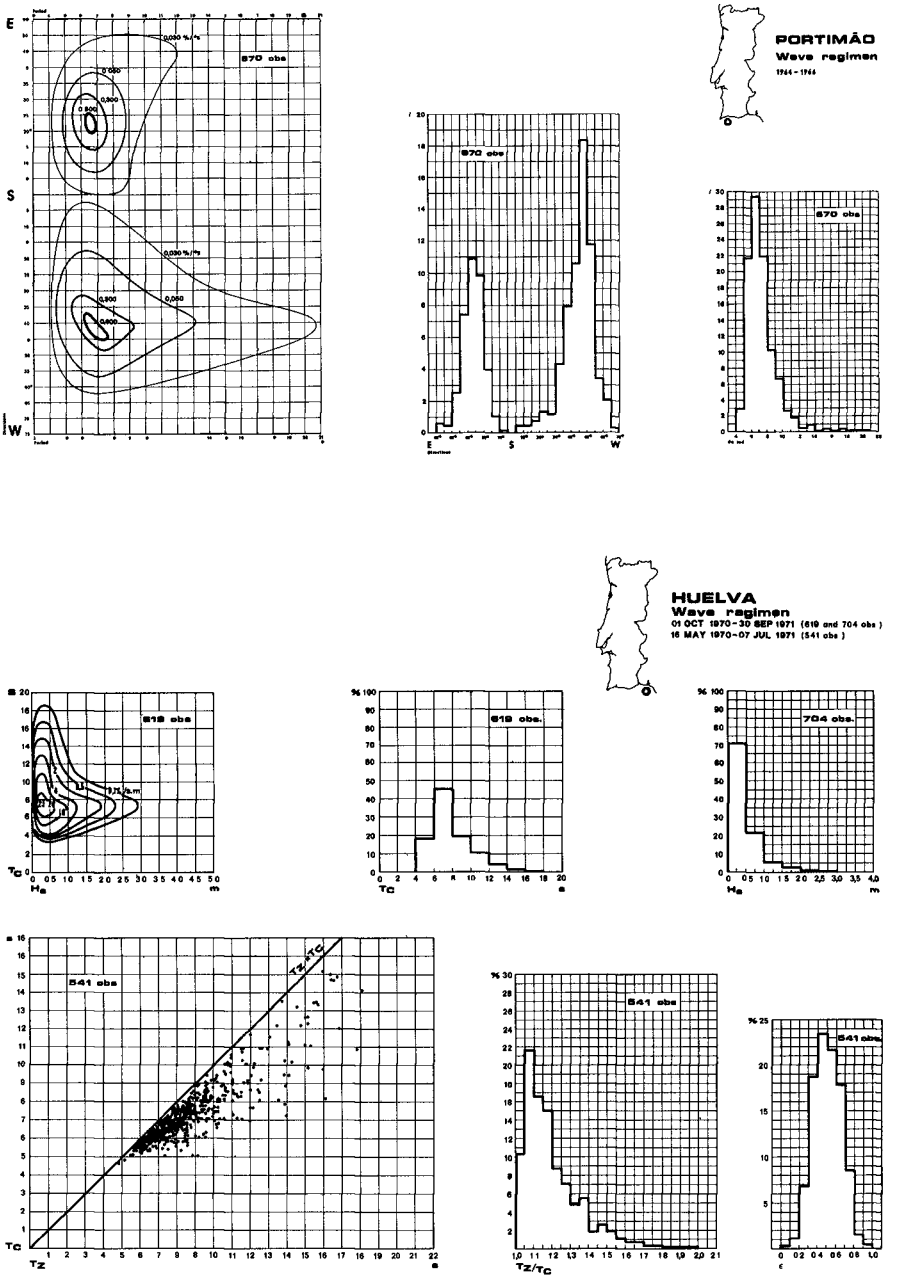
3.1 - Portimão

The only information available are wave direction and period observations (mean values of the period of the individual waves of the trains with 21 waves), using SIMATHA and references to wave heights based on visual observation from the lighthouses, which are considered with great reservation (in this case it is considered that the said observations are not sufficiently accurate owing to the high values estimated for the wave height, however other studies make reference to the results of observations carried out at lighthouses on the western coast, which agree closely with those obtained by the wave recorders).

The observations carried out in 1964/1966 by the Maritime Services, for a zone with depths between 10 and 15 m are presented. The general characteristics of the regimen can be analysed in figure 30. The periods of calm amounted to about 70%, 37% of the waves coming from the SE quadrant and 63% from SW quadrant, there being two different regimens, one for each quadrant. In the SE quadrant the periods are limited to maximums of about 11 to 12 s whereas in the SW quadrant there are periods greater than 16 s rising to maxima of about 20 s. The period distribution is asymmetric with a maximum of between 6 and 7 s. The calculations carried out for the maximum fetch, which can be defined for the SE quadrant owing to the limitation imposed by the neighbouring coast, have made it possible to determine the maximum period, which amounts roughly to 11 s and the maximum heights, about 4 m.

3.2 - Huelva

The observations made with a pressure wave recorder and radar between October 1970 and September 1971 will be considered. The wave



Figs.30 and 31 - Portimão's wave regimen (10 to 15m depth) and Huelva's wave regimen (10m depth).

recorder was located at a depth of 10 m. The values of the significant heights of the wave trains on the surface (H_S), the values of the crest period (T_C) and up zero crossing period (T_Z) as well as the spectral width (ε) were considered.

The general characteristics of the regimen can be analysed in figures 31 and 32. A range of periods T_C comprised between 4 and 18 s have been observed with a maximum at step 6-8 s. The values of height distribution presented include the states of calm. 70% of the states of the sea show heights between 0 and 0.5 m corresponding to maximum occurrence. Maximum heights which occur very seldom lie between 2.5 and 3.0 m (significant height values). The binary T_C, H_S has a very different distribution from those presented for the Portuguese west coast. It has a maximum at 6-8 s and 0-0.5 m, maximum values of wave heights associated with the most frequent periods and the heights associated with the larger periods are rather unimportant (these waves come from the North Atlantic with a great decrease in the energy of the wave trains owing to the refraction and diffraction). The relation T_Z/T_C shows values between 1.00 and 2.00, there being about 64% between 1.00 and 1.20. It is for the lowest values of the period that the values nearest to 1.00 are obtained (which is due to the filter effect). Hence the fact that these periods are similar to those of Portimão zone (which will better correspond to the values of T_Z).

As regards the distribution of the wave directions it must be said that this radar showed some deficiencies in so far as it was difficult to detect waves less than 60 cm high. This brought gaps of the order of 90% and the observations of wave directions were subsequently completed by a method similar to SIMATHA. The values of the binary direction-significant height have a maximum corresponding to the greatest density of occurence for the pair of values 210°/220°, 0/0.50 m, and another for values 180°/190°, 0/0.50 m (see figure 32).

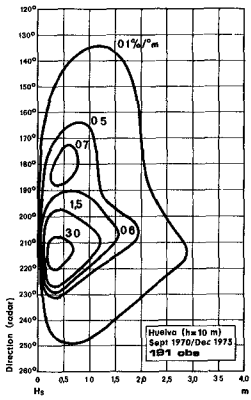


Fig.32 - Huelva. Correlation curves between wave directions and wave heights(10m depth).

Daily routine observations (two a day) were considered in the groupings made, storm recordings (extra routine) having been left out. The gaps observed in the wave recorder were less than 1%.

4 - GENERAL CHARACTERISTICS OF THE WAVE REGIMEN IN THE LAGOA DE ALBUFEIRA ZONE (center-south zone of the west coast)

The paper gives the values for the year of 1967, included in the experimental period of 1965-1968, with values obtained by a pressure wave recorder and worked out by the Lisbon Hydrographic Institute for the model study of the Tagus estuary (Lisbon harbour). There is no thrustworthy information of wave direction observation, although a SIMATHA had been placed in this zone. The wave recorder had been placed at a depth of 20 m.

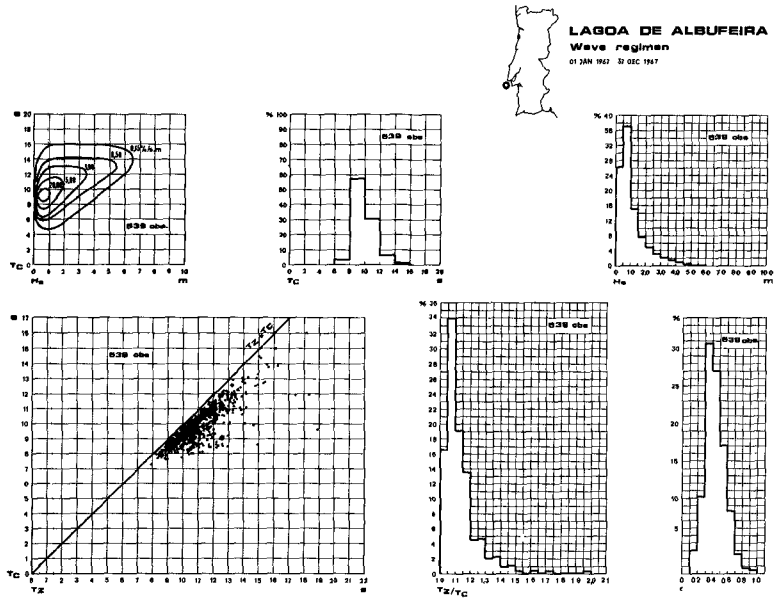
The general characteristics of the regimen can be analysed in figure 33. A range of periods T_C (crest periods) lying within 6 and 16 s, with a maximum of occurrence in step 8 to 10 s, has been observed. Height distribution is asymmetric, a percentage of 26% of waves below 0.5 m having been observed, with a maximum situated between 0.5 and 1.0 m and heights up to 6.0 m. These are significant height values in the zone where the observation was carried out. Extrapolation towards deep water, based on wave diagrams, gives heights of about 9.0 m for the NNW storms. T_C, H_S presents the distribution shown in figure 33, greater heights being connected with greater periods. As can be seen in this figure, the concentration of points regarding the low values of the period happens near the straight line $T_C = T_Z$ (as in the case of Huelva) and then spreads, the widest differences being found for the highest values of the period.

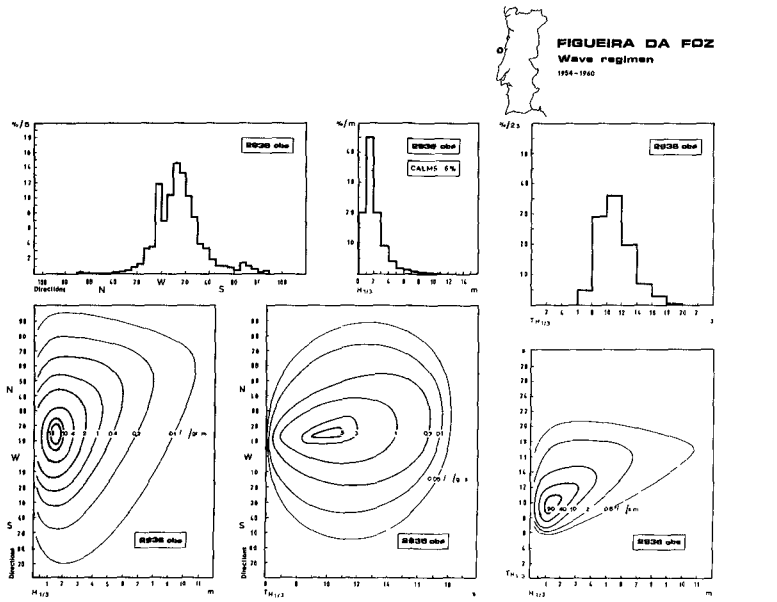
The parameters described for Huelva were considered and the same criterion was adopted in the statistic groupings. The gaps observed in the exploitation of this pressure wave recorder (in 1967) amounted to 34%. It therefore became necessary to take into account the month of November 1965 instead of November 1967 which was missing (this was possible because of the characteristics of regularity of the wave regimen during these years).

5 - GENERAL CHARACTERISTICS OF THE WAVE REGIMEN OF FIGUEIRA DA FOZ ZONE (north zone of the west coast)

The first elements of the wave regimen study, that were revealed between 1964 and 1966, were based on the observations made by the Figueira da Foz Harbour Authority using tachymeter and a signal buoy, placed at the depth of 12 m, from 1954 to 1960. With this system were made observations of heights, periods and directions (see figures 34 to 40).

The general characteristics of the wave regimen can be analysed in figure 34. In the method adopted observed heights were limited to 20 cm. One set of periods ranged from 6 to 20 s, (obtained by chronometry of 21 consecutive waves and calculation of the mean values of the individual periods) which are closer to the values of T_Z because the waves of smaller individual period are overlapped by the dominant waves and are not observed (which diminishes the relation between the maximum individual height and the significant height). Height distribution (significant heights, calculated according to the mean of one third of the waves with greater train height) is asymetric, there being a percentage of 20% of waves below 1.0 m, with 6% of calm sea (heights below the measuring





Figs.33 and 34 - Lagoa de Albufeira's wave regimen (20m depth) and Figueira da Foz's wave regimen (deep water).

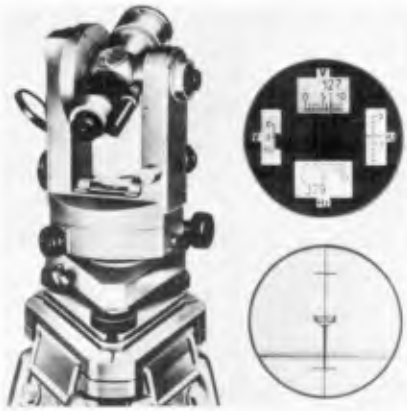


Fig.35 - Tachymeter, reading scales, signal buoy(Figueira da Foz).

Fig.36 - Observation tower(Figueira da Foz - May 1962).

Fig.37 - Breaking waves at Figueira da Foz (May 1962).

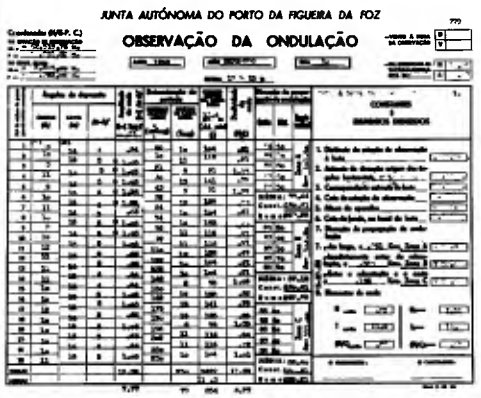


Fig.38 - Record of the observation and calculation of the values (Figueira da Foz).

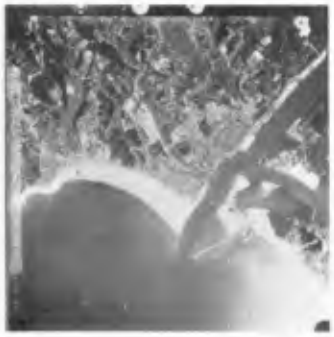


Fig.39 - Aerial view of Figueira da Foz(2nd March 1973 at 13.00h).

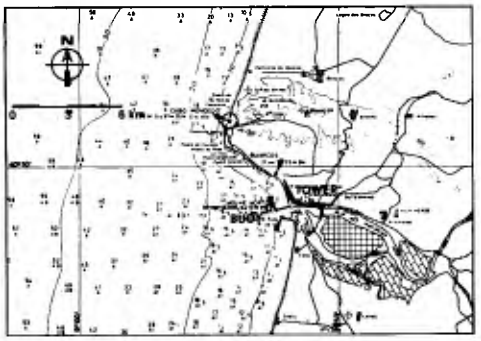


Fig.40 - Hydrographic survey of Figueira da Foz (1914, updated).

range of the tachymeter included), a maximum at step 1 to 2 m and heights up to 11 m. These values concern the height of waves off shore (deep water), by extrapolation of the values of the zone under observation. The distribution of the off shore wave direction is regular, almost symmetric around step W- 10^{o} to 20^{o}- N, very different from that in the south coast.

With this method of observation and during the time considered 18% of gaps due to various reasons were observed (among them the disappearance of the signal buoy during storms, lack of visibility, sundays and holidays during which the observation team was not active, etc.).

6 - CHARACTERISTICS OF OCEAN WAVE TRAINS

Further to the considerations made at the IX Coastal Engineering Conference (1964), the correlation graph between the mean values of the wave periods and the significant height values are presented, taking as a basis the graph presented in 1960 by Prof. Wiegel, which comprises all sorts of different observations, from experimental flumes, lakes, and gulfs to ocean zones, and including in this graph besides the observations of Figueira da Foz (deep water) also those of Lagoa de Albufeira and Huelva (both in the observation zone).

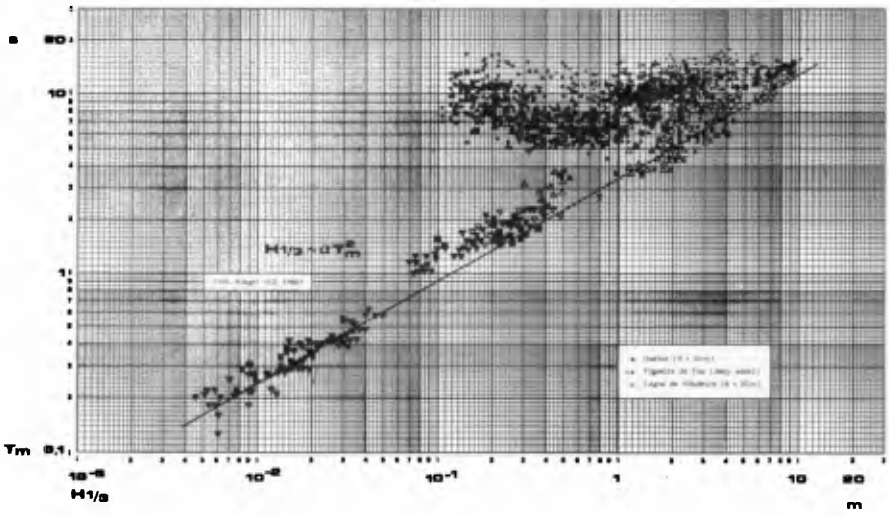


Fig. 41 - Graph of correlation between $H_{1/3}$ and T_m.

The values concerning these observations differ from the law defined by Sibul, the same as the values of the other observations carried out in the North Atlantic, but they tend towards the straight line defined from the experimental values in the zone of greater heights and periods. Figure 41 shows the points concentration concerning Figueira da Foz (1954 and an extreme value of 1956 with $H_S = 11$ m), Huelva (1971) and Lagoa de Albufeira (Jannuary 1967, which is a representative month); the points concentrations tend to the theoric limit straight line in Prof. Wiegel's graph.

Three spectral curves are defined hereafter regarding the cases of Huelva, Lagoa de Albufeira and Figueira da Foz and corresponding to typical cases. It can be said that, on the whole, the spectra of Huelva

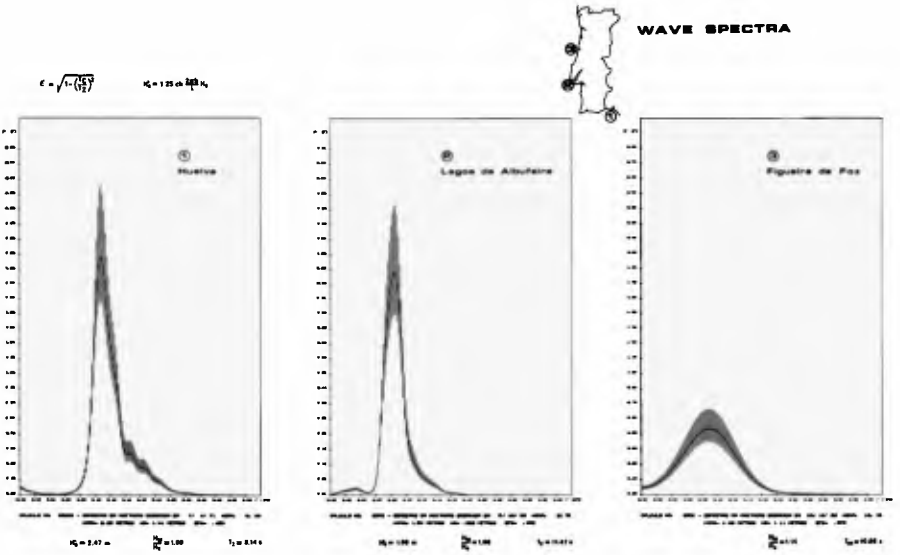


Fig. 42 - Wave spectra.

and Lagoa de Albufeira (obtained from the records of the pressure wave recorders and regarding the orbital movement near the bottom) are of the same type, with spectral width values near 0.45, which corresponds to maximum occurrences. There is however greater concentration of energy in the higher frequencies in the case of Huelva, the opposite being true in connexion with Lagoa de Albufeira. In the case of Figueira da Foz, the spectrum was obtained schematically from the tachymeter observations, which is less accurate, and a different type of spectral curve was obtained. As regards the relations between maximum and significant wave heights, the value for the two first cases is approximately 1.60, which is closer to Prof. Wiegel's values than to the value obtained for Figueira da Foz, 1.15. This shows the influence of the observation method (in which secondary waves overtopping dominant waves were not observed by tachymeter). In figure 42 values H_S concern the amplitude of the bottom orbital movement and the values H'_S the surface heights. It should be noted that accelerometer buoys supply direct information on the surface sea conditions, which has indubitable advantages.

In accordance with the data on figure 43 it can be said that: off Figueira da Foz, significant waves with heights between 12.0 and 12.5 m have a probability of occurrence of 1 every 10 years; in Lagoa de Albufeira the 8.0 m wave has a probability of 1 every 10 years (in the observation zone), and in the Huelva observation zone the probability of occurrence for 2.5 m waves is 1 a year. In the straight line regarding Figueira da Foz there is a point, at maximum heights, which deviates from the straight line; this is due to lack of observation during storms because

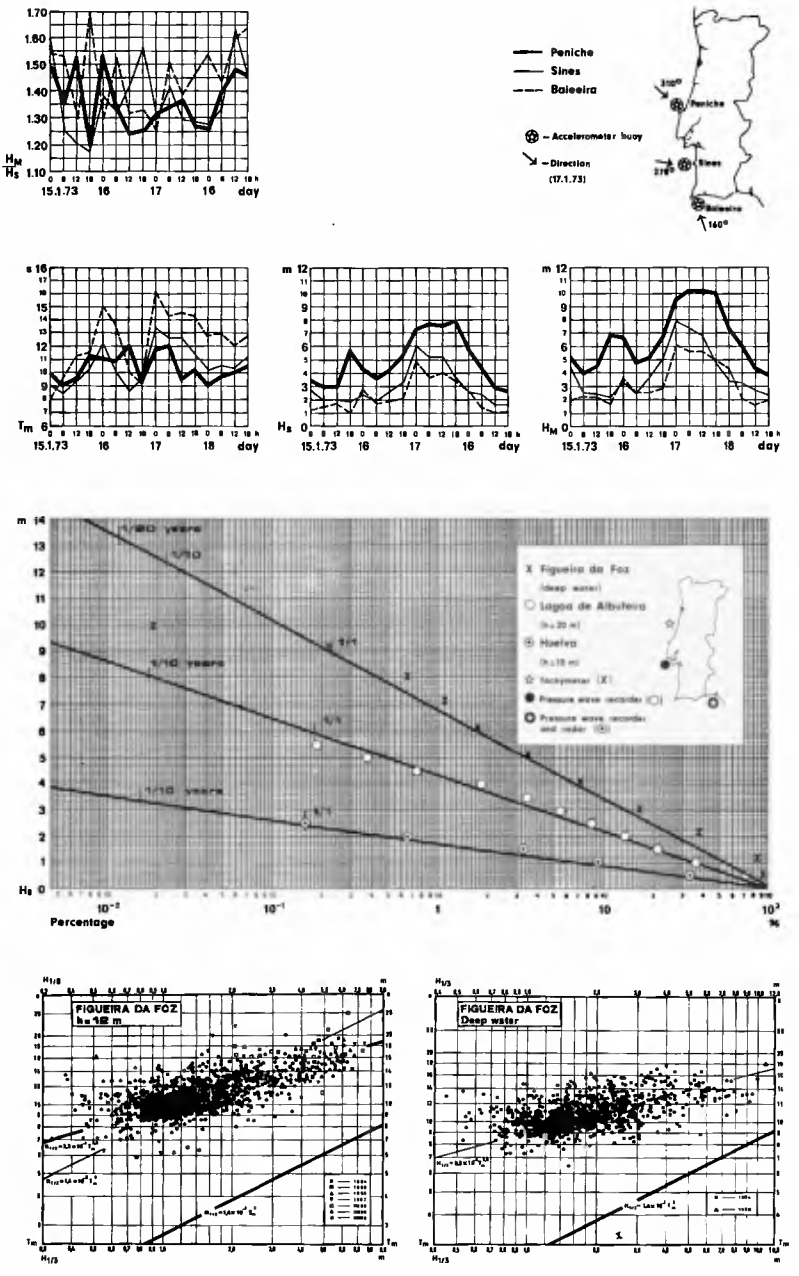


Fig.43 - Characteristic elements of the western and southern coast wave regimen.

there is frequent rupture and disappearance of the signal buoy on these occasions.

From the 3 accelerometer-buoys of the Harbour Department used in Peniche, Sines and Baleeira can be obtained typical data on the variation of the wave characteristics by analysing the data regarding the north storm that occurred in January 1973, which associated with a depression, caused damages in some works as well as erosions and overtopping in different places. The maximum H_S values recorded were 7.9 m (Peniche, 25 m

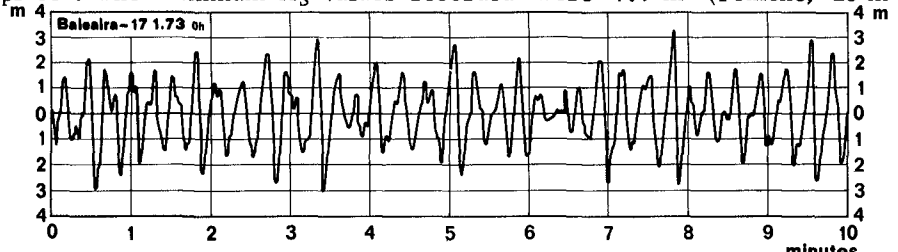


Fig.44 - Wave train recording(accelerometer buoy of Baleeira).

depth), 6.0 m (Sines, 43 m depth) and 4.8 m (Baleeira, 32 m depth). The mean periods were respectively 10.1 s, 13.3 s and 16.1 s. The periods at Baleeira were on the whole higher than on the other two places, which might be due to the attenuation of the smaller period wave components due to the refraction and diffraction to which swell is subject as far as Baleeira. Figure 43 shows the data regarding these observations, including the relationships between significant heights H_S and maximum individual heights H_M, and the wave directions in the zones under observation.

7 - CONCLUSIONS

The nature of the Portuguese coast, with rather high tides, particularly strong sea (on the west coast) and all sorts of coastal formations, fully justifies the existence of a well equipped and efficient network of posts to carry out a thorough observation of the waves.

A network of posts installed according to the schemes envisaged could supply useful information regarding any point of the coast by drawing wave diagrams to make it possible to know the regimen off shore and from it also that on the different parts of the coast (by drawing in computer the wave diagrams).

The ideal solution for wave observation seems to be to combine accelerometer buoys with radar controlled automatically by the radio-signal of the buoy. Radar would thus operate during the routine established for the accelerometer buoy and during the storm recordings, without the assistance of an operator.

The relations between T_m and $H_{1/3}$ are difficult to define for the observations considered in this work due to the scattering of the points. There is however a tendency of the extreme values towards the limit straight line defined in Prof. Wiegel's graph. In the case of Figueira da Foz approximate relations were defined as can be seen in figure 43.