MARITIME WORKS RECOMMENDATIONS

TRANSLATED VERSION OF THE ORIGINAL SPANISH TEXT

ROM 0.3-91

Waves

Annexe 1. Wave Climate on the Spanish Coast

Puertos del Estado

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PREFACE

ROM PROGRAM

Ports of the State (Puertos del Estado) through its Technical Department of Technology and Normative (Departamento Técnico de Tecnología y Normativa) has begun a program of technological development in the area of Maritime and Port Construction whose objective is to establish Recommendations or 'Codes of Good Practice' for the planning and execution of Maritime and Port Construction, which would constitute the beginnings of a future Spanish School in this Engineering field.

These Maritime Works Recommendations (ROM) shall define an ordered set of technical criteria that, while not being for the moment compulsory or normative, will help to inform project engineers, directors or executives of maritime and port works and ensure the quality levels demanded by these works.

Various technical commissions in conjunction with diverse specialists in collaboration with public and private installation and organisms, especially with the Center of Studies and Experimentation of Public Works (Centro de Estudios y Experimentación de Obras Públicas, CEDEX), are developing projects in different areas of maritime engineering with the goal of compiling the most advanced technology in this Field, contrast it with experience and current general practice, and systematically order the results in such a way as to facilitate the various state entities and firms involved in maritime engineering in their access to information necessary for the development of their projects.

In any case an attempt has been made to contribute to the gradual harmonization of the Spanish Codes with other currents codes, fundamentally those in the field of civil engineering encompassed within the Eurocodes.

In 1990 the first Recommendation of this program was published:

ROM 0.2-90 ACTIONS IN THE DESIGN OF MARITIME AND HARBOUR WORKS which has been in use since then, with good results, in all the maritime engineering projects corresponding to works under the Technical Direction of Ports of the State (Dirección Técnica de Puertos del Estado).

The ROM program has completed or is in an advanced stage of development, to this date, the following codes.

ROM 0. GENERAL RECOMMENDATIONS
- 0.1 Project Development Recommendations
- 0.2 Actions in the Design of Maritime and Harbour Works*
- 0.3 Recommendations for the Consideration of Environmental Actions I:Waves
  Annex I: Wave Climate on the Spanish Coast*
- 0.4 Recommendations for the Consideration of Environmental Actions II: Winds
- 0.5 Geotechnical Recommendations
- 0.6 Seismic Actions

ROM 1. BREAKWATER DESIGN AND CONSTRUCTION RECOMMENDATIONS.

ROM 2. BERTHING WORKS DESIGN AND CONSTRUCTION RECOMMENDATIONS.

ROM 3. APPROACHING AND WATERPLANE SURFACES DESIGN AND CONSTRUCTION RECOMMENDATIONS.

ROM 4. SUPERSTRUCTURE DESIGN AND CONSTRUCTION RECOMMENDATIONS.

* Published

4.1 Port Pavement Design Recommendations. Pavement Standardizations.

DEVELOPMENT OF THE EDITING OF THE ROM 0.3.WAVES

The ROM 0.3 RECOMMENDATIONS FOR THE CONSIDERATION OF ENVIRONMENTAL ACTIONS I: WAVES, is being edited by the technical commission designated by the former General Director of Ports of MOPT in resolutions made on the 20th of March, 10th of April and 23rd of October of 1991 under the responsibility of the Actual Technical Direction of State Ports (Dirección Técnica de Puertos del Estado).

The members of this commission and the entities to which they belong are the following:

— President:	Mr. Juan Muñoz Mitchell	(Ports of the State)
— Technical Director:	Mr. Francisco Esteban Rodríguez-Sedano	
— Secretary:	Mr. José Llorca Ortega	(Ports of the State)
— Participants:	Mr. Eduardo Arana Romero	(IBERINSA)
	Mr. José M.ª Berenguer Pérez	(CEPYC-CEDEX)
	Mr. José Conde Aldemira	(PCM)
	Mr. Vicente Negro Valdecantos	(INTECSA)
	Mr. Eloy Pita Carpenter	(Ports of the State)
	Mr. Javier Rodríguez Besné	(Ports of the State)
	Mr. Carlos Sanchidrián Fernández	(ALATEC, S.A.)

The Technical Commission, in the development of their work, counts on the express collaboration of the Center of Studies of Ports and Coasts (Centro de Estudios de Puertos y Costas, CEPYC) of CEDEX, and on the Technical Department of Maritime Climate of Ports of the State (Departamento Técnico de Clima Marítimo de Puertos del Estado).

During the process of editing the ROM 0.3 WAVES, the Technical Comission has found it necessary to include in the same a complete characterization of the wave climate along the Spanish coast, defined by statistical analyses based on the methodology of determination most advanced and reliable at this time.

The ultimate goal is to simplify in the most general cases the methodology of definition of the design waves along the Spanish coast, without having to refer to the localization and statistical analysis of the available raw wave data for the characterization of the wave climate in every coastal zone.

Because the available instrumental information along the Spanish coast still correspond to relatively short recording periods, and because the statistical method of analysis for extreme conditions is not yet totally consolidated, the need to update the wave climate periodically is anticipated, for this reason the Technical Commission has decided to publish the Wave Climate on the Spanish Coast as Annex I separately from the principal body of the ROM 0.3 in order to facilitate its revision.

Once this Annex has been elaborated, and given its great practical utility in the design of maritime works along the Spanish coast, and the autonomous character of the same with respect to the principal text of the Recommendation, the Technical Commissions have decided on its immediate publication as Annex I of the ROM 0.3-91 Waves, being at this moment the only document in force under this Recommendation. It is published as ROM 0.3-91 since the analysis of data was carried out in 1991 based on information registered up to 1990 inclusive.

The Technical Commission will analyze all comments, suggestions, and initiatives that are given in regards to the contents of Anex I of ROM 0.3-91. WAVES and these will be taken into account in posterior versions of the cited Recommendations.

Observations should be submitted to:

Puertos del Estado
Departamento Técnico de Tecnología y Normativa
Avda. del Partenón, 10
Campo de las Naciones
28042 Madrid

APRIL 1994

PART 1 GENERAL

PART 1 GENERAL

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PART 1 GENERAL

1.1 SCOPE OF APPLICATION

The Annex I of the Recommendation 0.3. Waves: Wave Climate on the Spanish Coast will be applicable in the design, construction and utilization of all maritime and port works regardless of their class and usage, as well as the materials and elements used in their construction, as long as they are located along the Spanish coast and are affected by the same waves that are analyzed by one of the available information sources.

1.2 CONTENTS

This Annex compiles all the information and criteria necessary for the characterization and approximate forecasting of the wave climate along the Spanish coast, and therefore for the definition of the design waves in deep water along practically the entire coast of Spain for extreme conditions as well as for normal conditions of operation. Furthermore it permits the determination of a design wave spectrum for extreme conditions in the cited geographical zone.

The Annex is structured in two parts:

Part 1. General. Includes all the general aspects necessary for the correct application and comprehension of the Annex: scope of application, general description of its contents, definitions, units used, notations and symbology, and references.

Part 2. Wave climate along the Spanish coast. Establishes, in terms of characterization of the wave climate; a zoning of the Spanish coast in 10 different areas, defined based on homogeneous climatic characteristics, on the configuration of the coast and on the location of the available instrumental information. Establishes the methodology of determination of the wave climate in each of the established zones based on the statistical analysis of the available wave information: Visual data originating from the National Data Center of Asheville and Instrumental Data recorded by REMRO buoys, defining the technical characteristics of the same.

Includes the following relationships of wave characterization in each of the defined areas: Combined distribution of visually observed wave height/direction (Wave Roses), sectorial frequencies of occurrence, unidimensional statistical analysis of the significant or visual wave height variable for normal conditions and for extreme conditions, bidimensional statistical analysis of significant wave height/mean period and mean period/peak period and spectral statistical analysis, analyzing the methodology used, and the reliability and the practical degree of application of the results.

Graphically presents the results obtained in the format of an Atlas of Wave Climate, compiling, in each page, all information for one of the established areas with the aim of facilitating the practical utilization of the same. Permits the complete characterization of deep water waves including the available instrumental information and the coefficients of refraction-shoaling, for each period and direction of interest, necessary for transferring the shallow or intermediate water results at each recorder site to deep water. And finally defines the methodology of determining of design waves in deep water based on the Wave Climate included in these Recommendations.

1.3 DEFINITIONS

The most commonly utilized basic terminology as it relates to this Annex is defined here. Only those terms and definitions most frequently used in the characterization and forecasting of waves over long periods of time and in the definition of design waves are included.

For any term not included here the other ROM Program recommendations can be referenced, in particular the corresponding section of the ROM 0.3. Recommendations for the Consideration of Environmental Actions I: Waves.

- CLIMATIC OR METEOROLOGIC YEAR: In Spanish latitudes the climatic or meteorologic year is considered as beginning the 22nd of June and ending of the 21st of June of the following year.
- COEFFICIENT OF DIRECTIONALITY: Coefficient which relates the extreme directional distributions of significant wave height in deep water to the extreme non-directional distribution corresponding to the analyzed zone.

  The extreme directional distribution is obtained by multiplying the nondirectional wave heights corresponding to distinct return periods, transferred to deep water, by the coefficient of directionality associated with the direction considered for the analyzed zone.
- CUMULATIVE WAVE HEIGHT DISTRIBUTION (MEAN SCALAR DISTRIBUTION): Relationship between the wave height values and their non exceedence probability during the mean climatic year.
- DEEP WATER: A wave is considered to be in deep water when the relative depth, or quotient between the water depth and the wave length corresponding to some representative wave period (mean period or peak period) determined by the Airy Theory, is greater than 0.5.
- DEVELOPING SEA WAVES: Waves in which the mechanism of generation and development of the wave is limited by the fetch length and/or the duration of the generating wind.
- DIRECTIONAL CUMULATIVE WAVE HEIGHT DISTRIBUTION (MEAN DIRECTIONAL DISTRIBUTION): Relationship between the wave height values and their non exceedence probability during the mean climatic year for waves originating from the directional sector considered.

  The defined probability is, therefore, conditioned that the waves principle direction of propagation is within the directional sector analyzed.
- DIRECTIONAL SECTOR: Angular sector of a determined amplitude. In this annex 22.5° sectors are considered.
- EXTREME CONDITIONS: The occurrence of the severest environmental conditions for which a structure or installation is designed.
- EXTREME WAVE HEIGHT DISTRIBUTION: Distribution function of the extreme values of the wave height variable. Relates the maximum foreseen values of this variable with the probability that these values are not exceeded in a year.
- FETCH: Defined, in relation to a point of observation or forecast, as the open water surface over which a wind, capable of generating waves at that point, blows.

  Generally determined by the fetch length parameter, defined simplistically as the length of the area of generation in the mean direction of the generating wind.
- FREQUENCY SPECTRUM OF WAVES: Expression that determines the average energy per unit of surface contained in each of the infinite monochromatic wave components of different frequency. When the energy distribution is expressed as a unique function of the frequency, independent of the direction of propagation, it is denominated as a Unidimensional or Frequency Spectrum. It is used as a model to describe the Sea State.
- HINDCASTING: Theoretical model of wave analysis based on pressure zones and/or wave generating winds deduced from past synoptic charts.
- FULLY DEVELOPED SEA WAVES: Wind waves that have reached the limit equilibrium with the generating wind independently of the fetch length and duration of wind. Therefore, it is a wave that is totally developed for a given wind velocity.
- INSTRUMENTAL WAVE DATA: Wave data gathered from instrumental recordings.
- INTERMEDIATE WATER: A wave is considered to be in intermediate water when the relative depth, or quotient between the water depth and the wave length corresponding to some representative wave period (mean period or peak period) determined by the Airy Theory, is within the following interval:

$$1/25 \leq d/L \leq 1/2$$

- JONSWAP SPECTRUM: Multiparametric theoretical frequency spectrum developed by Hasselman based on the Pierson-Moskowitz spectrum, as fitted to real spectra measured in the North Sea. Fundamentally permits the definition of partially developed

Seas, that is, those situations in which the wave generating mechanism is limited by the fetch and/or the duration of the generating wind.

— MEAN: First moment of a statistical distribution, for a sample of size n defined as:

$$\bar{x} = \sum_{i=1}^{n} \frac{x_i}{n}$$

The mean is a statistical parameter of position, since it indicates where the center of the sample data distribution (in the sense of center of gravity) is situated.

— MEAN PERIOD: Geometric-statistic parameter representative of the wave, defined, based on the analysis of a record according to the Zero Up Crossing Method, as the arithmetic mean of the periods of all the individual waves.

— NORMAL CONDITIONS OF OPERATION: The state in which an installation works without limitations, with no affect to its exploitation or operativeness due to environmental conditions.

— PEAK ENHANCEMENT FACTOR or adjustment of the spectral peak: Shape parameter of the theoretical JONSWAP spectrum that controls the sharpness of the spectral peak.

— PEAK FREQUENCY: Frequency at which the spectral density function reaches its maximum (peak) value.

— PEAK OF STORM: Sea state, caused by a storm, in which the greatest significant wave heights are recorded.

— PEAK PERIOD: Period at which the spectral density function reaches its maximum value. It is the inverse of the peak frequency.

— PLOTTING POSITION FORMULA: Estimation of the probability assigned to each ordered data sample. Plotting position formulas are necessary to represent the sampled data on probability paper, to which the chosen distribution function is then fitted either graphically or by least squares.

— PROBABILITY PAPER: Cartesian aid with axis or axes of distorted scale (in a non-linear sense) that allow the graphical representation of statistical distributions by means of a straight line.

— REDUCED VARIABLE: Variable defined as a linear transformation of the initial variable, with the aim of allowing a mathematical function, defined in terms of the reduced variable.

— REFRACTION: Process of wave transformation resulting in changes in wave height and direction of propagation. This occurs when a certain marine topography or the presence of currents or other phenomenon (such as wind) alter the velocity and/or direction of propagation of points on the wave crestline with respect to other points. In this annex the refraction phenomenon is considered to take place in shallow and intermediate water, and therefore fundamentally caused by bathymetry. The configuration that a wave subject to refraction will take on can be summarized by saying that the wave crestlines tend to orient themselves parallel to the bathymetry contours.

— REFRACTION/SHOALING COEFFICIENT: Coefficient for quantifying the wave height variation, due to the influence from the sea bed, from the deep water wave height.

Defined, at each point and for each period and wave direction, as the quotient of the wave height at that point and the deep water wave height.

The above is valid as long as, due to the range of depths and the location of the point analyzed, the phenomena that transform the wave from deep water to shallow water are exclusively refraction and shoaling.

— RETURN PERIOD: The average interval of time in which a value is exceeded only one time; that is, the average time between two consecutive exceedences of that value.

— SEA STATE: A temporal/spatial state in which the phenomenon of real waves can be considered stable statistically and in terms of energy. Representing, therefore, each one of the states through which the waves can pass during their evolution. In each of these states the real waves can be treated as a process stationary in time, homogenous in space, and ergodic (every sizable sample is equally representative of the whole). Under these conditions a description of waves during short periods of time can be based on a finite wave recording.

- SEA STATE CURVES: A curve that characterizes successive Sea States by means of a continuous function that represents a certain statistical parameter representative of the Sea State, in particular the significant wave height, with respect to time in a specific point.

- SEA WAVE OR WIND WAVE: Waves formed and developed on a water surface under the direct and continuous action of wind, generating elemental waves of random and independent height, period, phase and direction of propagation, whose interaction gives rise to a chaotic appearance of the water surface.

- SHALLOW WATER: A wave is considered to be in shallow water when the relative depth, or quotient between the water depth and the wave length corresponding to some representative wave period (mean period or peak period) determined by the Airy Theory, is less than 1/25.

- SHOALING: Modifications in the wave characteristics that take place due to a gradual depth variation when propagating through shallow or intermediate depths. This phenomenon gives rise to changes in the wave heights and lengths but not in the wave periods.

- SIGNIFICANT PERIOD: Geometrical-statistical parameter representative of the wave, defined, based on separating a record of waves into individual waves according to the step by Zero Up Crossing Method, as the arithmetic mean of the periods associated with one third of the highest waves recorded.

- SIGNIFICANT WAVE HEIGHT: Geometrical-statistical parameter representative of the wave, defined, based on separating a record of waves into individual waves according to the Zero Up Crossing Method, as the arithmetic mean of wave heights of one third of the highest waves recorded.

- SPECTRAL DENSITY: Average energy per unit of surface associated with each of the infinite monochromatic wave components of different frequency. It is expressed in units of energy per unit of frequency. The spectral density function coincides with the Fourier transform of the variance of the sea surface elevation distribution and, therefore, can be obtained in practice by applying the Fourier analysis of composite waves to a wave recording.

- SPECTRAL ZEROTH MOMENT: Spectral parameter equivalent to the area enclosed by the spectral density function. Consequentially, proportional to the average energy per unit of wave surface. Defined mathematically as:

$$m_0 = \int_0^\infty S(f)df$$

S(f) being the spectral density function.

- SPECTRAL SIGNIFICANT WAVE HEIGHT: Spectral parameter of waves considered as structural. Defined as four times the square root of the zeroth moment of the spectrum or area contained by the spectral density function. In this annex, the values of the statistical and spectral significant wave height corresponding to the same wave record can be considered practically coincident.

- STANDARD DEVIATION: Square root of the second moment with respect to the mean of a distribution function. Defined, for a data sample of size n, as:

$$\sigma = \sqrt{\sum_{i=1}^{n} (x_i - \bar{x})^2 / n}$$

with $\bar{x}$ being the mean. The standard deviation of a function is a measure of the scatter with respect to its mean value.If most of the area contained between the distribution curve on a cartesian coordinate system and the abscissa axis is close to the mean, the standard deviation will be small.

- STORM: A continuous series of Sea States that surpass a threshold value of the significant wave height. This threshold wave height is variable for each zone in function of the climatic characteristics of that zone.

- STORM CONDITION: Sea state in which a determined threshold significant wave height is exceeded. This threshold wave height is variable for each zone in function of the climatic characteristics of that zone.

- SWELL: Waves that leave the area of generation and propagate over waters without be subjected to significant wind actions, and therefore attenuating progressively until their complete extinction. Swells are less steep than Sea waves with large wave periods and wave lengths in a narrow range of frequencies, giving rise, in general, to an ordered and regular appearance of the water surface.

- VISUAL DATA: Wave data derived from visual observations generally from ships on route.

- VISUAL PERIOD: Wave period recorded by an observer with a chronometer, generally from a ship on route.

- VISUAL WAVE HEIGHT: Wave height recorded visually generally from a ship on route.

- WAVE CLIMATE: Characterization of waves over long periods of time or statistical description of the variation, in time, of the Sea States at a given site. Can be considered as defined based on the unidimensional and bidimensional statistics, of the geometrical-statistical and spectral parameters representative of the Sea State in the considered zone.

- WAVE LENGTH: Horizontal distance between two consecutive crests of a monochromatic or regular wave.

- WAVE RECORDING BUOY: Maritime device for collecting and transmitting wave data. The instrumental data analyzed in this annex has been recorded by waverider accelerometric surface buoys developed by Datawell. Deployed at one site, these buoys measure the vertical displacements of the water surface.

- WAVE ROSE: Commonly used graphic representation of the joint visual wave height/direction distribution, or of the frequency of occurrence of wave heights in each directional sector.

- WAVES: Alterations produced in the surface of the sea by wind acting continuously over an area (fetch) during a certain period of time; as long as this phenomenon yields a range of random waves, of more or less irregular form and with different directions of propagation, with periods between 1 and 30 seconds.

- WAVE STEEPNESS: Quotient of the wave height and wave length.

1.4 SYSTEM OF UNITS

The system of units used in these recommendations corresponds to the Legal System of Units of Measure that is obligatory in Spain, denominated the International System of Units (SI); with the exception of units of force for which the ton (t) is also used, due to its frequency of use as a measure of loads and forces in Spain.

The basic units of the International System most commonly used in the field of civil engineering are the following:

— Length	: Meter (m)
— Mass	: Kilogram (Kg) or its multiple the ton (t) (1 t = 1000 kg)
— Time	: Seconds (s)
— Temperature	: Centigrade degrees (°C)
— Force	: Newton (N) or its multiple the kilonewton (kN) (1 kN = 1000 N)
— Stress or Pressure	: Pascal (Pa) or its multiple the kilopascal (kPa) (1 kPa = 1000 Pa) (1 Pa = 1 N/m^2)
— Frequency	: Hertz (Hz) (1 Hz = 1 s^{-1})

The relationship of the ton force with the unit of force derived from the International System (Newton –N–) is the following: 1 t = 9.8 kN.

1.5 NOTATIONS

The fundamental notations, abbreviations and conventional symbols employed in this Annex, and their units, are shown in the table 1.5.1.

1.6 REFERENCE DOCUMENTS

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TABLE 1.5.1 FUNDAMENTAL NOTATIONS, ABBREVIATIONS AND CONVENTIONAL SYMBOLS USED IN THIS ANNEX

I. LATIN CAPITALS

SYMBOLS	DEFINITION	UNITS
C	Weibull distribution shape parameter	*
H	Generic wave height	m
H_{mo}	Spectral significant wave height	m
H_s	Significant wave height	m
H_{si}	Individual value of the significant wave height variable	m
$H_{s,R}$	Significant wave height associated with a return period, obtained from the instrumental scalar extreme distribution.	m
$H_{s,O}$	Significant wave height in deep water associated with a return period, for a determined direction.	m
$H_{s,T}$	Threshold significant wave height established for the definition of storm conditions.	m
H_v	Visual wave height	m
H_{vo}	Individual value of the visual wave height variable	m
$\overline{H}_s$	Mean significant wave height from the sample of storms considered for the obtainment of an extreme distribution.	m
H_1	Second threshold wave height level set in the application of the POT method, Goda 1988, for the obtainment of extreme distributions.	m
K_R	Refraction-Shoaling coefficient	*
K_α	Coefficient of directionality for the estimation of directional extreme distributions based on the corresponding non-directional extreme distribution.	*
L	Wave length.	m
$L_{\overline{T}}$	Wave length associated with the mean period formulated with the lineal or Airy theory.	m
N	Number of directional sectors that contribute incident waves at a point.	—
$P(H_s)$	Annual probability of not exceeding the significant wave height variable.	*
P'_{SECTOR}	Probability of occurrence of a directional sector.	*
$P_i(H_{vO})$	Absolute probability that the visual wave height not exceed the level H_{vo} in the mean climatic year, for waves originating from the directional sector i.	*
$P'(H_s)$	Distribution function that fits the extreme data set defined by the POT method, Goda 1988.	*
$P'_i(H_{vO})$	Conditional probability that the visual wave height not exceed the level H_{vo} in the mean climatic year, obtained from the mean directional distribution corresponding to the sector i	*
S(f)	Spectral density function.	m^2s
$T(H_{si})$	Mean return period of the level H_{si} of the significant wave height variable.	years

TABLE 1.5.1 (Continuation)

I. LATIN CAPITALS

SYMBOLS	DEFINITION	UNITS
T_{ef}	Effective time of data recording.	years
T_p	Peak wave period.	s
T_v	Visual wave period.	s
$\bar{T}$	Mean wave period.	s

II. LOWERCASE LATIN

SYMBOLS	DEFINITION	UNITS
a	Dimensionless factor used, in the formulation of the theoretical Jonswap spectrum, as exponent of the peak enhancement factor.	*
f	Frequency as an independent variable of a function.	Hz or s^{-1}
f_i	Frequency of occurrence of the directional sector i	–
$f_{p,max}$	Maximum value of the peak frequency in a recorded storm.	Hz or s^{-1}
$f_{p,min}$	Minimum value of the peak frequency in a recorded storm.	Hz or s^{-1}
$\bar{f}_p$	Mean value of the peak frequencies corresponding to the storms considered.	Hz or s^{-1}
g	Acceleration of gravity (9.81 m/s^2)	m/s^2
m_0	Spectral zeroth moment.	m^2
n	Sample size of design storm, considered in the extreme or spectral statistical analysis.	–
$n(H_s)$	Number of exceedences per mean climatic year of a given level of the H_s variable.	–
n_1	Number of storms that make up the total of the recorded data considered in the statistical analysis by the POT Method, Goda 1988.	–
p	Steepness (quotient of the wave height and wave length)	*

III. GREEK

SYMBOLS	DEFINITION	UNITS
α	Scale parameter of the JONSWAP spectrum.	*
α_v	Principal direction of wave propagation determined visually.	degrees
γ	Peak enhancement factor. Shape parameter that controls the sharpness of the JONSWAP spectrum peak.	*
γ_{max}	Maximum value of the peak enhancement factor in a storm sample.	*

TABLE 1.5.1 (Continuation)

SYMBOLS	DEFINITION	UNITS
γ_{min}	Minimum value of the peak enhancement factor in a storm sample.	*
$\bar{\gamma}$	Mean value of the peak enhancement factors associated with the storms considered.	*
λ	Mean number of storms per year in a statistical analysis of extremes determined by the POT method, Goda 1988.	–
ν	«Censoring parameter». POT method, Goda 1988.	–
σ_a	Shape parameter that adjusts the slope of the JONSWAP spectrum to the left of the spectral peak.	*
σ_b	Shape parameter that adjusts the slope of the JONSWAP spectrum to the right of the spectral peak.	*
σ_{fp}	Standard deviation of the peak frequency data set corresponding to the storms considered in the spectral statistical analysis.	Hz or s^{-1}
σ_x	Standard deviation of the significant wave height data set considered, in the storm analysis, by the POT method, Goda 1988.	m
σ_γ	Standard deviation of the peak enhancement factor data set associated with the storms considered in a spectral statistical analysis.	*
$\phi(H_s)$	Extreme equation. Distribution function of the extreme values of a variable obtained in the application of the Total Sample Method (Copeiro, 1978).	–

IV. ABBREVIATIONS

ABBREVIATIONS	MEANING
LWS	Lowest Water Spring Level.
CEDEX	Center of Studies and Experimentation of Public Works (Centro de Estudios y Experimentación de Obras Públicas).
CEPYC	Center of Studies of Ports and Costs (Centro de Estudios de Puertos y Costas).
DGP	General Directorate of Ports of the Ministry of Public Works and Transportation (Dirección General de Puertos del Mini terio de Obras Públicas y Transportes).
J	JONSWAP (Joint North Sea Wave Project) spectrum.
PCM	Maritime Climate Program carried out by the general Directorate of Ports of the Ministry of Public Works and Transportation.
POT	In extreme wave analysis, the method of relative maximums over the threshold (Peak Over Threshold Method).
REMRO	Spanish Network of Measure and Recording of Waves (Red Española de Medida y Registro de Oleaje).
ROM	Recommendations for maritime works (Recomendaciones para Obras Marítimas).
SPM	Shore Protection Manual.

LEGEND: * Dimensionless

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PART 2 WAVE CLIMATE ON THE SPANISH COAST

2.1 GENERAL

The characterization and forecasting of waves in deep waters along the Spanish Coast is essential in taking on any sort of maritime engineering study or project in this geographical region.

With the aim of avoiding the need for the engineer to locate and make a statistical analysis of the available raw wave data each time the complete definition of the Wave Climate in a determined zone is required, this Recommendation attempts to give the engineer all the available analyzed, up-to-date and contrasted information that exists on the Spanish Coast.

This information corresponds to the zones already analyzed and with the experience accumulated in the characterization and forecasting of waves over long periods of time, and to the practical application in the design of maritime works.

This information will simplify the design work in general cases and will orient decision making of the Designer, the Client or the appropriate Authority in this field. Furthermore, it will facilitate the definition of design waves along the Spanish coast, permitting the obtainment of representative wave parameters necessary for the structural and functional design of the entire maritime work.

As a consequence of the characteristics and limitations of the available wave data, the values included in this Recommendation define in an approximate manner, and not complete, the wave characteristics along the Spanish Coast.
The periodic updating of raw data, the increase of quantity and quality of available instrumental data, the unidimensional and bidimensional analysis of a greater number of representative wave parameters, the development of new analysis procedures, and the establishment of a methodology of separating extreme wave groups by type (Sea or Swell), should be the priorities in the improvement of results and consequentially in the optimization of any maritime work. On this note the importance that future wave data collection be directional should be pointed out.

At present, and in the absence of better information, the results collected in this Recommendation can be quite orientational in the characterization of the Wave Climate on the Spanish coast.

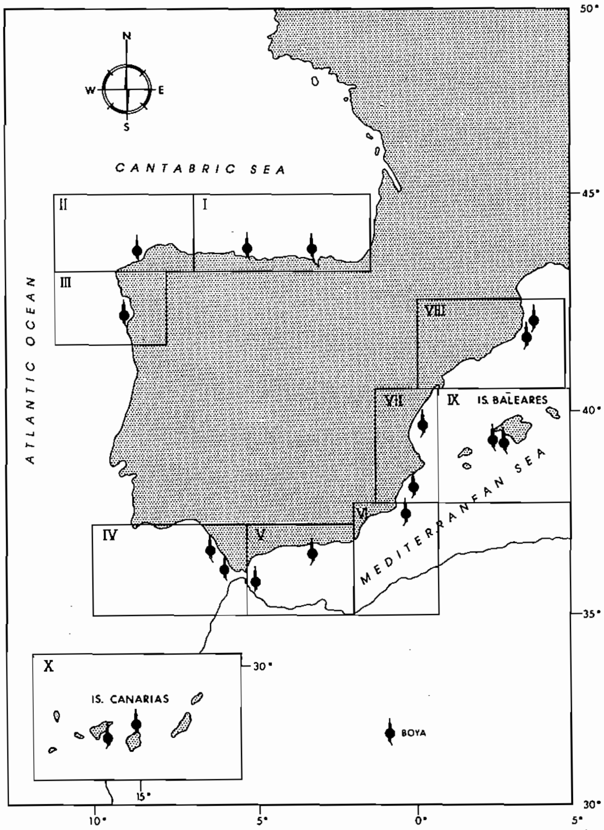
2.2 ZONING OF THE SPANISH COAST

For the characterization of the Wave Climate on the Spanish coast a zoning into 10 different areas is established, defined based on homogeneous climatic characteristics, the configuration of the coast and the location of the available data sources.

This zoning permits the assumption that the deep water wave characteristics are approximately the same in all sectors of each area that are affected by the same waves; that is to say those sectors that have similar fetch length for all the significant incident wave directions.

The zoning considered, as well as the geographical boundary coordinates of each one of the corresponding areas are defined in table 2.2.1.

TABLE 2.4.1 LOCATION AND CHARACTERISTICS OF THE INSTRUMENTAL DATA ANALYZED



Area	Recording buoy	Coordinates of area	Depth with respect to LWS (m)	Recording period	$H_{s,T}$ (m)
I	Bilbao (Morro)	43° 22' 55'' N 3° 4' 24'' N	35	1976-1984	3,0
	Bilbao (Ext.)	43° 24' N 3° 8' 36'' W	50	1985-1990	
	Gijón	43° 34' N 5° 39' W	23	1981-1990	
II	Coruña	43° 24' 45'' N 8° 23' W	50	1985-1990	3,0
III	Cabo Silleiro	42° 1' 48'' N 8° 56' 30'' W	75	1986-1990	3,0
IV	Sevilla	36° 44' 15'' N 6° 29' 6'' W	12	1983-1988	1,5
	Cádiz	36° 30' 20'' N 6° 20' 10'' W	22	1982-1990	
V	Ceuta	35° 54' 10'' N 5° 19' 30'' W	21	1984-1990	1,0
	Málaga	36° 41' 30'' N 4° 25' W	25	1984-1990	
VI	Cabo de Palos	37° 39' 15'' N 0° 38' 18'' W	67	1985-1990	1,5
VII	Alicante	38° 15' N 0° 25' W	50	1982-1990	1,0
	Valencia I	39° 27' 05'' N 0° 17' 43'' W	21	1982-1990	
VIII	Rosas	42° 11' 43'' N 3° 11' 15'' E	50	1986-1987	2,0
	Palamós	41° 49' 24'' N 3° 10' 42'' E	90	1988-1990	
IX	Palma de Mallorca	39° 24'/26,5' N 2° 39'/34,2' E	55/45	1983/ /1986-1987	1,5
X	Tenerife	28° 27' 18'' N 16° 14' 54 '' W	65	1981-1990	1,5
	Las Palmas I	28° 08' 30'' N 15° 27' 30'' W	42	1981-1990	2,0

LEGEND:

$H_{s,T}$ = Threshold significant wave height established for the consideration of storm conditions.

2.5. TECHNICAL CHARACTERISTICS OF THE RESULTS

2.5.1. JOINT DISTRIBUTION OF VISUAL WAVE HEIGHT/DIRECTION

For each one of the areas corresponding to the established zoning of the Spanish coast a joint distribution of visual wave height/direction (H_v–α_v) in deep water, or the frequency of occurrence of wave heights in each directional sector is obtained.

For each interval of heights within a sector, the frequency of occurrence is obtained as the quotient of the sum of observations in that wave height interval in all the directions contained in that sector, and the total number of valid observations.

All the data available in the Bank of Visual Data of CEPYC corresponding to observations made between 1950 and 1985, within each of the analyzed quadrangles has been used.

Directional sectors of 22.5° and wave height intervals of 0.5 m are considered.

Because the raw visual observations utilized are divided in function of wave type, Sea or Swell (bivariate H_v / T_v tables for Sea and Swell occurrences) the joint H_v—α_v distribution was carried out independently for both.

The graphic representation used, in the form of Directional Wave Roses, permits an approximate directional characterization of the most frequent waves (greatest arm length) and the severest waves (widest arms), in high seas along the Spanish Coast.

The scale of wave height is given in meters and the frequency in percent.

The wave roses given in these Recommendations can be used as basic data for the determination of mean wave distributions different from the combined «Sea + Swell» occurrence included in the Atlas of Wave Climate (e.g. mean Sea distribution and mean Swell distribution independently), whose practical application can be of interest, in some cases, for the dimensioning of maritime structures (e.g. when the range of wave periods is a main factor in the dimensioning). The practical development of the mentioned distribution is accomplished based on the histogram of visual wave heights.

2.5.2. MEAN DIRECTIONAL DISTRIBUTIONS. SECTORIAL FREQUENCIES OF OCCURRENCE

The mean directional distributions included in these Recommendations are the mean annual «Sea + Swell» distributions of the visual wave height.

The mean directional «Sea + Swell» distribution relates the different values of the visual wave height variable with the probability that these values are not exceeded in the average climatic year by either Sea or Swell waves originating from the directional sector considered. The defined probability is conditional that the waves have the principle direction of propagation within the analyzed sector.

Because the visual data used makes a distinction between Sea and Swell waves and given that the data is based on statistical bivariate H_v / T_v tables that do not permit the differentiation between simultaneous observations of Sea and Swell at the same location, the most adequate procedure for estimating the mean visual distributions was to consider the mean distributions corresponding to the combination of Sea + Swell. Given the above, it can be assumed that the mean distribution of combined Sea + Swell is most representative of the real sea state, and therefore most representative of the mean distribution elaborated from instrumental data, since the recorders don't distinguish between one type of wave or the other.

For the evaluation of the distinct mean directional distributions all the data available in the Bank of Visual Data of CEPYC corresponding to observations made between 1950 and 1985 and within each of the analyzed quadrangles has been used.

The observations have been grouped into 22.5° sectors.

The evaluation of the mean visual wave height distributions was carried out for each of the ten established areas, calculating only those directions that, due to the configuration of the coast and the recording site, are relevant for the design of maritime works located in the coastal areas covered by the characterization of the Wave Climate included in these Recommendations.

The directions of interest analyzed in the ten established areas are shown in table 2.5.2.1.

The determination of the directional distributions corresponding to the directions of interest was carried out by the following procedure:

- Calculation of mean directional Sea + Swell distribution as a product of the Sea and Swell distributions since it can be demonstrated by the theory of probabilities that the probability that a level H_{v0} is not exceeded either by Sea or by Swell or by both is the product of the probabilities of non exceedence of both events independently.

- Calculation of the mean directional distributions of Sea and of Swell, estimating the representative data set based on the histogram accumulated from visual wave height obtained from double entry H_v/T_v tables for Sea and Swell occurrences, considering only those observations taken within the analyzed sector. For the development of the histogram, wave height intervals of 0.5 m were considered.

- Fitting of the Sea and Swell data sets and consequently the resultant Sea + Swell distribution to the lognormal distribution function.

- Graphic evaluation of the lognormal distribution function, fitting a straight line to the spread of data points represented on the probability paper that corresponds to this distribution function. The fit is carried out visually giving more weight to the center of the distribution.

It is recalled that the probabilities given by the mean directional distributions are probabilities conditioned to the probability of occurrence of the direction analyzed; such that to obtain the absolute probability of exceeding a given wave height for a determined direction, one must multiply the complement of the probability obtained directly from the distribution by the probability of occurrence of the corresponding sector.

For the particular case of the mean distribution corresponding to the sector i, the following equation applies:

$$P_i\,(H_{v0}) = 1 - [1 - P'_i\,(H_{v0})] \cdot f_i$$

with:

$P_i\,(H_{v0})$: Absolute non exceedence probability of the level H_{v0}, corresponding to the sector i.

$P'_i\,(H_{v0})$: Conditional non exceedence probability of the level H_{v0}, obtained from the mean directional distribution corresponding to the sector i.

f_i : Frequency of occurrence of the sector i

Therefore, given that the non exceedence of a certain wave height at a point is influenced by the possible incident waves from different directions, the total non exceedence probability of each value of the variable shall be obtained from the sum of the absolute probabilities corresponding to all the incident sectors. That is:

$$P(H_{v0}) = 1 - \left\{ \sum_{i=1}^{N} [1 - P'_i\,(H_{v0})] \cdot f_i \right\}$$

with N being the number of incident sectors.

The frequency of occurrence of each sector in each analyzed area is obtained as the quotient of the sum of the number of observations in all the directions within the sector and the total number of valid observations. For its determination no distribution of calms has been carried out, considering these as grouped in an additional sector.

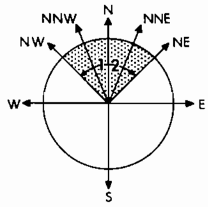
The different mean directional distributions are represented graphically on lognormal probability paper whose ordinate corresponds to the visual wave height (H_v) in meters and whose abscissa corresponds to the conditional non exceedence probabilities. The abscissas are also given in terms of a reduced variate (lineal scale on probabilistic paper). The use of this graphic aid serves to represent the mean distribution with a straight line.

In this graph the corresponding sectorial frequencies of occurrence are also included, which are necessary to obtain the absolute probabilities, are also included.

TABLE 2.5.2.1. DIRECTIONS OF INTEREST FOR THE DETERMINATION OF DIRECTIONAL DISTRIBUTIONS

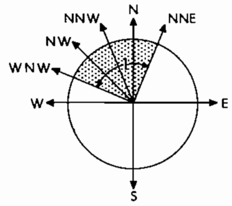
AREA-I

1-BILBAO 2-GIJON



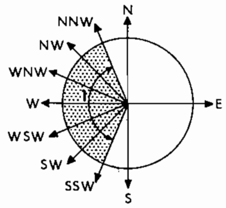
AREA-II

CORUNA



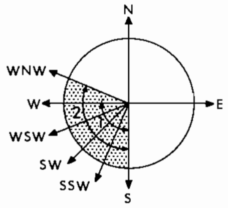
AREA-III

CABO SILLEIRO



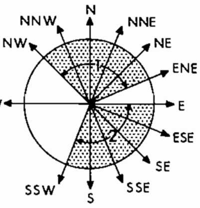
AREA-IV

1-SEVILLA, 2-CADIZ



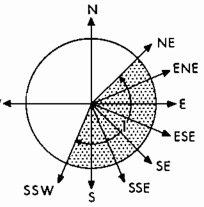
AREA-V

1-CEUTA 2-MALAGA



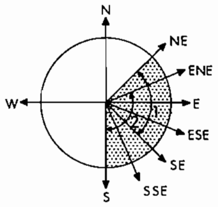
AREA-VI

CABO DE PALOS



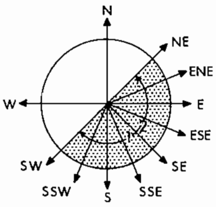
AREA-VII

1-VALENCIA I, 2-ALICANTE



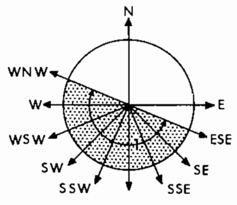
AREA-VIII

GERONA



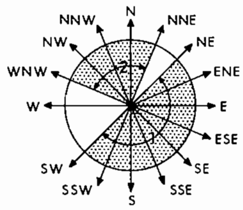
AREA-IX

PALMA DE MALLORCA



AREA-X

1-TENERIFE, 2-LAS PALMAS I



For the correlation of visual wave height/significant wave height in mean distributions, empirical relationships of recognized validity can be utilized [Nordestrom ($H_s = 1.68\ (H_v)^{0.75}$), Hogben and Lumb ($H_s = 1.23 + 0.88\ H_v$), Cartwright ($H_s = 0.59\ H_v$), ...], having previously established their validity based on instrumental data recorded in the analyzed area.

The relation: $H_s = H_v$ has, in general, given good results on the Spanish Coast.

In spite of the fact that the visual data are derived from a sufficient period of observation (35 years), the reliability of the mean distributions is only approximate given that the quality of the prediction is a function of the statistical quality of the raw data, which is intrinsically low due to the characteristics of the visual data sampling network.

In any case, the mean directional distributions included in these Recommendations can be considered satisfactory for their practical use.

2.5.3 MEAN SCALAR DISTRIBUTIONS

The mean scalar distribution included in these Recommendations is the mean annual distribution of significant wave height. This mean distribution relates the different values of the significant wave height variable to the probability that these values are not exceeded in the mean climatic year.

The evaluation of this mean distribution was carried out based on instrumental data for each one of the analyzed recording sites.

However, given the proximity of the two Bilbao buoys and considering the information accumulated from the «Bilbao (Exterior)» buoy as sufficient for the evaluation of the mean distributions in that zone, the mean distribution was not carried out on the «Bilbao (Morro)» buoy.

The number of years considered for the calculation of the different mean wave distributions with sufficiently representative valid data was, except in the areas VIII («Rosas» and «Palamós» buoys) and IX («Palma de Mallorca» buoy), greater than three. Nevertheless, in the area VIII, given the proximity of the buoys analyzed and the similarity of the mean distributions obtained in its central zone for different recording periods, it can be considered that the data collection period was greater than three years in this area. Furthermore, in area IX, the data analyzed have a low statistical quality (seasonal heterogeneity with gaps of data in the months of greatest wave activity), and therefore the distribution estimated in this area is highly unreliable. Except in the area IX, all the above generally guarantees, the reliability of the mean distributions obtained, considering estimations of mean wave distributions based on data collection periods greater than three years as being valid.

To determine the mean scalar distributions the following methodology was employed:

- Calculation based on the Significant Wave Height Sea State Curves whose information gaps of more than 12 hours were filled by linear interpolation.
  Based on these curves the representative data set is estimated.
  The continuous function that represents the evolution in time, of the «significant wave height» parameter at a determined point is denominated as sea state curve.
- Calculation of the non exceedence probability of different levels of the wave height, taking intervals of 0.20 m.
  For each value of the variable, the exceedence probability is obtained as the quotient of the time during which this variable is exceeded and the total duration of the recording period. The non exceedence probability shall be the complement.
- Obtained data are fit to a lognormal distribution function.
- Estimation of the lognormal distribution function by the least squares method, yielding practically identical results as those obtained using other methods such as the method of moments, maximum likelihood, and graphical methods giving more weight to the central zone of the distribution. In any cases the index of correlation obtained is greater than 99%. The agreement between the different methods is a consequence of the good fit of the data to the selected distribution function.

The distribution is represented graphically on logarithmic-normal probability paper whose ordinate corresponds to the significant wave height (H_s) in meters, and whose abscissas correspond to the non exceedence probability. The abscissas are also given in terms of a reduced variable (lineal scale on probabilistic paper).

The utilization of this graphic aid serves to represent the mean scalar distribution by a straight line.

2.5.4. EXTREME SCALAR DISTRIBUTIONS

The extreme scalar distribution given in these recommendations is the extreme distribution of the significant wave height.

This extreme distribution is a distribution function of the extreme values of the significant wave height variable. It relates the maximum foreseeable values of this variable to the probability that these values are not exceeded in one year.

This probability can also be expressed in terms of return or reoccurrence period. The return period (T) for a determined value of the variable H_{si} is defined as the average time interval in which that value is exceeded one time, that is, the average time between two consecutive events exceeding H_{si}.

The relationship between the non exceedence probability in one year and the return period, measured in years, is:

$$T(H_{si}) = 1 / [1 - P(H_s \leq H_{si})]$$

The estimation of this extreme distribution was carried out based on instrumental data for each one of the analyzed recording sites, except in the areas I and VIII in which the recorded data in consecutive periods for two buoys («Bilbao Morro + Bilbao Exterior» and «Rosas + Palamós» respectively), are assigned to one individual distribution with the aim of increasing the representativeness, in terms of extremes, of the data taken. This is considered correct due to the proximity and location of these buoys. The distribution obtained here refers to the latter of the indicated buoys.

The general method utilized for the estimation of the extreme scalar distributions is the Peak over Threshold Method (POT) (Goda, 1988) as this method is more reliable than the Annual Maximums Method especially when the available data correspond to a period of less than 20 years. However, in the determination of the extreme distribution of area IX, the Total Sample Method (Copeiro, 1978) was used, because very few years were registered at the recording site in this zone (buoy «Palma de Mallorca»). The application of this method is preferable when there are very few years of available data and therefore the methods of Maximums (or peak values) lack validity.

The Peak Over Threshold Method is based on extracting, from the temporal recorded series, those individual storms which are not dependant upon one another due to their proximity in time, and that surpass a certain threshold of significant wave height ($H_{s,T}$) in the peak of the storm; as raw data for the obtainment of the extreme distribution, the group of values reached by the significant wa\ e height in the peak of each one of the selected storms (n) is adopted.

To determine the extreme scalar distributions based on the POT method (Goda, 1988) the following methodology was employed:

- The threshold significant wave height neccesary for the definition of storm conditions ($H_{s,T}$), was established for each zone in function of the climatic characteristics of the recording site. *(See table 2.5.4.1).*
- Given that the absence of information in the most climatologically intense months is much more relevant, the calculation of the effective time of data recording (T_{ef}) was done taking into account the climatic weight of the recorded data. In this way the mean number of storms per year (λ), whose values are fundamental in the analysis, is estimated more exactly. *(See table 2.5.4.1).*
- Once the mean number of storms per year ($\lambda = n/T_{ef}$) is determined a second threshold wave height level ($H_1 > H_{s,T}$) is defined, counting the number of storms that surpass this level (n_1). The set of wave heights n_1 make up the total body of data used in the extreme analysis.
- The variables defined for setting the characteristics of the analyzed extreme data sets are given in the table 2.5.4.1.
- The extreme data are fit, generally by the least squares method, to Gumbel distribution functions (Asymptote I of the greatest value) or to a Weibull function with form parameters C = 0.75, 1.0, 1.4, and 2; using, in order to establish the theoretical frequencies of occurrence assigned to each of the extreme data sets, the Gringorten formulation for the Gumbel distribution and the Petruaskas-Agaard formulation for the Weibull distribution,

TABLE 2.5.4.1 CHARACTERISTICS OF THE EXTREME SAMPLES ANALYZED (POT METHOD-GODA, 1988)

AREA	RECORDING SITE	T_{ef} (years)	$H_{s,T}$ (m)	H_1 (m)	n	n_1	$\overline{H}_s$ (m)	σ_x (m)	λ	ν
I	BILBAO[1)] GIJÓN	12.68 7.98	3.0 3.0	4.0 4.0	256 103	107 44	5.11 4.87	0.900 0.661	20.191 13.054	0.418 0.427
II	CORUÑA	6.90	3.0	4.0	216	122	5.22	1.151	31.286	0.564
III	C. SILLEIRO	3.78	3.0	4.0	104	55	5.25	1.015	27.513	0.528
IV	SEVILLA CÁDIZ	4.76 7.92	1.5 1.5	2.0 2.0	70 158	35 90	2.63 2.97	0.560 0.899	14.70 19.952	0.500 0.569
V	CEUTA MÁLAGA	7.45 7.48	1.0 1.0	1.5 1.5	67 158	49 70	2.28 2.13	0.834 0.608	8.985 21.117	0.731 0.443
VI	C. PALOS	4.38	1.5	2.0	134	70	2.62	0.649	30.545	0.522
VII	ALICANTE VALENCIA I	7.34 7.56	1.0 1.0	2.0 2.0	236 219	29 28	2.54 2.47	0.522 0.437	32.156 28.934	0.124 0.128
VIII	PALAMÓS[2)]	5.05	2.0	2.5	45	24	3.32	0.769	8.916	0.533
IX	PALMA DE MALLORCA[3)]	—	—	—	—	—	—	—	—	—
X	TENERIFE L.PALMAS I	8.43 7.75	1.5 2.0	2.0 2.75	67 194	13 67	2.30 3.48	0.318 0.682	7.948 25.035	0.194 0.345

NOTES:
1) BILBAO (MORRO) + BILBAO (EXTERIOR)
2) ROSAS + PALAMÓS
3) Calculated by the Total Sample Method.

LEGEND:
T_{ef} : Effective time of data recording
$H_{s,T}$: Threshold significant wave height for definition of storm conditions
H_1 : Second threshold wave height level
n : N° of base storms considered
n_1 : N° of storms that make up the total of the recorded data
$\overline{H}_s$: Mean significant height of the set data
σ_x : Standard deviation of the set data
$\lambda = n/T_{ef}$: Mean number of storms per year
$\nu = n_1/n$: censoring parameter

substituting n_1 for n with the aim of considering in some way the distribution of base data. The choice of distribution function is made according to the highest coefficient of correlation.

– Based on the distribution function that fits the defined extreme data set (P'), the annual non exceedence probability of the value H_{si} is obtained by:

$$P\,(H_s \leq H_{si}) = 1 - \lambda\,[1 - P'\,(H_s \leq H_{si})]$$

and therefore, the return period in years will be:

$$T\,(H_{si}) = \frac{1}{[1 - P\,(H_s \leq H_{si})]} = \frac{1}{\lambda\,[1 - P'\,(H_s \leq H_{si})]}$$

– Estimation of the inexactness or uncertainty of the considered distribution from the magnitude of the absolute standard error for each level of accumulated probability or return period. Based on these values the confidence intervals are developed taking a determined number of standard error values at each side of the estimated fit curve as criteria, in function of the desired level of confidence.

The extreme distributions obtained by the POT Method are represented graphically on Gumbel probability paper, independently of the distribution function chosen for the fit.

Therefore, when a Weibull function has been used for the fit the graphic representation is not a straight line.

The use of one type of probability paper is done in order to facilitate the comparison of distributions by superimposition.

Also included in the graph is the upper limit of the envelope associated with a 90 % confidence level.

The ordinates correspond to a significant wave height (H_s) in m, and the abscissas correspond to the return period in years.

The uncertainty associated with each extreme distribution will be higher or lower in function of the effective time of data recording, the statistical quality of the data and, in function of the above, the method of extreme analysis used.

The extreme distributions included in these Recommendations estimated by the POT method (Goda, 1988), quantifying their uncertainty by establishing limits at both sides of the straight fit line associated with a level of confidence of 90 %, in general can be considered to be reasonably reliable for return periods less than 20 times the effective time of data recording considered. Therefore, if this criteria is accepted, in most cases the extreme distributions obtained can be considered reliable for maximum return periods of 100 to 250 years. For greater return periods the results obtained are considered of questionable reliability and should only be taken as indicative.

Given that the effective times of data recording are still very short and that the methods of extreme analysis in use are not totally verified, in all cases and especially for long return periods, the designer would be justified in evaluating the reliability of the extreme distributions included in these Recommendations by means of contrasting with distributions obtained from the application of other statistical extreme analysis methods, or by wave analysis, of sufficiently recognized validity for the zones considered (eg. numerical Hindcasting Models introducing wind data corresponding to past storms obtained from meteorological charts; SPM Method in the Mediterranean introducing the climatic characteristics of the zone of generation: fetch length, persistence and extreme distribution of wind velocities; ...), taking into consideration all available factors of analysis and experience.

The determination of the extreme distribution for the Palma de Mallorca buoy was carried out using the Total Sample Method (Copeiro, 1978).
This method is based on the hypothesis that if the distribution function of the variable H_s [mean wave distribution $P(H_s)$] is known in an interval in which $n(H_s)$ extreme values are taken, the extreme distribution function [extreme $\Phi(H_s)$ distribution] can be calculated by means of the extreme equation [$\Phi(H_s) = \{P(H_s)\}^{n(H_s)}$].

To determine this extreme distribution the following methodology was employed:

– The mean distribution considered [$P(H_s)$] was the instrumental mean scalar distribution, however the distribution function was fit to the data located in the medium-high zone or upper tail of the base data distribution.
The selected distribution function was the lognormal.

— The number of exceedences in one average climatic year for each level of H_s [$n(H_s)$] was determined based on the recorded Sea State curves, as the quotient of the total time in the year and the mean time in which this level is exceeded. The last value is obtained as the quotient of the total time that a determined level is exceeded and the number of times that this occurs during the recording period. The function $n(H_s)$ is then defined fitting a straight line to the spread of data points [H_s, $n(H_s)$] giving more weight to the zones with the most exceedences and neglecting those points with less than 10 exceedences.

— The representative extreme data set obtained with the extreme equation was fit using the Gumbel distribution.

This distribution is represented graphically on Gumbel probability paper, without including values corresponding to confidence intervals.

Due to the low quality of the sample data from area IX, neither the line in the upper range of the mean distribution, nor the recorded exceedences can be considered representative of the real population, therefore the extreme distribution for this area should be considered very unreliable and should only be taken as indicative.

2.5.5 EXTREME DIRECTIONAL DISTRIBUTIONS. HEIGHT/DIRECTION RELATIONSHIP

The scarce number of operative buoys on the Spanish Coast, along with the low volume of data recorded make the obtainment of directional instrumental extreme wave height distributions impossible. Therefore, at present, the only way of directly estimating directional extreme distributions would be from visual data or from data obtained by theoretical-empirical wave analysis models.

However, given the low reliability of the extreme distributions obtained from visual data and of those obtained from the application of wave analysis models (Hindcasting), these Recommendations include the methodology for the obtainment of extreme directional significant wave height distributions in deep waters. This is done for every recording site by assigning directionality, using the available visual data, to the instrumental scalar distribution, transferred to deep water.

The reliability of the extreme distributions obtained based on visual data is considered low due to the absence of data on the real annual maximums as a consequence of the logical tendency of ships to navigate in calm waters and, to a lesser extent, the overestimation inherent in visual observations when the waves surpass a certain threshold.

Likewise, the low reliability of the extreme distributions obtained based on the application of wave analysis models is due to the still insufficient verification and calibration of these models for the Spanish Coast.

The extreme directional distributions in deep water are defined, based on the extreme scalar distribution, multiplying the wave height transferred to deep water corresponding to a return period by a directionality coefficient (K_α), which is different for every direction, by means of the following methodology:

— For each recording site, and therefore for every extreme scalar distribution defined, the estimation of extreme directional distributions is carried out only for those wave directions in deep water that, due to the location of the recording buoy and to the configuration of the coast, are of interest at that site.
The directions of interest at each recording site are given in table 2.5.2.1.
— Given that the visual data used to assign directionality are deep water data, the extreme instrumental scalar distribution should be transferred to those waters with the aim of establishing the relationship between the high sea wave and that recorded at the buoy, which permits the attenuation of the propagated wave as well as the direction of the wave at the buoy to be known for a determined direction in deep water. For this, appropriate propagation studies should be carried out *(See section 2.7 WAVE PROPAGATION)*.
— For each area and recording site analyzed the K_α coefficients for each direction are established based on the approximate relationship between the different direction or directional sector extreme wave heights in deep water. For each direction the K_α coefficient is defined as the quotient of the wave height associated with that direction and the maximum height in any direction.

Therefore, the coefficient 1 is assigned to the direction in which the highest waves are generated.

- As the only available directional information is visual and even though the characteristics of the waves in extreme conditions differ from those corresponding to moderate climatic conditions, the lack of reliability of the former makes it unavoidable to make an approximate estimation of the relationship between extreme deep water wave heights in different directional sectors, and therefore of the coefficient K_α, based on the mean directional visual wave height distributions and on the combined distribution H_v / T_v (bivariate H_v / T_v table) corresponding to the sectors of interest.
- Given the low reliability of the system adopted for the evaluation of extreme waves and with the aim of contrasting the results obtained, the calculation of the K_α coefficient was carried out defining the extreme wave height by direction using three distinct procedures:
  - Based on the mean visual Sea + Swell wave height distribution resulting from fitting the data located in the middle-high range or upper tail of the base data set, assigning to each direction the mean of the wave heights whose annually exceedences are 1% and 0.1% (0.99 and 0.999 probability of the distribution) in each one of the mean annual distributions corresponding to each directional sector.
  - Based on the H_v / T_v table, assigning to each direction, the mean of the wave heights whose exceedence represent 5 % and 0.5 % of the number of the corresponding sector's Sea and Swell observations.
  - Based on the H_v / T_v table, assigning to each direction the mean of the wave heights that have been surpassed by 6 and by 20 observations in each corresponding sector.

  The percentiles used are empirical, having been set by CEPYC with the aim of capturing the upper spread of extreme waves and not just the extreme recorded or possible wave. The consideration of three approximations serves to focus on distinct indicators and thus to improve the reliability of the estimate. In general the areas where the visual data are well defined, as the number of observations is gradually decreased and thereby the threshold height increased the three approximations tend to produce similar results.

  However, in zones with data of poor quality, with irregular grouping of observations for the highest wave heights and intervals without any observations, there is significantly less agreement. This is the case, in general, in areas where the configuration of the coast is such that the type of observation (H_v / T_v) is a function of the specific location at which it is carried out, that is, fundamentally in the areas V, IX and X.
- For each recorded site and direction, the K_α coefficient established in these Recommendations has been defined conservatively taking into account the results obtained by the three estimates carried out, the climatic characteristics of each sector particular to the analyzed area and recording site (fetch length, persistence and intensity of winds), and accumulated experience. In those cases in which the three approximations have given similar results, the K_α value has been taken as the mean value of coefficients obtained by each one of the procedures.

  When each of the approximations have yielded very different K_α values, a value greater than the mean of the three estimates has been adopted, taking into account the climatic characteristics of each sector (fundamentally the fetch length).

Therefore, the non-directional extreme distribution transferred to deep water can be considered as associated with the severest direction or directions ($K_\alpha = 1$). The wave height corresponding to other directions for a given return period is determined by multiplying the wave height obtained from the non-directional extreme distribution, by the corresponding directional coefficient. *(See section 2.7).*

Although the procedure established in these Recommendations for assigning directionality to different non-directional extreme distributions is not strictly orthodox, it represents a conservative first attempt at defining sufficiently reliable directional extreme distributions in deep water based on the instrumental data available at present.

2.5.6 WAVE HEIGHT/PERIOD CORRELATION FOR STORMS CONDITIONS

The following wave height/period correlations for storm conditions are included in these recommendations:

- Significant Wave Height (H_s)/Mean Period ($\bar{T}$)
- Significant Wave Height (H_s)/Peak Period (T_p)

These relationships are necessary to transfer the instrumental wave distributions included in these Recommendations to deep water by means of propagation studies. Furthermore, these relationships are necessary for the structural and functional design of maritime works in that both design wave height and its corresponding periods influence their calculation. Since the periods associated with the highest waves are of greatest influence, the wave height/period relationships are obtained only for extreme conditions.

The above relationships have been established based on the bidimensional analysis of instrumental data for each of the wave recording sites considering, exclusively, the recordings whose significant wave height (H_s) surpasses the established storm condition threshold. This threshold ($H_{s,T}$) is given in table 2.4.1 for each of the wave recording sites based on the climatic characteristics.

The data from the Rosas and Palamós buoys in area VIII have been treated as one base data set in order to increase the statistical representativity of the data. This approach is considered valid due to the proximity of the buoys and the fact that the data recorded at the two sites was taken in consecutive time periods.

The final relationships that allow the estimation of the periods associated with extreme wave heights were obtained assuming the existence of a prevalent value or interval of values of wave steepness (H/L) in the Wave Height/Period joint frequency tables corresponding to each analyzed recording site.

In general and regardless of the characteristics of the analyzed data set of Sea States the Height/Period joint frequency tables normally suggest the existence of a prevalent H/L value in each zone, which can be assigned to the project conditions extrapolated from the data set. Nevertheless a clear and unique prevalent wave steepness does not always exist, making it necessary to consider an interval of values in the design. In any case the analyzed joint frequency tables suggest the existence, for each area and recording site, of an upper and lower limit of steepness, and therefore limit the representative periods that can be associated with each wave height *(See Figure 2.5.6.1).*

In light of the above, this Annex recommends the establishment of the design periods (T_p) based on the limit intervals of steepness ($p=H_s/L_{\bar{T}}$) and on the $T_p/\bar{T}$ relationship of the extreme waves at each recording site.

The steepness is defined in terms of the significant wave height (H_s) and the deep water wave length associated with the mean period ($L_{\bar{T}}$) and formulated by the lineal or Airy theory. That is:

$$p = \frac{H_s}{L_{\bar{T}}} = \frac{H_s}{g\,\bar{T}^2/2\pi} = \frac{2\,\pi\,H_s}{g\,\bar{T}^2}$$

The procedure used for the definition of limit intervals of steepness and the $T_p/\bar{T}$ relationship was the following:

— At the recording sites where the scatter of data was high, obtaining as a consequence a wide range of values between the upper and lower steepness limits, it was attempted, without success, to reduce the degree of scatter by just considering the data corresponding to the peaks of storms.
This situation is quite pronounced in areas I, II, III and in the «Las Palmas I» buoy of area X, where the weight of Swell waves (less steep waves) can not be neglected.
— A lineal $T_p/\bar{T}$ relationship is assumed.
— Due to the generally high degree of scatter observed in the base data set, the $T_p/\bar{T}$ relationship was established with four different data sets all treated based on the original data set with the following criteria:
  - Base data set.
  - Peak of storm data set
  - Modified base data set eliminating all the recordings whose $T_p/\bar{T}$ relationship do not fall within the range $0.9 \leq T_p/\bar{T} \leq 1.4$, as the $T_p/\bar{T}$ relationship is generally considered within this range.
  - Peak of storm data set modified in the same way.

  The different data sets are fitted by means of linear regression. The quality of the fit de-

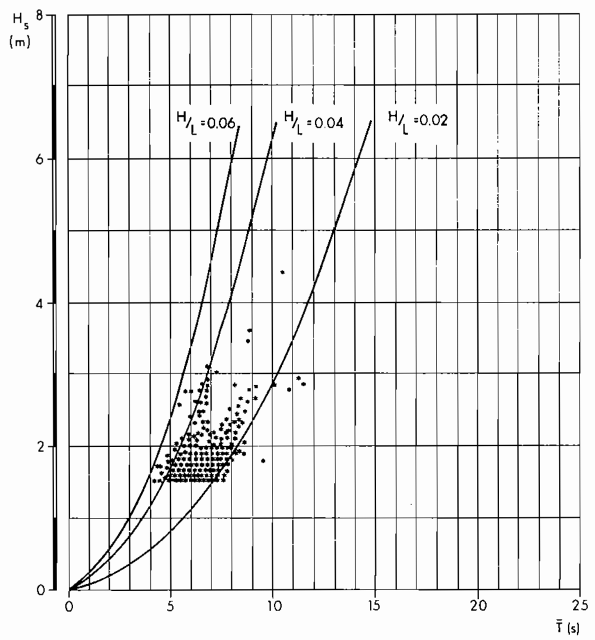


FIGURE 2.5.6.1 H_s - $\bar{T}$ joint frequency table for storm conditions. Upper and lower steepness limits. Tenerife buoy. 1981-1989.

creases as the recorded number of Swells increases. Thus, the fits carried out for areas IV, VI, VII, VIII, IX, and the «Tenerife» buoy in area X, have high correlation coefficients with ordinate values close to Zero at the origin and similar line slopes for all the data sets analyzed. The quality of the fit is lower in area V, dropping notably in areas I, II, III and in the «Las Palmas I» buoy of area X.

— In all cases, the final T_p / $\bar{T}$ relationship was established graphically, considering the fit line that, passing through the origin and maintaining the scope obtained by linear regression, best fits the represented data set.

At any rate, the limit steepness values and the T_p / $\bar{T}$ relationship obtained in the sites affected by the same waves show a good correlation, except the difference recorded between the Gijón and Bilbao buoys. In absence of more detailed studies this difference can be attributed to the great disparity in water depths at the recording sites that, for the long wave periods being recorded at these sites, has a substantial influence.

The lower steepness limit in some areas (0.015) is significantly less than the minimum value of 0.03 usually admitted for extreme waves (Sea waves). The sites where this occurs most acutely are those with a greater contribution of Swell waves (areas I, II, III and «Las Palmas I» of area X). Furthermore, in these cases, the quality of the T_p / $\bar{T}$ fit obtained by linear regression is not very high.

For all the analyzed data sets, and in particular for those corresponding to the above mentioned areas, more detailed analysis should be made in the future attempting to separate the different wave populations typologically (Sea and Swell). Similar recommendations are made in the works of other researchers (Goda, Petruaskas, Muir, ...), being a theme pending of investigation.

Therefore, the wave height/period correlations given in these Recommendation should be taken as a first approximation.

Due to the wide scatter in the results, at present it is necessary to check various periods associated with one particular wave height, within the interval of periods obtained for that height. Nevertheless, to establish design wave periods associated with wave heights of long return period and in zones where the Swell wave weight is substantial, it should be taken into account that the periods corresponding to the lower steepness limit (highest periods) could be overestimated for reasons already explained. In any case, design periods (T_p) greater than 22s should not be considered.

2.5.7 BASIC FREQUENCY SPECTRAL STRUCTURE FOR STORM CONDITIONS

With the aim of determining the frequency spectral characteristics for storm conditions on the Spanish coast, a statistical spectral analysis has been carried out; that is, a statistical analysis of the theoretical spectra's parameters fitted to data sets of real recorded peak of storm spectra.

All of the theoretical spectrum parameters that fit a real frequency spectrum make up a statistical set of values corresponding to each spectrum. Based on this set the unidimensional statistic of each parameters is carried out, calculating a histogram of the density function and the associated statistical parameters (mean, standard deviation, ...).

Since in general real recorded spectra fit theoretical JONSWAP spectra for engineering applications, each statistical set is made up of the group of parameters that fits each real spectrum. *(See Figure 2.5.7.1).*

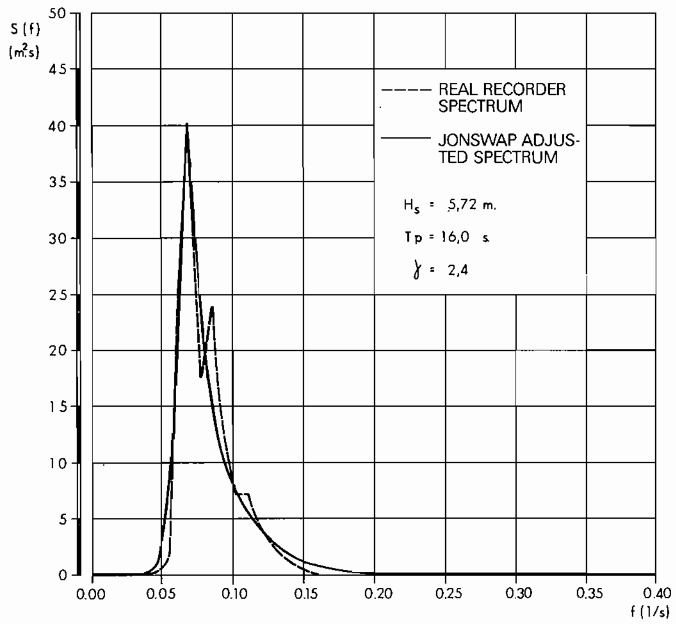


FIGURE 2.5.7.1. Real recorded spectrum fit to a JONSWAP spectrum. Cabo Silleiro buoy.

The JONSWAP spectrum is a multiparametric spectral, model whose analytical expression is a function of the following five parameters: α, f_p, γ, σ_a, and σ_b.

Its complete mathematical formulation is the following:

$$S(f) = Af^{-5} \cdot e^{-Bf^{-4}} \cdot \gamma^a = \left[\frac{\alpha \cdot g^2}{(2\pi)^4}\right] \cdot f^{-5} \cdot \left[e^{-\left[\frac{5}{4} \cdot f_p^4\right] \cdot f^{-4}}\right] \cdot \gamma^a$$

with:

S(f) : Spectral density function, in $m^2 \cdot s$
f : Frequency as an independent variable of the function, in Hz or 1/s.

g : Acceleration of gravity (9.8 m/s^2)

α : Scale factor. Corresponds to the Phillips parameter (dimensionless). Regulates the area enclosed by the spectral function (m_0), and therefore the mean energy ($\bar{E}$) and the spectral significant wave height ($H_{m0} \approx H_s$). In addition, this factor permits a simple approximation of the spectral function for high frequencies since the function in this range of frequencies is proportional to f^{-5}.
$S(f) \approx [\alpha \cdot g^2/(2\pi)^4] \cdot f^{-5}$.

f_p : Peak frequency, in Hz. This is the frequency corresponding to the maximum of the spectrum.

γ : Peak enhancement factor of the spectrum (dimensionless). Shape parameter that controls the sharpness of the spectrum's peak. Generally it takes on a value between 1 and 10.

a : Dimensionless factor equal to:

$$a = e^{-\left[\frac{(f - f_p)^2}{2\sigma^2 \cdot f_p^2}\right]}$$

σ being a dimensionless shape factor that fits the slope of the spectral function on both sides of the peak.

This factor is differentiated for the right and the left of the spectral peak by the denominations:

σ_a for $f \leq f_p$

σ_b for $f \geq f_p$

Therefore the statistical data set is made up of five J spectrum parameters $= \alpha, f_p, \gamma, \sigma_a$, and σ_b. However, in those cases in which the spectrum is considered as an analytical model it is common for σ_a and σ_b, given their small variability, to take on the following mean values:

$$\sigma_a \doteq 0.07 \qquad \sigma_b = 0.09$$

Consequently the statistics of the parameters f_p and γ is what basically defines the basic structure of a wave data sample's frequency spectrum, since α is only a multiplying or scale factor, in function of the significant wave height.

Based on the above, the basic structure of the wave frequency spectrum, at a determined recording site, is considered as the J spectrum defined with its f_p and γ parameters coincident with the mean values of the analyzed data set ($\bar{f}_p$ and $\bar{\gamma}$).

The basic spectral structure is defined, for each recording site considered, based on a data set made up of the real smoothed spectra according to the highest storms recorded at that site. Whenever it was possible a set of approximately twenty storms was considered.

The data from Rosas and Palamós buoys in area VIII have been treated as one data set in order to increase the statistical representativity of the data. This approach is considered valid due to the proximity of the buoys and the fact that the data recorded at the sites was taken in consecutive periods.

The real smoothed spectra are those provided by REMRO, for each analyzed recording site.

To fit a real recorded spectrum to a JONSWAP spectrum, the following iterative method was used:

— The real recorded spectrum is truncated at an upper and at a lower frequency such that the energy eliminated in the tails of the spectrum is insignificant.
— From the peak of the real recorded spectrum, f_p is determined and assigned to the J spectrum.
— The following constant values are taken:
  $\sigma_a = 0.07$ for $f \leq f_p$
  $\sigma_b = 0.09$ for $f > f_p$
— For the first approximation an initial value of γ is set.
— α is assigned a value such that both spectra, real and J, have the same energy (m_o) between the established frequency limits.
— The necessary iterations are carried out modifying the value of γ until the theoretical spectrum and the recorded spectrum have practically the same spectral density in the peak.

Because the selected theoretical spectrum is basically representative of developing Sea waves the quality of the fit diminishes in the areas affected by a significant amount of Swell waves (areas I, II, III and in the «Las Palmas» buoy of area X). Improving the quality of the estimation would require separating the different wave populations.

The validity of the zoning of the Spanish Coast for the definition of wave climate is confirmed by the fact that the $\bar{\gamma}$ and $\bar{f}_p$ values obtained in the recording sites affected by the same waves are very similar, except for the differences recorded in the Gijón and Bilbao buoys located in area I. This difference can be attributed to the marked difference in water depths at the two buoy's deployment sites.

For each recording site the theoretical JONSWAP spectrum, that fits the real recorded spectrum of the analyzed data set, is represented graphically with the value of γ closest to $\bar{\gamma}$. The ordinates correspond to the spectral density in $m^2 \cdot s$ and the abscissa to the frequency in s^{-1}.

With the aim of giving a complete definition of the wave frequency spectrum structure for storm conditions at a given site, a table of the following statistical parameters representative of the analyzed data set is also included:

$\bar{\gamma}$, γ_{max}, γ_{min}, σ_γ, $\bar{f}_p$ (in s^{-1}), $f_{p,\ max}$ (in s^{-1}), $f_{p,\ min}$ (in s^{-1}), σ_{fp} (in s^{-1}) as well as the number of storms considered in the statistical analysis (n).

Apart from defining the basic structure of the wave frequency spectrum at a recording site ($\bar{\gamma}$, $\bar{f}_p$), this table permits the analysis of the degree of variability of the parameters analyzed in the data set, and therefore the degree of variability at the considered recording site.

In spite of the fact that the selected theoretical spectrum for the fit is valid for developing Sea waves, but is not totally valid for Swell waves or for situations with simultaneous Sea and Swell waves and in spite of the simplicity of the fit method and of admitting the raw recorded spectra previously smoothed by REMRO, the results obtained can be considered valid as a first approximation to the wave frequency spectral structure on the Spanish Coast.

2.6 PRESENTATION OF RESULTS

2.6.1 ATLAS OF WAVE CLIMATE ON THE SPANISH COAST

The relationships of wave characterization that define the Wave Climate on the Spanish Coast, obtained based on the statistical analysis of the available information, are presented graphically in the form of a Wave Climate Atlas.

This Atlas is structured such that each sheet includes an ordered summary of all the results obtained for one of the established areas, as well as the location and technical characteristics of the data analyzed in that area.

The disposition of the results is as follows:

— Heading: Characteristics and location of the analyzed data.
— Block A: Visual Observations: Wave Roses
— Block B: Visual Observations: Mean Directional Distributions. Sectorial Frequencies.
— Block C: Instrumental Data: Mean Scalar Distributions
— Block D: Instrumental Data: Extreme Scalar Distributions. Height/Direction Relationship.
— Block E: Instrumental Data: Wave height/period correlation for storm conditions.
— Block F: Instrumental Data: Basic Frequency Spectrum Structure for storm conditions

This presentation aims to permit the comparison and contrasting of the distinct results, facilitate their practical use for the determination of design waves, as well as to give a global view of the Wave Climate in each one of the established areas on the Spanish Coast.

Likewise, this disposition facilitates decision making with respect to which results are valid for areas outside the immediate vicinity of the recording sites.

The Atlas of Wave Climate constitutes the table 2.6.1.1 of this Annex.

2.6.2 LEGEND

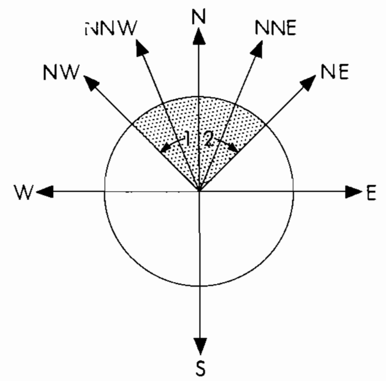
The notations, abbreviations and conventional symbols used in the Atlas of Wave Climate are given in table 2.6.2.1.

TABLE 2.6.2.1 NOTATIONS, ABBREVIATIONS AND CONVENTIONAL SYMBOLS USED IN THE ATLAS OF WAVE CLIMATE

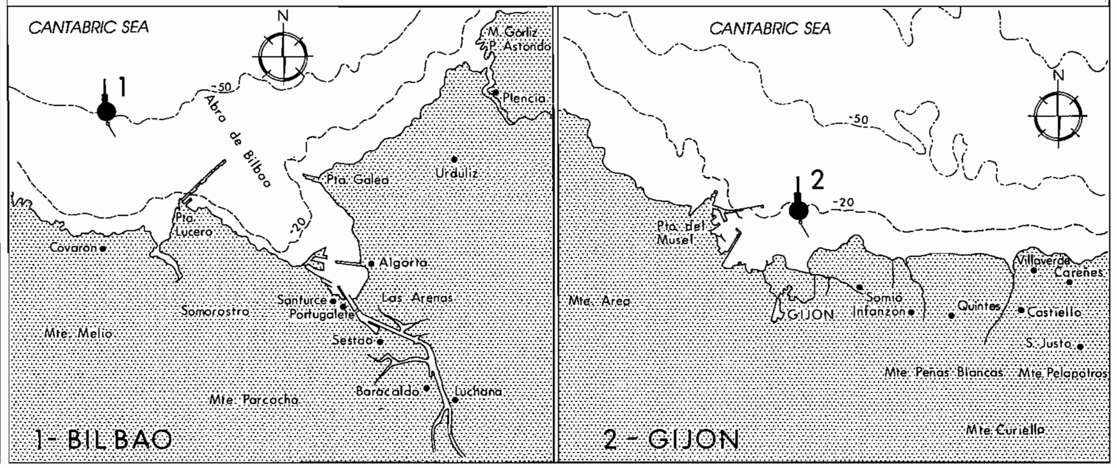
SYMBOL	DEFINITION
H_s	Significant wave height
H_v	Visual wave height
K_α	Coefficient of directionality for the estimation of directional extreme distributions based on the corresponding non-directional extreme distribution.
$L_{\bar{T}}$	Wave length associated with the mean period formulated with the lineal or Airy theory.
P_{SECTOR}	Probability of occurrence of a directional sector.
$S(f)$	Spectral density function.
T_p	Peak wave period.
$\bar{T}$	Mean wave period.
f	Frequency as an independent variable of a function.
$f_{p,max}$	Maximum value of the peak frequency in a recorded storm sample.
$f_{p,min}$	Minimum value of the peak frequency in a recorded storm sample.
$\bar{f}_p$	Mean value of the peak frequencies corresponding to the storms considered.
g	Acceleration of gravity (9.8 m/s^2)
n	Sample size of storms, considered in the extreme or spectral statistical analysis.
p	Steepness (quotient of the wave height and the wave length).
γ	Peak enhancement factor. Shape parameter that controls the sharpness of the JONSWAP spectrum peak.
γ_{max}	Maximum value of the peak enhancement factor in a storm sample.
γ_{min}	Minimum value of the peak enhancement factor in a storm sample.
$\bar{\gamma}$	Mean value of the peak enhancement factors associated with the storms considered.
σ_{fp}	Standard deviation of the peak frequency data set corresponding to the storms considered in the spectral statistical analysis.
σ_γ	Standard deviation of the peak enhancement factor data set associated with the storms considered in a spectral statistical analysis.

AREA – I

SIGNIFICANT DIRECTIONS



LOCATION OF INSTRUMENTAL DATA



ANALYZED DATA

INSTRUMENTAL DATA

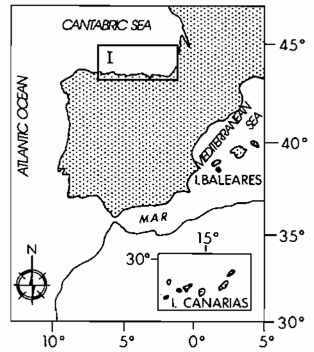
BUOY	LOCATION	DEPTH (m)	REC. PERIOD
1- BILBAO (Ext)	43º 24' 00"N 3º 8' 36" W	50	1985/1990
2- GIJON	43º 34' 00"N 5º 39' 00"W	23	1981/1990

VISUAL OBSERVATIONS

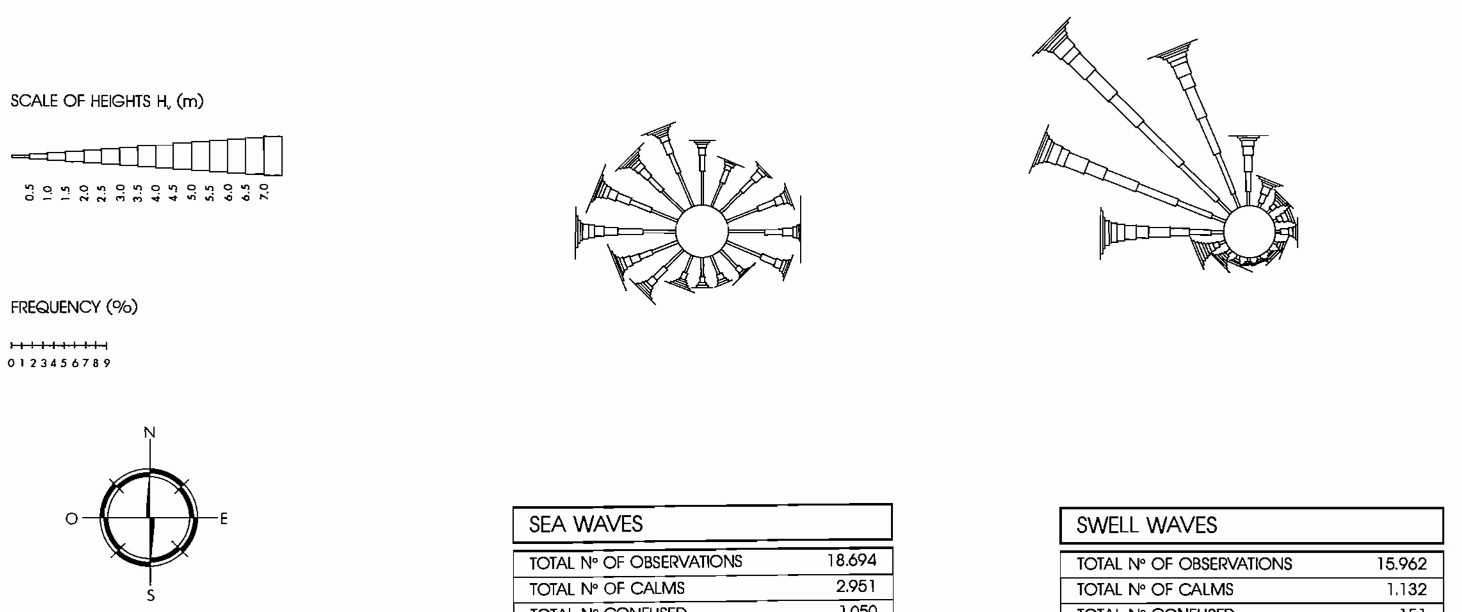
QUADRANGE:
43º N - 45º N
1,5º W - 7º W

RECORDING PERIOD: 1950 - 1985

GEOGRAPHIC LOCATION OF THE ANALYZED DATA



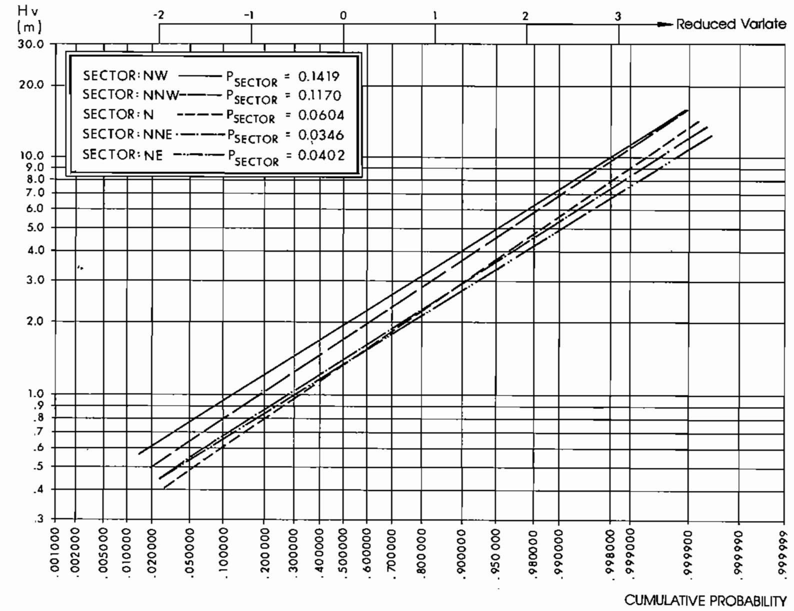
A — VISUAL OBSERVATIONS: WAVE ROSES



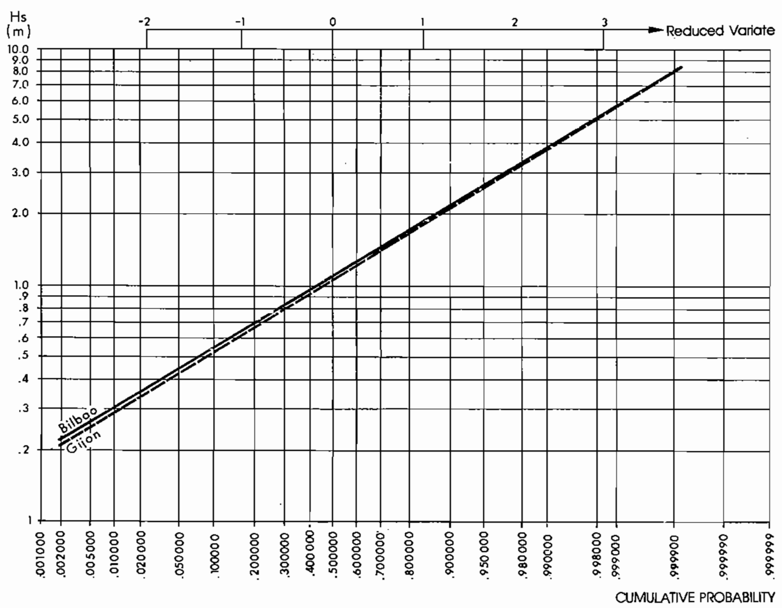
SEA WAVES	
TOTAL Nº OF OBSERVATIONS	18.694
TOTAL Nº OF CALMS	2.951
TOTAL Nº CONFUSED	1.050

SWELL WAVES	
TOTAL Nº OF OBSERVATIONS	15.962
TOTAL Nº OF CALMS	1.132
TOTAL Nº CONFUSED	151

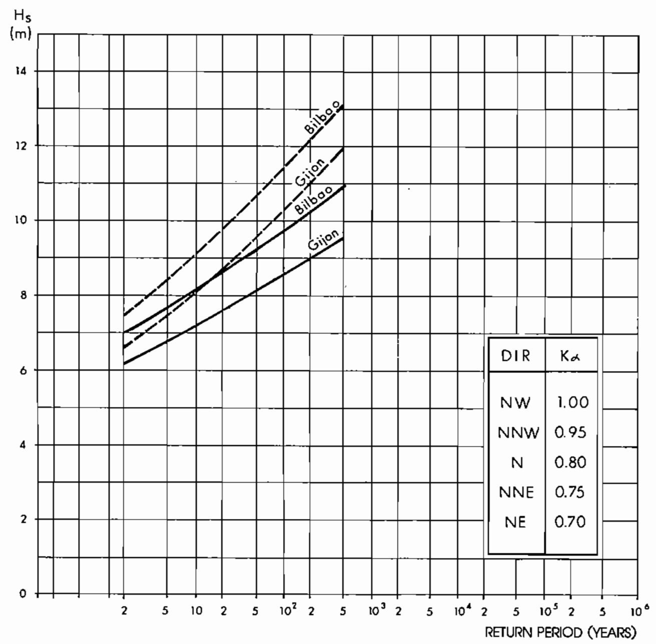
B — VISUAL OBSERVATIONS: MEAN DIRECTIONAL DISTRIBUTIONS



C — INSTRUMENTAL DATA: MEAN SCALAR DISTRIBUTIONS



D — INSTRUMENTAL DATA: EXTREME SCALAR DISTRIBUTIONS



DIR	Kα
NW	1.00
NNW	0.95
N	0.80
NNE	0.75
NE	0.70

----- 90 % CONFIDENCE BAND

E — INSTRUMENTAL DATA: WAVE HEIGHT/PERIOD CORRELATION FOR STORMS

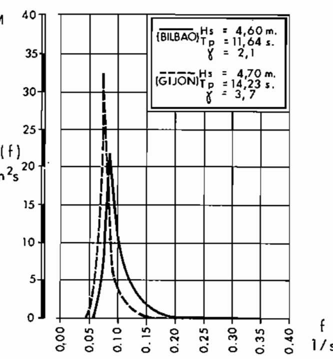
BUOY	$P = H_s / L_{\bar{T}} = \frac{2\pi H_s}{g\bar{T}^2}$	$T_p / \bar{T}$	FINAL RELATIONSHIP H_s (m) T_p (s)	DESIGN VALUES H_s (m)	DESIGN VALUES T_p (s)
BILBAO (Ext)	0.015 ~ 0.04	≃1.30	$T_p = (5{\sim}8.5)\sqrt{H_s}$	5	11~19
				7	13~22
				9	15~25
				11	16,5~28
GIJON	0.010 ~ 0.05	≃1.22	$T_p = (4{\sim}9.7)\sqrt{H_s}$	5	9~21,5
				7	10,5~25,5
				9	12~29
				11	13~30

* IN NO CASE SHALL DESIGN PERIODS GREATER THAN 22 SECONDS BE CONSIDERED

F — INSTRUMENTAL DATA: BASIC FREQUENCY SPECTRUM FOR STORMS ($H_s \geq$ 3,00 m)

THEORETICAL JONSWAP SPECTRUM FIT TO THE REAL RECORDER SPECTRUM CORRESPONDING TO THE PEAK OF STORM WITH VALUE OF γ CLOSEST TO $\bar{\gamma}$.

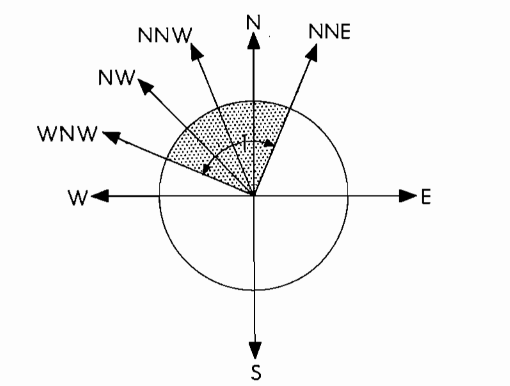
* (1/s)



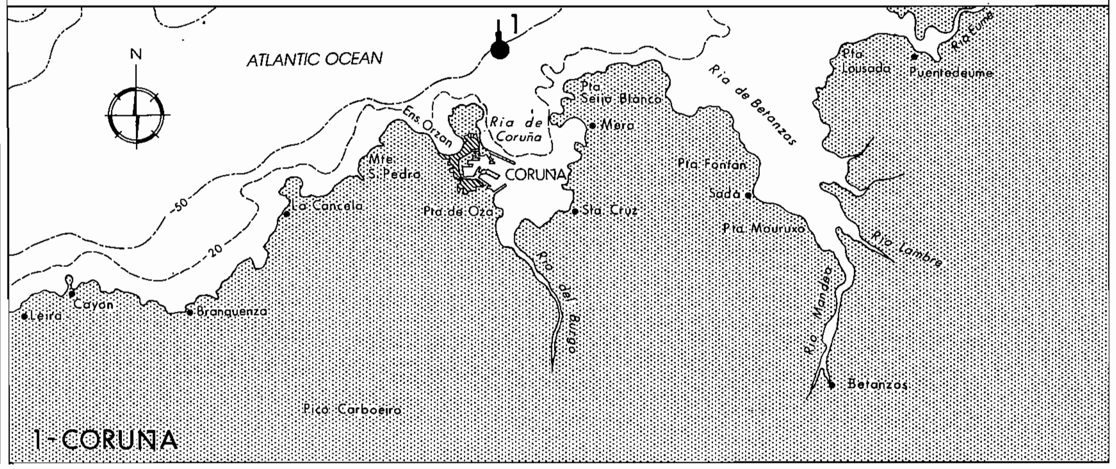
BUOY	THEORETICAL JONSWAP SPECTRUM $\bar{\gamma}$	γ_{max}	γ_{min}	σ_γ	$\bar{f_p}$*	$f_{p,max}$*	$f_{p,min}$*	σ_{fp}*	n
BILBAO	1.9	5.4	0.9	0.97	0.07	0.11	0.05	0.012	18
GIJON	3.9	8.4	1.5	1.97	0.07	0.10	0.06	0.011	20

AREA – II

SIGNIFICANT DIRECTIONS



LOCATION OF INSTRUMENTAL DATA



ANALYZED DATA

INSTRUMENTAL DATA

BUOY	LOCATION	DEPTH (m)	REC. PERIOD
1- CORUÑA	43º 24' 45'' N 8º 23' 00'' W	50	1985 / 1990

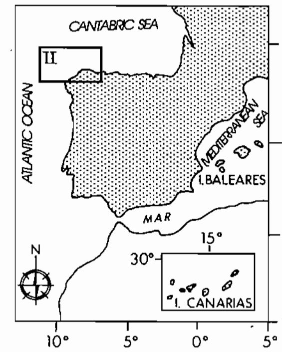
VISUAL OBSERVATIONS

QUADRANGE:

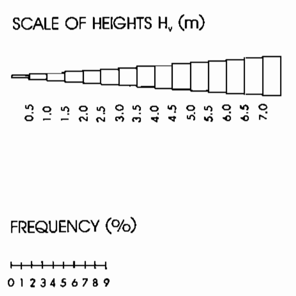
43,2º N - 45º N
7º W - 11º W

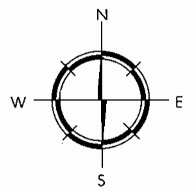
RECORDING PERIOD: 1950 - 1985

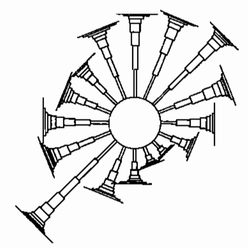
GEOGRAPHIC LOCATION OF THE ANALYZED DATA

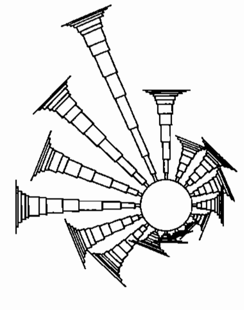


A – VISUAL OBSERVATIONS: WAVE ROSES





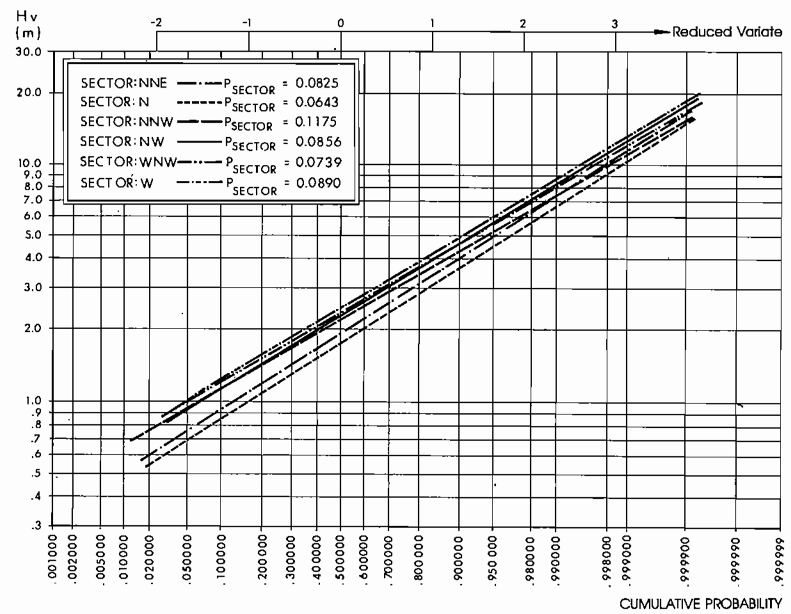




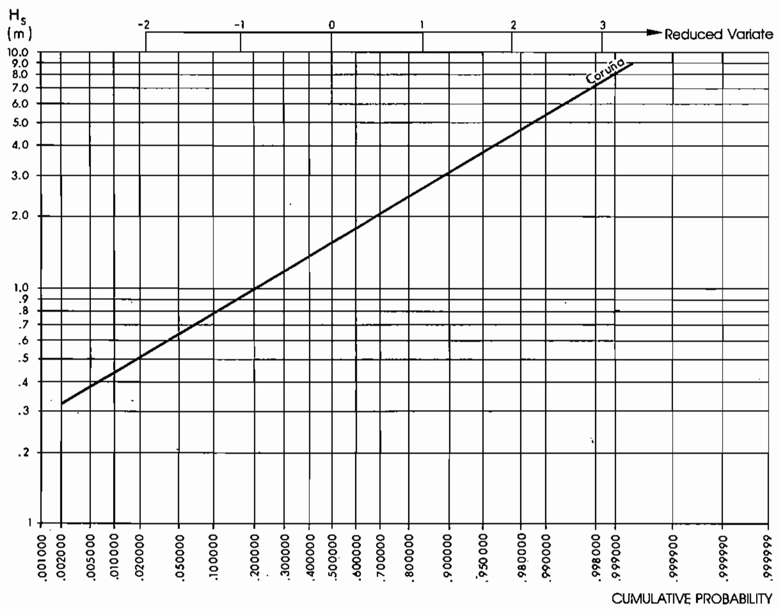
SEA WAVES	
TOTAL Nº OF OBSERVATIONS	123.593
TOTAL Nº OF CALMS	9.071
TOTAL Nº CONFUSED	14.839

SWELL WAVES	
TOTAL Nº OF OBSERVATIONS	100.333
TOTAL Nº OF CALMS	5.553
TOTAL Nº CONFUSED	5.566

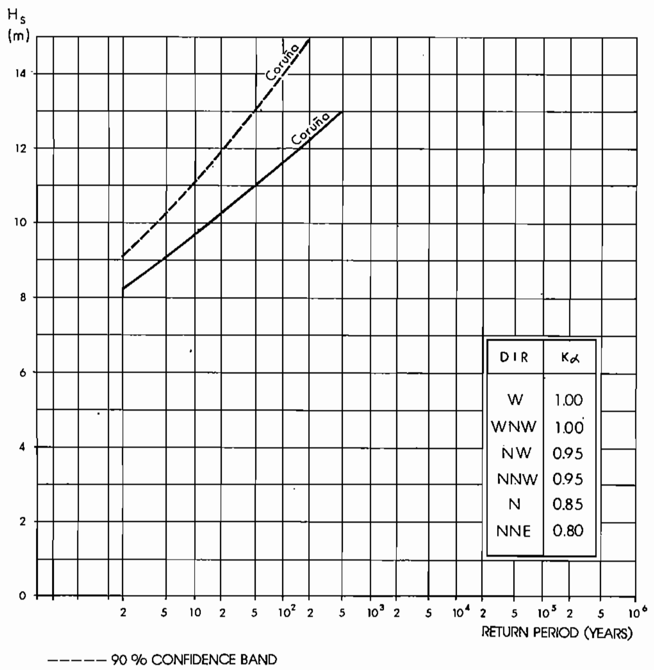
B – VISUAL OBSERVATIONS: MEAN DIRECTIONAL DISTRIBUTIONS



C – INSTRUMENTAL DATA: MEAN SCALAR DISTRIBUTIONS



D – INSTRUMENTAL DATA: EXTREME SCALAR DISTRIBUTIONS



DIR	Kα
W	1.00
WNW	1.00
NW	0.95
NNW	0.95
N	0.85
NNE	0.80

E – INSTRUMENTAL DATA: WAVE HEIGHT/PERIOD CORRELATION FOR STORMS

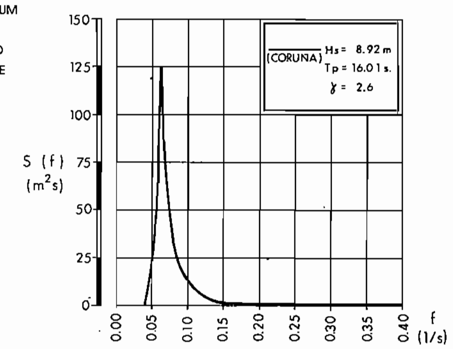
BUOY	$P = H_s / L_{\bar{T}} = \frac{2\Pi H_s}{g\bar{T}^2}$	$T_p / \bar{T}$	FINAL RELATIONSHIP H_s (m) T_p (s)	DESIGN VALUES H_s (m)	DESIGN VALUES T_p * (s)
CORUÑA	0.015 ~ 0.06	≃1.25	$T_p = (4 \sim 8.2)\sqrt{H_s}$	7	10.5~21.5
				9	12 ~ 24.5
				11	13 ~ 27
				13	14.5~29.5

* IN NO CASE SHALL. DESIGN PERIODS GREATER THAN 22 SECONDS BE CONSIDERED

F – INSTRUMENTAL DATA: BASIC FREQUENCY SPECTRUM FOR STORMS (Hs ≥ 3,00 m)

THEORETICAL JONSWAP SPECTRUM FIT TO THE REAL RECORDER SPECTRUM CORRESPONDING TO THE PEAK OF STORM WITH VALUE OF γ CLOSEST TO $\bar{\gamma}$.

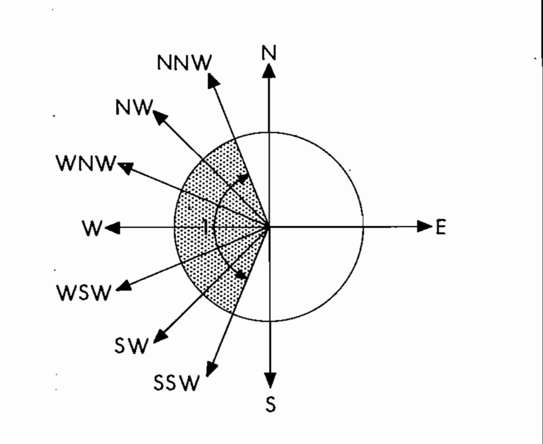
**(1/s)



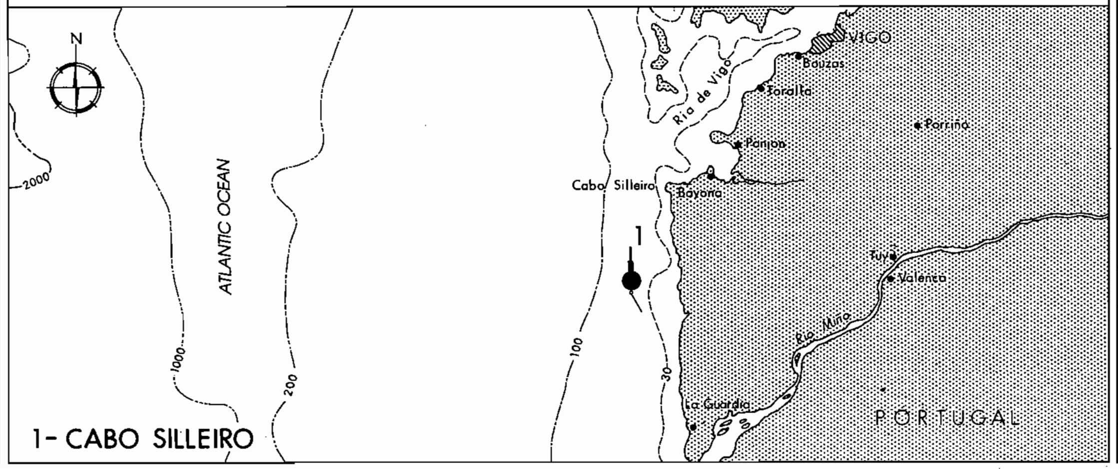
BUOY	THEORETICAL JONSWAP SPECTRUM $\bar{\gamma}$	γ_{max}	γ_{min}	σ_γ	$\bar{f_p}$ **	$f_{p,max}$ **	$f_{p,min}$ **	σ_{f_p} **	n
CORUÑA	2.6	6.5	1.3	1.27	0.07	0.12	0.05	0.016	14

ROM 0.3 - 91 - WAVES
ATLAS OF WAVE CLIMATE ON THE SPANISH COAST

SIGNIFICANT DIRECTIONS



LOCATION OF INSTRUMENTAL DATA



ANALYZED DATA

INSTRUMENTAL DATA

BUOY	LOCATION	DEPTH (m)	REC. PERIOD
1- CABO SILLEIRO	42º 1'48"N 8º 56'30"W	75	1986 / 1990

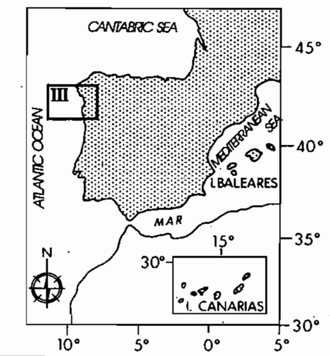
VISUAL OBSERVATIONS

QUADRANGE:
41,5º N - 43,2º N
8,0º W - 11,0º W

RECORDING PERIOD: 1950 - 1985

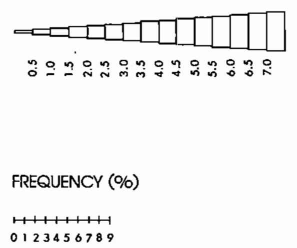
AREA – III

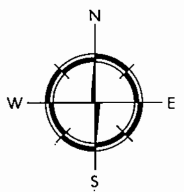
GEOGRAPHIC LOCATION OF THE ANALYZED DATA

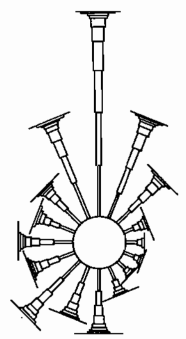


A — VISUAL OBSERVATIONS: WAVE ROSES

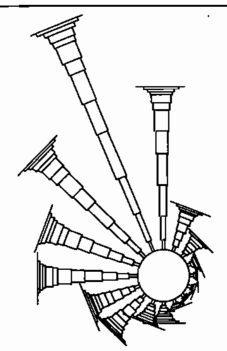
SCALE OF HEIGHTS H_v (m)





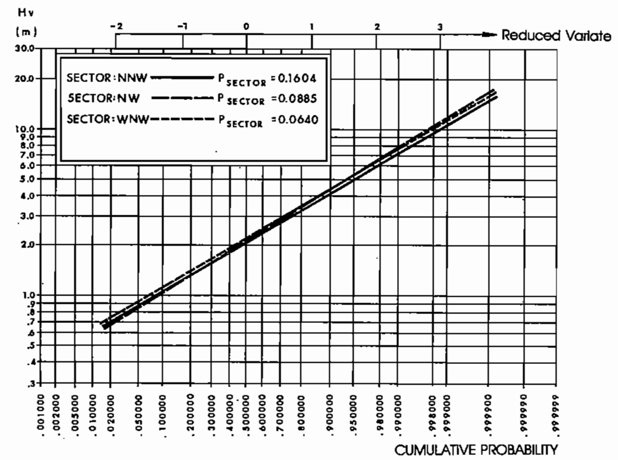


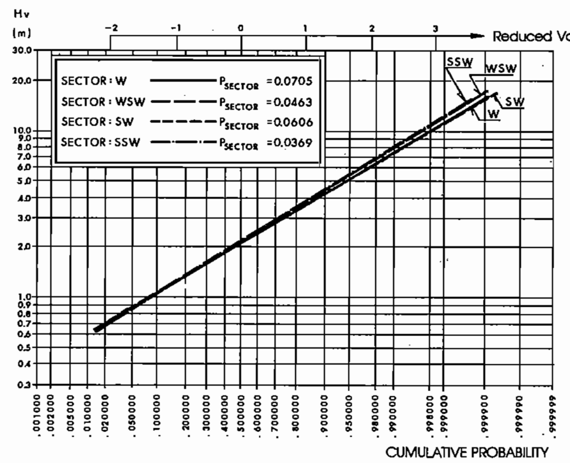
SEA WAVES	
TOTAL Nº OF OBSERVATIONS	77.868
TOTAL Nº OF CALMS	7.318
TOTAL Nº CONFUSED	9.479



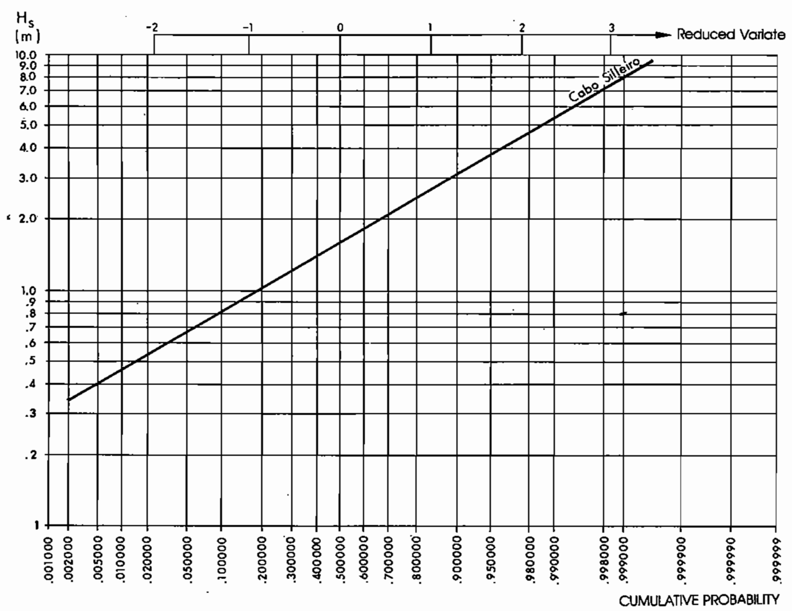
SWELL WAVES	
TOTAL Nº OF OBSERVATIONS	65.955
TOTAL Nº OF CALMS	3.747
TOTAL Nº CONFUSED	3.167

B — VISUAL OBSERVATIONS: MEAN DIRECTIONAL DISTRIBUTIONS

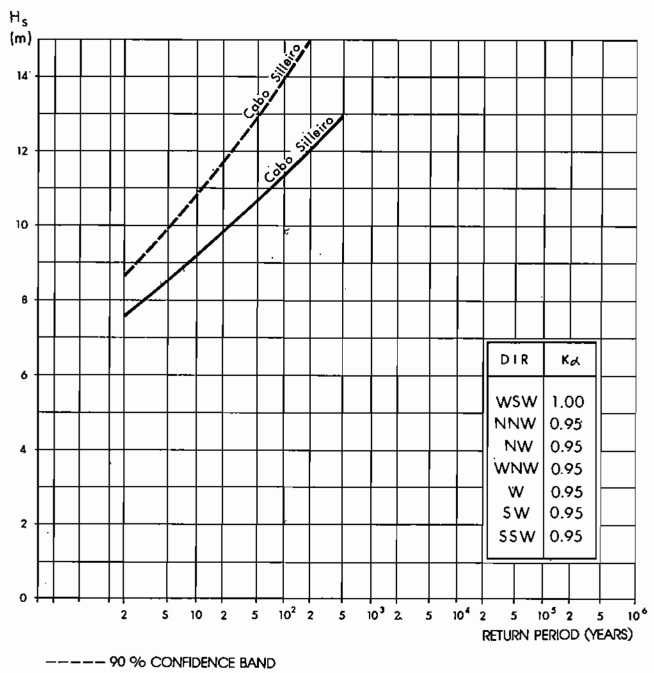




C — INSTRUMENTAL DATA: MEAN SCALAR DISTRIBUTIONS



D — INSTRUMENTAL DATA: EXTREME SCALAR DISTRIBUTIONS



DIR	K_α
WSW	1.00
NNW	0.95
NW	0.95
WNW	0.95
W	0.95
SW	0.95
SSW	0.95

E — INSTRUMENTAL DATA: WAVE HEIGHT/PERIOD CORRELATION FOR STORMS

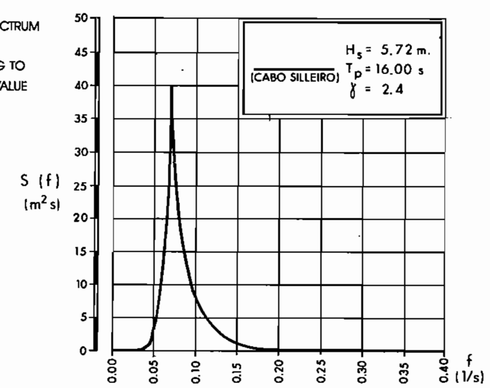
BUOY	$P = H_s / L_{\bar{T}} = \frac{2\pi H_s}{g\bar{T}^2}$	$T_p / \bar{T}$	FINAL RELATIONSHIP H_s (m) T_p (s)	DESIGN VALUES H_s (m)	DESIGN VALUES T_p (s) *
CABO SILLEIRO	0.015 ~ 0.06	≃1.25	$T_p = (4 \sim 8.2)\sqrt{H_s}$	7	10.5~21.5
				9	12 ~ 24.5
				11	13 ~ 27
				13	14.5~29.5

* IN NO CASE SHALL DESIGN PERIODS GREATER THAN 22 SECONDS BE CONSIDERED

** (1/s)

F — INSTRUMENTAL DATA: BASIC FREQUENCY SPECTRUM FOR STORMS (Hs > 3,00 m)

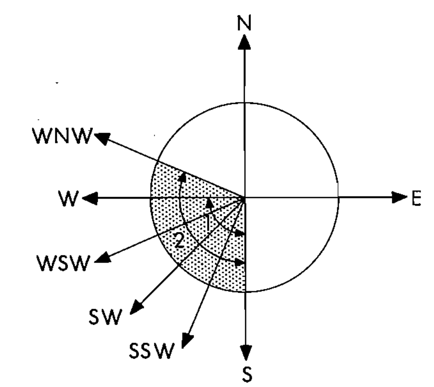
THEORETICAL JONSWAP SPECTRUM FIT TO THE REAL RECORDER SPECTRUM CORRESPONDING TO THE PEAK OF STORM WITH VALUE OF γ CLOSEST TO $\bar{\gamma}$.



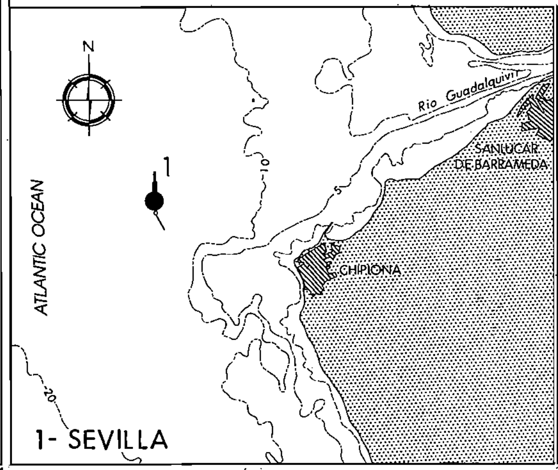
THEORETICAL JONSWAP SPECTRUM

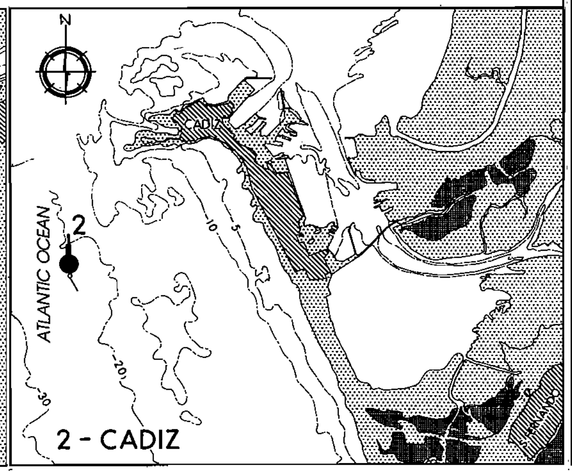
BUOY	$\bar{\gamma}$	γ_{max}	γ_{min}	σ_γ	$\bar{f_p}$ **	$f_{p,max}$ **	$f_{p,min}$ **	σ_{f_p} **	n
CABO SILLEIRO	2.4	4.0	1.3	0.69	0.07	0.09	0.05	0.008	20

SIGNIFICANT DIRECTIONS



LOCATION OF INSTRUMENTAL DATA





ANALYZED DATA

INSTRUMENTAL DATA			
BUOY	LOCATION	DEPTH (m)	REC. PERIOD
1- SEVILLA	36º 44' 15"N 6º 29' 6" W	12	1983 / 1988
2-CADIZ	36º 30' 20"N 6º 20' 20"W	22	1982/1990

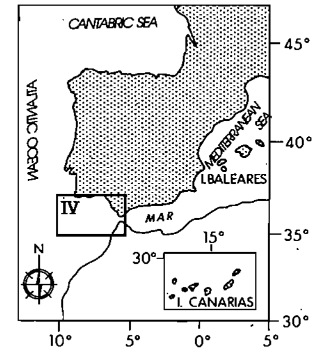
VISUAL OBSERVATIONS

QUADRANGE: 35º N - 37.1º N; 5.6º W - 10º W

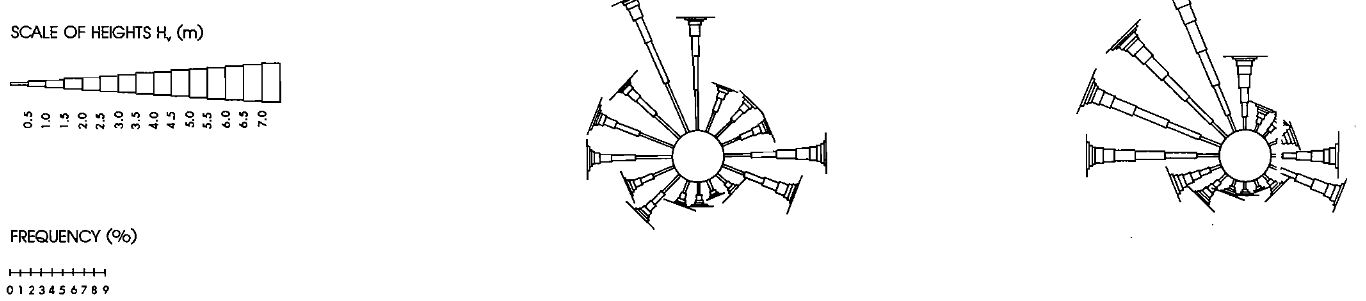
RECORDING PERIOD: 1950 - 1985

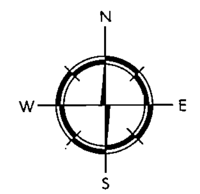
AREA – IV

GEOGRAPHIC LOCATION OF THE ANALYZED DATA



A – VISUAL OBSERVATIONS: WAVE ROSES

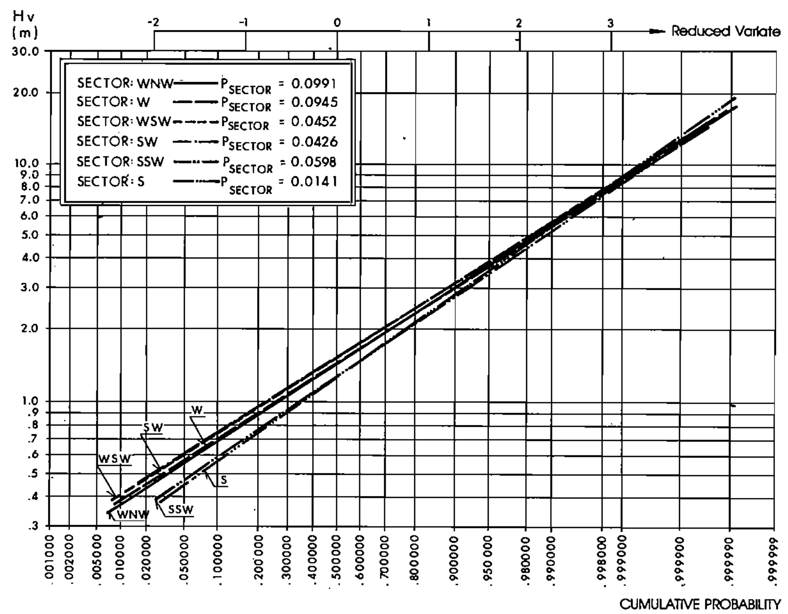




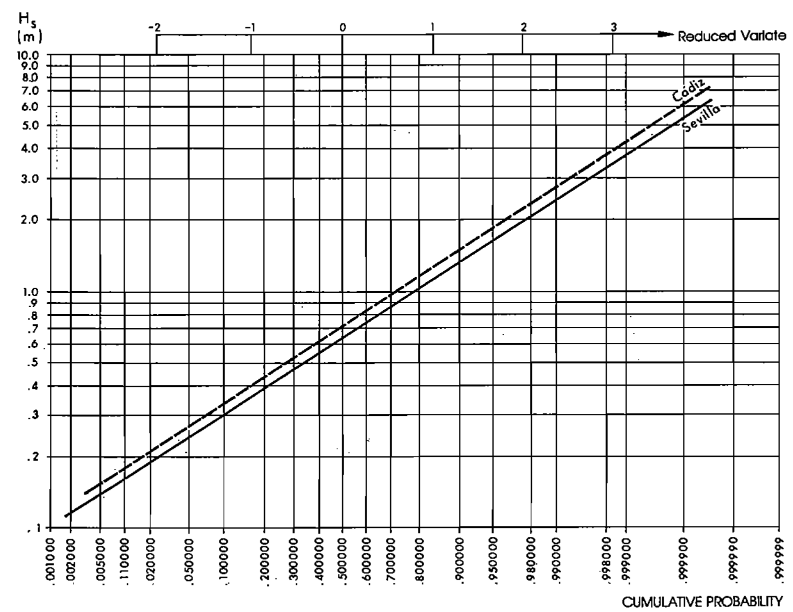
SEA WAVES	
TOTAL Nº OF OBSERVATIONS	84.515
TOTAL Nº OF CALMS	5.884
TOTAL Nº CONFUSED	8.684

SWELL WAVES	
TOTAL Nº OF OBSERVATIONS	51.294
TOTAL Nº OF CALMS	5.262
TOTAL Nº CONFUSED	2.412

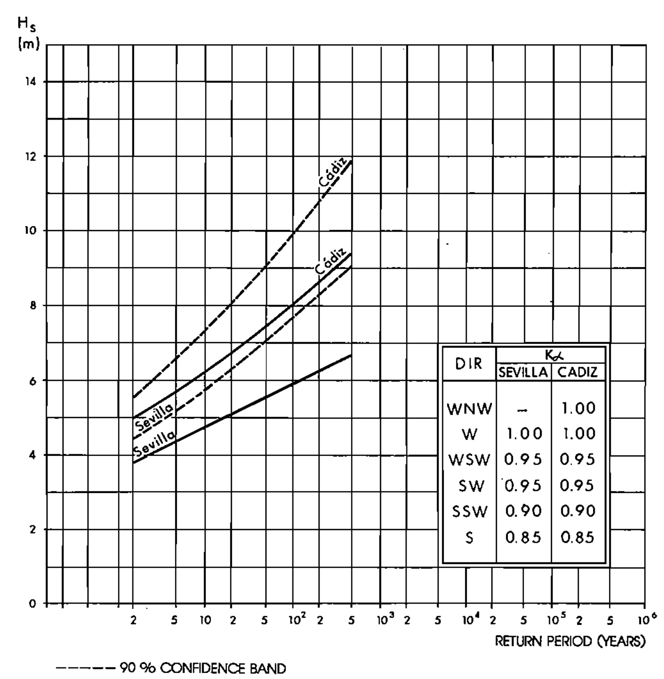
B – VISUAL OBSERVATIONS: MEAN DIRECTIONAL DISTRIBUTIONS



C – INSTRUMENTAL DATA: MEAN SCALAR DISTRIBUTIONS



D – INSTRUMENTAL DATA: EXTREME SCALAR DISTRIBUTIONS



DIR	K_α SEVILLA	K_α CADIZ
WNW	–	1.00
W	1.00	1.00
WSW	0.95	0.95
SW	0.95	0.95
SSW	0.90	0.90
S	0.85	0.85

------ 90 % CONFIDENCE BAND

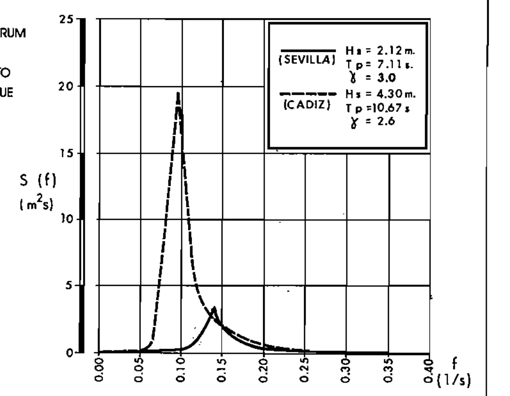
E – INSTRUMENTAL DATA: WAVE HEIGHT/PERIOD CORRELATION FOR STORMS

BUOY	$P = H_s / L_{\bar{T}} = \frac{2\Pi H_s}{g\bar{T}^2}$	$T_p / \bar{T}$	FINAL RELATIONSHIP H_s (m) T_p (s)	DESIGN VALUES H_s (m)	DESIGN VALUES T_p (s)
SEVILLA	0.02 ~ 0.06	≃1.25	$T_p = (4\sim7)\sqrt{H_s}$	3 5 7 9	7 ~ 12 8.5~15.5 10.5~18.5 12 ~ 21
CADIZ	0.02 ~ 0.06	≃1.25	$T_p = (4\sim7)\sqrt{H_s}$	4 6 8 10	8 ~ 14 9.5~17 11 ~ 19.5 12.5~22

F – INSTRUMENTAL DATA: BASIC FREQUENCY SPECTRUM FOR STORMS ($H_s \geq$ 1,50 m)

THEORETICAL JONSWAP SPECTRUM FIT TO THE REAL RECORDER SPECTRUM CORRESPONDING TO THE PEAK OF STORM WITH VALUE OF γ CLOSEST TO $\bar{\gamma}$.

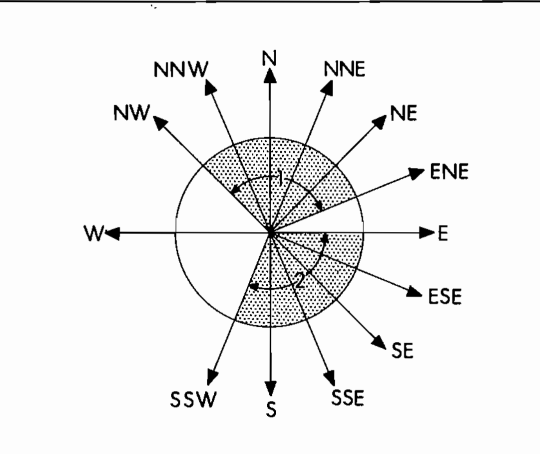
*(1/s)



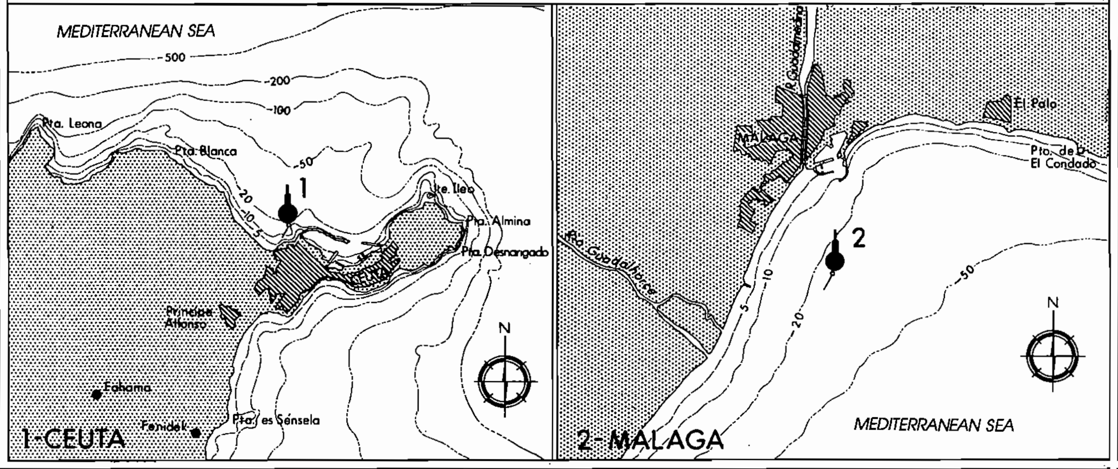
BUOY	THEORETICAL JONSWAP SPECTRUM $\bar{\gamma}$	γ_{max}	γ_{min}	σ_γ	$\bar{f}_p$*	$f_{p,max}$*	$f_{p,min}$*	σ_{f_p}*	n
SEVILLA	3.2	8.9	0.9	2.01	0.12	0.16	0.05	0.024	21
CADIZ	2.6	5.9	0.8	1.34	0.10	0.125	0.07	0.016	17

AREA – V

SIGNIFICANT DIRECTIONS



LOCATION OF INSTRUMENTAL DATA



ANALYZED DATA

INSTRUMENTAL DATA

BUOY	LOCATION	DEPTH (m)	REC. PERIOD
1-CEUTA	35º54' 10"N 5º 19' 30"W	21	1984/1990
2-MALAGA	36º41'30"N 4º25' 0"W	25	1985/1990

VISUAL OBSERVATIONS

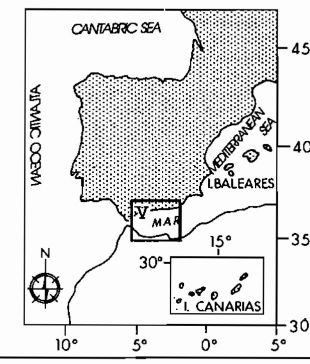
QUADRANGE:

35º N - 37º N

2º W - 5.6ºW

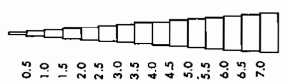
RECORDING PERIOD: 1950 - 1985

GEOGRAPHIC LOCATION OF THE ANALYZED DATA

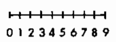


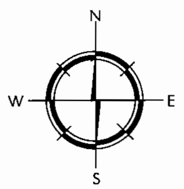
A – VISUAL OBSERVATIONS: WAVE ROSES

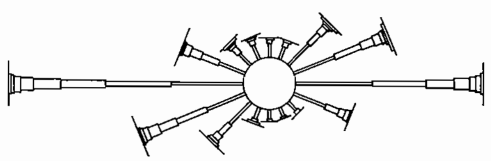
SCALE OF HEIGHTS H_v (m)



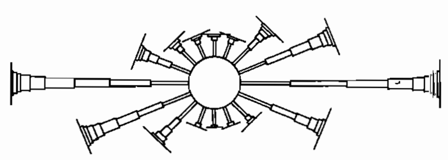
FREQUENCY (%)





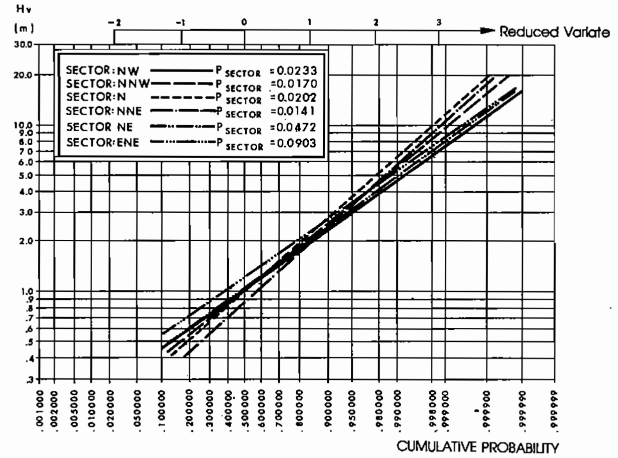


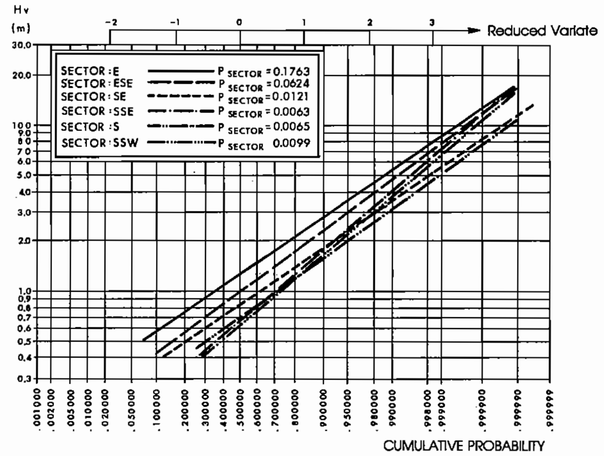
SEA WAVES	
TOTAL Nº OF OBSERVATIONS	91.522
TOTAL Nº OF CALMS	6.266
TOTAL Nº CONFUSED	8.753



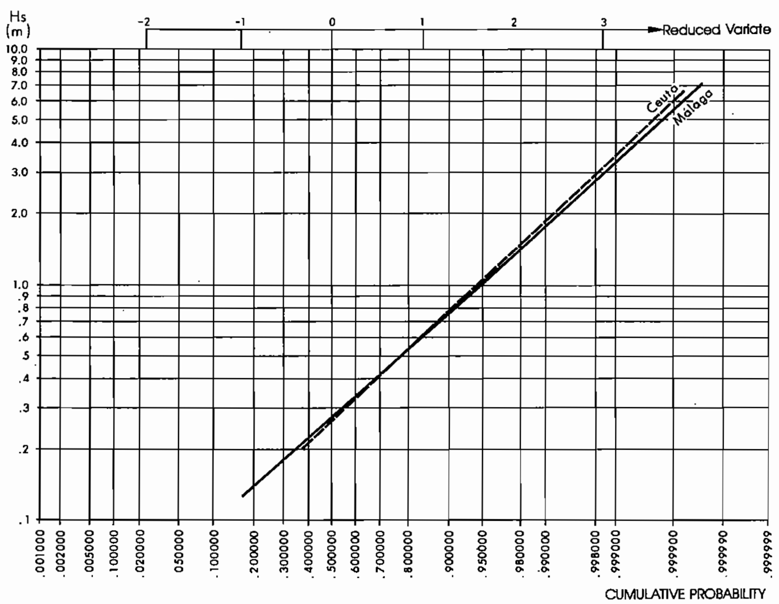
SWELL WAVES	
TOTAL Nº OF OBSERVATIONS	41.977
TOTAL Nº OF CALMS	11.247
TOTAL Nº CONFUSED	2.858

B – VISUAL OBSERVATIONS: MEAN DIRECTIONAL DISTRIBUTIONS

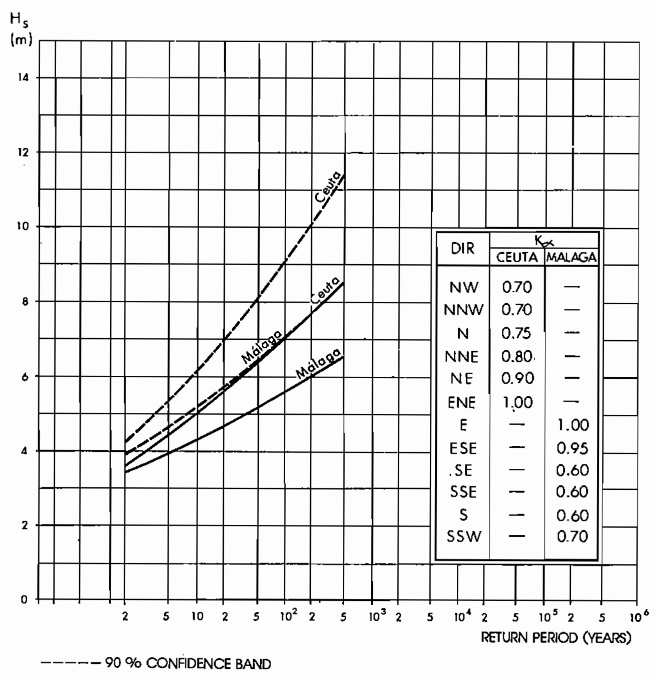




C – INSTRUMENTAL DATA: MEAN SCALAR DISTRIBUTIONS



D – INSTRUMENTAL DATA: EXTREME SCALAR DISTRIBUTIONS



DIR	K_α CEUTA	K_α MALAGA
NW	0.70	—
NNW	0.70	—
N	0.75	—
NNE	0.80	—
NE	0.90	—
ENE	1.00	—
E	—	1.00
ESE	—	0.95
SE	—	0.60
SSE	—	0.60
S	—	0.60
SSW	—	0.70

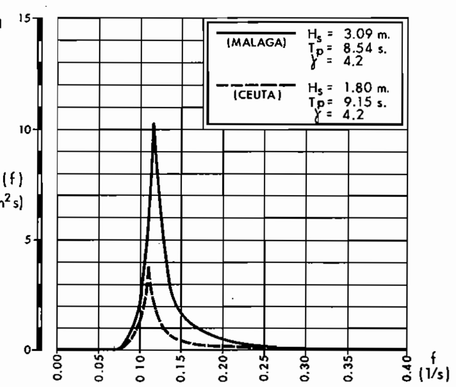
E – INSTRUMENTAL DATA: WAVE HEIGHT/PERIOD CORRELATION FOR STORMS

BUOY	$P = H_s / L_{\bar{T}} = \frac{2\Pi H_s}{g\bar{T}^2}$	$T_p / \bar{T}$	FINAL RELATIONSHIP H_s (m) T_p (s)	DESIGN VALUES H_s (m)	DESIGN VALUES T_p (s)
CEUTA	0.02 ~ 0.035	≃1.20	$T_p=(5.1\text{-}6.8)\sqrt{H_s}$	3	8.5~12
				5	11.5~15
				7	13.5~18
				9	15 ~ 20
MALAGA	0.025 ~ 0.04	≃1.20	$T_p=(4.8\text{-}6.1)\sqrt{H_s}$	3	8.5~10.5
				5	10.5~13.5
				7	12.5~16

F – INSTRUMENTAL DATA: BASIC FREQUENCY SPECTRUM FOR STORMS (H_s > 1,00 m)

THEORETICAL JONSWAP SPECTRUM FIT TO THE REAL RECORDER SPECTRUM CORRESPONDING TO THE PEAK OF STORM WITH VALUE OF γ CLOSEST TO $\bar{\gamma}$.

*(1/s)

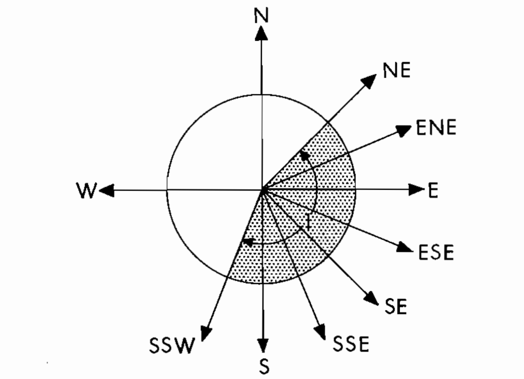


THEORETICAL JONSWAP SPECTRUM

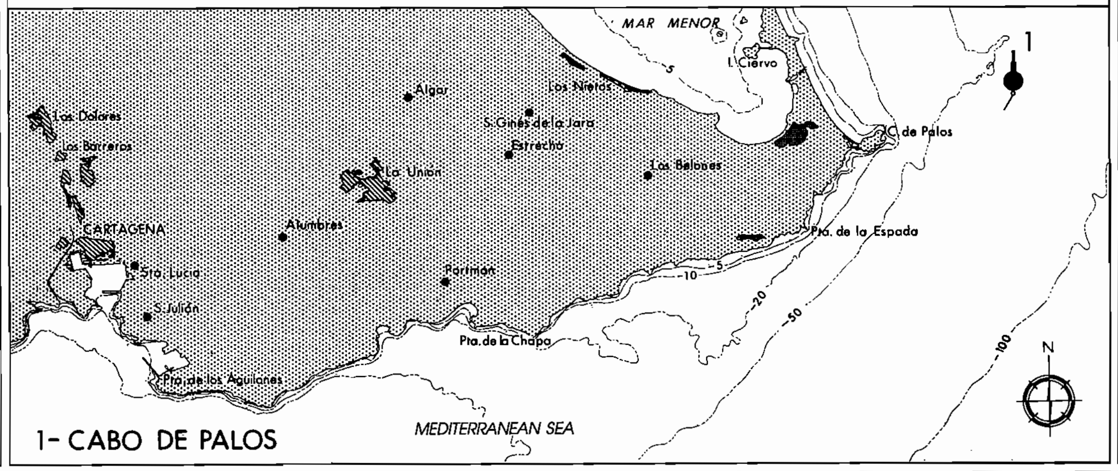
BUOY	$\bar{\gamma}$	γ_{max}	γ_{min}	σ_γ	$\bar{f_p}$*	$f_{p,max}$*	$f_{p,min}$*	σ_{f_p}*	n
CEUTA	5.0	14.4	3.2	1.69	0.11	0.13	0.08	0.014	18
MALAGA	3.6	10.3	1.2	2.18	0.13	0.16	0.12	0.015	14

AREA – VI

SIGNIFICANT DIRECTIONS



LOCATION OF INSTRUMENTAL DATA



ANALYZED DATA

INSTRUMENTAL DATA

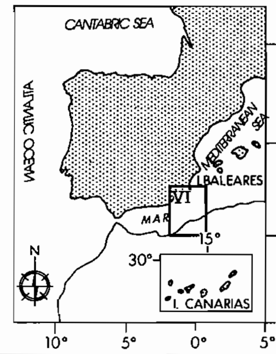
BUOY	LOCATION	DEPTH (m)	REC. PERIOD
1- CABO DE PALOS	37º 39' 15" N 0º 38' 18" W	67	1985 / 1990

VISUAL OBSERVATIONS

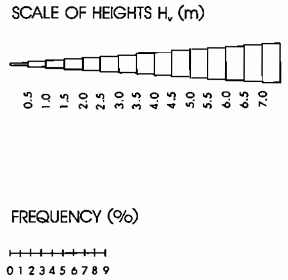
QUADRANGE: 35º N – 38º N; 2º W – 2º E

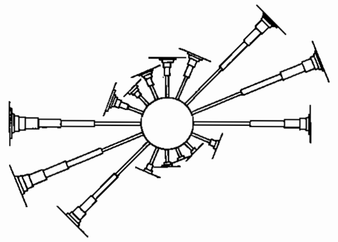
RECORDING PERIOD: 1950 - 1985

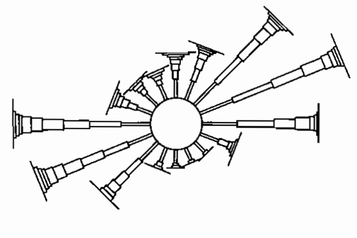
GEOGRAPHIC LOCATION OF THE ANALYZED DATA

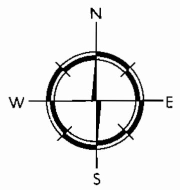


A — VISUAL OBSERVATIONS: WAVE ROSES





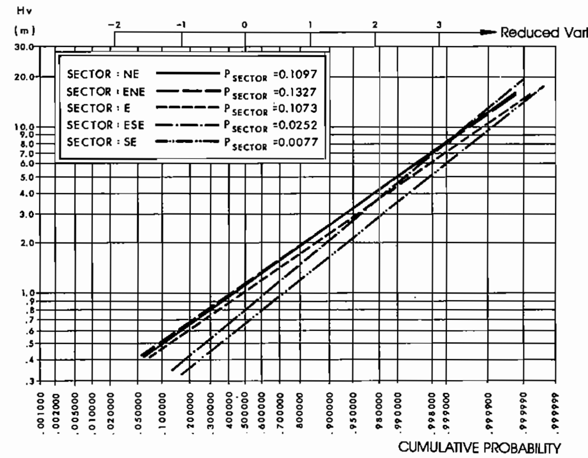


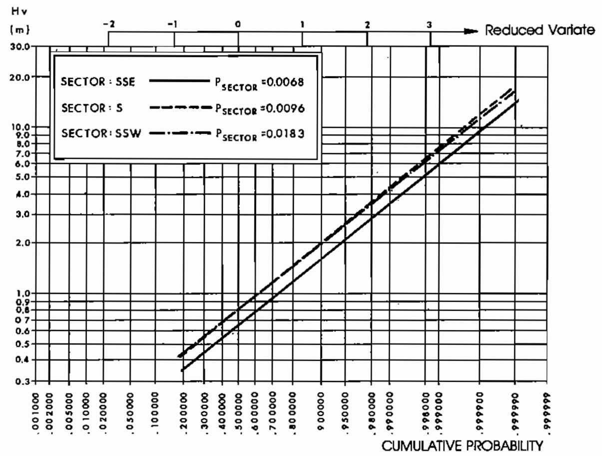


SEA WAVES	
TOTAL Nº OF OBSERVATIONS	116.135
TOTAL Nº OF CALMS	7.354
TOTAL Nº CONFUSED	9.937

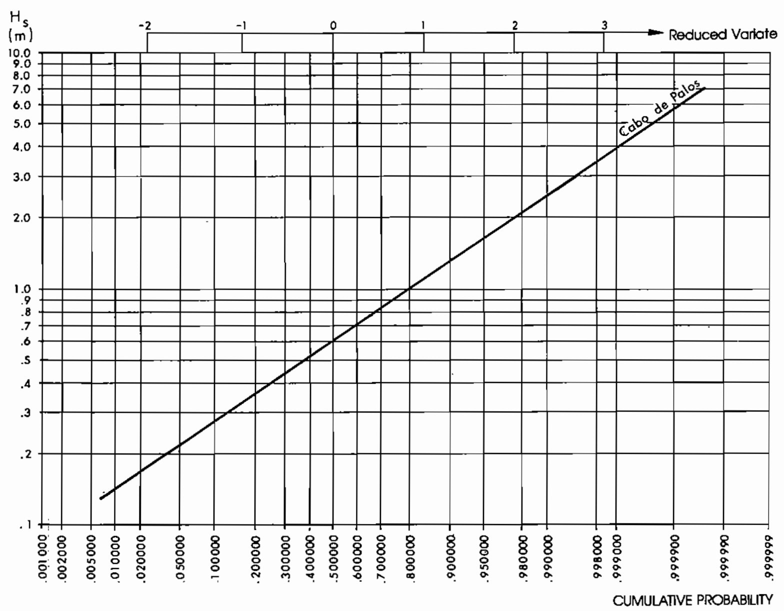
SWELL WAVES	
TOTAL Nº OF OBSERVATIONS	57.591
TOTAL Nº OF CALMS	12.281
TOTAL Nº CONFUSED	3.567

B — VISUAL OBSERVATIONS: MEAN DIRECTIONAL DISTRIBUTIONS

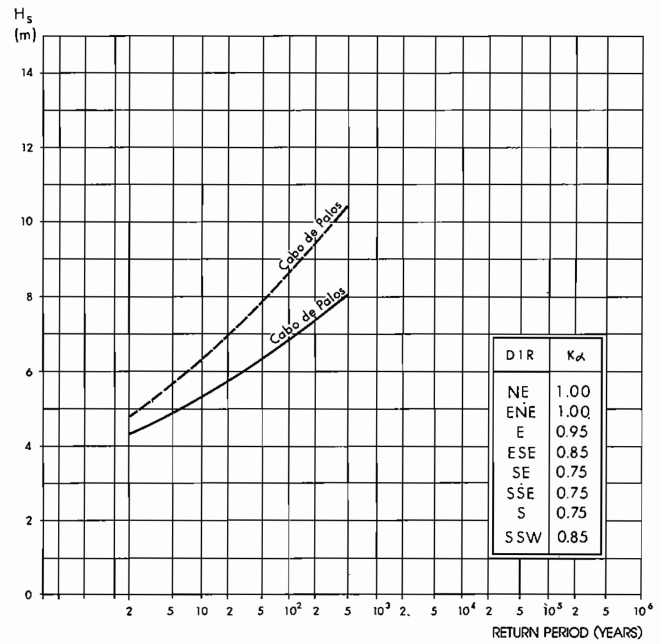




C — INSTRUMENTAL DATA: MEAN SCALAR DISTRIBUTIONS



D — INSTRUMENTAL DATA: EXTREME SCALAR DISTRIBUTIONS



DIR	K_α
NE	1.00
ENE	1.00
E	0.95
ESE	0.85
SE	0.75
SSE	0.75
S	0.75
SSW	0.85

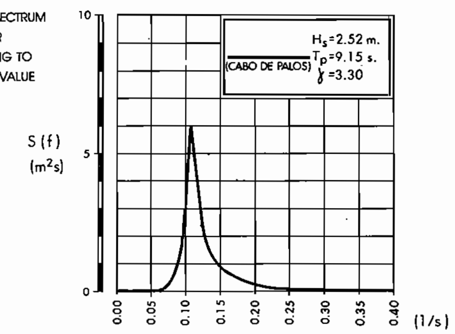
E — INSTRUMENTAL DATA: WAVE HEIGHT/PERIOD CORRELATION FOR STORMS

BUOY	$P = H_s / L_{\bar{T}} = \frac{2 \Pi H_s}{g \bar{T}^2}$	$T_p / \bar{T}$	FINAL RELATIONSHIP H_s (m) T_p (s)	DESIGN VALUES H_s (m)	DESIGN VALUES T_p (s)
CABO DE PALOS	0.035 ~ 0.06	≃1.20	$T = (3.9\text{-}5.1)\sqrt{H_s}$	4 6 8	7.5 ~ 10 9.5 ~ 12.5 11 ~ 14.5

F — INSTRUMENTAL DATA: BASIC FREQUENCY SPECTRUM FOR STORMS (H_s > 1,50 m)

THEORETICAL JONSWAP SPECTRUM FIT TO THE REAL RECORDER SPECTRUM CORRESPONDING TO THE PEAK OF STORM WITH VALUE OF γ CLOSEST TO $\bar{\gamma}$.

*(1/s)



THEORETICAL JONSWAP SPECTRUM

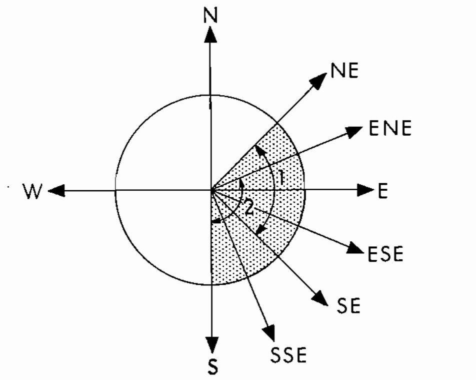
BUOY	$\bar{\gamma}$	γ_{max}	γ_{min}	σ_γ	$\bar{f_p}^*$	$f_{p,max}^*$	$f_{p,min}^*$	$\sigma_{f_p}^*$	n
CABO DE PALOS	3.2	6.3	1.4	1.24	0.13	0.15	0.10	0.014	18

ROM 0.3 - 91 - WAVES

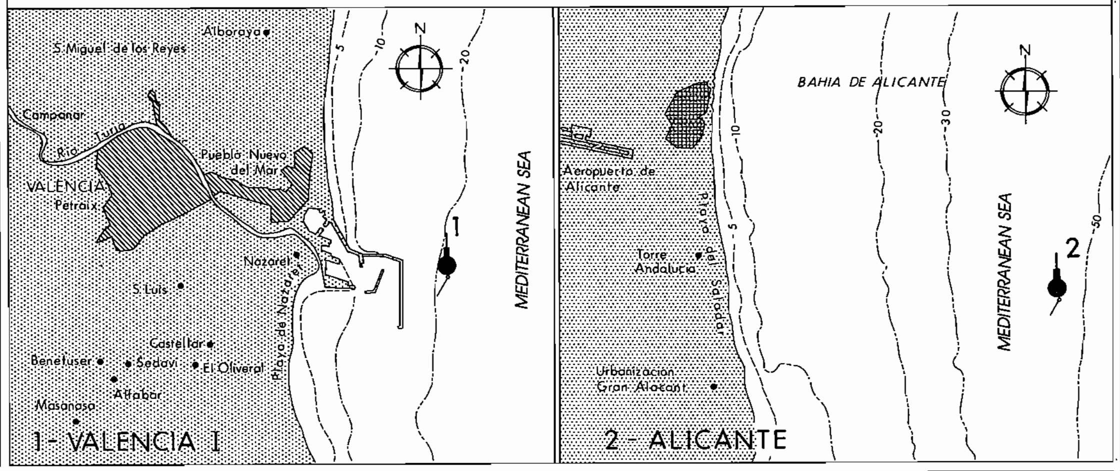
ATLAS OF WAVE CLIMATE ON THE SPANISH COAST

AREA – VII

SIGNIFICANT DIRECTIONS



LOCATION OF INSTRUMENTAL DATA



ANALYZED DATA

INSTRUMENTAL DATA

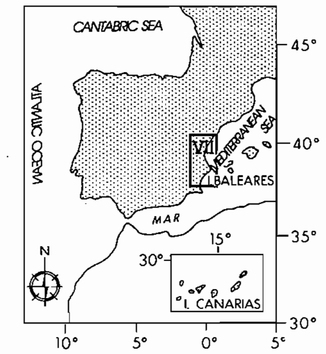
BUOY	LOCATION	DEPTH (m)	REC. PERIOD
1- VALECIA I	39º 27'05"N 0º 17'43"W	21	1982/1990
2- ALICANTE	38º 15'00"N 0º 25'00"W	50	1982/1990

VISUAL OBSERVATIONS

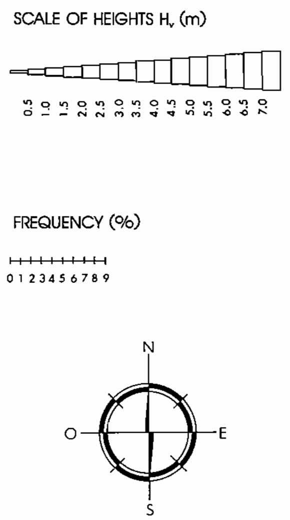
QUADRANGE: 37.8º N – 40.5º N; 1.0º W – 2.0º E

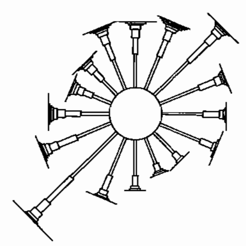
RECORDING PERIOD: 1950 - 1985

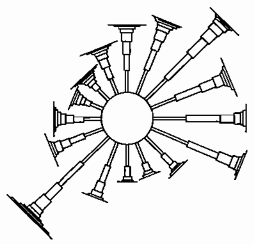
GEOGRAPHIC LOCATION OF THE ANALYZED DATA



A – VISUAL OBSERVATIONS: WAVE ROSES



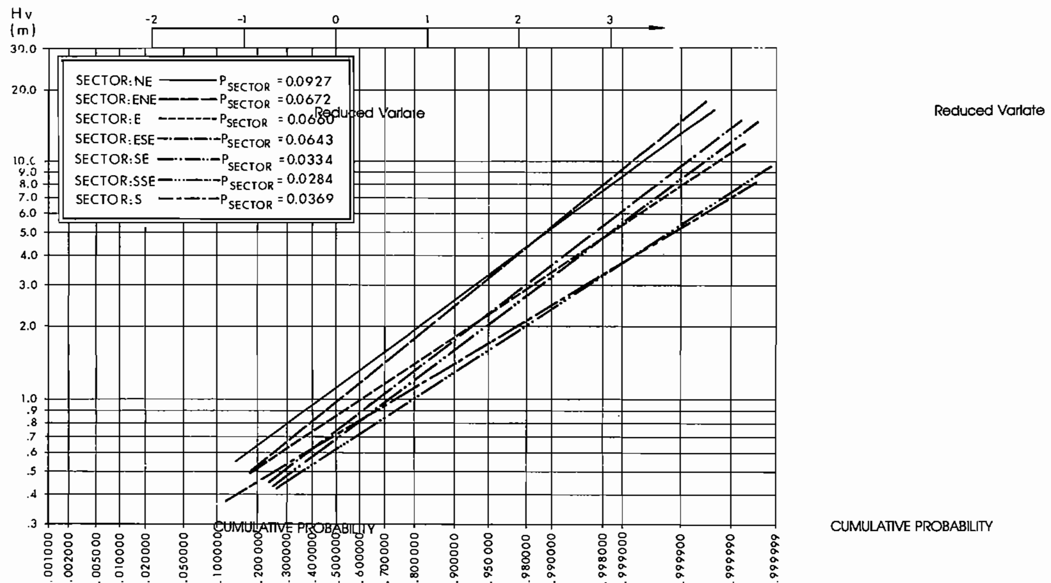




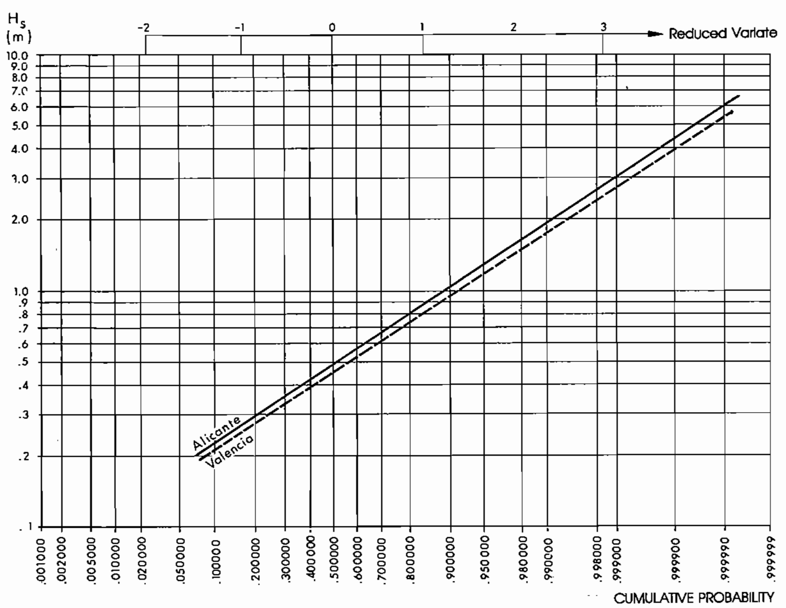
SEA WAVES	
TOTAL Nº OF OBSERVATIONS	25.878
TOTAL Nº OF CALMS	2.294
TOTAL Nº CONFUSED	1.432

SWELL WAVES	
TOTAL Nº OF OBSERVATIONS	13.504
TOTAL Nº OF CALMS	2.197
TOTAL Nº CONFUSED	803

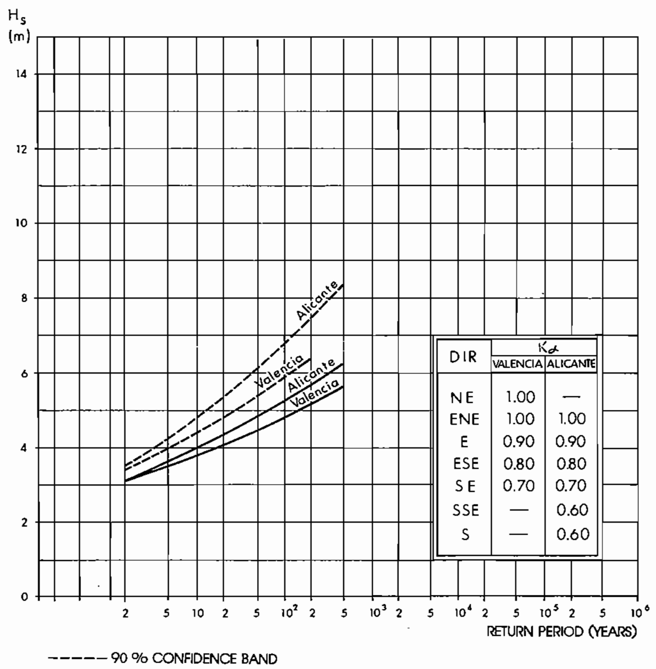
B – VISUAL OBSERVATIONS: MEAN DIRECTIONAL DISTRIBUTIONS



C – INSTRUMENTAL DATA: MEAN SCALAR DISTRIBUTIONS



D – INSTRUMENTAL DATA: EXTREME SCALAR DISTRIBUTIONS



DIR	K_α VALENCIA	K_α ALICANTE
NE	1.00	—
ENE	1.00	1.00
E	0.90	0.90
ESE	0.80	0.80
SE	0.70	0.70
SSE	—	0.60
S	—	0.60

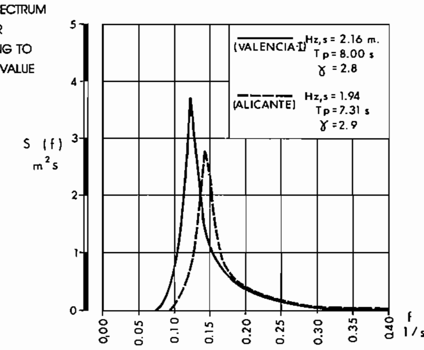
E – INSTRUMENTAL DATA: WAVE HEIGHT/PERIOD CORRELATION FOR STORMS

BUOY	$P = H_s / L_{\bar{T}} = \frac{2\pi H_s}{g\bar{T}^2}$	$T_p / \bar{T}$	FINAL RELATIONSHIP H_s (m) T_p (s)	DESIGN VALUES H_s (m)	DESIGN VALUES T_p (s)
VALENCIA I	0.025 ~ 0.04	≃ 1.25	$T_p = (5{\sim}6.3)\sqrt{H_s}$	3	8.5~11
				5	11~14
				7	13~16.5
ALICANTE	0.025 ~ 0.04	≃ 1.25	$T_p = (5{\sim}6.3)\sqrt{H_s}$	3	8.5~11
				5	11~14
				7	13~16.5

F – INSTRUMENTAL DATA: BASIC FREQUENCY SPECTRUM FOR STORMS (Hs > 1,00 m)

THEORETICAL JONSWAP SPECTRUM FIT TO THE REAL RECORDER SPECTRUM CORRESPONDING TO THE PEAK OF STORM WITH VALUE OF γ CLOSEST TO $\bar{\gamma}$.

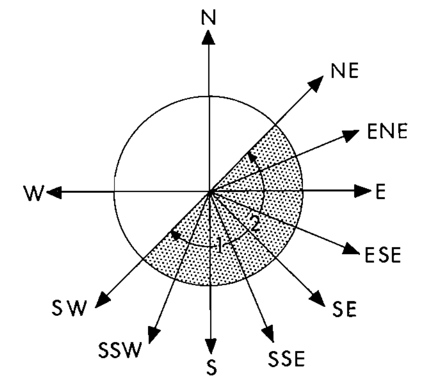
* (1/s)



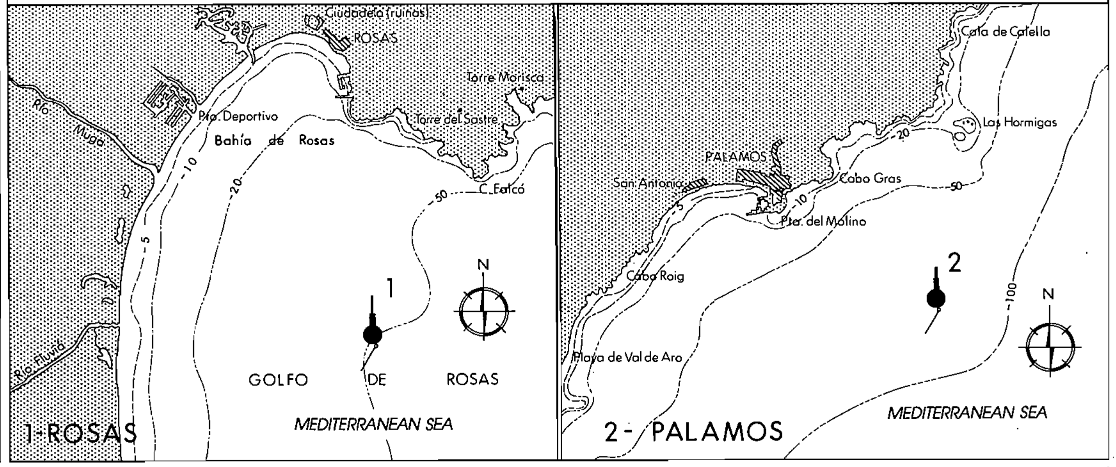
BUOY	$\bar{\gamma}$	γ_{max}	γ_{min}	σ_γ	$\bar{f_p}$*	$f_{p,max}$*	$f_{p,min}$*	σ_{f_p}*	n_t
VALENCIA I	2.7	4.2	1.5	0.87	0.13	0.16	0.10	0.017	16
ALICANTE	2.8	4.2	1.4	1.01	0.13	0.19	0.09	0.032	20

ROM 0.3 - 91 - WAVES
ATLAS OF WAVE CLIMATE ON THE SPANISH COAST

SIGNIFICANT DIRECTIONS



LOCATION OF INSTRUMENTAL DATA



ANALYZED DATA

INSTRUMENTAL DATA			
BUOY	LOCATION	DEPTH (m)	REC. PERIOD
1- ROSAS	42º 11' 43"N 3º 11' 1,5"E	50	1986/1987
2-PALAMOS	41º49'24"N 3º 10'42"E	90	1988/1990

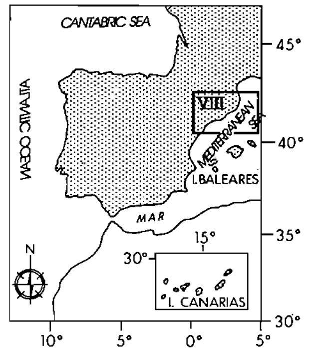
VISUAL OBSERVATIONS

QUADRANGE: 40.5º N - 42.5º N; 0.0º W - 4.5º E

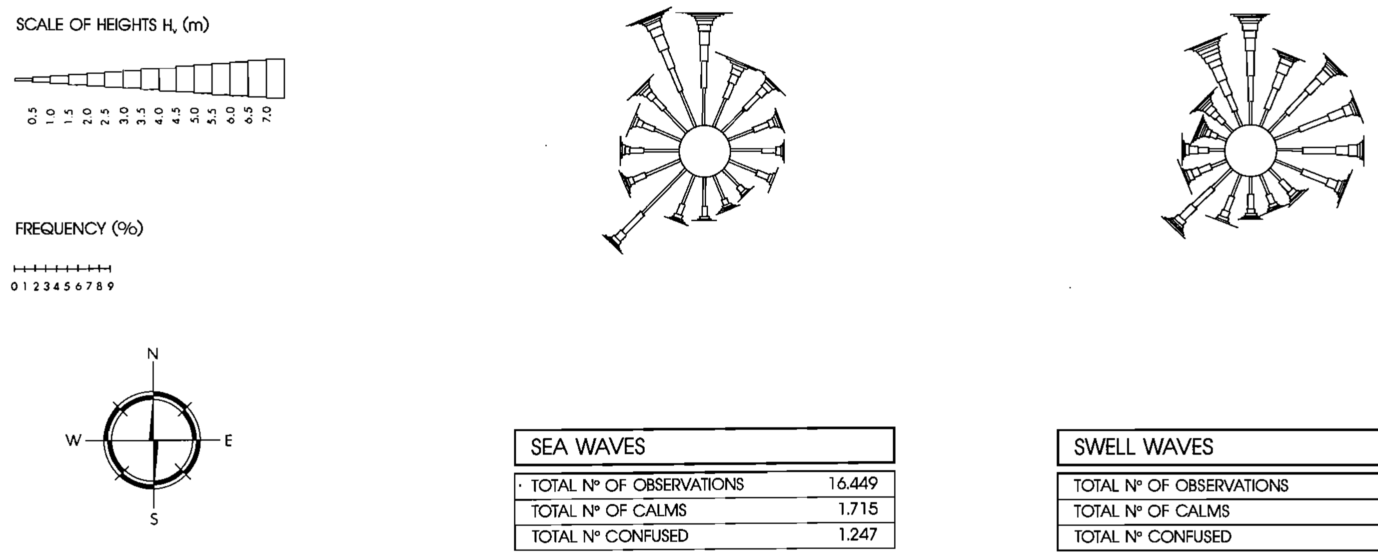
RECORDING PERIOD: 1950 - 1985

A R E A – VIII

GEOGRAPHIC LOCATION OF THE ANALYZED DATA



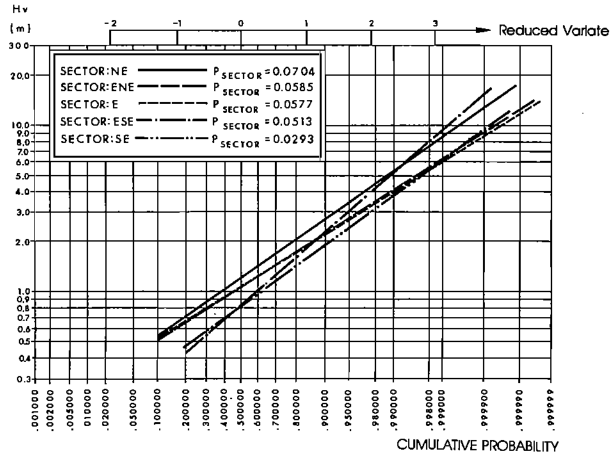
A – VISUAL OBSERVATIONS: WAVE ROSES

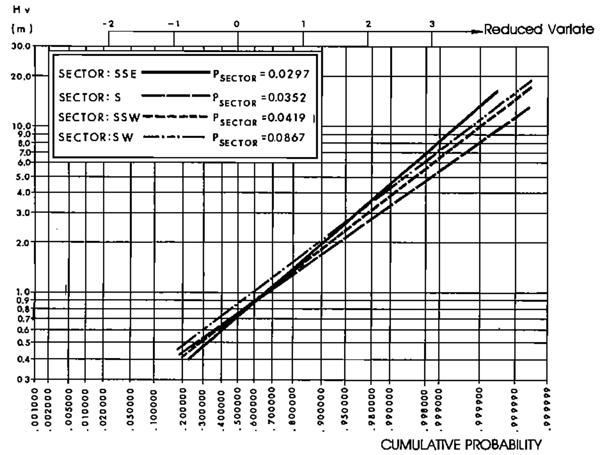


SEA WAVES	
TOTAL Nº OF OBSERVATIONS	16.449
TOTAL Nº OF CALMS	1.715
TOTAL Nº CONFUSED	1.247

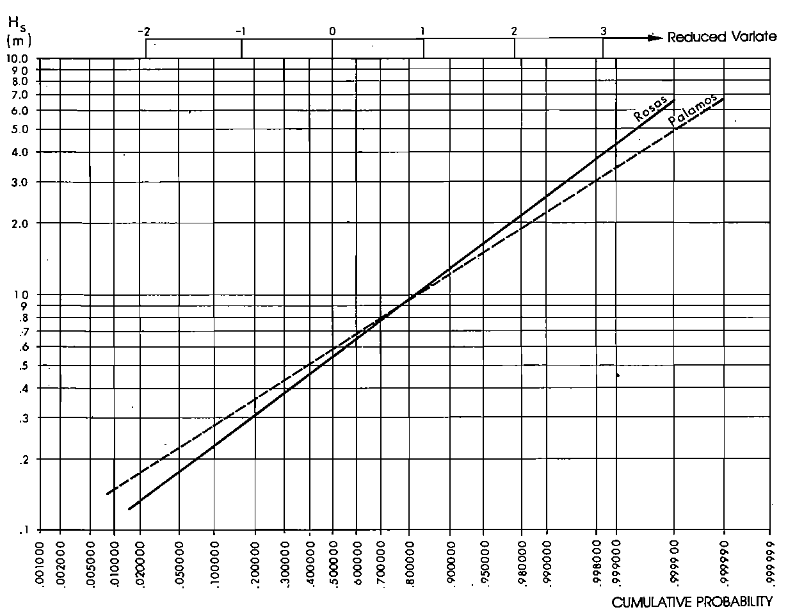
SWELL WAVES	
TOTAL Nº OF OBSERVATIONS	8.232
TOTAL Nº OF CALMS	794
TOTAL Nº CONFUSED	333

B – VISUAL OBSERVATIONS: MEAN DIRECTIONAL DISTRIBUTIONS

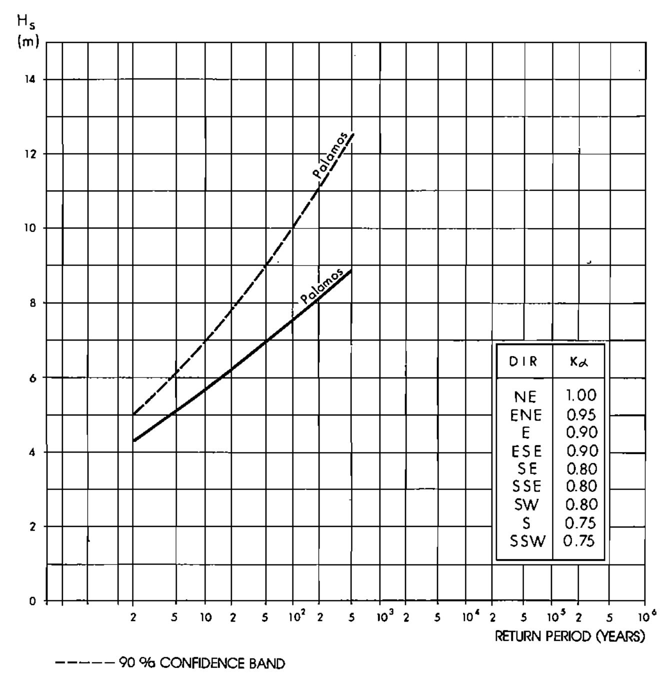




C – INSTRUMENTAL DATA: MEAN SCALAR DISTRIBUTIONS



D – INSTRUMENTAL DATA: EXTREME SCALAR DISTRIBUTIONS



DIR	K_α
NE	1.00
ENE	0.95
E	0.90
ESE	0.90
SE	0.80
SSE	0.80
SW	0.80
S	0.75
SSW	0.75

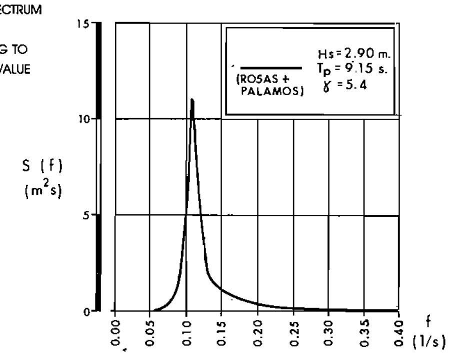
E – INSTRUMENTAL DATA: WAVE HEIGHT/PERIOD CORRELATION FOR STORMS

BUOY	$P = H_s / L_{\bar{T}} = \frac{2\Pi H_s}{g\bar{T}^2}$	$T_p / \bar{T}$	FINAL RELATIONSHIP H_s (m) T_p (s)	DESIGN VALUES H_s (m)	DESIGN VALUES T_p (s)
ROSAS + PALAMOS	0.03 ~ 0.04	≃1.15	$T_p = (4.6 \sim 5.3)\sqrt{H_s}$	4	9 ~ 10.5
				6	11 ~ 13
				8	13 ~ 15
				10	14.5 ~ 16.5

F – INSTRUMENTAL DATA: BASIC FREQUENCY SPECTRUM FOR STORMS (Hs > 1,00 m)

THEORETICAL JONSWAP SPECTRUM FIT TO THE REAL RECORDER SPECTRUM CORRESPONDING TO THE PEAK OF STORM WITH VALUE OF γ CLOSEST TO $\bar{\gamma}$.

*(1/s)

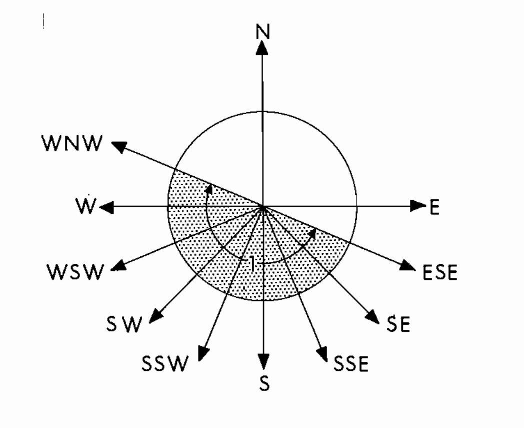


BUOY	THEORETICAL JONSWAP SPECTRUM $\bar{\gamma}$	γ_{max}	γ_{min}	σ_γ	$\bar{f}_p$*	$f_{p,max}$*	$f_{p,min}$*	σ_{fp}*	n
PALAMOS + ROSAS	4.6	8.2	2.3	1.65	0.108	0.125	0.08	0.012	13

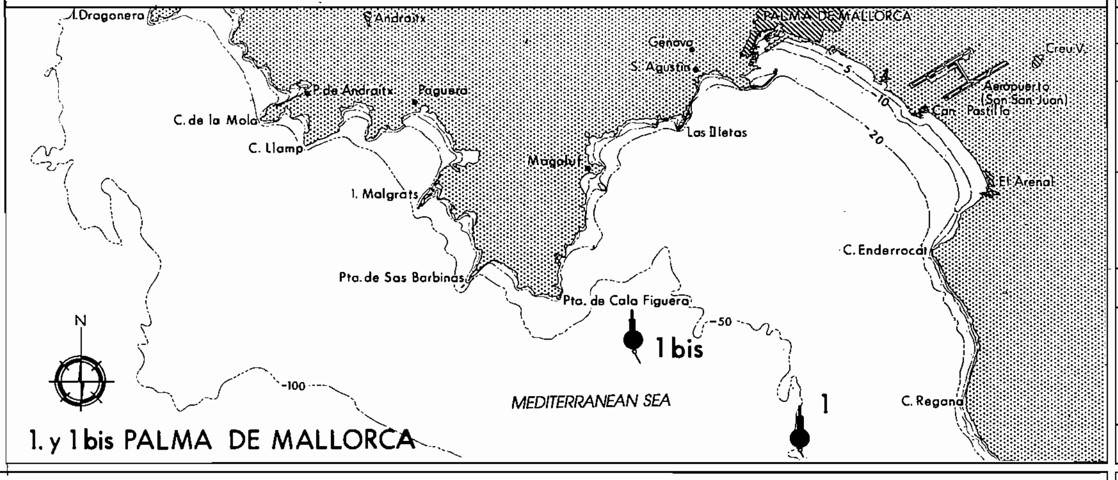
ROM 0.3 - 91 - WAVES
ATLAS OF WAVE CLIMATE ON THE SPANISH COAST

AREA – IX

SIGNIFICANT DIRECTIONS



LOCATION OF INSTRUMENTAL DATA



ANALYZED DATA

INSTRUMENTAL DATA

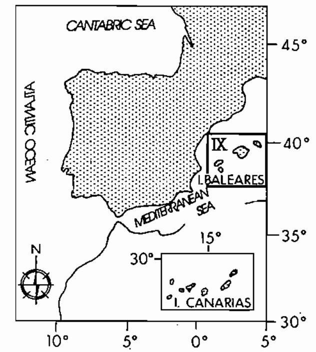
BUOY	LOCATION	DEPTH (m)	REC. PERIOD
1-PALMA DE MALLORCA	39°24'26.5'N 2°39'34.2'E	55/45	1983 / /1986 - 1987

VISUAL OBSERVATIONS

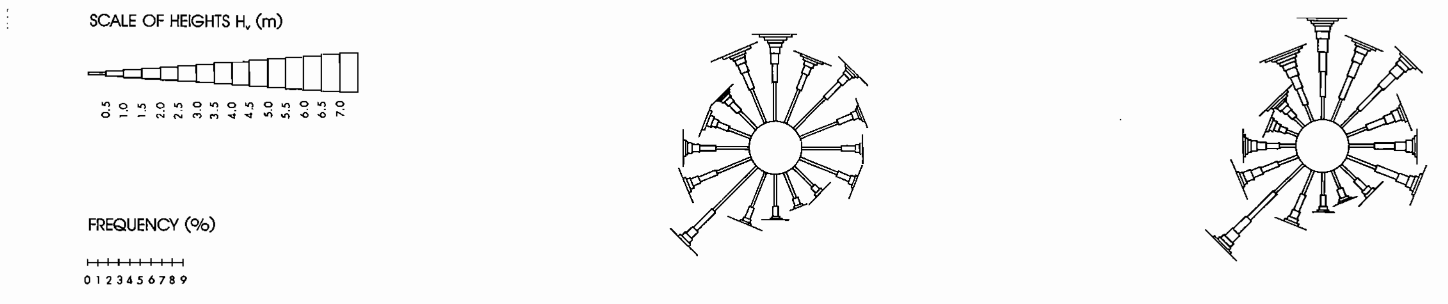
QUADRANGE: 38.3° N – 41° N; 0.5° E – 5.5° E

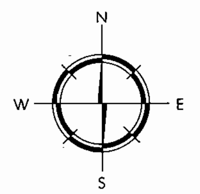
RECORDING PERIOD: 1950 - 1985

GEOGRAPHIC LOCATION OF THE ANALYZED DATA



A — VISUAL OBSERVATIONS: WAVE ROSES

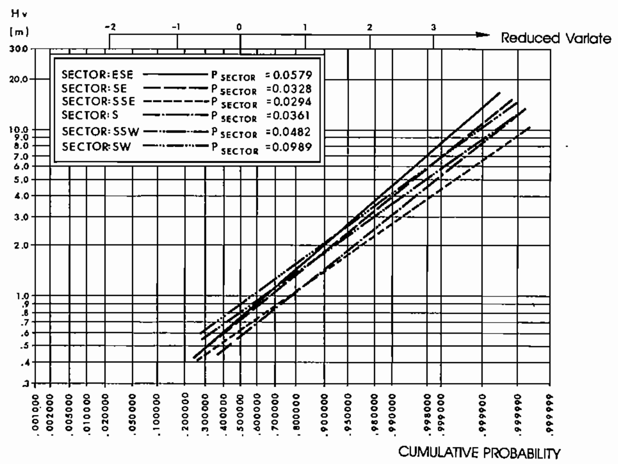


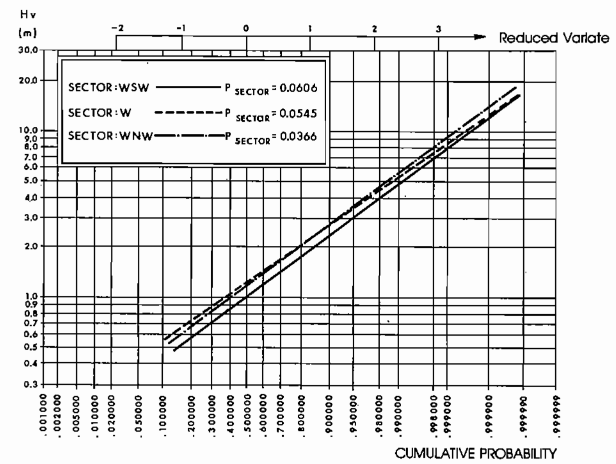


SEA WAVES	
TOTAL Nº OF OBSERVATIONS	46.150
TOTAL Nº OF CALMS	4.488
TOTAL Nº CONFUSED	2.466

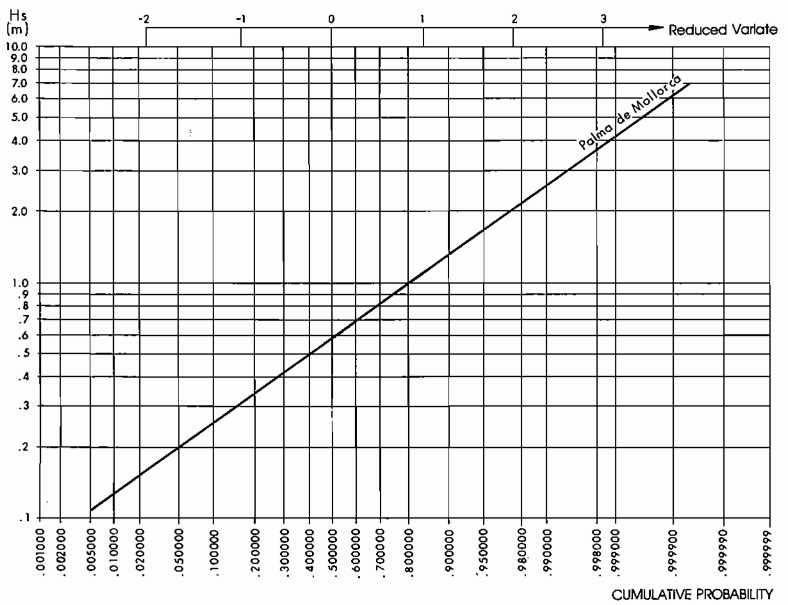
SWELL WAVES	
TOTAL Nº OF OBSERVATIONS	24.229
TOTAL Nº OF CALMS	2.579
TOTAL Nº CONFUSED	1.119

B — VISUAL OBSERVATIONS: MEAN DIRECTIONAL DISTRIBUTIONS

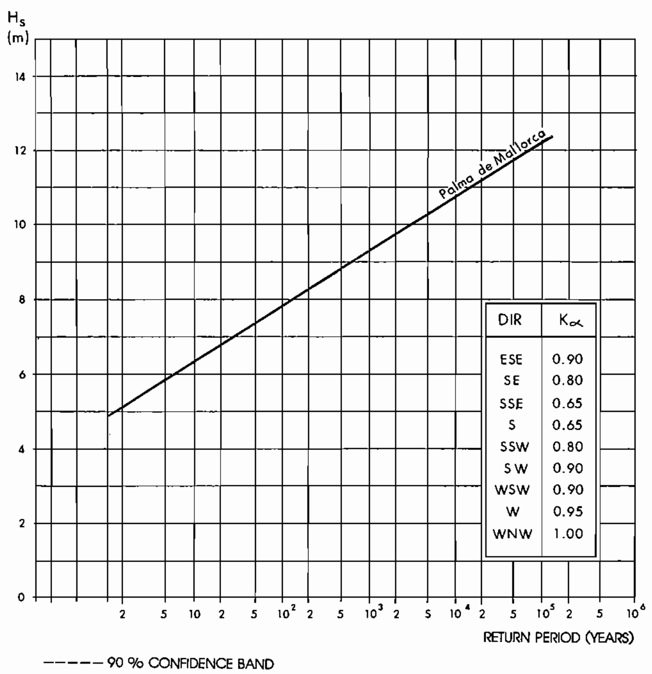




C — INSTRUMENTAL DATA: MEAN SCALAR DISTRIBUTIONS



D — INSTRUMENTAL DATA: EXTREME SCALAR DISTRIBUTIONS



DIR	K_α
ESE	0.90
SE	0.80
SSE	0.65
S	0.65
SSW	0.80
SW	0.90
WSW	0.90
W	0.95
WNW	1.00

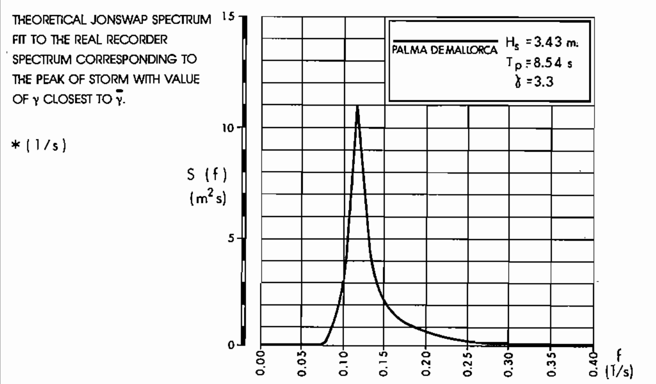
E — INSTRUMENTAL DATA: WAVE HEIGHT/PERIOD CORRELATION FOR STORMS

BUOY	$P = H_s / L_{\bar{T}} = \frac{2\pi H_s}{g \bar{T}^2}$	$T_p / \bar{T}$	FINAL RELATIONSHIP H_s (m) T_p (s)	DESIGN VALUES H_s (m)	DESIGN VALUES T_p (s)
PALMA DE MALLORCA	0.035 ~ 0.06	≃ 1.12	$T_p = (3.6–4.8)\sqrt{H_s}$	4	7.0 ~ 9.5
				6	8.5 ~ 12.0
				8	10.0 ~ 13.5

F — INSTRUMENTAL DATA: BASIC FREQUENCY SPECTRUM FOR STORMS (Hs ≥ 1,50 m)

THEORETICAL JONSWAP SPECTRUM FIT TO THE REAL RECORDER SPECTRUM CORRESPONDING TO THE PEAK OF STORM WITH VALUE OF γ CLOSEST TO $\bar{\gamma}$.

* (1/s)



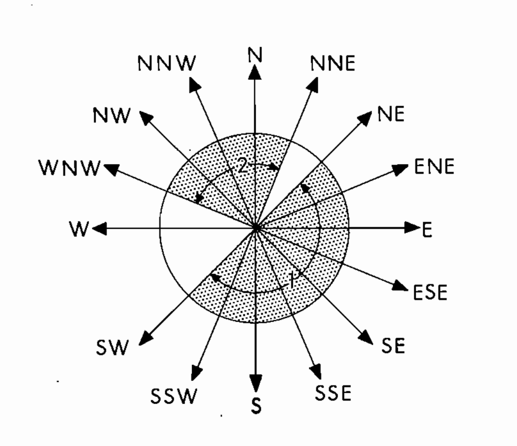
THEORETICAL JONSWAP SPECTRUM

BUOY	$\bar{\gamma}$	γ_{max}	γ_{min}	σ_γ	$\bar{f_p}^*$	$f_{p,max}^*$	$f_{p,min}^*$	$\sigma_{f_p}^*$	n
PALMA DE MALLORCA	3.3	6.4	2.0	1.05	0.11	0.13	0.09	0.011	19

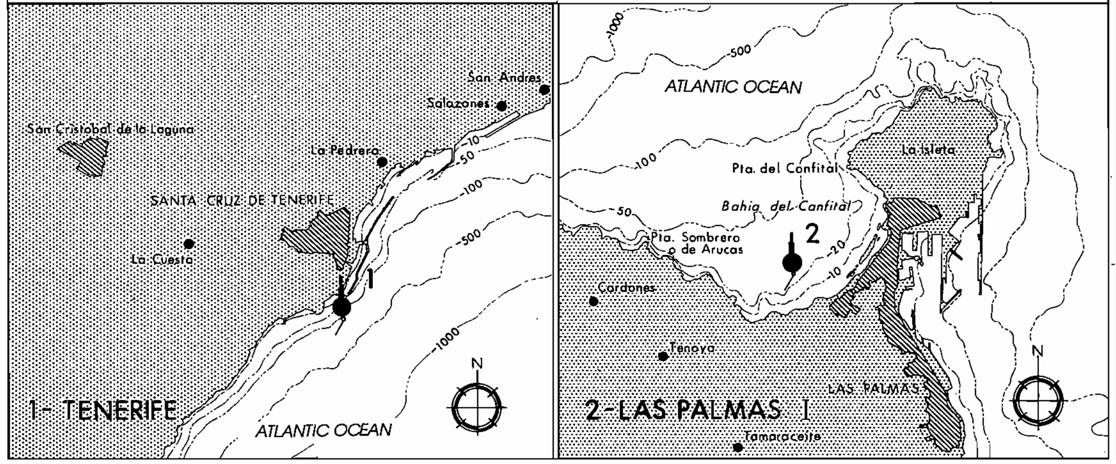
ROM 0.3 - 91 - WAVES
ATLAS OF WAVE CLIMATE ON THE SPANISH COAST

AREA – X

SIGNIFICANT DIRECTIONS



LOCATION OF INSTRUMENTAL DATA



ANALYZED DATA

INSTRUMENTAL DATA

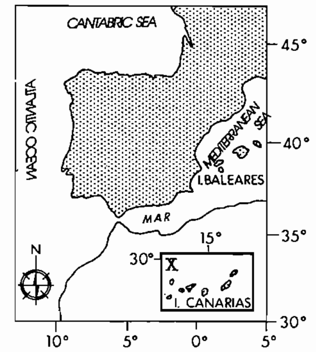
BUOY	LOCATION	DEPTH (m)	REC. PERIOD
1- TENERIFE	28º 27' 18" N 16º 14' 54" W	65	1981/1990
2- LAS PALMAS I	28º 08' 30" N 15º 27' 30" W	42	1981/1990

VISUAL OBSERVATIONS

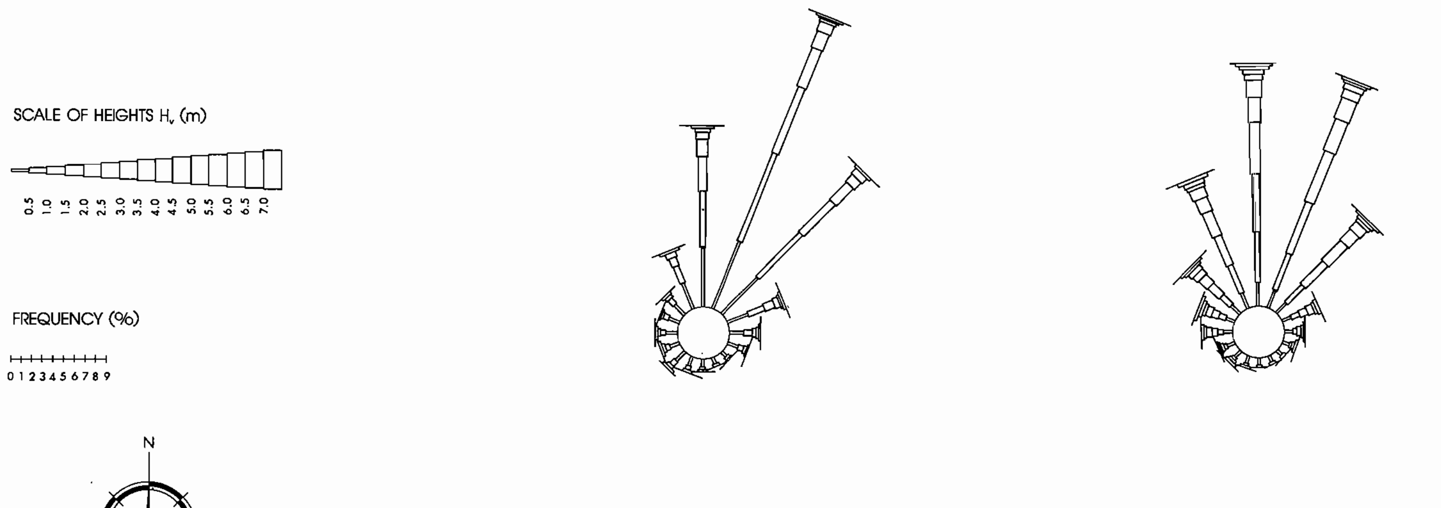
QUADRANGE:
26.5º N - 30.5º N
12.0º W - 20.0º W

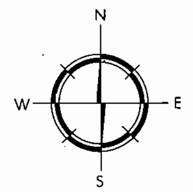
RECORDING PERIOD: 1950 - 1985

GEOGRAPHIC LOCATION OF THE ANALYZED DATA



A — VISUAL OBSERVATIONS: WAVE ROSES

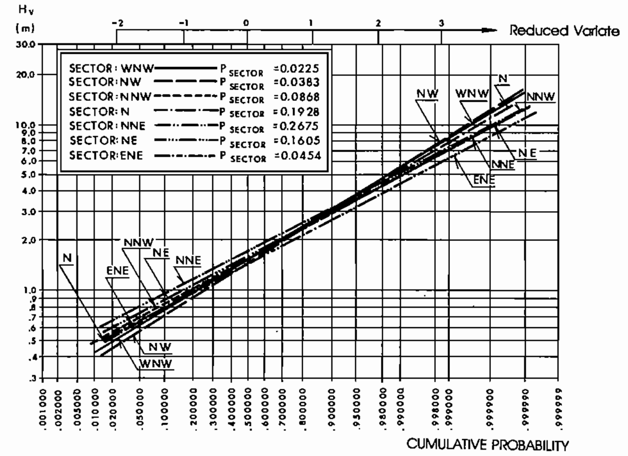


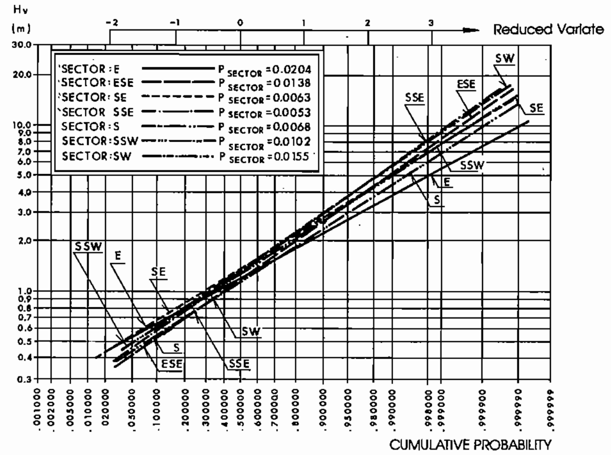


SEA WAVES	
TOTAL Nº OF OBSERVATIONS	121.303
TOTAL Nº OF CALMS	7.204
TOTAL Nº CONFUSED	12.618

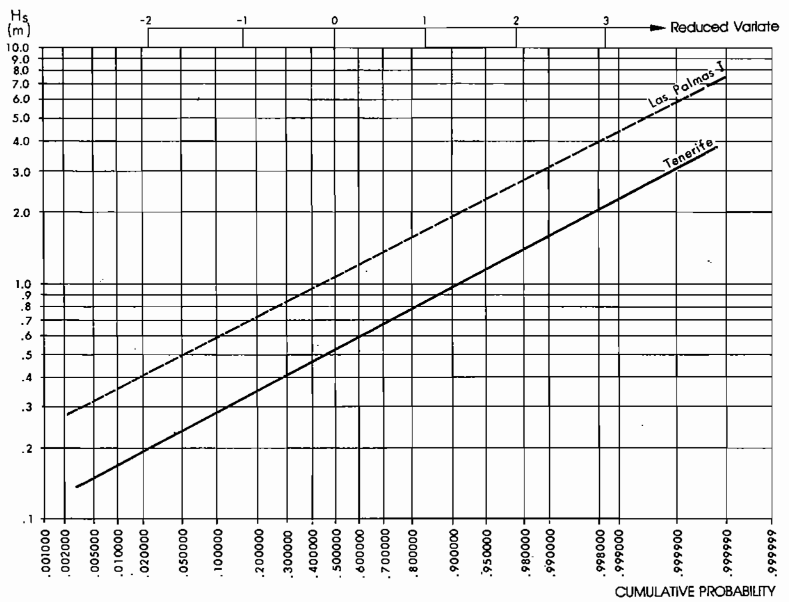
SWELL WAVES	
TOTAL Nº OF OBSERVATIONS	85.313
TOTAL Nº OF CALMS	9.317
TOTAL Nº CONFUSED	4.948

B — VISUAL OBSERVATIONS: MEAN DIRECTIONAL DISTRIBUTIONS

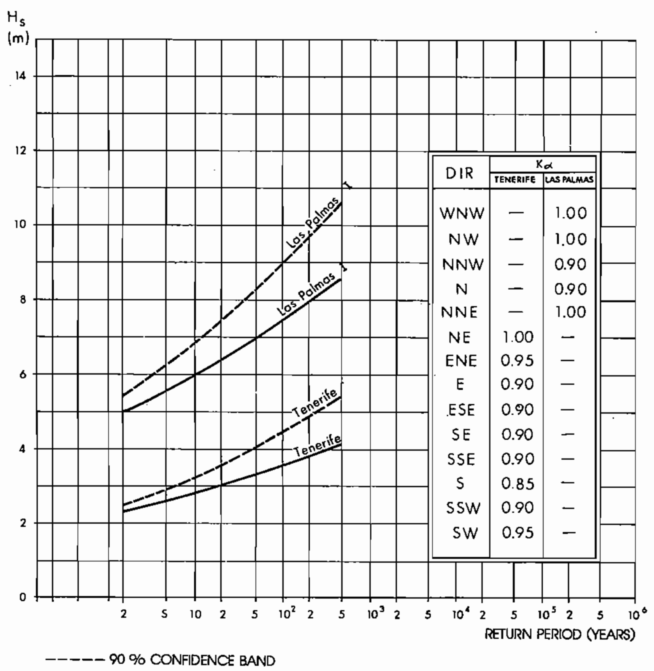




C — INSTRUMENTAL DATA: MEAN SCALAR DISTRIBUTIONS



D — INSTRUMENTAL DATA: EXTREME SCALAR DISTRIBUTIONS



DIR	$K_{\alpha t}$ TENERIFE	$K_{\alpha t}$ LAS PALMAS
WNW	—	1.00
NW	—	1.00
NNW	—	0.90
N	—	0.90
NNE	—	1.00
NE	1.00	—
ENE	0.95	—
E	0.90	—
ESE	0.90	—
SE	0.90	—
SSE	0.90	—
S	0.85	—
SSW	0.90	—
SW	0.95	—

E — INSTRUMENTAL DATA: WAVE HEIGHT/PERIOD CORRELATION FOR STORMS

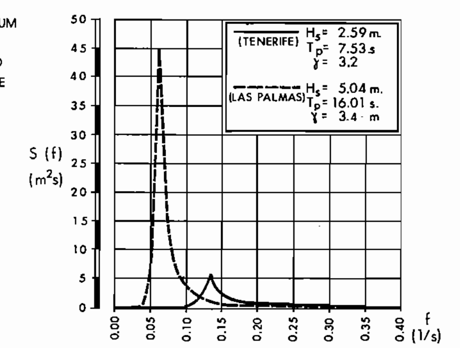
BUOY	$P = H_s / L_{\bar{T}} = \frac{2\pi H_s}{g\bar{T}^2}$	$T_p / \bar{T}$	FINAL RELATIONSHIP H_s (m) T_p (s)	DESIGN VALUES H_s (m)	DESIGN VALUES T_p * (s)
TENERIFE	0.02 ~ 0.06	≃1.30	$T_p = (4.3\text{~}7.4)\sqrt{H_s}$	2	6.0~10.5
				4	8.5~14.5
				6	10.5~18.0
LAS PALMAS I	0.015 ~ 0.06	≃1.35	$T_p = (4.4\text{~}8.8)\sqrt{H_s}$	4	8.5~17.5
				6	10.5~21.5
				8	12.5~24.5
				10	14.0~27.5

* IN NO CASE SHALL DESIGN PERIODS GREATER THAN 22 SECONDS BE CONSIDERED

F— INSTRUMENTAL DATA: BASIC FREQUENCY SPECTRUM FOR STORMS ($H_s \geq$ 1.5 m. TENERIFE, 2.0 m. LAS PALMAS)

THEORETICAL JONSWAP SPECTRUM FIT TO THE REAL RECORDED SPECTRUM CORRESPONDING TO THE PEAK OF STORM WITH VALUE OF γ CLOSEST TO $\bar{\gamma}$.

** (1/s)



BUOY	THEORETICAL JONSWAP SPECTRUM $\bar{\gamma}$	γ_{max}	γ_{min}	σ_γ	$\bar{f_p}$**	$f_{p,max}$**	$f_{p,min}$**	σ_{f_p}**	n
TENERIFE	3.1	6.1	1.7	1.14	0.13	0.17	0.10	0.022	16
LAS PALMAS I	3.0	6.8	1.2	1.38	0.08	0.10	0.06	0.013	20

2.7 WAVE PROPAGATION

For a complete characterization of deep water waves based on the information available on the Spanish Coast, it is necessary to transfer the results obtained from instrumental data to deep water, since these data were in general recorded in shallow or intermediate water and is therefore affected by different processes of attenuation, transformation and deformation caused fundamentally by the bathymetry.

Given the range of depths and sites in which the analyzed buoys are deployed, the influence of the bathymetry in the wave propagation to these sites is considered by means of a Refraction and Shoaling analysis.

The relationship between deep water waves and recorded waves is obtained through propagation studies which determine the modification of the significant wave height and the principle direction of the wave's propagation from deep waters to the considered recording site.

Assuming that the representative wave periods (significant period or peak period) remain constant, propagation studies have been carried out in the different recording sites, for each one of the incident deep water wave directions that is of interest at that site, and with previously selected periods.

The waves are propagated with the periods (T_p) associated with the biggest storms, from deep water to the analyzed recording site, determining the attenuation of waves with a corresponding refraction and shoaling coefficient (K_R). This coefficient relates the variation in wave height, due to bathymetry, to the deep water wave height for each wave period. At each point this coefficient is defined as the quotient of the wave height at that point and the deep water wave height.

The storm wave heights considered at each recording site to determine the test wave periods were obtained from the corresponding extreme scalar distribution. With the aim of carrying out propagations that are truly representative without unnecessarily multiplying the number of tests and given the wide range of periods associated with each storm wave height in some zones *(See section 2,5,6 Wave Height/Period Correlations for Storm Conditions)*, the periods were chosen from this range but were corrected taking into account the recorded waves significant periods, assuming the relationship $T_s = 0{,}95\ T_p$.

The numerical propagation model used was a parabolic diffraction/refraction model developed by CEPYC. The propagated waves were regular and unidirectional, yielding the refraction-shoaling coefficient (K_R). The coefficients obtained, corresponding to the periods of interest, are given in table 2.7.1.

The significant wave height associated with a return period in deep water in a determined direction, can be obtained from the available instrumental results by means of the K_R coefficient, through the following equation:

$$H_{s,0} = H_{s,R} \cdot K_\alpha / K_R$$

with:

- $H_{s,0}$: Significant wave height in deep water associated with a return period, for a determined direction.
- $H_{s,R}$: Significant wave height associated with a return period, obtained from the instrumental scalar extreme distribution.
- K_α : Coefficient of directionality for a considered direction.
- K_R : Refraction - Shoaling coefficient in the recording site for the considered direction and the established period associated with that wave height.

TABLE 2.7.1 REFRACTION - SHOALING COEFFICIENT (K_R) CORRESPONDING TO PROPAGATION OF WAVES FROM DEEP WATER TO THE ANALYZED RECORDING SITE

AREA	RECORDING SITE	DIR \ T(s)	7	9	11	13	15	17	19
I	BILBAO EXTERIOR	NW	—	0.98	0.93	0.86	0.80	0.80	0.90
		NNW	—	0.98	0.94	0.93	0.93	0.92	0.90
		N	—	0.98	0.94	0.91	0.88	0.85	0.80
		NNE	—	0.98	0.96	0.95	0.95	0.93	0.90
		NE	—	0.98	0.94	0.94	0.94	0.91	0.83
	GIJÓN	NW	—	0.86	0.82	0.80	0.76	0.84	0.82
		NNW	—	0.85	0.82	0.84	0.85	0.88	0.88
		N	—	0.93	0.98	1.02	0.99	0.91	0.84
		NNE	—	0.89	0.88	0.87	0.88	1.01	1.02
		NE	—	0.89	0.90	0.90	0.95	0.85	0.99
II	CORUÑA	W	—	0.97	0.90	0.89	0.71	0.81	0.82
		WNW	—	0.98	0.94	0.92	0.89	0.89	0.94
		NW	—	0.98	0.94	0.92	0.88	0.85	0.80
		NNW	—	0.97	0.92	0.85	0.82	0.81	0.78
		N	—	0.97	0.90	0.74	0.62	0.58	0.61
		NNE	—	0.98	0.96	0.88	0.79	0.54	0.54
III	CABO SILLEIRO	NNW	—	1.00	0.97	0.92	0.88	0.89	0.85
		NW	—	1.00	0.97	0.94	0.91	0.89	0.88
		WNW	—	1.00	0.97	0.94	0.92	0.91	0.93
		W	—	1.00	0.97	0.94	0.91	0.91	0.93
		WSW	—	1.00	0.98	0.97	1.00	1.10	0.83
		SW	—	1.00	0.97	0.95	0.89	0.95	0.79
		SSW	—	1.00	0.97	0.93	0.85	0.82	0.80
IV	SEVILLA	W	—	—	0.96	0.97	0.74	0.43	0.47
		WSW	—	—	0.97	0.88	0.72	1.11	1.24
		SW	—	—	1.10	1.26	1.97	1.52	1.02
		SSW	0.90	0.96	1.16	—	—	—	—
		S	0.91	0.91	0.91	—	—	—	—
	CÁDIZ	WNW	—	—	—	0.87	0.93	0.93	0.86
		W	—	—	—	0.81	0.77	0.98	1.08
		WSW	—	—	—	0.99	1.05	1.10	1.18
		SW	—	—	—	0.92	0.92	0.95	0.93
		SSW	0.96	0.92	0.92	—	—	—	—
		S	0.99	0.86	0.84	—	—	—	—
V	CEUTA	NW	0.94	0.91	0.82	0.72	0.66	—	—
		NNW	0.95	0.90	0.83	0.78	0.75	—	—
		N	0.95	0.92	0.93	0.94	0.97	—	—
		NNE	0.96	0.97	0.98	1.05	1.13	1.15	—
		NE	0.94	0.90	0.92	1.06	1.33	1.15	—
		ENE	—	—	0.79	0.67	0.66	0.93	—
	MÁLAGA	E	0.93	0.91	0.91	0.93	0.93	—	—
		ESE	0.95	0.95	0.95	0.90	0.84	—	—
		SE	0.94	0.90	0.89	—	—	—	—
		SSE	0.93	0.87	0.87	—	—	—	—
		S	0.93	0.85	0.82	—	—	—	—
		SSW	0.93	0.70	0.67	—	—	—	—

TABLE 2.7.1 (Continuation)

AREA	RECORDING SITE	DIR \ T(s)	7	9	11	13	15	17	19
VI	CABO DE PALOS	NE	—	0.99	0.92	0.85	—	—	—
		ENE	—	0.99	0.95	0.85	—	—	—
		E	—	0.99	0.97	0.96	—	—	—
		ESE	—	0.99	0.97	0.94	—	—	—
		SE	—	0.99	0.96	0.94	—	—	—
		SSE	—	0.99	0.98	0.96	—	—	—
		S	—	0.99	0.98	0.97	—	—	—
		SSW	—	0.99	0.90	0.78	—	—	—
VII	ALICANTE	ENE	1.00	0.98	0.94	0.92	0.92	—	—
		E	1.00	0.98	0.93	0.88	0.90	—	—
		ESE	1.00	0.98	0.94	0.91	0.90	—	—
		SE	1.00	0.98	0.93	0.84	0.79	—	—
		SSE	1.00	0.97	0.90	0.85	0.81	—	—
		S	1.00	0.97	0.90	0.80	0.80	—	—
	VALENCIA I	NE	0.94	0.88	0.87	0.83	0.87	—	—
		ENE	0.94	0.90	0.79	0.75	0.80	—	—
		E	0.94	0.94	0.93	0.95	0.98	—	—
		ESE	0.94	0.91	0.93	0.95	0.96	—	—
		SE	0.94	0.89	0.89	0.89	0.89	—	—
VIII	PALAMÓS	NE	1.00	1.00	0.98	0.94	—	—	—
		ENE	1.00	1.00	0.98	0.95	—	—	—
		E	1.00	1.00	0.99	0.96	—	—	—
		ESE	1.00	1.00	0.99	0.97	—	—	—
		SE	1.00	1.00	0.99	0.97	—	—	—
		SSE	1.00	1.00	0.99	0.97	—	—	—
		S	1.00	1.00	0.98	0.96	—	—	—
		SSW	1.00	1.00	0.99	0.96	—	—	—
		SW	1.00	1.00	0.99	0.95	—	—	—
IX	PALMA DE MALLORCA	ESE	1.00	0.89	0.79	0.53	—	—	—
		SE	1.00	1.00	0.78	0.70	—	—	—
		SSE	1.00	0.97	0.90	0.85	—	—	—
		S	1.00	0.97	0.93	0.93	—	—	—
		SSW	1.00	0.98	0.96	0.99	—	—	—
		SW	1.00	0.97	0.88	0.80	—	—	—
		WSW	1.00	0.98	0.96	0.96	—	—	—
		W	1.00	0.98	0.94	0.89	—	—	—
		WNW	1.00	0.99	1.05	1.12	—	—	—
X	TENERIFE	NE	0.92	0.67	0.62	0.60	0.58	—	—
		ENE	1.00	0.97	0.92	0.89	0.88	—	—
		E	1.00	1.01	0.87	0.79	0.75	—	—
		ESE	1.00	0.99	1.01	0.96	0.81	—	—
		SE	1.00	0.98	0.98	0.95	0.90	—	—
		SSE	1.00	0.99	0.96	0.91	0.92	—	—
		S	1.00	0.99	0.93	0.88	0.84	—	—
		SSW	1.00	0.97	0.91	0.85	0.81	—	—
		SW	1.00	0.98	0.92	0.86	0.84	—	—
	LAS PALMAS I	WNW	—	0.95	0.91	0.88	0.87	0.83	0.82
		NW	—	0.95	0.91	0.89	0.91	0.95	0.99
		NNW	—	0.95	0.89	0.85	0.81	0.78	0.77
		N	—	0.92	0.79	0.69	0.66	0.64	0.63
		NNE	—	0.94	0.72	0.61	0.60	0.60	0.60

2.8 DETERMINATION OF DESIGN WAVE IN DEEP WATER BASED ON THE ESTIMATION OF WAVE CLIMATE INCLUDED IN THESE RECOMMENDATIONS

From the Atlas of Wave Climate included in these Recommendations, and taking into account the pertinent propagations, it is possible to establish a design wave in deep water (H_s, T_p, α), for extreme conditions as well as for normal conditions of operation, in any point included in one of the areas defined on the Spanish Coast, as long as that point is affected by the same waves that are recorded by the buoy analyzed in that area. Likewise, the design spectrum can be established for extreme conditions. (JONSWAP/H_s, f_p, γ/α).

The determination of design waves for extreme conditions is based on the extreme scalar distribution of the considered buoy (Block D), obtaining a wave height for a return period associated with the probability of occurrence or acceptable risk during the service phase of the work ($H_{s,R}$).

Substituting this wave height in the equation that relates the wave height with the period in that buoy (Block E) the range of periods (T_p) for this wave height is established. From this range the design period, that is most detrimental for the analyzed phenomenon or effect, is chosen. However the periods in the upper extreme of the established range can be disregarded when the fetch length in the design direction is clearly shorter than the fetch length of the severest wave direction ($K_\alpha = 1$).

In no case shall design periods greater than 22 seconds be considered.

Next, assuming that the periods remain constant and for each one of the possible incident directions, the waves with their established periods are propagated from deep water to the site of the buoy considered, determining the refraction-shoaling coefficient (K_R) *(See table 2.7.1).*

Finally, the design wave height in deep water ($H_{s,0}$) is calculated for each direction through the equation: $H_{s,0} = H_{s,R} \cdot K_\alpha / K_R$ *(See section 2.7),* with K_α being the coefficient of directionality (Block D).

For each deep water direction the theoretical JONSWAP spectrum with the following spectral parameters can be established as the design spectrum:

$$H_{m0} = 4\,(m_0)^{1/2} = H_{s,0}$$
$$f_p = 1/T_p$$
$$\gamma = \bar{\gamma}$$
$$\sigma_a = 0.07, \text{ for } f \leq f_p$$
$$\sigma_b = 0.09, \text{ for } f > f_p$$

with $H_{S,0}$ and T_p being the significant wave height and the peak period, respectively, corresponding to the design wave in extreme conditions for the analyzed direction, and $\bar{\gamma}$ the peak enhancement factor corresponding to the basic structure of the wave frequency spectrum for storm conditions in the considered buoy (Block F).
Nevertheless in those cases in which the scatter of the recorded γ values is great, it could be necessary to consider a range of peak enhancement factors, selecting among them that which is most detrimental for the analyzed phenomenon or effect. The grade of variability of the recorded spectral parameters is included, for each of the recording sites, in the Block F table.

The determination of design waves in deep water for normal conditions of operation is fundamentally based on the mean directional distributions of visual Sea + Swell wave height and on the sectorial frequencies of occurrence in the considered zone (Block B), obtaining the visual wave height, in each incident direction of interest, corresponding to the limit level of exceedence established in function of the functional and operative criteria of the project.

Given that the reliability of the mean visual wave height distributions is only approximate, those should be contrasted with the mean scalar significant wave height distribution of the corresponding buoy (Block C). For this, the contribution of all the incident directional sectors should be considered carrying out the pertinent propagations to the site of the considered buoy, and applying the correlation between the visual and the significant wave height in that zone. In the absence of other data the relationship $H_v = H_s$ for waves in deep water can be used. The application of this relationship has in general yielded good results on the Spanish Coast.

For the assignment of periods to the design wave height in normal conditions of operation the height/period relationships for storm conditions in the corresponding buoy (Block E) can be used, as long as the limit conditions of operations correspond to storm conditions. The modifications that take place in the wave height from deep water to the buoy site shall be taken into account.

Other mean visual wave height distributions (e.g. mean Sea distribution, and mean Swell distribution) can be obtained from the wave roses (Block A). These distributions could be necessary to determine the design wave height in normal conditions of operation in those cases in which the range of periods for one class of waves, is the predominant factor for the definition of the limits of operation (e.g. levels of agitation in basins and berths by the presence of local (Sea) waves, resonance of a mooring system, ...).

The methodology of determination of design wave heights in deep water based on the Atlas of Wave Climate is schematized in figure 2.8.1.

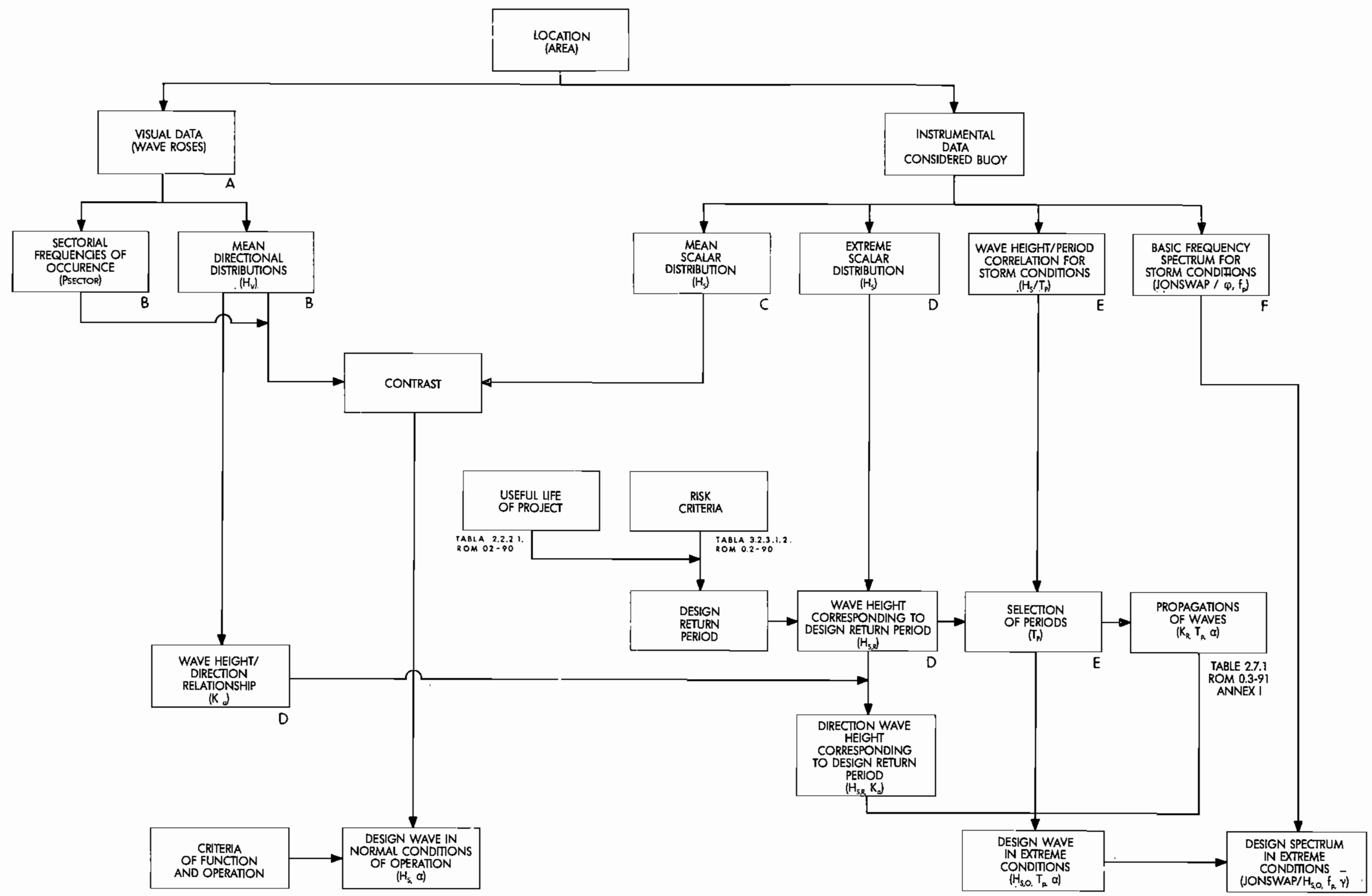


FIGURE 2.8.1. Methodology for the determination of design waves from the Atlas of Wave Climate.