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NEW TRENDS IN OCEAN WAVE RESEARCH IN INDIA

M. BABA

Centre for Earth Science Studies, Regional Centre, Cochin - 18.

ABSTRACT

The studies on waves in India have seen rapid strides during the last decade. A review of the latest developments in the interpretation of ship-based observations, in wave hindcasting and in the instrumental measurement of waves is given. The new approaches in the study of short-term distributions, seasonal or year-round wave climatology and the long-term distributions are given in detail. The necessity for the consideration of nonlinear effects in the short-term distribution of wave heights and periods is highlighted. The developments in the relatively new fields of ocean wave research (in India), like the wave spectra, numerical methods in wave hindcasting and transformation, tapping of wave energy, remote sensing techniques etc. are discussed. The limitations in ocean wave research in India and a few recommendations for future research are given.

Key-words: Wave hindcasting, Wave distributions, Wave spectra, Wave energy.

INTRODUCTION

The importance of the ocean gravity waves in many areas of marine activity was seriously felt during the Second World War and years after that. A serious effort to understand the various mechanisms of their generation, growth, propagation, decay, etc. was started since then. In India too, some studies to understand the wave climate were initiated in the fifties, mainly for understanding coastal processes (Varadachari, 1958; Sastry, 1958). The need for an indepth study of the waves in the seas surrounding India (Fig. 1) was felt in the late sixties and early seventies, with a spurt in the investments, which run to millions of rupees every year, on offshore oil industry and coastal and harbour development projects. This paper attempts to review and to consolidate all the latest developments in India in this field. It also tries to project some important aspects of waves, which require some concentrated study in the light of India's increased activities in the oceans in various areas.

SOURCES OF WAVE INFORMATION

Ship-observations

The ship-based visual observations reported by the India Meteorological Department in its Daily Weather Reports, for 0830 and 1730 IST have been a major source of wave information till recently. A considerable amount of information thus gathered have been presented in the form of atlasses, charts, etc. (Srivastava and George, 1976; NPOL, 1978; NIO, 1980, Different statistical properties of these observed waves, both sea and swell, and their sea-

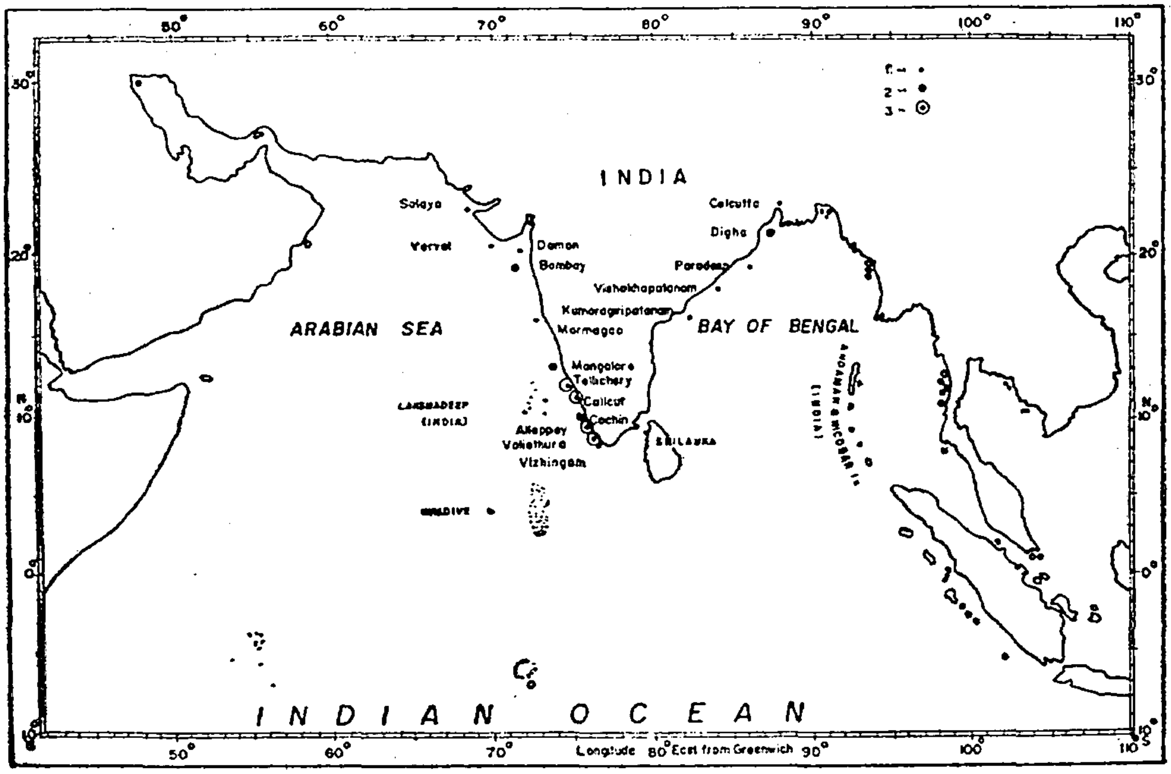

Fig. 1. The seas surrounding India with the locations where major fixed/moored wave recording stations were established (see also Table 1) for periods less than one year (1), one — two years (2) and more than two years (3).

sonal and year to year variations have been studied (Mukherjee and Sivaramakrishnan 1982a and b Thiruvengadathan, 1984).

Eventhough these observations provide large amount of information on the spatial distribution of wave parameter over the seas surrounding India, the limitations in the observational accuracies affect the predictions for a given location. In addition, the avoidance of the ships of a storm area or rough sea, which are of critical importance to the offshore designer, is a major drawback of this data.

Wave hindcasting

As the information on winds or pressure over the seas, collected by the ships, many using the instrumental methods, is more reliable than visual wave observations and may be used for hindcasting the waves utilizing the various available emperical solutions relating the wave and wind parameters. Many hindcasting methods have been used for the Indian waters starting from the Wilson's methods (Srivastava, 1964) to SMB and PNJ methods (Dattatri and Renukaradhya, 1971; Rao and Prasad, 1982; Reddy, Prasad and Reddy, 1980, It has been reported (Dattatri and Renukaradhya, 1971) tha the SMB method gives reasonably good estimates of wave heights for wind velocities lower than 20 knots.

Thiruvengadathan (1984) has recommended the following relation between wind speed and wave heights, for the steady states, which prevail during the monsoon season both in the Arabian sea and Bay of Bengal:

$$H = 0.17 + 0.0087\,V + 0.014167\,V^2 \quad (1)$$

where H — characteristic wave height (m)

V — wind speed (m/sec)

Eventhough the relationship suggested is too simplified, it may be useful in obtaining first hand information of wave heights, within the assumptions used in its formulation. Some microlevel studies to understand the wind-wave interaction in a model tank were initiated by Dattatri (1978).

A simpler parametric method using a 3/2 power law and a single parameter wind wave growth equation has been developed by Joseph, Kawai and Toba (1981) and has been tested for Indian cyclonic conditions (Joseph, 1984) and for monsoonal wave prediction (Joseph, unpublished). Capabilities have been developed in this model to estimate the spectral quantities using a representative wave parameter predicted, assuming the presence of similarity structure in growing wind waves. This model being hybrid in nature is also capable of predicting both sea and swell, the latter achieved through a special spectral treatment as described in detail by Joseph, Kawai and Toba (1981).

The spectral hindcasting methods as such are not tried for the Indian conditions. Resio and Vincent (1979) found significant differences among predictions from different wave models for varying duration and fetch conditions. These differences are most pronounced at short fetches and durations, which is not the case for Indian seas, especially for the monsoonal climatic conditions. Hence many of the available wave models may be suitable here, but a detailed study, also incorporating spectral models is warranted before reaching to any conclusion in this matter.

The wave measurements are made using fixed stations, from moored buoys. The wave measurements using shipborne wave recorder on board RV *Gaveshani*, **ORV** *Sagar Kanya* **and FORV** *Sagar Sampada* has recently increased our capabilities of wave measurements in the Arabian Sea and Bay of Bengal in all seasons. This data collected by these ships have been used to study the wave climate along a few selected regions (Sathe, Somayajulu and Gopalakrishna, 1979; Das, Varkey and Raju, 1979; Fernandez, Gouveia, Sathe and Nagarajan, 1981; Gouveia, Raju and Murthy, 1981; Sathe and Gouveia, 1982; Vethamony, Gopalakrishnan and Varkey, 1984.

A detailed picture of the wave recording from moored or fixed stations is provided in Table I. Eventhough one of the earliest attempts to record waves has been made by NPOL at Cochin, the first comprehensive year-round data

Table I. Details of wave recordings from fixed/moored stations in Indian seas.

Location	Type of recorder	Mean water depth (m)	Period From	Period To	Duration in months	Reported in
Cochin	Pressure	3.0	6/65	7/66	2	Srivastava, Vijayarajan and Joseph (1968)
Mangalore III	Pressure	10.0	6/68	6/69	16	Dattatri (1973 & 1978); Sundararamam, Varkey, Vijayarajan, John and Joseph (1974); John (1977).
Bombay High	Waverider	30.0	6/78	7/78	1	Deo and Narasimhan (1979); Gadre and Kanetkar (1981)
Bombay High	Waverider	75.0	5/78	7/78	12	Rao and Sundar (1982); Nayak and Anand (1981).
Salaya	Waverider	39.0	Monsoon	1976	4	Gadre and Kanetkar (1981)
Veraval	Waverider	15.0	Monsoon	1976	4	—do—
Mangalore I	Waverider	12.0	Monsoon	1974	4	—do—
Mangalore II	Waverider	11.0	Monsoon	1975	4	—do—
						Dattatri (1978 and 1983).
Calangute (Goa)	OSPOS	15.0	11/73	5/74	6	Swamy, Das and Varkey (1976).
Thumba (TVM)	OSPOS	20.0	4/76	3/77	12	Swamy, Varma, Pylee, Raju and Chandramohan (1979).
Daman	Waverider	Not known	11/82	Not known	Not known	Nayak (1983).
Visakhapatnam	Waverider (2)	17.0 & 15.0	4/81	12/81	9	Gadre and Kanetkar (1983).
Digha (WB)	Pressure	4.0	4/68	3/70	24	Dharkaviraj and Sarkar (1978).
Paradeep	SBWR*	30.0	9/80	—	1	Fernandez, Gouveia, Sathe and Nagarajan (1981).
Kumaragiri-patham	SBWR	250–500	9/80	10/80	1	Vethamoni, Gopalakrishna and Varkey (1984).
Valiathura (TVM)	Pressure	5.5	12/79	Continuing	59	Baba, Kurian, Thomas, Hameed, Kumar and Harish
Alleppey	Pressure	5.5	5/80	Continuing	54	(1983); Baba, Joseph, Kurian, Thomas, Hameed,
Calicut	Pressure	3.5	4/81	4/85	35	Kumar and Harish (1983); Baba, (1983); Thomas and
Tellicherry	Pressure	3.5	7/80	12/84	41	Baba (1983); Baba, Hameed, Kurian, Thomas,
Cochin	Waverider	20.0	12/81	12/82	7	Harish, Joseph, Kumar and Varghese (1985); Baba and Harish (1985); Harish and Baba (1985); Hameed and Baba (1985); Baba (1985).
Cochin	Waverider	15.0	1/83	12/83	12	Baba and Mathew (1985).
Vizhinjam (TVM)	Waverider	25.0	3/84	12/84	4	Joseph, Mohanan and Varghese (1984).
Vizhinjam (TVM)	Waverider	48.0	5/84	6/84	2	Joseph (1985).

*SBWR — Shipborne wave recorder.

sets have been produced off Mangalore and Digha. After this some piece-meal recordings have been made at different parts of India, but in some cases giving vital (for design) information on monsoon wave climate (Gadre and Kanetkar, 1981).

Information on waves covering 3–5 years have been gathered along the Kerala coast, from four stations off Trivandrum, Alleppey, Calicut and Tellicherry. In addition, the measurement of waves from closely spaced stations (Table I) between Vizhinjam and Tellicherry gives the spatial distribution of different wave parameters. All these records are accompanied by observed information on wave direction. Along the east coast of India, the data were very few except at Digha for 2 years.

Some efforts for the development of electronic wave recording systems have been made in India (Peshwe, Diwan, Joseph and Desa, 1980; Sivadas, 1981; Saxena, Gaikward and Rao, 1981 and Gaikward and Hebbar, 1983). Among these the one developed by Sivadas (1981) appears to be the most extensively used and thoroughly tested. However, this is an area where considerable research inputs are required.

Distribution of Wave Parameters

For the prediction of any wave parameter at a given location or for the simulation of the wave field in model studies a detailed knowledge of the statistical distribution of the various wave parameters is essential. The distributions may be classified into three; viz. short-term, wave climate and long-term. In the short term distribution of wave height, period, etc., the behaviour of a time series for a short duration of several minutes are examined. The wave climate statistics with the time scale of a year or so aims at the general description of seasonal and annual wave conditions at specific locality. The long term statistics examines the distribution of these parameters for sufficiently long period extending to several years as per the design requirements.

Short-term distributions

Wave heights: By assuming that the wave frequency spectrum consists of a ralatively narrow band of frequencies, and that the sea waves are the superposition of many sinusoidal components of about the same frequency but of random phase, Longuet-Higgins (1952) found that the probability distribution of wave heights must be a Rayleigh distribution, the cumulative form of which is expressed as

$$P(H) = \exp\left[-\frac{\pi}{4}\left(\frac{H}{\overline{H}}\right)^2\right] \qquad (2)$$

where P(H) — the probability of exceedence of wave height H and

$\overline{H}$ — the mean wave height.

Many investigators (Dattatri, 1973; Dattatri, Raman and Jothisankar 1979; Deo and Narasimhan, 1979; Fernandez Gouveia, Sathe and Nagarajan, 1981) report this to be satisfactory for actual field data.

Lately it has been observed (Baba, 1984) that the actual wave heights, especially those with lower probabilities deviate from this distribution (Fig. 2), possibly due to the nonlinear effects, associated with the wave-wave interactions, wave shoaling, breaking etc. Baba and Harish (1985) found that this distribu-

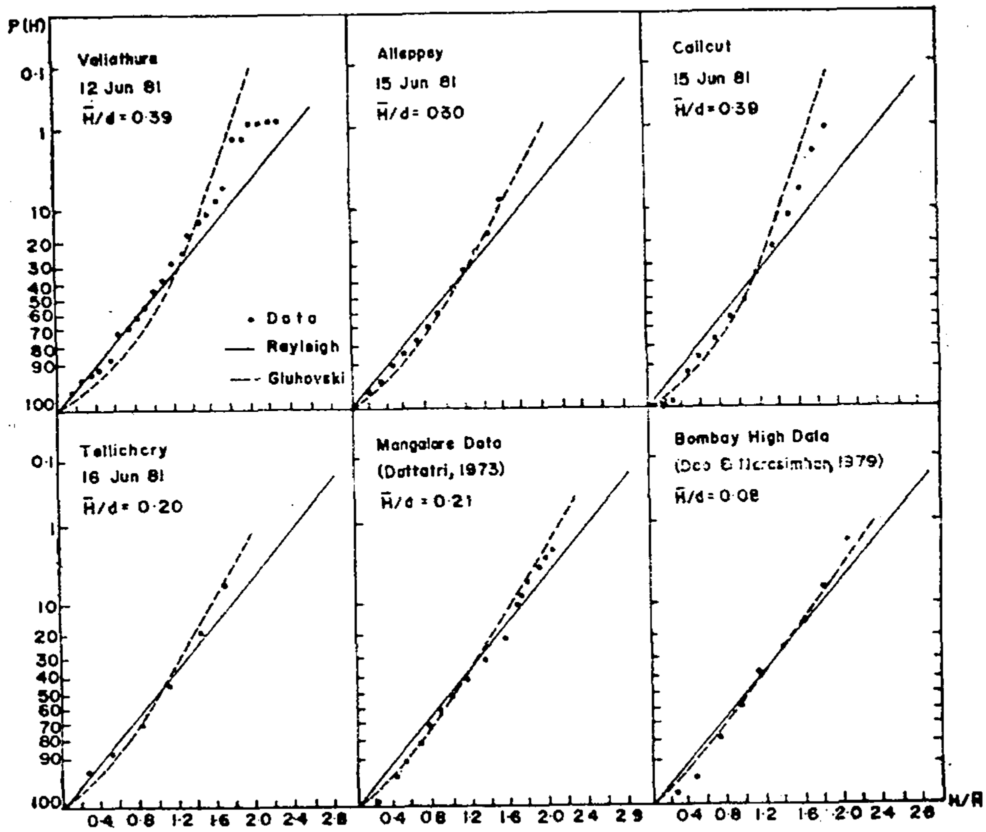

Fig. 2. Typical cases of short-term wave height distributions and their comparisons with Rayleigh and Gluhovski distributions.

tion is controlled by a relative mean height ($\overline{H}/d$) parameter, and for very low values of it (< 0.05), the Rayleigh is valid and for higher values a distribution suggested by Gluhovski (1968)

$$P(H) = \exp\left[-\frac{\pi}{4\left(1+\frac{\overline{H}/d}{\sqrt{2\pi}}\right)}\left(\frac{H}{\overline{H}}\right)^{\frac{2}{1-\overline{H}/d}}\right] \tag{3}$$

is more closer to the actual field conditions. This has been further confirmed by Hameed and Baba (1985) after a comparison with various nonlinear distribution functions, and established, further, that the wave steepness do not influence the wave height distribution substantially.

Wave periods: The distribution of individual wave periods have been studied by Dattatri, Raman and Jothisankar (1979); Deo and Narasimhan (1979); Baba and Harish (1985). These are compared with the probability density function p(T) of Bretschneider (1959) for the square of the wave periods (T^2):

$$p(T) = 2.7\left(\frac{T^3}{\bar{T}^4}\right) \exp\left[-0.675\left(\frac{T}{\bar{T}}\right)^4\right] \qquad (4)$$

where $\bar{T}$ is the mean wave period and the one proposed for normalized wave period, η by Longuet-Higgins (1975)

$$p(\eta) = 0.5\,(1 + \eta^2)^{-3/2} \qquad (5)$$

where $\eta = (T-\bar{T}_s)\,/\,V\,\bar{T}_s$ (6)

V — the spectral narrowness parameter

$$V = \left[(m_2 m_0 - m_1^2)\,/m_1^2\right]^{1/2} \qquad (7)$$

$$\bar{T}s = 2\pi\, m_0/m_1 \qquad (8)$$

where m_n denotes n^{th} moment of the energy spectrum about the origin

$$m_n = \int_0^\infty \omega^n\, S(\omega)\, d\omega \qquad (9)$$

W — the frequency in rad/sec;

$S(\omega)$ — the spectral density function.

It has been shown by above workers that both the distributions are not satisfactory for the generally wide band conditions prevailing along our coasts. However, Dattatri, Raman and Jothisankar (1979) report that the Longuet-Higgins is better among the two and Deo and Narasimhan (1979) found it vice versa. A detailed examination of the Bretshneider distribution shows that it explains the wave periods satisfactorily when dominated by swells (Baba and Harish, 1985). This might be due to the strong base of this function on the narrow bandedness of the wave spectrum, which can be observed in the swell-dominated sea state. This observation and the simulation of the wave periods, as a whole, are subjects for an interesting and useful study.

Joint distribution of H and T: The joint distribution of individual heights and periods are also analysed for the Indian coasts (Dattatri, Raman and Jothisankar, 1979; Deo and Narasimhan, 1979; Baba and Harish, 1985). The prominent joint distribution functions tested are given below:

Bretschneider (1977), assuming Rayleigh distribution for wave heights (Eq. 2), Rayleigh distribution for the square of the wave periods (Eq. 4) and zero correlation between H and T has suggested the joint probability distribution

$$p(H,T) = p(H)\,p(T) \qquad (10)$$

Similar distribution with Gluhovski function for wave heights (Eq. 3) has been proposed by Gluhovski (1968). Longuet-Higgins (1975) has derived the theory of the joint distribution for waves with a very narrow band spectrum, which can be written as

$$p(\xi,\eta) = \xi^2/\sqrt{2\pi}]\exp[-\xi^2)1+\eta^2)/2] \qquad (11)$$

where ξ — the normalized wave amplitude

η — the normalized wave period.

This takes a symmetrical form as given in the original paper.

For all the above distributions the primary condition is a zero correlation between H and T. But correlations ranging from 0.45 to 0.78 have been obtained for Mangalore data (Dattatri, Raman and Jothisankar, 1979) and from 0.06 to 0.69 for various locations of Kerala coast (Baba and Harish, 1985).

Thus the ocean waves exhibit a distinctly positive correlation and this tendency has been formulated in the theory of the CNEXO group (Ezraty, Laurent and Ahran, (1977). The time interval between successive positive maxima is estimated by extending the theory of Cartwright and Longuet-Higgins (1956), and is employed as the substitute of zero up-crossing wave period. The proposed joint distribution is as follows:

$$p(h, T_1) - \frac{\alpha^3 h^2}{4\sqrt{2\pi}\in(1-\in^2)T_1^5}\exp\left\{-\frac{h^2 T^{-4}}{8\in^2}\left[(T_1^2-\alpha^2)^2+a^2\alpha^4\right]\right\} \qquad (12)$$

Here $h = H/\sqrt{m_o}$: nondimensional wave height

$T_1 = \bar{T_1}\, T/\bar{T}_c$: nondimensional wave period

where $\bar{T}_c$ is the mean time between two successive positive maxima

$$\bar{T}_c = (2\pi/\alpha)(m_2/m_4)^{1/2} \qquad (13)$$

$$\alpha = (1+\sqrt{1-\in^2})/2 \qquad (14)$$

$$a^2 = \in^2/1-\in^2 \qquad (15)$$

Integrating the left-hand side of Eq. (11) with respect to h leads to the probability density of T, from where T, may be estimated:

$$p(T_1) = \alpha^3 a^2 T_1/\{(T_1^2-\alpha^2)^2+a^2\alpha^4\}^{3/2} \qquad (16)$$

Harish and Baba (unpublished) found that for the different locations of Kerala coast the joint distribution of non-dimensional heights and periods for mean E value of 0.76 is very close to the theoretical joint distribution calculated for the same E value. The pattern of the joint distribution of individual wave heights and periods for the Bombay High (Deo and Narasimhan, 1978, p. 118) and for the Mangalore data (Dattatri, Raman and Jothisankar, 1979, p. 3770) show close similarity with the CNEXO distribution, rather than the symmetrical distribution suggested by Longuet-Higgins.

Wave grouping: One of the characteristic features of ocean waves to occur in groups of high waves is well known to the fishermen and navigators. After the catastrophies connected with the failure of 'Sines breakwater' in

Table II. Some significant results from intermediate and deepwater wave recordings*

Location	Water depth (m)	H_{max} (m)	T H_{max} (sec)	Remarks
Mangalore	12	6.5	N.A.	1974
	11	7.0	N.A.	1975
	10	5.4	8.9	1968
Bombay High	30	7.6	N.A.	
Salaya	39	8.0	N.A.	
Veraval	15	7.7	N.A.	
Daman	30	8.2	10.0	During the storm of 8th Nov. 1982
Cochin	15	2.6	10.0	Monsoon of 1983 was weak
Vizhinjam	48	6.5	8.8	2nd June 1984

*as per the publications cited in Table I.
N.A. — Not available

Portugal and breakage of Liberian tanker 'San-Nikolas' in the Gulf of Mexico, much attention is paid to the wave grouping by oceanographers and engineers. To assess the reasons for the above catastrophies and also to incorporate this statistical phenomena (!) in engineering modelling and design much work have been done world over.

The group of high waves are referred to as 'runs' and the 'run length' is measured in terms of the number of successive high waves, which exceed a certain given magnitude. Dattatri (1983), found for the Mangalore data maximum run length of 4 for $H > H_s$, which is consistent with the values reported elsewhere. The correlation co-efficient of successive wave heights obtained is between 0.06 and 0.45 with a mean of + 0.24.

Thomas, Baba and Harish (unpublished) on an analysis of long swells at Valiathura (Trivandrum) found a higher run length of 6 waves for $H > H_s$ and 16 waves for $H > \bar{H}$ which are higher than the values reported till date (Siefert, 1976; Goda, 1983,). The increase in runlengths is with the increase in the 'spectral peakedness parameter Q_p. A much higher correlation between wave heights ranging upto 0.8 is found in this case. Such a high value is sparsely reported in literature (Goda, 1983). A high correlation between H and T and a very low correlation between individual periods are also seen.

A significant begining has been made in the study of wave grouping. Some indepth study on the distribution of velocities under ocean waves has been done by Satyanarayana (1982). But to evolve a reliable picture with a capability of prediction of various wave parameters, as applicable to the Indian coasts, much work is yet to be done.

Wave climatology

A detailed information on the wave climate in the Arabian sea and Bay of Bengal is available in the wave atlasses already published (NPOL; 1978; NIO, 1982). In spite of the limitations in the data used, these are the only accounts of spatial and temporal variations of different wave parameters for these regions. But, for the entire Indian Ocean we are still forced to depend on atlasses prepared elsewhere (US Navy, 1948; Anonymous, 1968,.) based on widely scattered visual information. Extensive work has been done by Mukherjee and Sivaramakrishnan (1980a and b) and many others in examining the sea and swell distributions in some detail using the IMD, MONEX and ISMEX data.

Wave climatologies for different locations, where recording has been done are reported in various publications as mentioned in Table 1. Wave climatic variations during the monsoonal rough weather season and the remaining fairweather season of the year are available in the form of height and period occurrence plots, scatter diagrams, persistence graphs for Valiathura, Thumba, Alleppey, Cochin, Calicut, Tellicherry, Mangalore, Calangute, Bombay High, and Digha,. Measured wave directions, which are vital in all applications of the wave data, are available for Valiathura, Alleppey, Calicut and Tellicherry.

The modified method for the preparation of wave persistence diagrams using the cumulative heights and durations (Sathe and Gouveia, 1982) appears to be more useful than the earlier methods. This has been successfully used for the year-round data from the Kerala coast.

Long term distributions

At present main source of long term distributions of wave heights are either the ship observations reported by IMD or the extrapolations of waves recorded for one year (sometimes even less) or hindcasts from storms known to have occurred in the area and their extrapolation. Among these, considerable work has been done with the shipbased observations and sufficiently long terms, 10 years in the NPOL Atlas and 5 years in the NIO Atlas, have been covered.

The available extreme value distribution functions are mainly four, viz., Log-normal, Exponential, Weibull and Gumbel. The probability distribution for all of them in general can be given as

$$p(H) = \exp[-H/A]^n \qquad (17)$$

where A and n are constants and assigned different values for each distribution. Some work has been done on the extrapolation of measured data using these theoretical models. Different investigators have found that no distribution is superior over others (Dattatri, 1978). Table III gives some typical values predicted for some locations along the west coast using the log-normal distribution. Here it may be seen that the values predicted by two authors for Bombay High and similarly for Mangalore vary considerably. In the case

Table III. Predicted heights of design wave for different locations.

Location	H_{max} 1 Year	in m. 10 Year	100 Year	Works
Bombay High	10.4	12.0	13.7	Deo and Narasimhan (1979)
Bombay High	8.2	9.2	10.0	Gadre and Kanetkar (1981)
Salaya	8.5	10.8	13.4	—do—
Veraval	8.1	9.2	10.3	—do—
Mangalore				
Site I (1974)	6.8	7.6	8.6	—do—
Site II (1975)	7.4	9.6	11.8	—do—
Site III (1968)	5.4	7.1	—	Dattatri (1978)
Digha	2.4	—	5.2	Dharkaviraj and Sarkar (1978)

of Bombay High it is the limited (in time) number of records (in the first case) used makes the difference. But at Mangalore at all the three occasions the entire monsoon data is covered, but for different years. Similar fluctuations in the recorded maximum significant wave heights for a period of three years at various locations is evident from Table IV. This leads to the conclusion that the use of recorded data of many years duration must be made for a more accurate and reliable estimate of design wave height.

No serious effort to use the hindcast method for the long term distribution of waves in the Indian waters are seen in the literature.

Table IV. Variation in maximum significant wave heights from long term recorded information.

Location	1980	1981	1982
Valiathura (TVM)	2.1	4.2	2.5
Alleppey	2.0	2.7	2.6
Calicut	—	2.4	1.4
Tellicherry	1.5	1.1	1.0

OTHER AREAS OF WAVE RESEARCH

Wave spectra

The application of spectral methods in the analysis of ocean wave data and the use of simulated spectra in coastal and ocean engineering is becoming an accepted practice of the day. When the wave-by-wave analysis reveals the non-linearity of the wave phenomena, the spectrum throws light into the irregularity of it.

The spectral information on the waves in the Indian situation are limited. Eventhough some attempts to calculate the spectra using the values of H_s and T_z were made in the past (Sundararamam, Varkey, Vijayarajan, John and Joseph, 1974), detailed reports on measured spectra, obtained either by auto-covariance or FFT method, are published only recently.

Dattatri (1978) and Deo and Narasimhan (1979) have studied the measured spectra at intermediate waters off the Mangalore and Bombay High areas respectively, and found that the spectra are closer to the Scott's spectrum (1965):

$$S(\omega) = 3.424\, m_o \exp\left[-(\omega-\omega_o)^2/0.065\,(\omega-\omega_o+0.26)\right]^{\frac{1}{2}} \quad (18)$$

where m_o — zeroth spectral moment

ω — frequency in rad/sec.

ω_o — spectral peak frequency in rad/sec.

Deep water spectra for the Mahanadi Basin (Fernandez, Gouveia, Sathe and Nagarajan, 1981), off Godavari (Vethamony, Gopalakrishna and Varkey, 1984) and off Vizhinjam (Joseph, 1985) are also available. Among these, Joseph (1985) reports that the spectral form is more closer to the one suggested by Toba (1972):

$$S(f) = \alpha\, u_* \, g\, f^{-4} \quad (19)$$

where α — a constant, whose value ranges from 0.06 to 0.12 depending upon the fetch

g — acceleration due to gravity

u_* — friction velocity

f — frequency in Hertz.

Some results of the studies on the shallow water spectra for four locations (See Table 1) of the Kerala coast are reported by Harish and Baba (1985). A detailed examination of the year-round spectra at these locations shows that they are generally multipeaked with the shape parameters, Q_p and ϕ_p and the high frequency portion resembling that of Pierson-Moskowitz (1964) spectrum:

$$S(f) = A g^2 (2\pi)^{-4} f^{-5} \exp\left[-(5/4)\,(f/f_m)^{-4}\right] \quad (20)$$

where A — Phillip's constant $= 0.046\,(X/u_{10})^{-0.22}$

x — Fetch in m

u_{10} — velocity of wind at 10 m height above sea surface in m/sec

f_m — spectral peak frequency $= 16.04/(x.u_{10})^{0.38}$

Thus the results obtained by various authors for the Indian coasts are different. However, the fact that these studies are reported for widely varying water depths, different locations, etc. are to be considered in a final validation.

Now almost all engineering applications demand for the directional information, which has become a prerequisite in the safer design of structures, energy development programmes, planning of offshore operations, etc. There is an urgent need to study the directional spectra in the context of Indian seas.

Wave transformation

As the waves enter the shallow water, they undergo refraction, shoaling, etc., which finally change the wave heights, directions, etc. Graphical methods of construction of wave refraction diagrams have been done by many authors (Varadachari, 1958; Sastry, 1958; Reddy, 1962; Varadarajulu, 1972; Murthy, 1977; Kurup, 1977; Dhanalakmi, 1980 and many others). This laborious procedure has been recently replaced by simple numerical computer methods (Mahadevan and Renukaradhya, 1983).

Kurian, Baba and Hameed (unpublished) has modified a computer programme originally suggested by Dobson (1967) to incorporate the bottom friction and also a shallow fine depth grid. A comparison of the predicted wave heights with the nearshore recordings showed very good conformity. An extension of this programme to predict energy distribution along the Trivandrum coast provided satisfactory results when compared with actual field measurements (Kurian and Baba, 1984).

In addition to this, wave transformation around marine structures have been reported by Murthy (1977), Kurup (1977), Dattatri (1978), Baba (1984), and Gadre and Kantetkar (1983).

Wave Power

Waves are now recognized as one of the alternate sources of renewable energy. Some recent works on the computation of wave power potential along the Indian coasts (Das, Ramesh and Varkey, 1980; Gopinathan, Sathe and Ramaraju, 1979; Rao and Sunder, 1982) using the expression:

$$P = \frac{r\,g}{4\pi} H_s^2\, T_z \text{ Watts} \tag{21}$$

(where r is the specific weight of seawater which is taken as 10.05 x 10^3 Newtons/m^3, g — in m/sec^2, H_s — in meters and T_z — in sec), show that west coast has greater potential than the east coast. Das, Ramesh and Varkey (1980) has calculated from ship wave data of IMD a mean power potential of 23 KW/m for the whole year and 35 KW/m for monsoon period for the Indian coasts. The above works give varied picture of wave energy potential, primarily due to the limitations in the source wave data used for the computations. More accurate picture of this may be obtained from long term field measurements. Raju, Vendhan and Bhattacharya (1982) give various courses of action for the successful utilization of wave energy. A good beginning has already been made to experiment a Multifunctional Wave Regulation System, with the main purpose of tapping the wave energy (Raju, Ravindran and Korde, 1983).

Remote Sensing

The use of satellite data in estimating wave parameters, though with some present day limitations, have been tried with reasonable results (Rao, Viswambaran and Rao, 1984) and bears considerable potential in the study of wave climatology of large and remote areas of the Indian seas. Ocean wave imaging using synthetic aperture radar technique (Bhattacharya, 1983) is a potential tool in wave monitoring. Aerial photographic surveys can also be tried for some selected studies connected with important marine constructions and objects.

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