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Ocean wave spectra off Cochin, west coast of India

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Spectra of waves off Cochin are generally multipeaked and wide-banded with high frequency sides showing similar slopes. The slope is milder than that proposed by Phillips (1958) for fully developed sea conditions. Examination of weather maps relating to the period of study explains the multipeakedness in the spectra to be due to the presence of sea waves and swells. The observed spectra are closer to those of Scott and Scott-Wiegel with the latter fitting the peak better. An average spectrum defined in terms of only wave heights is proposed for the location studied.

Though wave measurement and analysis have been reported for different locations (e.g. Mangalore, Bombay, Karwar, Trivandrum, Alleppey, Calicut, Tellicherry, etc.) along the west coast of India[1], no report on Cochin, one of the leading ports of the country, is available. An attempt is made in this paper to highlight the spectral characteristics of the waves recorded in intermediate waters off Cochin. This may be useful in the design and operation of harbour facilities, offshore structures and many other marine applications.

Materials and Methods

Wave records used for analysis were collected[2] using a waverider buoy at a water depth of 15 m (Fig. 1). Continuous records extending up to 3 h were collected at weekly intervals during 1983. Twenty six records corresponding to February and June-September were used in the present study.

For the computation of spectrum auto-covariance method was used. Records were digitized at an interval of 1 s. Harris[3] and Baba *et al.*[4] recommended the use of about 512 data points to obtain a reasonable estimate of the wave spectrum in the case of *pressure records. To examine* the suitability of this recommendation in the case of waverider data, 2 long records with 2500 data points were taken. The energy density was assumed to be negligible beyond 0.5 Hz. Spectra were computed with 500, 1000, 1500, 2000 and 2500 data points; 4 spectra were computed with 250 data points also. Typical spectra computed for 2 successive records with 250 data points and the whole 500 data points; spectra for the above 500 data points and the next 500 data points and the whole 1000 data points and so on are shown in Fig. 2 (A to D). Spectra became smoother with the increase in number of data points, but much difference could not be observed when the number of data points increased beyond 500. Spectrum with 500 data points was more or less similar to that with 2500 data points. Spectra and spectral estimates for 2 successive 250 data points showed much variations compared to others.

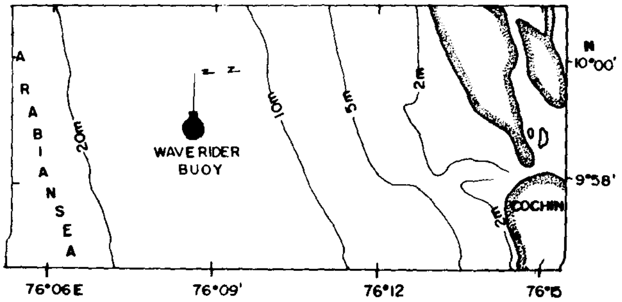

Fig. 1 – Location of waverider buoy off Cochin

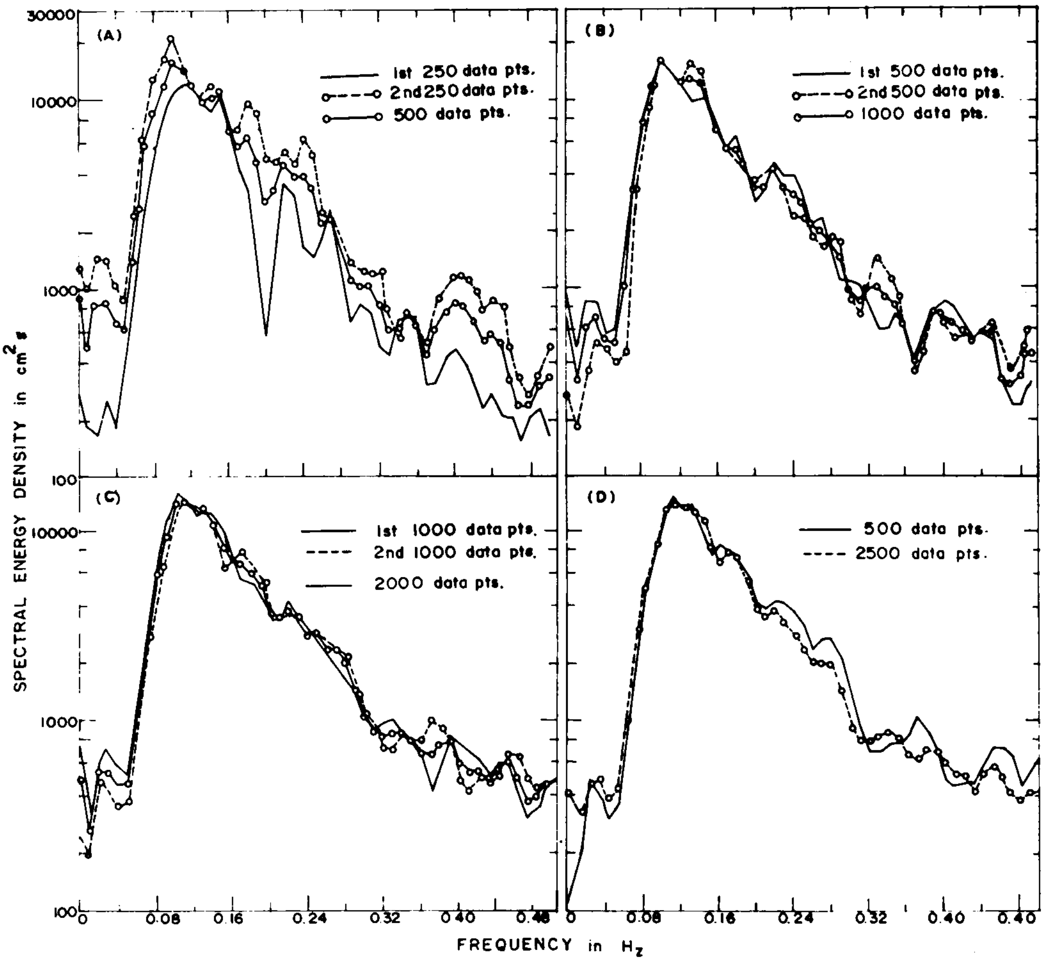

Fig. 2 – Spectra for different record lengths

Of the various spectral estimates, the significant wave height (H_{ss}) and spectral peakedness parameter[5] Q_p,

$$Q_p = \frac{2}{m_0^2} \int_0^\infty f S^2(f)\,\mathrm{d}f \qquad \ldots (1)$$

(where m_0 is zeroth moment of the spectrum, $S(f)$-the spectral density and f-the frequency) showed variations while others like spectral band width parameter, spectral narrowness parameter, spectral peak period, etc. were more or less same for different record lengths. The wave height averages obtained from zero-up-crossing analysis for successive records covering these long records also showed variations. Thus it seems that the variation in H_{ss} and Q_p values would be due to change in energy content or sea state. The estimates other than Q_p and H_{ss} were dependent on powers of frequency and that may be the reason why they did not show much variations. Thus increasing the record length beyond 500 data points did not improve the spectral estimates. Instead, the data could be a mixture of different sea states. This indicates that 500 data points are necessary and sufficient for computation of spectrum. Therefore all the 26 records were analysed for 500 data points. Accordingly for zero-up-crossing analysis[5], an equivalent length of wave record, which had about 100 waves, was used.

Results and Discussion

Wave spectra—Typical spectra off Cochin are shown in Fig. 3. Spectra are generally broad-banded with significant portions of energy being distributed over a wide band of frequencies. The low frequency sides show steeper slopes compared to high frequency sides. High frequency sides show similar slopes. The slopes of the high frequency sides of the spectra are milder than f^{-5}, the one proposed by Phillips[6], with values ranging between f^{-3} and $f^{-3.5}$. The reason for

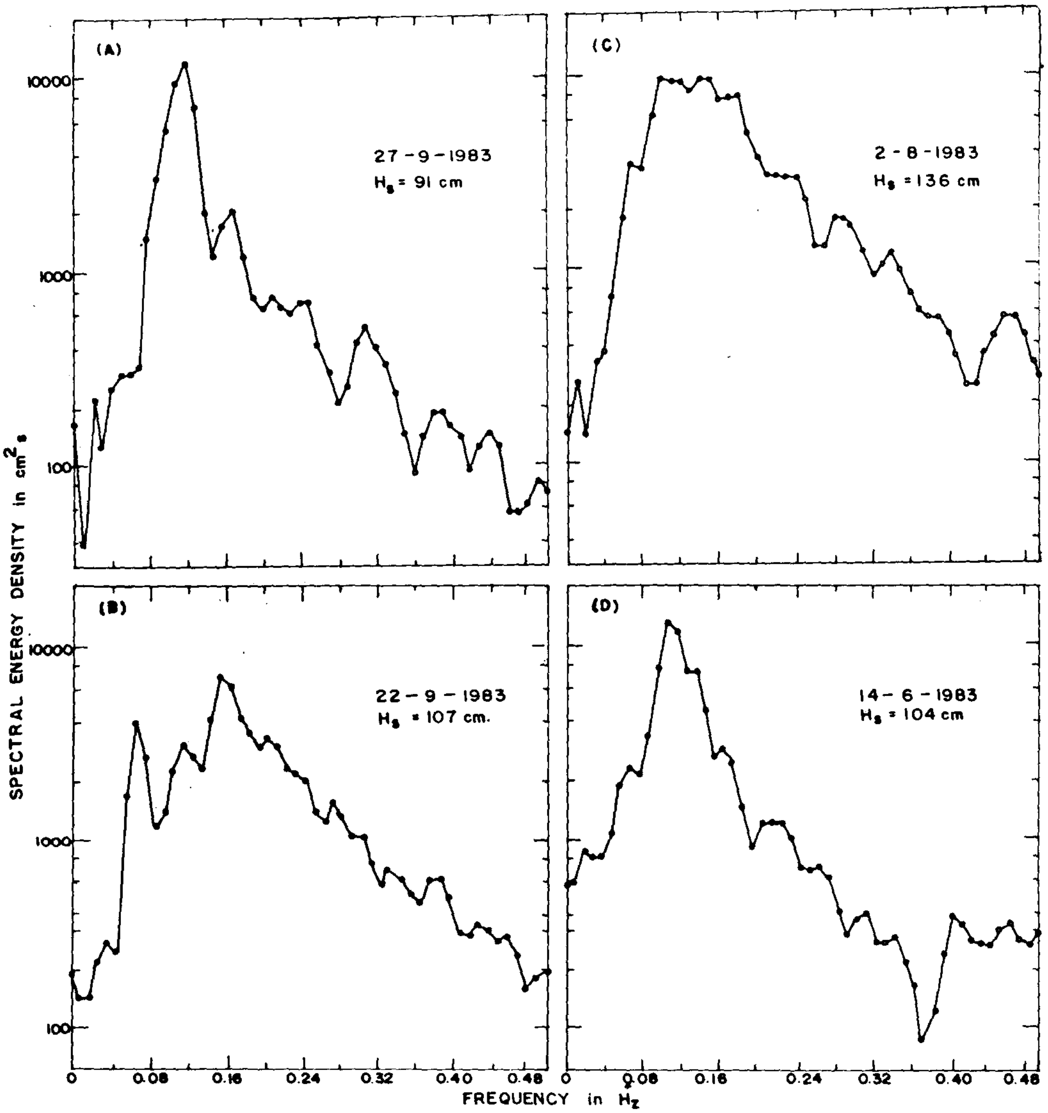

Fig. 3 — Typical wave spectra off Cochin

this milder slope would be that the sea is not fully developed due to fetch limitations and also that observations made are at shallow depths. Earlier reports show that the slope is generally f^{-5} for shallow waters[5,7-9].

Most theoretical spectra have a single peak. But most of the observed spectra are multiple-peaked. Multiple peaks occur at approximately 1.5 or 2 times the frequency of the main peak. This is similar to the spectra of several other locations[8-11]. Multiple peaks can be due to waves coming from 2 or more fetches, due to formation of higher order harmonics because of the presence[9] of reefs, shoals, etc. or inherent in the wave generation mechanism[5]. The present study area does not show the presence of any shoals, etc. The synoptic chart corresponding to 22 September 1983 (Fig. 4A) shows that winds in NW and W directions exist away from the coast and SW direction near the coast. The winds near the coast on that day could generate wind waves and the minor peaks around 0.4 Hz (Fig. 3A) could be due to this. The NW and W winds could result in swell waves reaching the coast and the major peaks around 0.08 and 0.18 Hz could be the result of these swells. Similarly for the synoptic chart of 14 June 1983 (Fig. 4B) winds in W and SW directions were identified. The swells due to west wind could result in the main peak and the minor peaks must be the result of local wind waves due to SW wind (Fig. 3D). Thus multiple peaks are explained to be due to combination of swell and local wind waves. This explanation may not be always true as Dattatri[8] found multi-peakedness in waves generated in a wave flume.

Even for similar sea conditions, the spectral form will depend on various factors like geographical location, duration and fetch of wind, stage of growth and decay of storm, existence of swell, etc. Ochi and Hubble[12] evolved a 6-parameter spectrum necessary to cover a variety of conditions. At the other extreme is the one-parameter spectrum recommended and adopted by 11th towing tank conference[8]. The useful representation of spectra will be to arrive at standard sea spectra for particular sea environment and geographical location. Measured spectra can be compared with the various theoretical spectra to see which of them can be used as a standard for the location. There are many theoretical spectra put forth for both fully developed and partially developed seas. A comparison of measured spectra with theoretical spectra of Bretschneider[13], Neumann[14], Scott[15] and Scott-Wiegel[16] was made for typical records (Fig. 5A and B). The reason for selecting these particular spectra was that they are two parameter spectra involving m_0 and ω_0 (the peak spectral frequency in rad.s^{-1}).

Theoretical spectra[13-16] were computed for m_0 and ω_0 values of the measured spectra and were compared with the measured spectra. Scott[15] and Scott-Wiegel[16] spectra appear to be closer to the present data, with Scott-Wiegel spectrum fitting the peak better. For other locations of the west

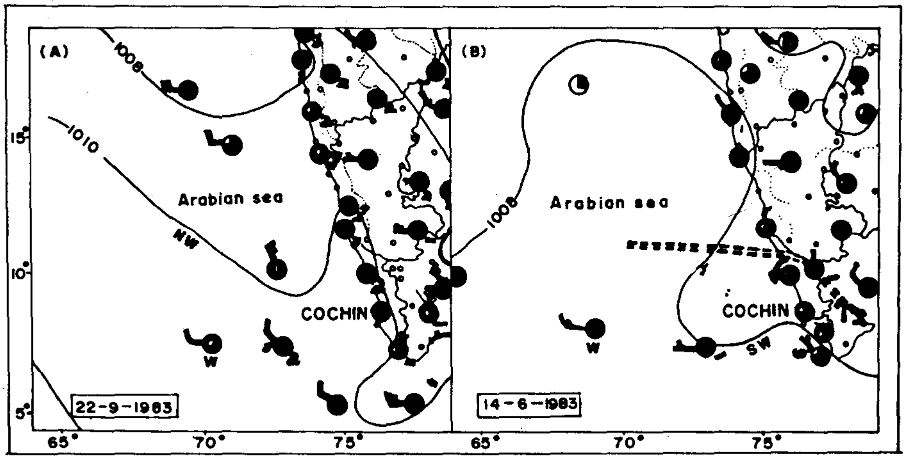

Fig. 4 – Synoptic daily weather maps for 0800 hrs IST

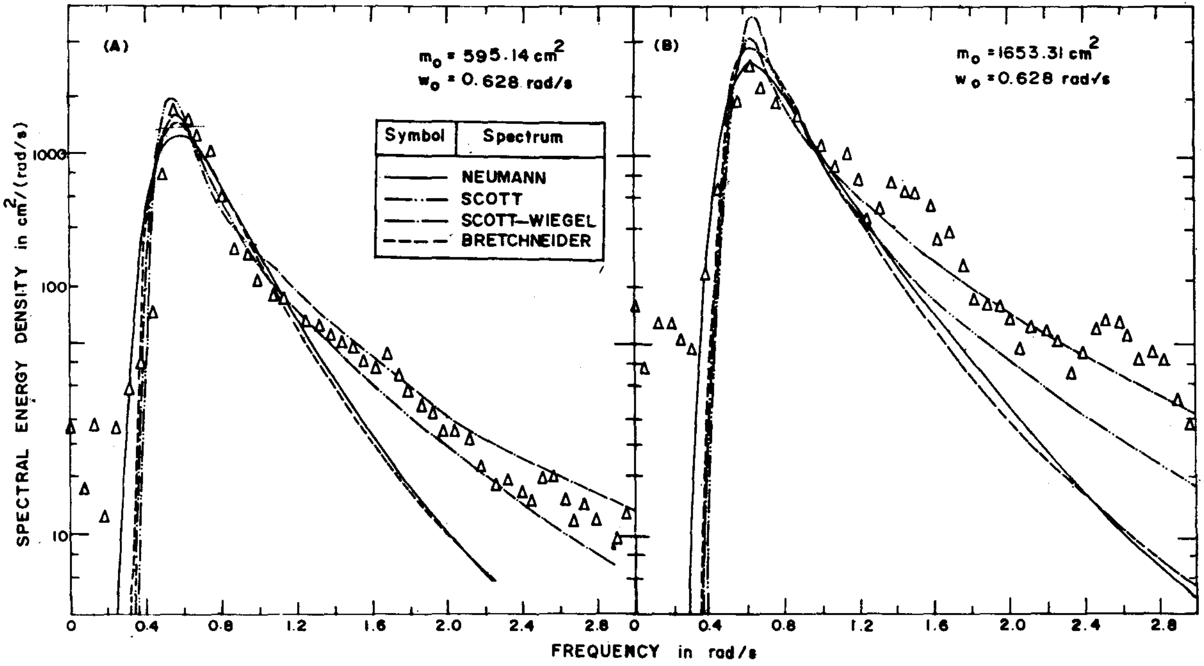

Fig. 5—Comparison of measured and theoretical spectra

coast[8,9,17] Scott spectrum was the nearest fit.

According to Scott[15] an average spectrum appropriate to the wave height and geographical location, which can be usefully summarised by the arithmetic means of energy densities at a set of frequencies which closely cover the range in which the energy density is not negligible, is better than any fixed spectrum. To see whether there is possibility of an average spectrum at this location, different sets of spectra with almost same significant wave heights were compared (Fig. 6A). Spectra showed similar shapes. Fig. 6B shows that average spectra for different sets have similar shape with the peak spectral density increasing with the average significant wave height, H_s. At the high frequency side, spectra coalesce, which can be anticipated since the high frequency side of all the spectra analysed show almost similar slopes. This result indicates that there is possibility of deriving an expression for the average spectrum for the location.

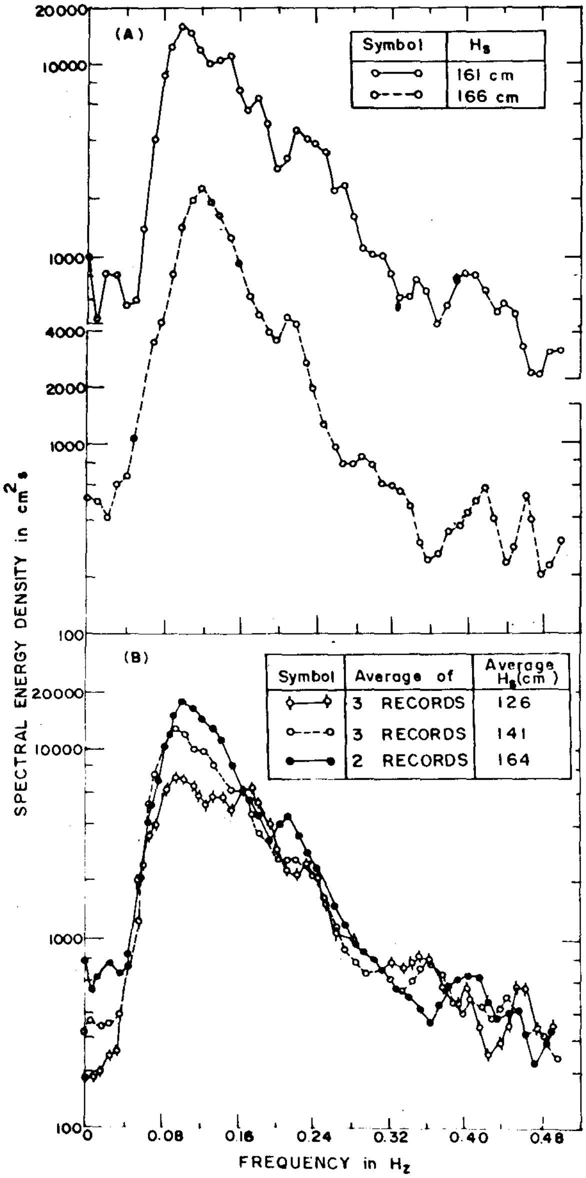

Fig. 6 – Representative spectra: (A) Spectra with almost same significant wave heights; (B) Average spectra for different significant wave heights

Spectral parameters – In addition to the characteristics of the spectrum, the wave height and period parameters obtainable from spectrum are of importance in design. Area under the wave spectrum (m_0-the zeroth moment of the spectrum) represents half the mean square value of surface elevations (η_{rms}). Thus for an ideal narrow band spectrum

$$H_s = 4\,m_0^{1/2} \qquad \ldots (2)$$

A similar expression for a wide band process is not yet given.

As for wave period, the main information obtainable from spectrum is peak frequency f_p. Its inverse T_p is assumed to be very close to significant wave period, T_s. Another period parameter which can be derived from wave spectrum is mean wave period, given by:

$$T_{zs} = (m_0/m_2)^{1/2} \qquad \ldots (3)$$

where m_2 is the second moment of the spectrum. In direct statistical methods, wave parameters are calculated directly from the record, whereas in spectral analysis they are calculated in terms of spectral moments.

The values of significant wave height obtained from spectrum using Eq. 2 are close to those obtained from zero-up-crossing analysis (Fig. 7A). The ratios between the above two are close to the values given by others[9,11,19,20]. The differences between average zero-crossing periods (Table 1) obtained from both the methods are more than those between significant wave heights. This may be because T_{zs} depends on higher order spectral moments which are highly sensitive to the high frequency cut-off. However, the results are in agreement with those of Goda[5] (Table 1). In the present data T_p is more closer to T_z than T_{zs} (Table 1). The range of T_p observed (5.3-11.1 s) compares well with the observations for other locations of the west coast of India, except for the shallow water values reported along the SW coast (Table 2).

The shape of the spectrum is important in engineering design in cases like slow drift oscillations of moored objects, wave forces on other struc-

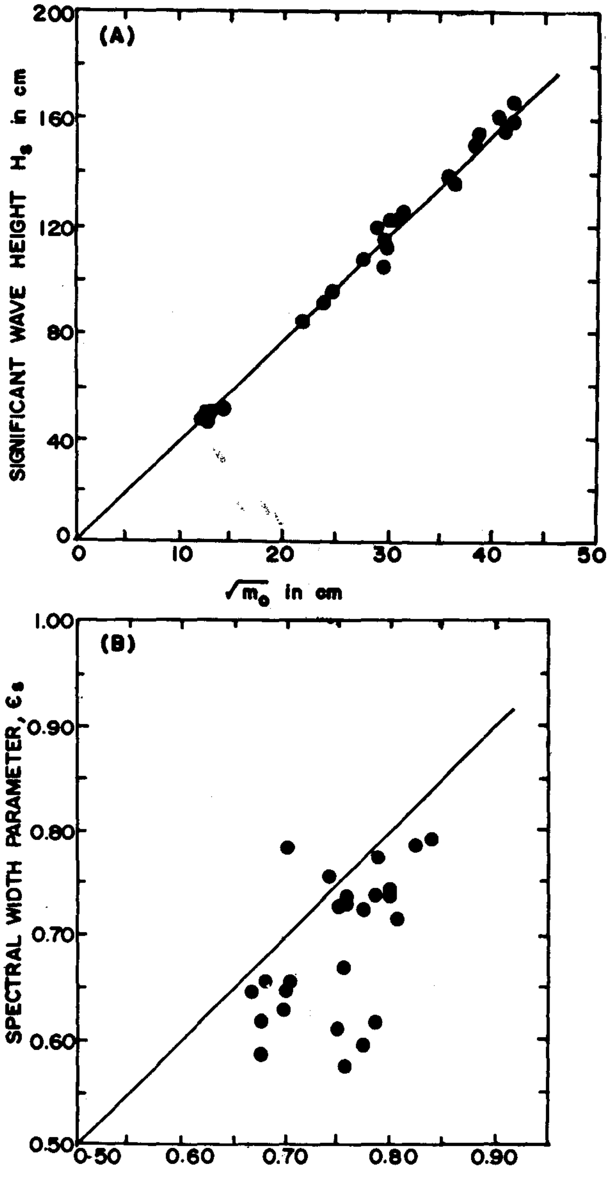

Fig. 7 – Comparison of wave parameters obtained by zero-up-crossing and spectral analysis

tures, wave loads on ships, stability of rubble-mound breakwaters, wave group formations and so on. There are various parameters to represent the shape of the spectrum. The parameters ε_s is a measure of spectral band width which is given by[18]

$$\varepsilon_s = (1 - m_2^2/m_0 m_4)^{1/2} \qquad \ldots (4)$$

where m_0, m_2 and m_4 are the zeroth, second and fourth spectral moments respectively. In terms of wave periods it is given by[18]

$$\varepsilon = \left[1 - \left(\frac{T_c}{T_z}\right)^2\right]^{1/2} \qquad \ldots (5)$$

Table 1 – Comparison of spectrally obtained height and period values with those of others reported

$H_s/m_0^{1/2}$	T_{zs}/T_z	T_z/T_p
3.80 (Goda[11])	0.83 (Goda[5])	0.83 (Goda[5])
3.80 (Wilson & Baird[19])	0.81 (Present data)	0.89 (Present data)
3.77 (Forristall[20])		
3.70 (Baba & Harish[9])		
3.84 (Present data)		

Table 2 – Different spectral parameters for the west coast of India

Location	Peak period T_p (in s)	Spectral width parameter	Spectral peakedness parameter	Spectral narrowness parameter
Cochin (Present data)	5.3-11.1	0.64-0.83	1.26-2.60	0.38-0.52
Vizhinjam[21]	7.1-12.5	0.62-0.79	—	—
S W coast of India[7,22]	7.7-16.7	0.68-0.90	0.9-2.44	—
Mangalore[6]	10.6	0.65-0.74	1.44-2.38	0.33-0.48
Karwar[23]	10.0	0.73-0.85	—	—
Bombay[24]	9.1-11.1	0.79-0.86	—	—

where T_c is average crest period and T_z is average zero-crossing period. Small values of ε or ε_s indicate that the wave energy is concentrated in a narrow band of frequencies and higher values represent a wide band spectrum. For an ideal narrow band process the value should be zero. In the present study values are high (Table 2) indicating that the spectra are wide-banded. ε_s values are less than ε without any definite relation between the two (Fig. 7B). The reason for the lower values of ε_s may be the same as the one given in the case of T_{zs}. Chakraborti and Snider[25] for North Atlantic data and Dattatri[8] for Mangalore data observed ε_s to be less than ε, whereas Goda[5] and Harring *et al.*[26] found ε to be less than ε_s.

Another parameter to measure the width of the spectrum is the spectral narrowness parameter[18] given by

$$\nu = (m_0 m_2/m_1^2 - 1)^{1/2} \qquad \ldots (6)$$

The value of ν increases with the width of the spectrum. Rye[27] found ν to be between 0.2 and 0.4 for single-peaked spectra. For the present data the values are higher (Table 2). Since ν also depends on higher order moments it cannot be regarded as a satisfactory measure. Longuet-Higgins[28] has shown that

$$\nu = 0.5\, \varepsilon_s \qquad \ldots (7)$$

for a narrow band process. Dattatri[14] for Mangalore data observed that

$$\nu = 0.5\, \varepsilon \qquad \ldots (8)$$

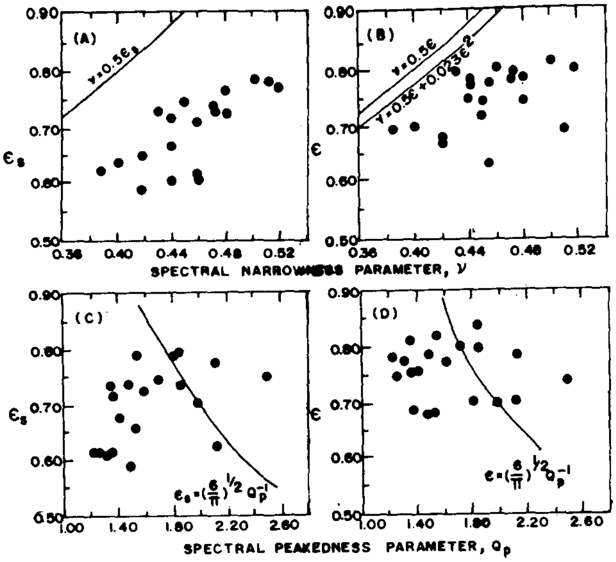

Fig. 8 – Analysis of spectral shape parameters

rather than $\nu = 0.5\ \varepsilon_s$. Goda[29] found an approximate relation,

$$\nu = 0.5\,\varepsilon + 0.023\,\varepsilon^2 \ \text{for}\ 0 < \varepsilon < 0.85 \qquad \ldots (9)$$

and observed that this nearly coincides with the relation given in Eq. 7 for a very narrow banded spectrum. The relationship given in Eqs 8 and 9 are, however, closer to the present data than Longuet-Higgin's equation (Fig. 8). This may be due to the influence of higher order spectral moments on ε_s.

Goda's spectral peakedness parameter given by Eq. 1 will take the value of 1 for the white noise, around 2 for wind waves and higher values for swells[11]. The Q_p values derived in the present study are given in Table 2. For a narrow band process Ewing (cited in Dattatri, *et al.*[18]) deduced the relation

$$\varepsilon_s = (6/\pi)^{1/2}\, Q_p^{-1} \qquad \ldots (10)$$

There is no good agreement between the present data and the Eq. 10 (Fig. 8C) which is in conformity with Chakraborti, *et al.*[25] and Dattatri *et al.*[18]. The latter found the fit to be better with ε and used instead of ε_s (Fig. 8D). In Q_p *vs* ε the scatter is reduced slightly. The ranges of parameters of spectral shape (Table 2) for Cochin are comparable with those for other locations along the west coast of India.

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