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Evaluation of wave characteristics in the Gulf of Kutch, Gujarat

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Various statistical wave parameters based on the measured wave data at the Gulf of Kutch for 1 y were computed. Wave activity was generally stronger during April to September and weaker during the rest of the year. Highest significant wave height of 2.75 m and maximum wave height of 3.75 m occurred in April, apparently caused by an unusual depression in the Arabian Sea. Predominant zero-crossing wave periods varied between 3 and 8 s. The wave records were analysed using Tucker's, the statistical (zero-upcrossing) and the spectral methods and the results compared. The design wave height based on Weibull distribution was predicted to be 4.2 and 4.4 m for return periods of 50 and 100 y respectively.

The Gulf of Cambay and the Gulf of Kutch on the west coast and the Sunderbans on the east coast of India have been identified as potential sites for the development of tidal power plants in India. The location is technically suitable for the construction of tidal barriers across the Hansthal creek in the Gulf of Kutch (Fig. 1). The present study has been initiated to evaluate the wave climate in Hansthal creek region in different months, and to estimate the design wave height for the proposed construction of tidal barriers and related coastal structures. The general oceanographic conditions in this region are dominated by the southwest monsoon period from June to September and the non-monsoon period from October to May. The occurrence of depression during the southwest monsoon increases the wave activity in this region. The spring tidal range reaches up to 7 m with associated current speed exceeding 2 m s^{-1}.

Methods

A Datawell wave rider buoy was deployed at 15 m water depth at Hansthal creek, where the construction of tidal barriers are proposed (Fig. 1). The waves were recorded for 20 min duration at 3 h intervals in analog form on a chart paper roll and in digital form in magnetic cassettes. Among the various methods put-forward for analysing analog wave records, the Tucker's method is the most efficient and reasonably accurate in arriving at different statistical parameters[1]. In the present study, significant wave height, maximum wave height, zero-crossing wave period, wave period corresponding to maximum wave height and spectral width parameters were computed from the analog records using Tucker's method.

$$\frac{1}{H_1\sqrt{m_0}} = 2 \times \sqrt{2 \ln Nz} \times \left[1 + \frac{0.289}{\ln Nz} - \frac{0.247}{(\ln Nz)^2}\right] \quad \ldots(1)$$

$$\frac{1}{H_2\sqrt{m_0}} = 2 \times \sqrt{2 \ln Nz} \times \left[1 - \frac{0.211}{\ln Nz} - \frac{0.103}{(\ln Nz)^2}\right] \quad \ldots(2)$$

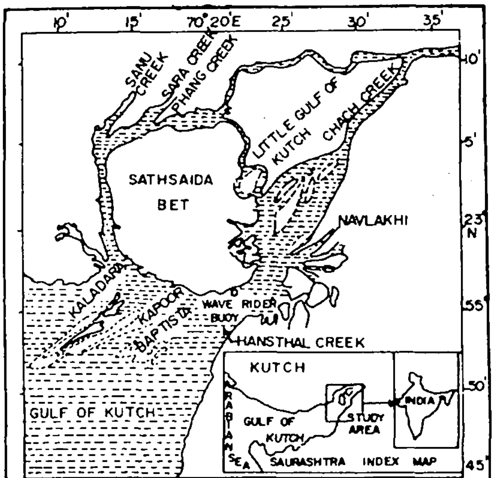

Fig. 1 – Location map

where H_1 = sum of highest crest and lowest trough, H_2 = sum of second highest crest and second lowest trough and Nz = number of total zero-up crossings. The highest value of m_0 obtained by either Eq. (1) or (2) was used for computing significant wave height (Hs) as,

$$Hs=4\sqrt{m_0} \quad \ldots (3)$$

The spectral width parameter (ε) is given by,

$$\varepsilon=\sqrt{1-\left(\frac{N_2}{N_c}\right)^2} \quad \ldots (4)$$

where, Nc = total number of crests in the record. The zero-crossing wave period (Tz) is given by,

$$Tz=\frac{P}{Nz} \quad \ldots (5)$$

where, P = period of each wave record in s, which is equal to 1200 s in the present study. The wave steepness (S) is given by,

$$S=\frac{Hs}{L} \quad \ldots (6)$$

where, L = wave length at measured location of 15 m depth estimated using linear wave theory[2].

Digital data were analyzed using statistical and spectral methods. Fast Fourier Transform (FFT) algorithm was used for computing raw spectrum of wave record using the equation,

$$S(f)=\frac{1}{Nf0}\left[\sum_{j=0}^{j=N-1} x(j)^{\exp(ij)}\right]^2 \quad \ldots (7)$$

where, $[x(j)]_{j=0}^{j=N-1}$ is the time series $=2\pi f/f0$, $i=\sqrt{-1}$, f = frequency $=0$, $f0/N$, $2f0/N$, ... $(N-1)f0/N$, $f0$ = sampling frequency = 2 Hz, and N = 2048.

In the statistical method, waves and their corresponding periods were identified by zero up-crossing method, when the time series record crosses zero elevation from negative to positive values.

The longterm distribution for significant wave height using Weibull probability distribution is given by[3,4],

$$F(Hs)=1-\exp\left[-\left(\frac{Hs}{Hc}\right)^{\gamma}\right] \quad \ldots (8)$$

where, Hc and γ are parameters of Weibull distribution. The return period is given by,

$$Rp=\frac{\tau}{[1-F(Hs)]} \quad \ldots (9)$$

where, τ = time interval between observations = 3 h in this case.

Results and Discussion

Monthwise percent frequency distribution of significant wave heights (Hs) is shown in Fig. 2. Wave activity was very low in January with significant wave height always <0.5 m. In November, December and February, the significant wave heights were mostly <0.5 m, and for about 20% of the time they varied between 0.5 and 1 m. During March, September and October, wave heights varied between 0.1 and 1 m. During June, July and August, significant wave height mostly varied between 0.5 and 1.5 m. The waves were unusually high in April with significant wave height varying between 0.5 and 2.5 m.

Monthwise percent frequency distribution of maximum wave height is shown in Fig. 3. In January, maximum wave heights were <0.5 m. In February the heights varied between 0.1 and 1 m, in May between 0.5 and 4 m and in April between 0.1 and 3.5 m. During remaining months of the year, maximum wave heights varied between 0.1 and 2.5 m.

Monthwise percent frequency distribution of zero crossing wave period is shown in Fig. 4. During June to September, zero crossing wave period mostly varied between 3 and 7 s and during November, December and February, it varied between 3 and 10 s. In April and May, it varied between 3 and 15 s. Percentage distribution of wave period corresponding to the maximum wave height is shown in Fig. 5.

Variation of spectral width parameter based on Eq. (4) is shown in Fig. 6. It mostly varied from 0.3 to 0.6 during November to March indicating that the wave energy is distributed in narrow band of frequencies than that for the rest of year when the spectral width parameter mostly varied between 0.5 and 0.9. Fig. 7 shows that wave steepnesses during November to March were less compared to those occurring in the remaining months. The joint distribution of significant wave height and zero up-crossing wave period for different months are shown in Fig. 8. The steepness parameter line (Hs/Tz^2) in Fig. 8 also indicates that the wave steepnesses were large during April to September compared to those of other months.

Cumulative distribution of significant wave height and maximum wave height during different months is shown in Fig. 9. In April, the maximum

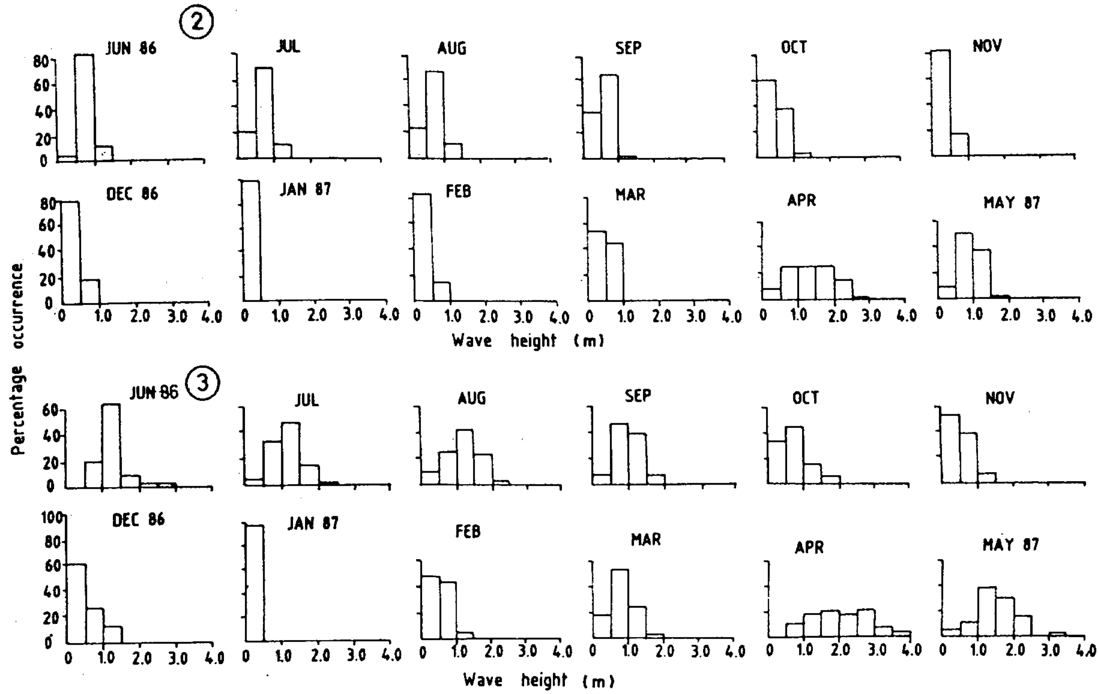

Fig. 2 – Percentage distribution of significant wave height

Fig. 3 – Percentage distribution of maximum wave height

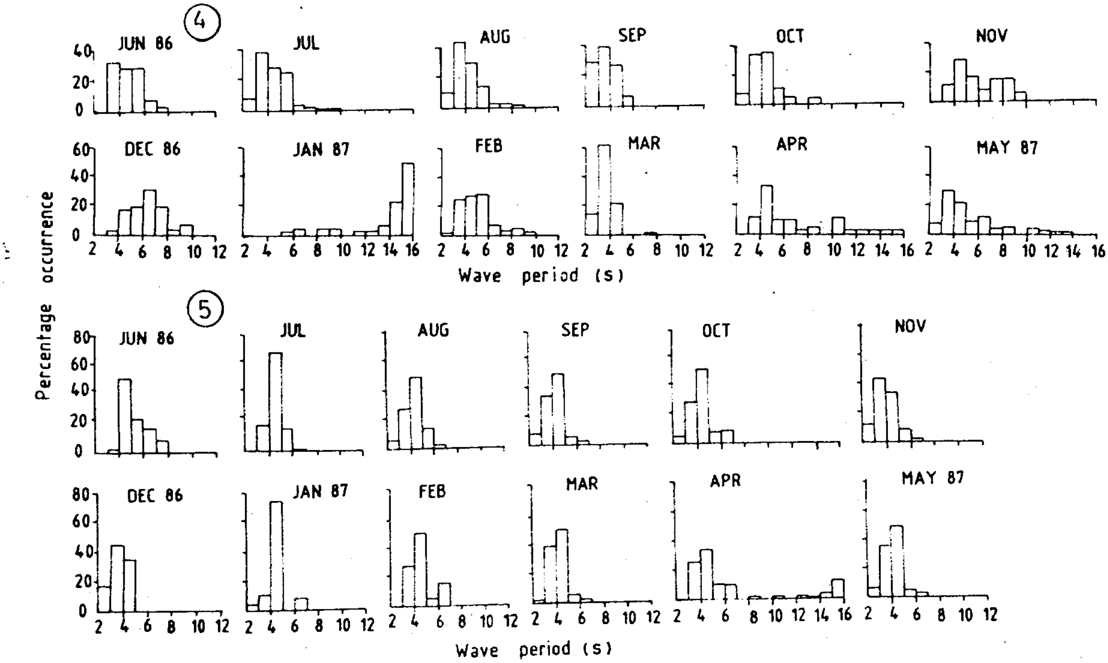

Fig. 4 – Percentage distribution of zero crossing wave period

Fig. 5 – Percentage distribution of wave period corresponding to maximum wave height

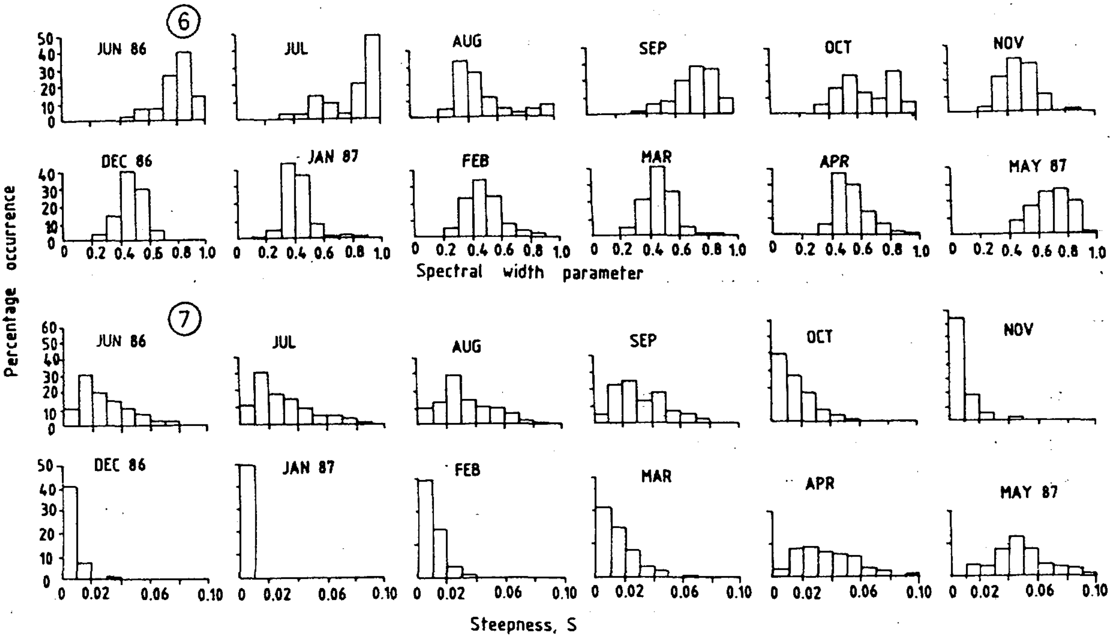

Fig. 6 — Percentage distribution of spectral width parameter

Fig. 7 — Percentage distribution of steepness

wave height of 1 m exceeded 88% of the time, 2 m exceeded 50% of the time and 3 m exceeded 12% of the time. During December and January, >95% of the time, the wave heights were <0.5 m.

Typical wave spectra representing wave climate of different months of the year are presented in Fig. 10. Because of very low waves, energy spectra for the months of January, February and December were not computed. In general, the spectra were single peaked. However, a few records with the occurrence of 2 peaks in July, August and September indicate the superposition of 2 independent wave trains at the site.

Design wave estimation—Occurrence of double peak spectra were observed only in few records and mostly the peak wave energy was concentrated to a single frequency during the study period. The significant wave heights (*Hs*) computed for the study period are plotted on a Weibull probability paper (Fig. 11). The least square fit for the distribution gives the Weibull parameters Hc and γ as 0.468 m and 1.1 respectively. Using these distribution parameters in Eq. (9), the significant wave height of the design wave for return periods of 50 and 100 y were estimated to be 4.2 and 4.4 m respectively. The design wave heights estimated in the present study is based on the limited data for 1 y. However, for a reasonable prediction of design wave, it would be necessary to have at least 5 to 10 y of measured data, so that the year to year changes in the wave climate can properly be accounted for. Further more, as the study location is prone to occurrence of storms and cyclones, it is likely to encounter higher waves than those recorded during the study period. These events may significantly influence the extreme value distribution and correspondingly the estimation of design wave heights.

Comparison—Significant wave heights computed using Tucker's method (H_{ST}), the statistical method (H_{SS}) and spectral method (H_{4rms}) during the study period were compared (Fig. 12). The linear regression by least square method gives the following relationships,

$$H_{ST} = -0.064 + 1.184\, H_{SS}$$

$$H_{SS} = -0.128 + 1.12\, H_{4rms}$$

It shows that the estimation based on Tucker's method gives slightly lower values than that given by statistical method, whereas estimation based on spectral method gives higher value than that given by the statistical method when the significant wave height exceeds 1 m.

Similarly the zero crossing wave periods estimated based on the above 3 methods, are compared by linear regression analysis (Fig. 12). The following relationships are obtained:

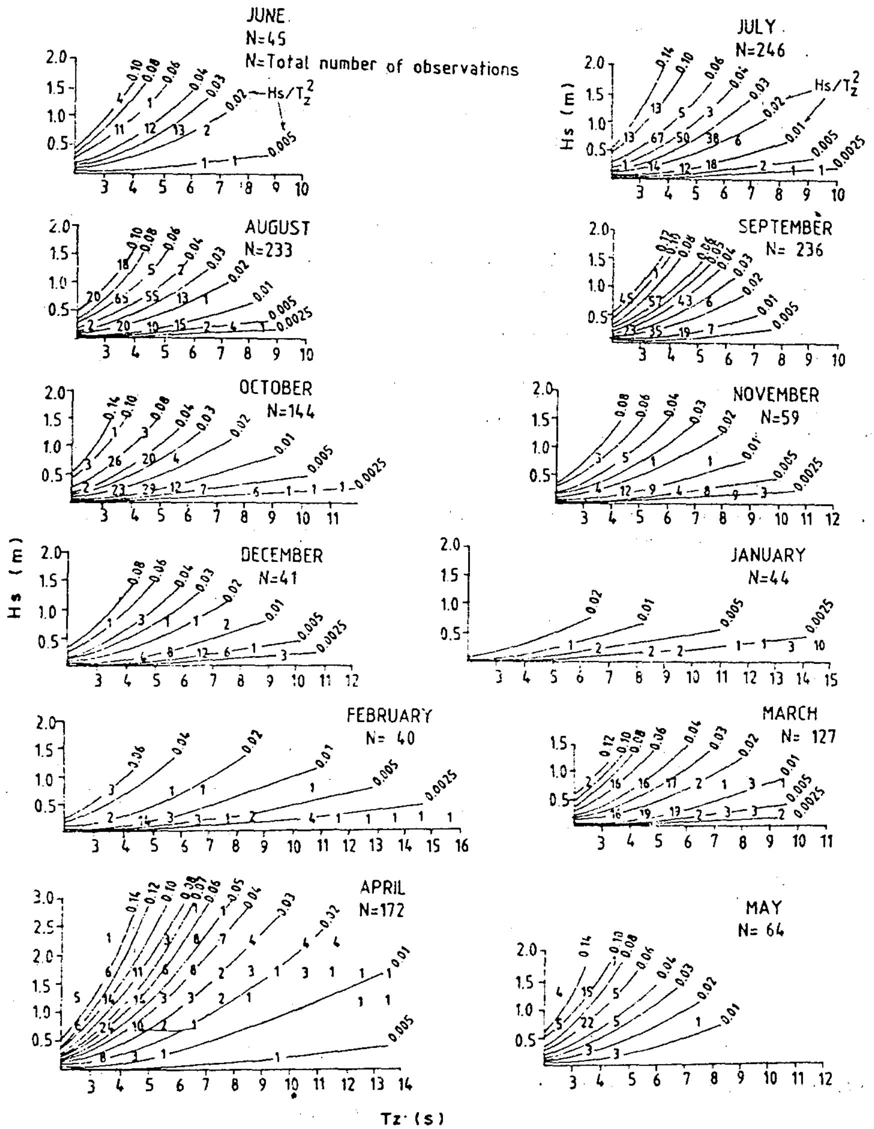

Fig. 8 – Joint distribution of significant wave height and zero crossing wave period

$$Tz_T = 1.029 + 0.688\ Tz_S$$
$$T_{m02} = 1.120 + 0.539\ Tz_T$$

where, Tz_T, Tz_S and T_{m02} represent zero-crossing wave period by Tucker's method, statistical method and spectral method respectively.

The above relationships indicate that the zero crossing wave period obtained using Tucker's method is slightly less than statistical method, and the values obtained by spectral method are slightly less than Tucker's method.

The present study shows that wave climate in the study region is dominated by southwest monsoon period (June to September) and non-monsoon period (October to May). High waves with comparatively shorter periods occur during southwest monsoon and the sea appears to be calm in non-monsoon period except for the cyclonic period. Estimation of significant wave heights using different methods shows that the variations are less and hence, when analog records are available, the Tucker's method can satisfactorily be used with simplicity. However, in the estimation of

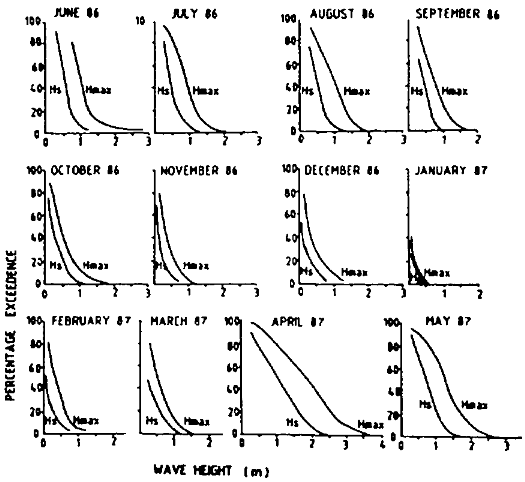

Fig. 9 – Cumulative distribution of significant wave height and maximum wave height

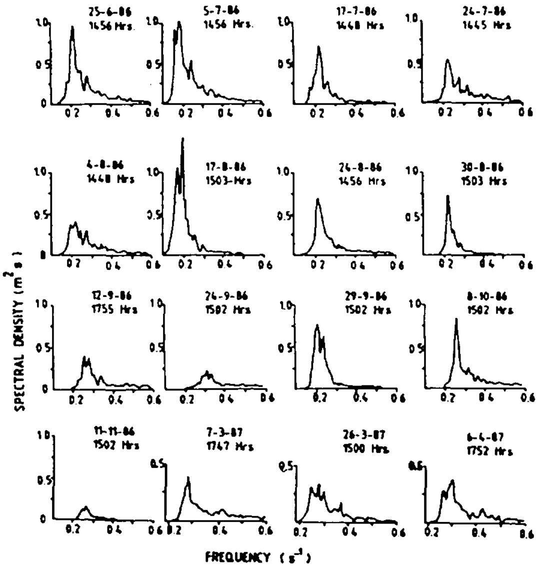

Fig. 10 – Typical wave spectra

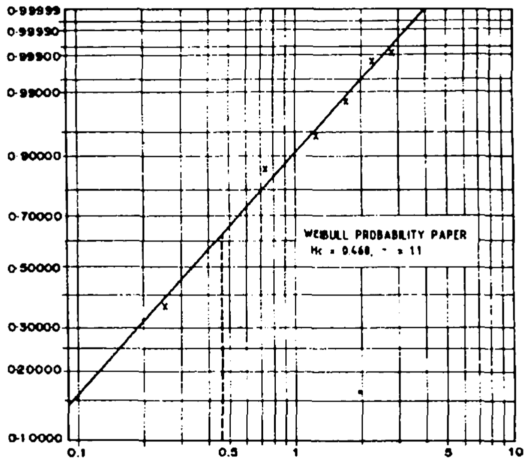

Fig. 11 – Weibull probability distribution

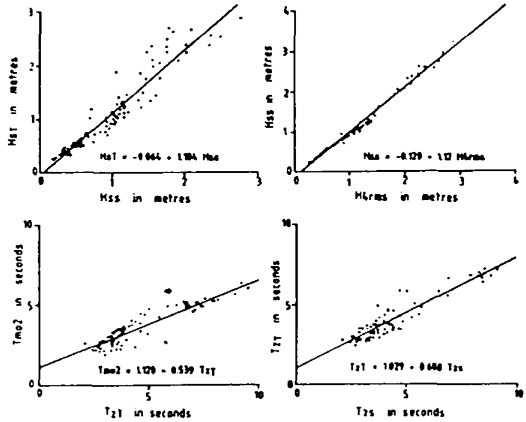

Fig. 12 – Comparison of different methods

zero crossing wave periods, the results show considerable variation among different methods.

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