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Short Communications

Estimation of design wave heights based on extreme value statistics for Kakinada coast, Bay of Bengal

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Statistical analyses for longterm distribution of significant wave heights were performed using Lognormal, Weibull, Gumbel and Fretchet distributions for waves measured off Kakinada from June 1983 to May 1984. Fretchet distribution showed large scattering in the plot resulting in the estimated extreme wave height on much higher side. The extreme wave height estimated based on Lognormal distribution was also relatively higher, while the Weibull distribution gave relatively lower values. Gumbel distribution appears to estimate the extreme wave height reasonably well and gives a realistic value for the study region. The extreme wave estimated based only on the monsoon wave data deviated significantly from the estimate based on 1 y wave data as expected.

Extreme statistical analysis requires a large wave data base for a longer period. Nevertheless the available wave data are often only for a limited duration, and it becomes inevitable to arrive at an estimate based on such limited database. Kakinada is a minor port town along the central east coast of India. Wave climate over this region is dominated by southwest and northeast monsoons. Severe wave conditions are common during the cyclones, which are quite frequent along the east coast. In the present study wave heights have been analysed for obtaining longterm distributions and extreme value statistics for this area.

Longterm wave statistics—Longterm wave statistics describes seasonal or annual wave condition, often by the cumulative distribution of wave heights. Assuming that the wave frequency spectrum consists of a relatively narrow band of frequencies and that the ocean waves are the result of the superposition of many sinusoidal components with a narrow band of frequencies, but of random phase, it is shown that the probability distribution of wave heights must follow a Rayleigh distribution[1]. Several longterm wave statistical distributions have been used[1]. The following are the 4 common types of longterm distribution suggested for describing the characteristics of wave parameters:

Lognormal:

$$P(H)=\frac{1}{\sqrt{2\pi}}\int_0^H \frac{1}{\alpha h}\exp\left[-\frac{1}{2}\left(\frac{\ln h-\theta}{\alpha}\right)^2\right]dh$$

Weibull:

$$P(H)=1-\exp\left[-\left(\frac{H-\varepsilon}{\theta}\right)^{\alpha}\right] \quad \ldots (2)$$

Gumbel:

$$P(H)=\exp\left\{-\exp\left[-\left(\frac{H-\varepsilon}{\theta}\right)\right]\right\} \quad \ldots (3)$$

$$\text{Fretchet: } P(H)=\exp\left[-\left(\frac{H}{\theta}\right)^{-\alpha}\right] \quad \ldots (4)$$

where, $P(H)=\text{prob}\,[H(t)\leq H]$, cumulative probability function, α = shape parameter, θ = scale parameter and ε = location parameter.

The difficulty lies in determining how good or bad the adopted type of distribution would be at a probability level beyond the range of the curve fitting since this can only be obtained by extrapolation. It is a common practice to express the probability of occurrence of extreme events in terms of statistical return periods. The extreme wave is the largest wave expected to occur in a return period, generally corresponding to the life of a structure. The return period (R_p) is expressed as,

$$R_p=\Delta t/[1-P(H)] \quad \ldots (5)$$

where, Δt = time interval between consecutive wave observations expressed in years.

Datawell wave rider buoy was installed at 90 m water depth off Kakinada (long. 82°28′E; lat. 16°42′N), and the waves were recorded for 20 min duration for every 3 h from June 1983 to May 1984. From the analog records of waves, significant wave heights were estimated using the Tucker's method[2]. Significant wave heights were grouped at 0.5 m interval and the cumulative probability values were estimated. A computer programme was developed to fit the probability of occurrence of wave heights in Lognormal, Weibull, Gumbel and Fretchet distributions (Eqs 1-4). The extreme wave heights for various return periods were estimated using Eq. 5. As the waves were recorded in 3 h interval, Δt in Eq. 5 was taken as 3 h.

Various distributions for 1y wave data are shown in Fig. 1. The line of best fit obtained by the method of least squares shows considerable scattering of data in Fretchet and Lognormal distributions. Weibull distribution shows a reasonably close fit except in the lowest range. Gumbel distribution however shows relatively close fit over a wide range of observed values. Ochi[3] has reported that Weibull distribution does not satisfactorily represent distribution for the lower range of significant wave heights, and the lognormal distribution for the higher range. The measured 1y wave data show variation of significant wave heights within a narrow range of 0.5 to 3 m. Severe storms or cyclones did not occur during the year under study.

Extreme wave heights based on different distributions for return periods of 10, 25, 50, 75 and 100 y are presented in Table 1. Fretchet distribution shows unusually high extreme values (11.66-23.41 m) as compared to other distributions. These usually high values and the presence of large scattering of data in Fig. 1 indicate doubtful applicability of Fretchet distribution to the data under study. Larres[4] observed that as an approximation, the extreme wave height of 10 y return period would be about 1.39 times the highest annual wave height and that of 100 y return period would be about 1.78 times the highest annual wave height. As per this thumb rule, for the highest annual significant wave height of 2.6 m, recorded during the study period, 10 and 100 y extreme wave heights would be 3.6 and 4.6 m respectively. Weibull distribution is very steep line of best fit (Fig. 1), and the extreme wave heights for 10-100 y return periods vary within 3.1 to 3.4 m. Estimated extreme wave heights as per Lognormal distribution are 4.97 and 7.72 m for return periods 10 and 100 y respectively. Gumbel distribution gives wave heights of 3.68 and 4.34 m for return periods of 10 and 100 y which confirms fairly well with the relationship reported by Larres[4]. Based on the present limited study, it appears that Gumbel distribution is more realistic for extreme value analysis for waves observed in the Bay of Bengal.

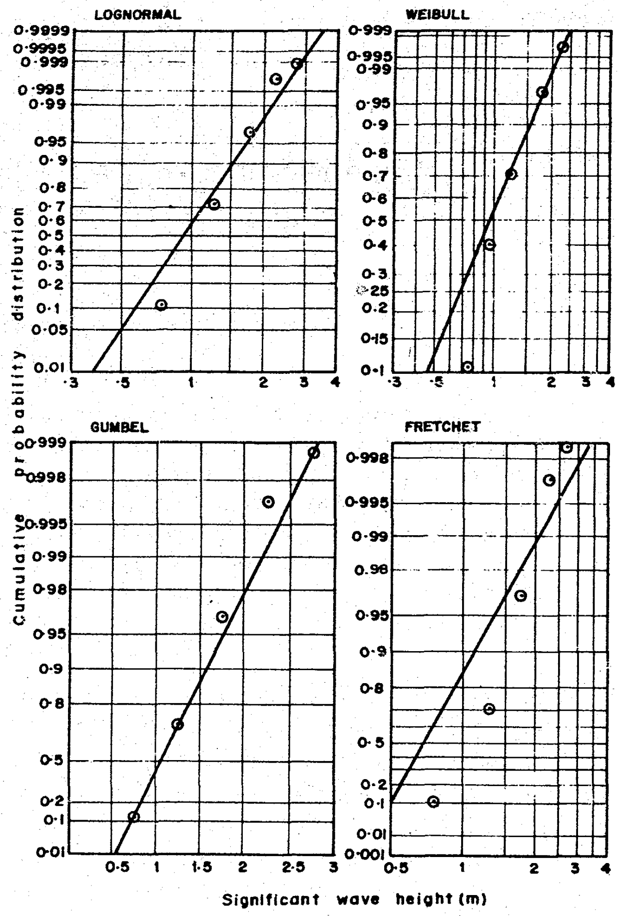

Fig. 1—Various longterm distributions for 1 y wave data

Table 1—Extreme wave heights (m) based on 1y wave data

Return Period (y)	Lognormal	Weibull	Gumbel	Fretchet
10	4.97	3.10	3.68	11.66
25	6.54	3.22	3.94	15.37
50	7.32	3.31	4.15	19.01
75	7.58	3.35	4.26	21.36
100	7.72	3.39	4.34	23.41

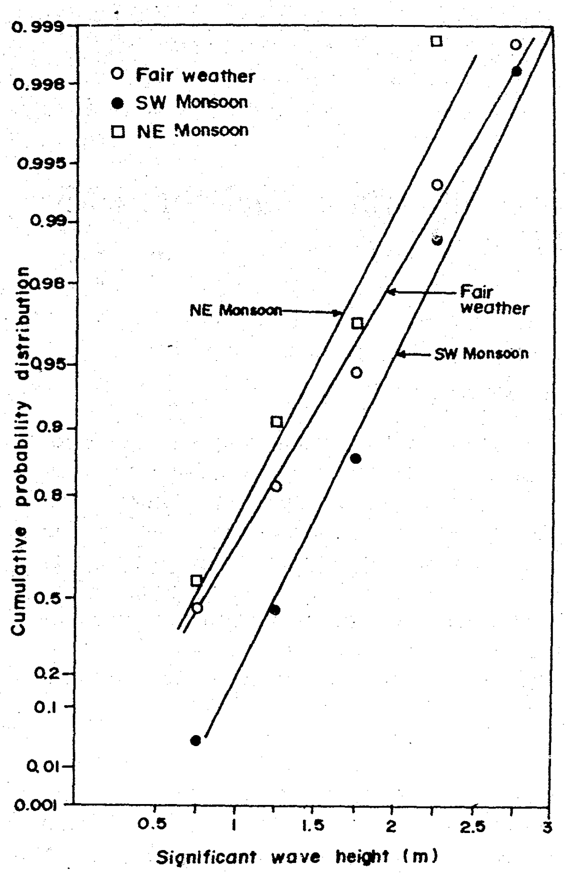

Fig. 2—Gumbel distribution for seasonwise wave data

Wave climate along the Indian coastal region is dominated by southwest and northeast monsoons and quite often, wave measurement programmes are limited only to monsoon period instead of covering 1 y cycle. The extreme wave heights are estimated with these limited data. To determine the extent of deviation of such an estimate based on limited seasonal data, wave heights were grouped for southwest monsoon (June-September), northeast monsoon (October-January) and fair weather (February-May) and analysed independently by Gumbel distribution.

Table 2—Extreme wave heights (m) based on seasonwise wave data using Gumbel distribution

Season	Return period in years				
	10	25	50	75	100
Fair weather (Feb.-May)	3.99	4.29	4.52	4.64	4.74
SW monsoon (June-Sept.)	3.81	4.04	4.23	4.33	4.41
NE monsoon (Oct.-Jan.)	3.35	3.64	3.79	3.89	3.97

Longterm distribution of these wave heights for 3 seasons as obtained by Gumbel distribution is presented in Fig. 2. Extreme wave heights for return periods of 10, 25, 50, 75 and 100 y are presented in Table 2. It is observed that the design wave heights arrived at, based on fair weather period waves and southwest monsoon waves, are higher by about 1.09 and 1.02 times than that estimated based on 1 y data. The extreme wave height for northeast monsoon wave data is low and is about 0.91 times that estimated based on 1 y data.

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