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MONSOON WAVE GROUPS OFF NORTH-WEST COAST OF INDIA

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ABSTRACT

Wave data collected at four different locations along North-west coast of India is analysed to determine extent of wave groupiness based on wave height series. Two different statistical methods proposed by Goda (1970) and Kimura (1980) are tested for computation of wave groupiness. Longest run of high waves contained 5 waves with $H > H_s$ and 14 waves with $H > H_m$. Correlation coefficient between successive wave heights noted is as high as 0.6 indicating high dependency and is found to be an important parameter in the analysis. Computational results show that the probability of occurrence of a group is predicted reasonably well by theory of Kimura which accounts for the memory between the successive wave heights. Data set for all locations is separated into growing and decaying states and analysis is extended to compare the groupiness parameters. This is also verified using peak spectral energy variation during growth and decay states. More pronounced group formation is observed in growing state in all four locations. Relatively smaller run length is observed in shallow water location than deep water region.

NOMENCLATURE

J_1	Average run length
J_2	Average of total run
Q_p	Spectral peakedness parameter $2 / (m \cdot m) \int_0^{\infty} S^2(f) \cdot f \, df$
$r_{HH}(1)$	Correlation coefficient with lag number one
σ	Standard deviation of wave heights
N	Number of zero-upcrossing waves
e	Spectral width parameter $(1 - m^2 / (m_0 \cdot m^4))^{.5}$
H_s	Significant wave height
H_m	Mean wave height
H_{max}	Maximum wave height

INTRODUCTION

Offshore activity along the West coast of India has considerably increased in recent years in connection with production of oil and natural gas, proposed installation of ocean energy plants etc. North-west coast of India has become a thrust zone from a strategic point of view as varieties of offshore platforms and rigs are installed for oil and gas exploration. Analysis of waves and evaluation of environmental parameters is of immense value as far as functional, operational and economy aspects of these structures are concerned. Knowledge of spectral density and probability distribution of wave maxima may not always provide an adequate description of random behaviour of ocean waves (Sarpakaya and Isaacson, 1981). Different types of damaging effects can occur due to grouping phenomenon even when energy spectra and wave height distribution patterns are identical (Johnson, et al. 1978). Wave group phenomenon is considered as an important factor in the analysis related to offshore structures, stability of rubble mound breakwaters, overtopping of waves above seawalls, slow drifting oscillations of moored vessels etc. In arriving at return period, correction factor needs to be accounted corresponding to the groupiness extent, considering the fact that the occurrence of large valued wave heights which tends to group together making average duration between successive storms containing a design wave larger than true return period (Nolte, 1973).

Present study on wave groups has been carried out considering these facts in view and efforts are made to determine the various groupiness parameters.

MONSOON WAVE DATA

Wave measurements are carried out using Datawell Wave Rider buoy at four locations along the North-west coast of India (Fig. 1). For the present analysis total of 135 monsoon

wave records are utilised. In Table 1, geographical feature of site, site code, period of wave data collection, number of records/waves and highest wave recorded are given.

software which checks raw data for spikes, steepness, constant signals, same signs etc. is used for the analysis. Samples with 2048 data points in 1024 sec. and number of waves between 40 and 600 and significant wave height less than 0.9 times maximum height are included. By using FFT algorithm raw spectrum is computed. Smoothed spectrum is computed by taking moving average of 8 raw spectral estimates. Various statistical wave parameters are obtained apart from spectral width and peakedness parameter.

Wave groups: Run occurs when wave heights exceed sequentially a level of significance H_s or H_m . Run length j_1 is the number of successive waves exceeding certain level and is a measure of groupiness. Goda (1970), proposed a theory of run length statistics based on the assumption that successive waves are independent. Average run length can be theoretically computed as,

$$j_1 = 1/(1-p) \quad \dots \quad (1)$$

and probability of wave group occurrence as,

$$P(j) = (1-p)(p)^{j-1} \quad \dots \quad (2)$$

Total run j_2 is defined as the number of wave heights between the exceedence of two successive group of waves above a certain level and is an indicator of frequency of occurrence of runs,

$$j_2 = 1/p + 1/(1-p) \quad \dots \quad (3)$$

Kimura (1980) presented a theory of run length for the case of mutually correlated wave heights on the basis of characteristics of Markov process. Following equations are used to obtain wave group parameters.

$$j_1 = 1/(1-p_{22}) \quad \dots \quad (4)$$

and

$$P(j) = (1-p_{22})p_{22}^{(j-1)} \quad \dots \quad (5)$$

where

$$p_{22} = \int_{H_s}^{\infty} \int_{H_s}^{\infty} p(H_1, H_2) dH_1 dH_2 \int_{H_s}^{\infty} Q(H_1) dH_1$$

$p(H_1, H_2)$ is the joint probability density function for two successive wave heights H_1 and H_2 , assuming wave heights follow Rayleigh distribution and $Q(H_1)$ is the probability density function.

Sequence of wave heights for a typical wave record is shown in Figure 2. This plot depicts the formation of wave groups with average run length j_1 and total run j_2 for waves exceeding significant wave height, H_s . Figure 3 shows variation of H_s over selected period of observation at different locations. For each location total data is divided into two groups, based on H_s recorded during growing wave height condition (G) or decaying condition (D) (Rye, 1974). Wave group parameters observed during these two cases are compared to identify the difference if any, in groupiness characteristics.

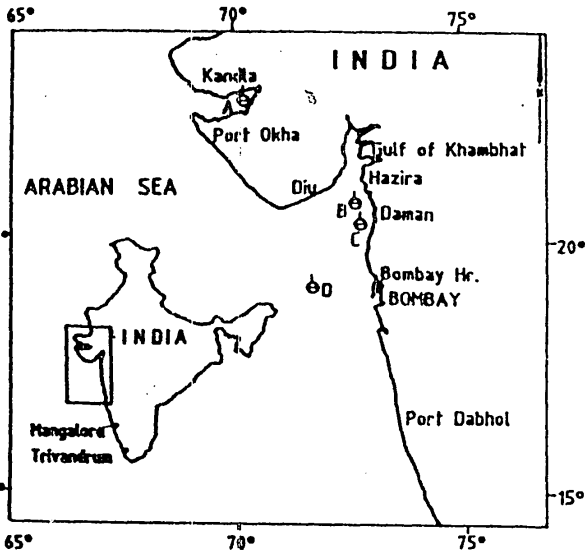


FIG.1 LOCATIONS OF RECORDING STATIONS OFF NORTH-WEST COAST OF INDIA

Table 1. Location map showing buoy stations

Buoy station	KANDLA	HAZIRA	DAMAN	BOMBAY HIGH
Location code	(A)	(B)	(C)	(D)
Water depth (m)	10	16	25	60
Distance (Km) from shore	0	16	25	150
Period	JUL 14	JUL & AUG 85	JUN 82	JUL 83
No. of records	32	29	28	46
No. of waves	916	5681	4827	6602
Max (m)	2.99	4.41	4.44	7.00

It is obvious that Bombay-High area belongs to deep-sea region, Daman belongs to intermediate water depth and other two locations are shallow water nearshore areas.

METHOD OF ANALYSIS

Statistical and Spectral Analysis: Digitized records of 20 minutes each on computer compatible tapes are analysed by zero-upcrossing and spectral methods. Specially developed

RESULT AND DISCUSSION

Run length statistics: In Table 2, average values of ordinary run, j_1 total run j_2 and length of conditional run containing H_{max} with waves exceeding H_s and H_m for each location are tabulated. Average run length

Table 2. Statistics of wave group parameters

Location	H > H _s			H > H _m			Corr. Coeff. $\sqrt{H/H}$ (1)	
	Run - j_1	Total Run j_2	Run with H _{max}	Run - j_1	Total Run j_2	Run with H _{max}		
KANDLA	(G)	125	16.70	172	2.33	5.25	6.44	0.325
	(D)	127	17.15	170	2.33	5.20	4.22	0.321
	(D)	129	17.70	170	2.33	5.12	3.93	0.314
HAZIRA	(G)	119	16.00	144	2.14	4.73	4.17	0.221
	(D)	117	16.03	141	2.07	4.61	3.89	0.282
	(D)	114	16.07	136	1.99	4.40	3.65	0.171
DAMAN	(G)	125	16.89	169	2.09	4.52	4.00	0.198
	(D)	120	16.14	154	2.09	4.55	3.86	0.176
	(D)	116	15.49	140	2.09	4.60	3.73	0.163
BOMBAY HIGH	(G)	143	8.57	253	2.30	4.06	5.00	0.273
	(D)	138	8.67	211	2.29	4.06	4.61	0.271
	(D)	135	8.77	203	2.29	4.04	4.58	0.268
THEORY (GODA 1970)	116	7.41	116	2.00	4.00	2.00		

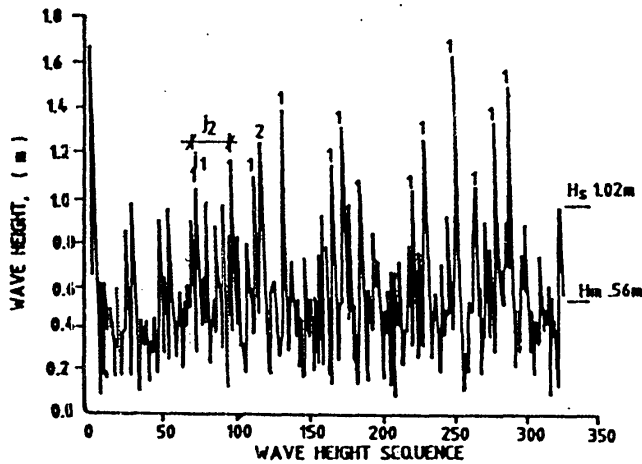


FIG.2 SEQUENCE OF INDIVIDUAL WAVE HEIGHTS FROM A TYPICAL RECORD (KANDLA, 1-7-1986, 1800 Hrs.)

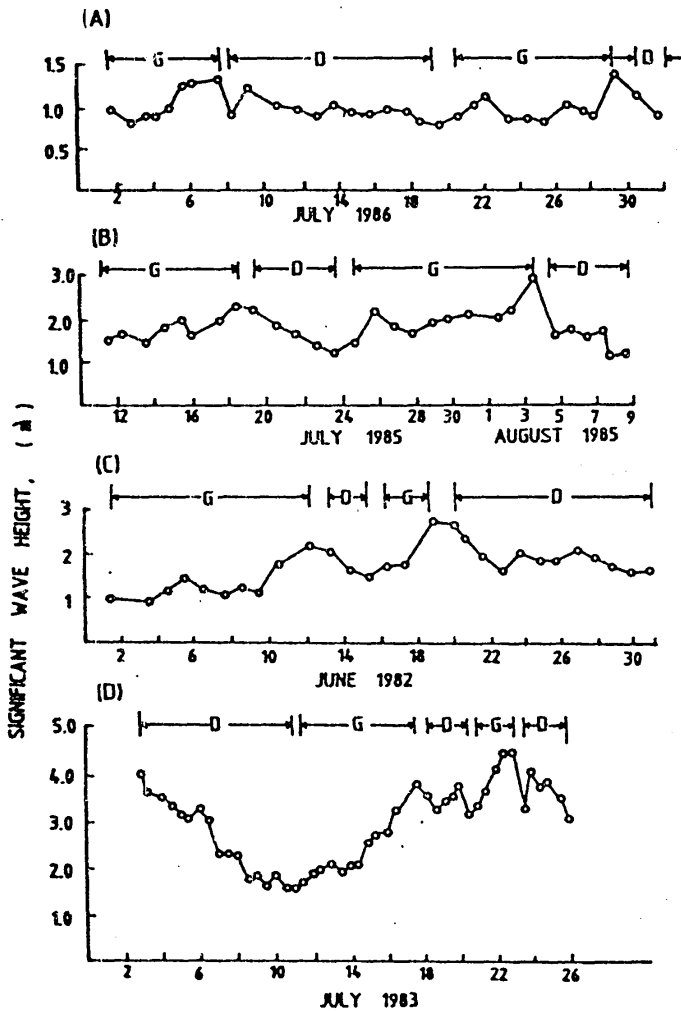


FIG.3 VARIATION OF SIGNIFICANT WAVE HEIGHT H_s

$j_1(H > H_s)$ of Bombay High region (deep sea) is found to be slightly greater than that of relatively shallow water locations. Total run j_2 of shallow water is as high as twice the values obtained for deep sea indicating a comparatively infrequent occurrence of groupiness in shallow water region. Thompson and Seelig (1984) showed that the shallowness of recording site has significant influence on the wave group parameter in surf zone.

Wave Spectra: Figure 4 is 3-D plot of spectral density showing actual picture of sea state during monsoon period for Bombay-High location. Early and later part of the

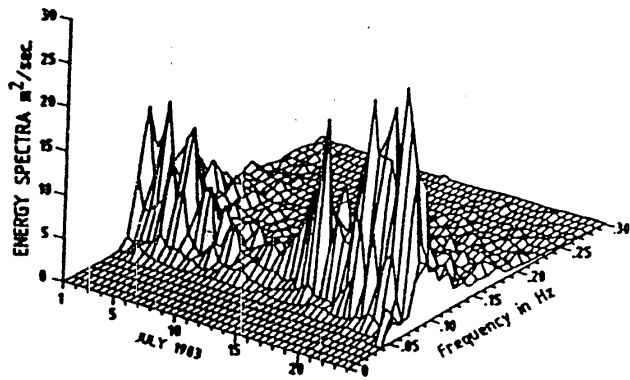


FIG.4 MONTHLY VARIATION OF WAVE SPECTRA

month July 1983 sea state is found to be of reasonably high wave energy with a calm state in middle of the month. This phenomenon is also seen in Figure 2 D, showing variation of H_s over the month. In order to distinguish the variation of spectra, contour lines of spectral densities are drawn for each location. Figure 5 is a frequency-time plot of wave spectra (Draper, 1976). Peak period for all records are ranges from 8 to 12 sec. Ridge line corresponding to peak frequency indicates the location of peak of energy spectra (Fig. 5 D). Maximum spectral energy which was $5.05 \text{ m}^2 \cdot \text{Hz}$ on 1st of July '83 1500H grew to $12.75 \text{ m}^2 \cdot \text{Hz}$ at 1500H on 11th and then decreased gradually to $2.36 \text{ m}^2 \cdot \text{Hz}$ at 1500H on 21st of July. This phenomenon is repeated with increase in spectral density to $26.6 \text{ m}^2 \cdot \text{Hz}$ at 1500H on 24th of July. Wave energy is distributed over a wide band of frequency ranging from 0.05 to 0.3 Hz with spectral width parameter β varying from 0.78 to 0.80 . Very low and multi-peaked energy spectra with maximum density of $2.5 \text{ m}^2 \cdot \text{Hz}$ are observed at intermediate and shallow waters as confirmed by Mandal and Nayak (1988). Distinct secondary peaks observed are due to 2nd and 3rd harmonics of main peaks caused by non-linear interaction of spectral components in shallow waters.

The average run length j_1 for $H > H_s$ and $H > H_m$ during growing state is found to be higher compared to that of decaying state. The j_1 ($H > H_s$) for growing state is 1.29, 1.19, 1.25 and 1.43 for Kandla, Hazira Daman and Bombay-high respectively whereas corresponding values for decaying state are 1.25, 1.14, 1.16 and 1.35. Another statistics of interest is the length of run containing maximum wave height called conditional run which indicates whether high wave comes singly or stick together. Observations noted in Table 2 confirm that higher waves come only in a group (Goda, 1970; Zuengi and Quihua, 1987). Analysis indicates that longest run contains 5 waves for $H > H_s$ and 14 waves for $H > H_m$ at all locations. Studies carried out by Dattatri (1983) for waves off Mangalore and Thomas et al. (1986) for swell waves off Trivandrum identified more than 5 waves in a longest run for

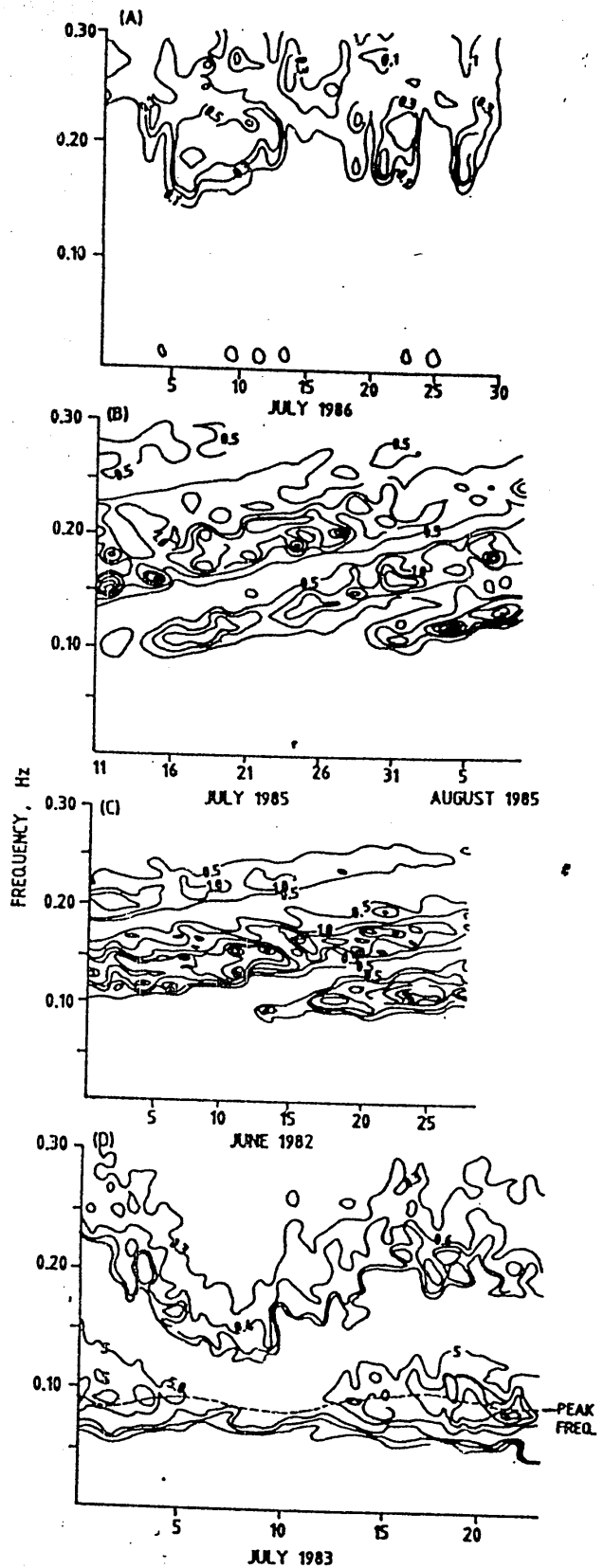


FIG. 5 SPECTRAL CONTOURS AS A TIME-FREQUENCY PLOT

H_m (for locations refer Fig. 1).

Probability of run length: Figures 6 A, B, C and D are plots for probability of run length of waves exceeding H_m and H_s . Theoretical probabilities of Goda (1970) (Eqn. 2) and Kimura (1980) (Eqn. 5) are also superimposed. The observed probabilities for total data with growing and decaying states are also marked. Average probability of group formation for the observed data indicates that Goda's (1970) theory predicts lower

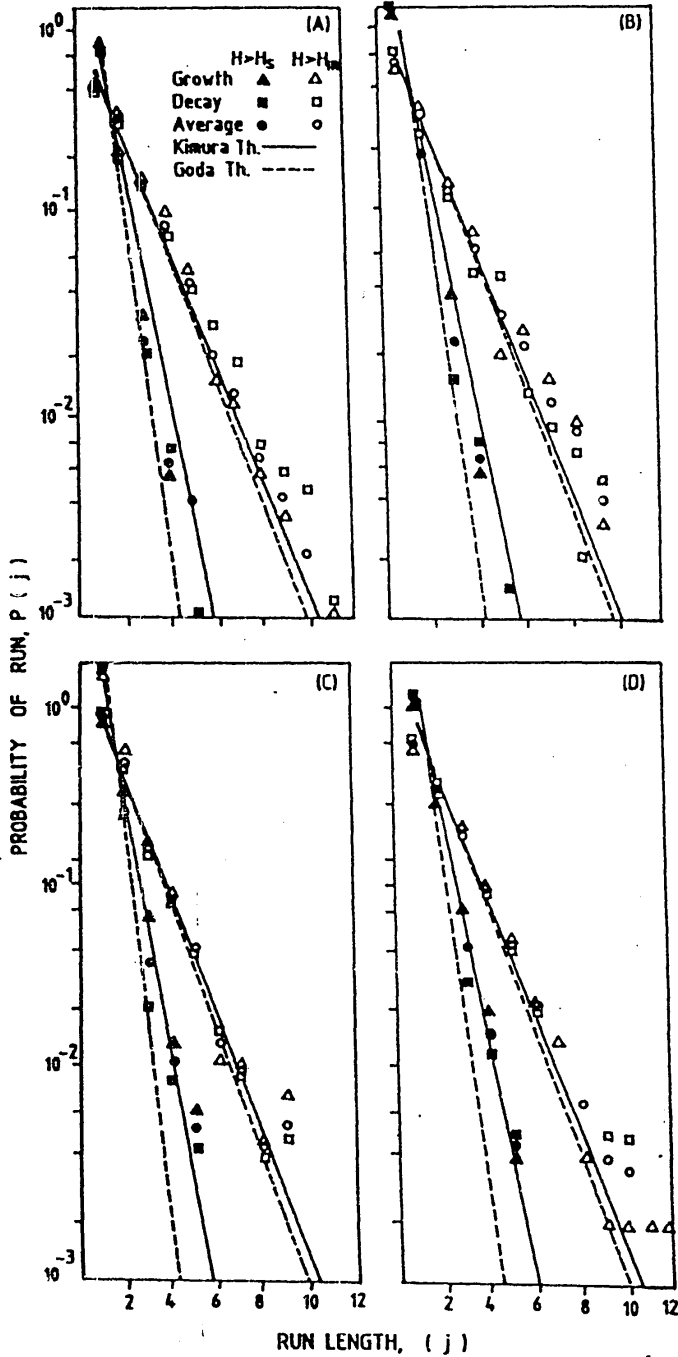


FIG. 6 PROBABILITY OF OCCURRENCE OF RUN LENGTH, $P(j)$ FOR WAVES EXCEEDING H_m AND H_s WITH THEORY

values whereas Kimura's (1980) theory seems to be in good agreement at correlation coefficient $\gamma_{HH}^{-1}(1) = 0.2$.

Considering the set of growing and decaying records separately, it is found that a trend of observed probabilities is higher in the former case for both $H > H_s$ and $H > H_m$. This is in agreement with results of Rye (1974).

Figures 7 A, B, C and D show the variation of average run length $j_1(H > H_s)$ with peakedness parameter Q_p . No significant difference is found between the two states. But data as a whole, show a trend towards an increase in j_1 is observed with an increase in Q_p . Similar observations have been made by Goda (1970), Dattatri (1983) and Thomas et al (1986). Deep water data of Bombay High (Fig. 7 D) shows relatively a better trend than that for shallow water data (Figs. 7 A, B and C). Thomas et al (1986) suggest that this departure may be due to the non-linear effect in shallow water. But Elgar et al (1984) explain that this is due to the neglected correlations of waves in a narrow band spectrum rather than non-linear effects and recommend the linear theory. However, spectral width parameter showed no systematic trend with variation of $j_1(H > H_s)$ for all locations and hence, not presented here.

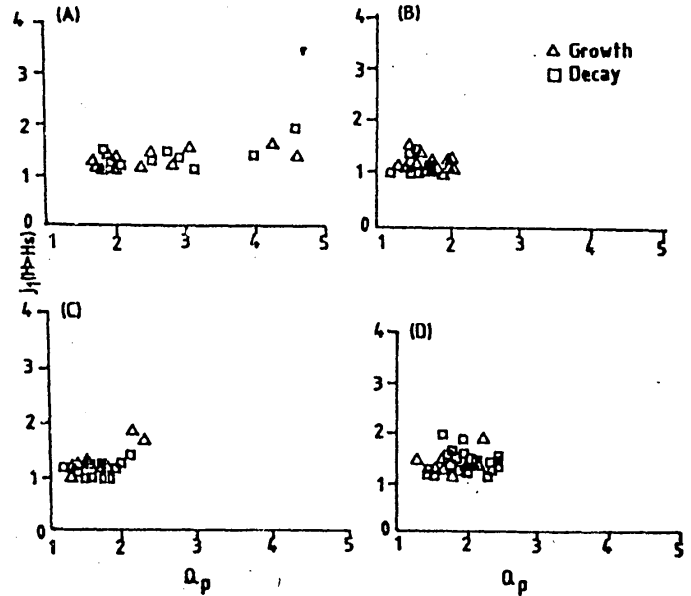


FIG. 7 VARIATION OF MEAN RUN LENGTH, $j_1(H > H_s)$ PEAKEDNESS PARAMETERS, Q_p

Correlation coefficient: Correlation between the successive wave height (Rye, 1974) is calculated using equation given below and average values are tabulated in Table 2.

$$\gamma_{HH}^{-1}(1) = 1 / (\sigma^{-2}(N-1)) \sum_{i=1}^{N-1} (H_i - H_m)(H_{i+1} - H_m)$$

On comparing $\gamma_{HH}^{-1}(1)$ for growing and decaying states greater values are observed in the

case of former indicating pronounced groupiness. It is observed that data points in Figure 8 for $\sqrt{HH}(1)$ v/s $j_1(H>H_g)$ are less scattered and more organised than in Figure 7 as observed by Thomas et al (1986). An increase of (1) is also observed at all locations. It may also be noted that theory proposed by Kimura predicts reasonably well, especially in deep water region.

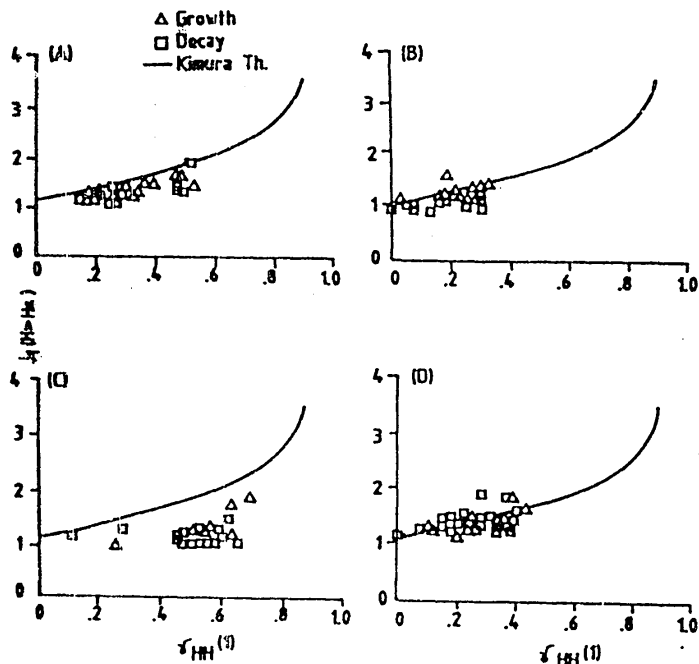


FIG. 8 RELATIONSHIP BETWEEN MEAN RUN LENGTH, $j(H>H)$ AND CORRELATION COEFFICIENT BETWEEN SUCCESSIVE WAVE HEIGHTS

Explanation for pronounced group formation in growing state may not be obvious because theoretically wave group formation tends to be more pronounced for narrow band spectra representing swell dominated decay state (Longuet-Higgins, 1957). Based on analysed field and simulated data Goda (1970) recommended Q_p as the controlling factor which is also supported by Rye (1974). However, relationship between j_1 and $\sqrt{HH}(1)$ explains the two states more meaningfully. This phenomenon may be due to the energy input to waves from wind during growing state which would result in generating higher waves with greater tendency to exceed certain wave height. Probability of group formation seems to be less in the case of decay state, in which the energy redistribution and transformation takes place.

CONCLUSIONS

1. Wave heights are mutually dependent. Correlation coefficient noted is as high as 0.6 and is an important factor in wave group analysis.
2. Wave groupiness is found to be slightly high in deeper water than shallow water and occurrence of groupiness in shallow waters

is comparatively infrequent.

3. More pronounced group formation is observed in the case of growing state due to the higher correlation between successive wave heights.

4. Kimura's theory seems to be a better fit for groups of waves off North-west coast of India.

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