Indian Journal of Marine Sciences
Vol. 9, March 1980, pp, 45-50

Wave Forecasting Methods & Their Applicability —A Case Study Off Visakhapatnam

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Received 18 *June* 1979; *revised received* 13 *August* 1979

SMB and PNJ methods of wave forecasting have been applied with some modifications for hindcasting waves in a case study, during the transit of a cyclone over Bay of Bengal. Significant wave periods calculated by these methods are completely different, out of which SMB periods are in good agreement with the observed wave periods in shallow water. Significant wave heights computed by the 2 methods are almost of the same order and well comparable with each other. However, SMB method is preferable since forecasting curves are available for higher wind speeds also and the resultant values are in better agreement with observed data. Wave heights in shallow water calculated for $f = 0.02$ seem to agree well with the observed values in both these methods.

Wave forecasting methods are used to predict wave characteristics in advance, so that amphibious operations can be planned and executed more efficiently. Wave hindcasting—the process of determining wave climate around any region based on meteorological information taken from old weather charts—is also made possible by the use of wave prediction techniques. Several wave prediction methods[1-4] are now available; but each of these is semiempirical or semitheoretical and is based on its own set of original data. The SMB[1] and PNJ[2] methods are the most widely used along the American and European coasts. The above methods can directly be applied to weather situations where uniform wind blows over a stationary fetch. Kaplan[5], Bretschneider[4] and Wilson[6] have shown that the same methods can be used with some modifications for predicting waves during cyclones. Since all the existing forecasting methods are based on the observations off the American and European coasts, the applicability and reliability of the methods for the Indian coasts have to be tested. This has been done by hindcasting the deep water wave conditions off Visakhapatnam for a typical cyclonic system in the Bay of Bengal and compared them with the observed wave data during the same period. The shallow water wave conditions near Visakhapatnam have been evaluated from the deep water wave characteristics by including correction terms due to bottom friction and shoaling and the values have been compared with the recorded nearshore wave data.

Methods

Reliable wave data collected for 1973 by the Visakhapatnam Port Authorities in connection with the outer harbour investigation work were used. A typical cyclone that occurred in the Bay of Bengal in Dec 1973 was selected for the present investigation. The system appeared as a low depression at lat. 6° and long. 87° on 5th December, intensified into a cyclonic storm by 8th, moved north-northwest almost parallel to the coast past Visakhapatnam and crossed the coast near Calcutta (Fig. 1). The movement of the storm was in such a manner that the fetch remained almost same during the transit of the cyclone while the wind speeds and durations varied gradually. SMB and PNJ methods of wave forecasting were applied to this case with some modifications. The entire step by step methodology followed in analysing the wind field and in evaluating the wave characteristics is given below.

The first task in wave forecasting is to select the optimum fetch line along which maximum waves are generated. To do this, the wave generating area for each synoptic map is delineated using the rules of thumb given by Kaplan[5]. Fetch lines in 4 different directions from the point of forecast (70°, 80°, 90° and 100° from N) are drawn and a number of points along the fetch line at intervals of 50 nautical mile have been fixed (Fig. 2A). The geostrophic wind velocity at the above points is directly read from geostrophic wind chart[7] for the known values of the isobar spacings and latitudes (determined from synoptic charts). The surface wind velocities are computed as per the procedure given by Bretschneider[7] from the knowledge of the sea-air temperature difference and isobaric curvature. The surface wind direction has been assumed to be around 18° towards the cyclone centre from the tangent to the isobars[8]. The computed wind speeds and directions at different points have been compared with

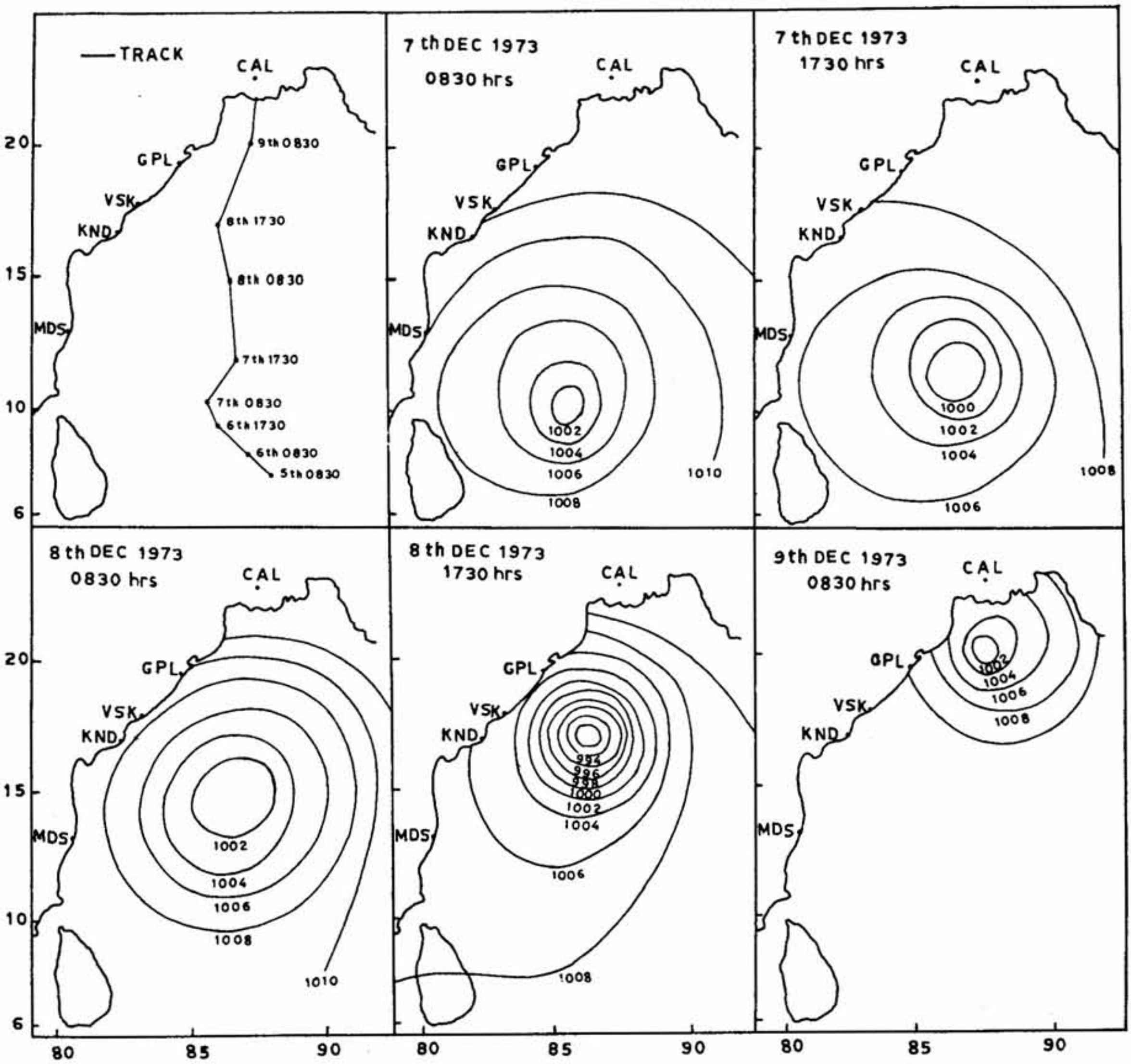


Fig. 1—Track of the cyclone and the synoptic maps

the available ship data in the neighbourhood as a cross check. The component of the wind velocity u in the direction of each fetch line is calculated for the pre fixed points. The squares of the wind velocity components along the lines with distance are plotted (Fig. 2B). The particular curve which contains maximum area beneath it corresponds to the optimum fetch line. The average wind velocity along the optimum fetch line for the first synoptic chart $\bar{u}_1$ has been calculated; similarly $\bar{u}_2$ for the next synoptic chart has been determined. If t is the time interval between the synoptic maps then the fetch is under the influence of $\bar{u}_1$ up to a time t/2 from the first synoptic map. From there onwards the fetch is considered to be under the influence of $\bar{u}_2$ up to a time t/2 from the second synoptic chart. In other words each synoptic map is assumed to represent an average picture in time on either side. Having determined the fetch, wind speed and duration, the significant wave height and period are readily obtained from the Bretschneider curves[4]. The value of E is read for the above wind field making use of the PNJ curves from which the significant wave height and period are evaluated as per Longuet-Higgins statistics[9]. Similarly for the 2nd synoptic map, average wind velocity component $\bar{u}_2$ along the optimum fetch line with corresponding duration is determined. But now the energy due to the waves already generated by $\bar{u}_1$ has to be added and this is done using a longer duration (effective duration) which is determined from the Bretschneider's constant energy curves[4]. Thus for the subsequent charts the optimum fetch line, the average wind component along this line and the effective duration constitute the wind field. The significant wave heights and periods computed from PNJ and SMB curves at specified times during the transit of the cyclone have been compared.

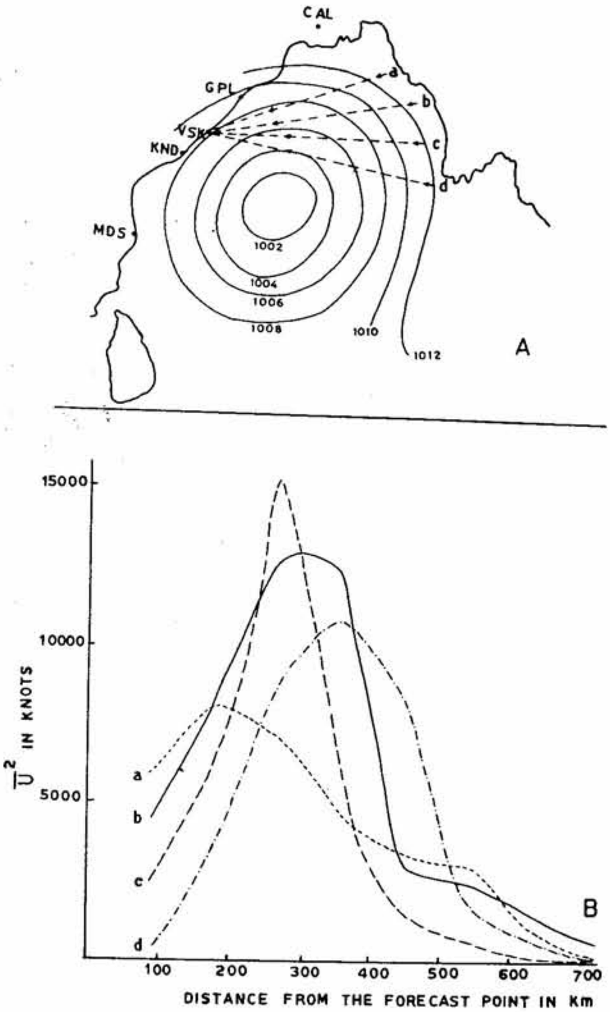


Fig. 2—(A) Fetch lines in different directions (a,b,c & d). (B) Determination of optimum fetch line

The above wave forecast is valid for deep water where the depth h is greater than one half the wave length. But as the waves enter shallow waters the wave heights are altered considerably although the wave periods remain almost unchanged[10]. Hence to compute wave heights in shallow water near the observation point off Visakhapatnam, the losses due to bottom friction, shoaling and refraction have to be taken into account. The refraction coefficient is taken as unity, since the bottom topographic variations up to the observation point are fairly regular and gradual. The losses due to bottom friction and shoaling are evaluated as described by Bretschneider[11]. Since the value of coefficient of friction f, given by various workers in this field[12], varies from 0.01 to 0.05, the computations for 3 values of f (0.01, 0.02 and 0.05) have been carried out to see which of the transformed waves are nearer to the observed ones.

Results and Discussion

Fig. 2A represents a typical synoptic map on which fetch lines in different directions are drawn, and Fig. 2B shows $\bar{u}^2$ versus distance from the coast along each fetch line. It is evident from these curves that the curve b encloses maximum area with the x-axis and this corresponds to the optimum fetch line. Further it has been found on analysis that the fetch line b is the optimum fetch line for all the 5 synoptic situations presented in Fig. 1. This is possible because the transit of the cyclone has been in such a way that the fetch is almost stationary. In Table 1 computed values of the surface wind speed along the optimum fetch line at different points at intervals of 50 nautical mile are presented for the corresponding values of the latitude φ and the distance between the isobars ΔN. A few observed values at the specified times and locations as reported from nearby ships are presented in the next column for comparison. Although the observed values are very few, they are sufficient to show a good agreement between the computed values and the observed ones. The angle between the wind direction and the optimum fetch line (α) is entered in the next column. The values of the wind component along the optimum fetch line (u) in the Table show variations with distance from the coast. The average wind speed within the minimum fetch for each case ($\bar{u}$), as entered in the last column, varies with time. At 0830 hrs on 7th Dec the $\bar{u}$ value is about 24 knots while it decreased to about 16 knots at 1730 hrs on the same day. But on the next day it gradually increased and reached a maximum value of about 94 knots by 1730 hrs.

Table 2 shows the values of the significant wave height (H_S) and the significant wave period (T) in deep water as computed separately by SMB and PNJ methods for the specified times. The wind field parameters, viz. fetch (F), average wind speed ($\bar{u}$) and the effective duration (t) are also presented in the Table. The fetch length in general is more than the required minimum fetch; but the duration is less than the minimum duration except for the last case where the fetch is less than the minimum fetch. Thus duration limited cases are encountered most of the time while the last case happens to be a fetch limited case. The wave characteristics where wind speeds exceeded 52 knots could not be calculated by PNJ method since PNJ curves are not available for higher wind speeds.

SMB wave period has decreased from 5.8 sec on 7th Dec at 0830 hrs to 5.4 sec at 1730 hrs on the same day. Decrease in wave period, inspite of a large increase in the effective duration during the interval, occurs because of the decrease of the wind speed from about 24 to 16 knots. But the PNJ wave period during the same time has increased from 8.4 to 9.5 sec following the increase in the effective duration. On 8th Dec at 0830 hrs the SMB wave period increased to 9 sec, inspite of a considerable decrease in the effective

Table 1—Computation of Surface Winds within the Fetch

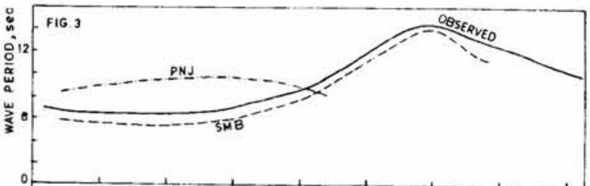
Time (hrs, IST)	Distance from forecast point (nautical mile)	Latitude (φ) deg	Isobar separation (ΔN) (nautical mile)	Wind speed knots		α deg	Wind component (U) knots	Av. wind speed ($\bar{u}$) knots
				Surface (U_S)	Observed (U_O)			
				7-12-73				
0830	50	17.7	39.7	26.9	—	9	26.6	
	100	18	43.7	24.9	—	8	24.7	24.5
	150	18.1	47.6	22.4	20	10	22.1	
1730	50	17.7	75.4	15.4	—	5	15.3	
	100	18	71.4	15.4	—	12	15.1	15.7
	150	18.1	67.5	18	15	14	17.5	
	200	18.2	77.4	15.7	—	18	14.9	
				8-12-73				
0830	50	17.7	27.8	41.9	—	32	35.5	
	100	18	29	39.9	35	20	37.5	40.8
	150	18.1	23	47.5	—	11	46.6	
	200	18.2	25.8	44.2	—	7	43.8	
1730	50	17.7	15.1	82.8	—	41	62.5	
	100	18	11.9	94	85	15	90.9	93.3
	150	18.1	9.5	113.1	—	4	112.8	
	200	18.2	7.9	123.9	—	35	106.9	
2130	50	17.7	12.2	82.8	—	65	34.9	
	100	18	11.9	94	—	59	48.4	
	150	18.1	11.8	98.7	—	38	78.5	55.5
	200	18.2	8.5	122	—	58	64.7	
	250	18.4	7.6	135	—	68	50.6	

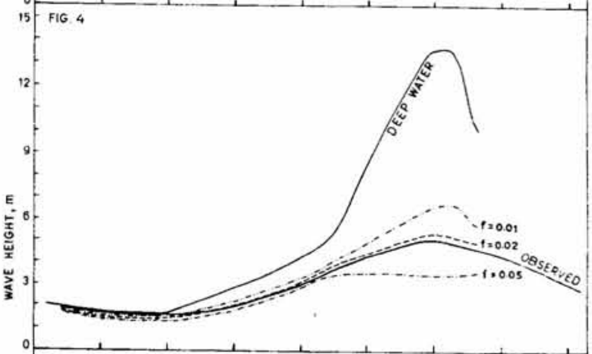
Table 2—Deep Water Wave Characteristics (Computed)

Time (hrs, IST)	Fetch(F) (nautical mile)	Wind speed ($\bar{u}$) knots	Effective duration (t) hr	Significant wave period (T) sec		Significant wave height (H_S) m	
				SMB	PNJ	SMB	PNJ
				7-12-73			
0830	150	24.5	9	5.8	8.4	2.1	2.8
1730	200	16	74	5.4	9.5	1.77	1.34
				8-12-73			
0830	200	41	9	9	8.5	5.12	4.33
1730	200	93.5	6	14.2	—	13.4	—
2130	250	55.5	38	11.8	—	10.36	—

duration, which again may be attributed to the increase in wind speed during this time. PNJ wave period during the same interval decreased inspite of a considerable increase in the wind speed which may be attributed to the decrease in the effective duration. Thus the SMB wave periods seem to be controlled more by the wind speed rather than the duration; while the PNJ wave periods are better controlled by the effective duration. It has to be kept in mind that the term wave period here actually refers to the significant wave period; which is the average period of the 1/3 highest waves in the spectrum. According to PNJ method an increase in the wind speed seems to alter the wave spectrum in such a way that the significant period actually shifts towards lower values as higher and higher waves with smaller periods start forming. The periods computed by SMB and PNJ methods are completely different and there is no comparison. The computed values have to be compared with the observed periods to judge which of the 2 methods is more accurate. Since the observations on wave periods in deep water are not available, the observed periods in shallow water off Visakhapatnam are used for comparison. This can be done because there will not be much change in the wave periods due to shallow water effect[10]. The computed wave periods through SMB and PNJ methods as well as the corresponding observed wave periods are plotted (Fig. 3). There is a good comparison between the computed SMB wave periods and the observed wave periods while the comparison with PNJ periods is very poor. Thus SMB method seems to be more accurate and practicable for the computation of wave periods. However, a comparison of the computed values with recorded wave observations in deep water has to be made if this is to be confirmed.

Deep water wave heights—The significant wave heights in deep water, computed through SMB and PNJ methods, are given in the last 2 columns of Table 2. The wave heights generally follow the changes in wind speed both in SMB and PNJ methods. At lower wind speeds (in most of the cases) SMB method seems to give lower values compared to PNJ method, while at higher wind speeds the PNJ method gives lower values than SMB method. This happens because the minimum fetch and duration are small in PNJ method than in the SMB method, with the result that waves stop growing in PNJ method much earlier than that in





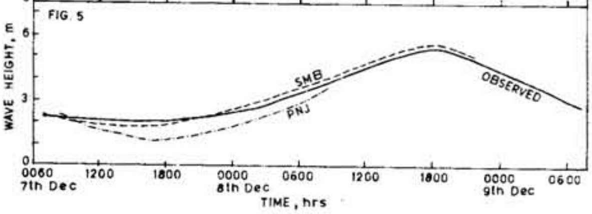


Fig. 3—Comparison of the computed SMB and PNJ wave periods with observed values

Fig. 4—Shallow water wave heights for different values of f

Fig. 5—Comparison of the calculated shallow water wave heights with observed values

Table 3—Shallow Water Wave Heights (Computed)

Time (hrs, IST)	Depth at which shallow water effect starts m		Significant wave heights (H_S) at forecast point m	
	SMB	PNJ	SMB	PNJ
		7-12-73		
0830	26.23	54.91	2.07	2.24
1730	22.88	70.46	1.74	1.11
		8-12-73		
0830	63.13	44.52	3.88	3.52
1730	157.3	—	5.3	—
2130	108.6	—	4.99	—

the SMB method. However, the order of the wave heights calculated by SMB and PNJ methods are the same for the situations considered.

Shallow water wave heights—A proper value of the frictional factor f has to be selected for computing the wave heights in shallow water from those in deep water. Since various workers[12] suggested different values for f ranging from 0.01 to 0.05, the wave heights have been calculated for 3 different values (0.01, 0.02 and 0.05) and presented in Fig. 4 along with deep water wave heights calculated from SMB method. The shallow water wave heights as shown in figure are very much reduced as a result of the shoaling and frictional effects. The computed values nearly coincide with the observed values for $f=0.02$. The shallow water wave heights at the forecasting point as obtained from SMB and PNJ methods are presented in Table 3. Since SMB and PNJ wave periods are different, the corresponding wave lengths also happen to be different for each case. As a result of this, the depth h (L/2) at which the shallow water effect starts is not the same in the 2 methods (Table 3). The wave heights calculated at the forecasting point using the 2 methods are of the same order, comparable and in good agreement with the observed wave heights (Fig. 5) at the forecast point.

Acknowledgement

The authors thank the Visakhapatnam Port authorities for supplying recorded wave data. The junior authors are indebted to the CSIR, New Delhi for the award of research fellowships.

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