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Waves in a cyclone field

A. K. MUKHERJEE
Meteorological Office, Pune
and
T. R. SIVARAMAKRISHNAN
Cyclone Warning Radar Station, Port Trust Building, Madras

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सार – मई/जून 1976 के गोपनाथ चक्रवात के झंझा क्षेत्र में बनीं पवनों/तरंगों की वास्तविक समय मापों से चक्रवात में तरंग बंटन का एक निदर्श विकसित किया गया है और उसके अभिलक्षणों का वर्णन किया गया है । समागमित तरंगों की ऊर्जा की गणना की गई है । पवनचाल और तरंग ऊंचाई से संबंधित अनेक सूत्रों की उपयुक्तता की भी जांच की गई है । अघूर्ण तरंगों के लिए कुछ परिवर्तन के साथ ओ० एम० फिलिप्स का निदर्श उपयुक्त प्रतीत हुआ है ।

ABSTRACT. From the real time measurements of winds/waves made in the storm field of Gopnath cyclone of May/June 1976, a model for wave distribution in a cyclone has been proposed and the characteristics described. The energy of the waves encountered has been calculated. The validity of the various formulae relating wind speed with wave height has been tested. O. M. Philips' model for irrotational waves is found to fit in with some deviations.

1. Introduction

Generation of water waves from the storm field is the result of high wind speeds associated with the energy transfer. The energy of the waves could sustain for long so much so they travel even to far away distances as 'swells'. Several investigators like Sverdrup (1947), Munk (1951), Eckart (1953) and Philips (1957) attempted to explain the mechanism of wave growth and decay. Nevertheless the rigorous applications on operational basis are limited as observations from storm fields were lacking normally and hence the verification could not be completed. Ever since the oil findings over Bombay High area some rigs are stationed and they record observations on waves and meteorological conditions. The severe cyclonic storm of May/June 1976 passed through Bombay High area. The analysis of the data reveals some interesting results about waves apart from surface winds (Mukherjee and Sivaramakrishnan 1977).

2. Data

Three jack up rigs — *Sagar Samrat, Hakon Magnus* and *Shenon Doah* were located over Bombay High area which had recorded continuous observations. The part of storm track along with the positions of the rigs is given in Fig. 1.

The present set of observations is most interesting so far as detailed observation on waves/winds in the hurricane field are seldom available. The only set of complete observations due to Arakawa (1953) was taken on board ships and some amount of subjectivity, especially for waves must have entered, because the platform on which the observers are standing were not steady. In the present case, the rigs were standing on legs in the part of the sea where the depth is between 81 to 84 metres. The observations are taken with reference to the markings on the legs and hence they were very accurate. Moreover the rigs were steady and as such the subjectivity in observations is minimum under the existing rough weather conditions.

3. Results and discussion

The wave record is given in Fig. 2. All diagrams given in this paper contain wave length in feet since the original data were in FPS units.

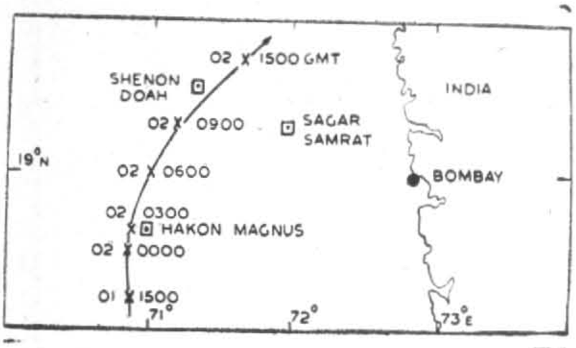

Fig. 1. Position of drilling rigs and track of storm

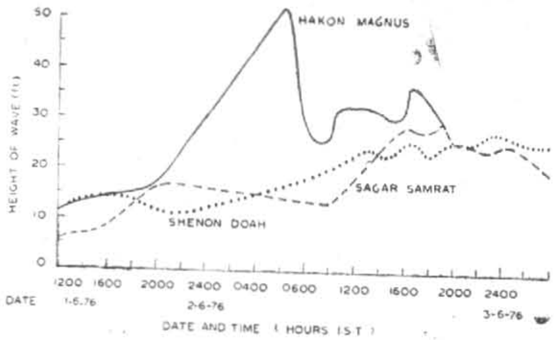

Fig. 2. Waves observations

Hakon Magnus recorded in general highest values always. In fact the eye of the cyclone passed over the ship. Corresponding to the first maximum peak of wind recorded by her, waves attained the maximum height of about 50′ (nearly 15 m). The eye passed then and the wave height fell. But corresponding to second peak, the wave height had not increased sufficiently as happened for the first peak. The reasons may be as follows :

As the storm approches the area is nearing to the eyewall and hence steadily windspeed inincreases. So the growth of wave has started already. In other words, the peak wind speed affects a troubled sea and so the maximum wave height occurs. But all the roughness is gone when the eye is over the area. Now suddenly strong wind blows. Hence part of energy has to be spent on wave generation and the remaining only on wave growth.

The composite of wave field (Fig. 3) is interesting. Here the core of maximum wave height is spread in both front and rear sectors of right side of the storm. Comparing this with Arakawa model, the isopleths showed the core of maximum wave heights to the rear side of his model. In our case viewing from the centre, wave height decreases rapidly on the right front quadrant whereas it decreases slowly in the right rear quadrant. This may be because of the feed due to monsoon current which the storm had brought with it.

Fig. 4 gives the wave direction composite. The region of confusion pervades to the right rear sector from the centre whereas the waves emnate out to the front.

The maximum energy of the waves recorded by each ship could be estimated. The values are:

1.72×10^6 Joules for *Sagar Samrat.*

5.01×10^6 Joules for *Hakon Magnus.*

1.18×10^6 Joules for *Shenon Doah.*

all values per metre of waves crest per wavelength. The wave height of the wave with the above energy was 30 ft. (*Sagar Samrat*), 52 ft (*Hakon Magnus*), and 28 ft (*Shenon Doah*) respectively. Assuming energy of waves is due to transfer of kinetic energy from water surface interaction *in situ,* Emax is expected near the centre of the storm. This is confirmed by the value we get for *Hakon Magnus.*

Estimate of wave height from surface wind considerations has been tried. The height in feet of the greatest waves of high wind speeds is normally about 0.8 of wind speed in kt. (H. O. Publn. 604). Scripp's Institution has devised a formula as $H = 0.022\ U^2$ where U is in knots., H is in feet when the entire range of wind speeds is considered. Again Suthen (1945) has given the same at $H = 0.026\ U^2$ from the equivalent simple wave consideration. These two approximations respectively yielded 220 and 250 feet for the waves. The WMO Tech Note (1976) on wave forecasting has presented a graphical form for such calculations.

Again several others like Darbyshire (1959) gave formulae for the same. But these methods are rigorously applicable when the sea is fully developed. With such hurricane wind strength, the fully developed seas can be obtained and hence the validity of different formulae were tested. The results are produced in Table 1. It is inferred that WMO Tech Note method gives a value within 10% of the observed value for the wave height.

Among the various theories some take the motion of waves to be rotational while some assume it to be irrotational. Gerstner (1802) and Rankine (1863) formed their theories on the assumption that the waves are rotational. They suggested the vorticity for the waves to be given by :

$$\zeta = \frac{-2\sigma\, a^2 k^2 e^{2kz_0}}{1 - a^2 k^2 e^{2kz_0}}$$

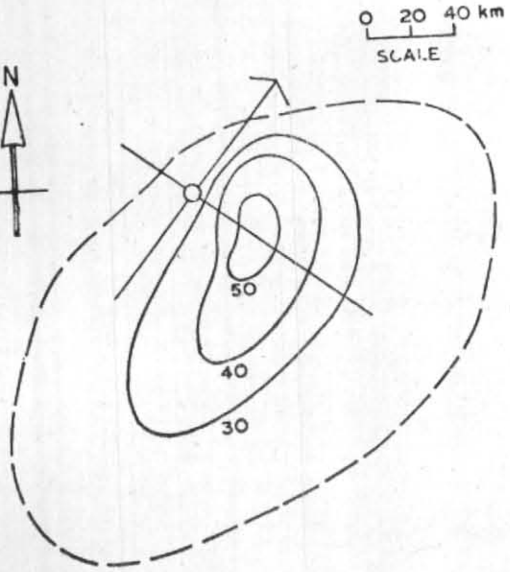

Fig. 3. Composite of wave height chart (in feet)

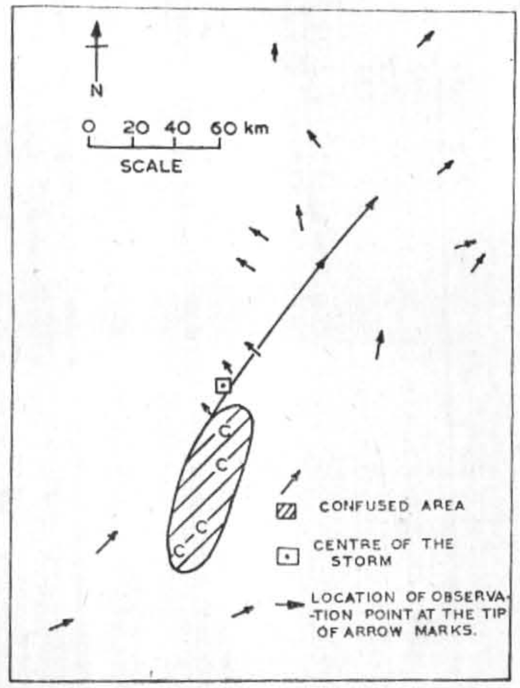

Fig. 4. Direction of swell storm over area

where, K is wave number. $\sigma = 2\pi / T$, where

a = amplitude and T is wave period. The standard method used in meteorology is to arrive at the vorticity from surface wind considerations. As the two measurements are at surface level, they should be of same order if not exactly the same. But when the values of vorticity were calculated, for different grid points, the values calculated from wave consideration were of the order 10^{-6} sec^{-1} while these from surface wind considerations ranged from 10^{-3} to 10^{-4} sec^{-1}. Thus the values from wave consideration, were two to three order less. Hence the waves are taken to be irrotational.

Hence an irrotational model was attempted. Of the different models Philips' (1957) is preferred as it arrives at the result without any specific assumptions such as sheltering hypothesis of Jeffreys or the assumptions of energy transfer of Sverdrup and Munk. Accordingly, the mean square surface displacement is given by :

$$\overline{X}^2 = P^2 \, t / 2\sqrt{2} \, \rho \, U_c \, g$$

where,

P = Value of pressure component

t = elapsed time

ρ = density of water

U_c = Convection velocity

g = Acceleration due to gravity

TABLE 1

Method	Formula	Calculated value
Scripp's Institution Method	$H=0.026\ U^2$	260 feet
Suthen's (1945) formula	$H=0.022\ U^2$	220 feet
Darbyshire's formula	$H=1.39\times10^{-4}U^2$	36.69 m
SMB curves	$H=2.667\times10^{-4}U^2$	70.4 m
Neumann's method	$H=7.065\times10^{6}\times U^{5/2}$	133 m
Wave forecasting diagram of WMO Tech No. 446	——	16 m
H. O. Publication No. 604	$H=0.8\times U$	80 feet

Note : The wind velocity considered for the above calculations was 100 knots, *i.e.*, 5138 cm per second.

In order to apply the theory, the quantities must be converted to elements which are measured in meteorology. Russel and McMillon (1952) has established wave height

H is as $H^2 = 8\overline{X}^2$

P is from $P = A \, \rho_a \, U^4_x$

where, A is constant

ρ_a = density of air

U_x = friction velocity

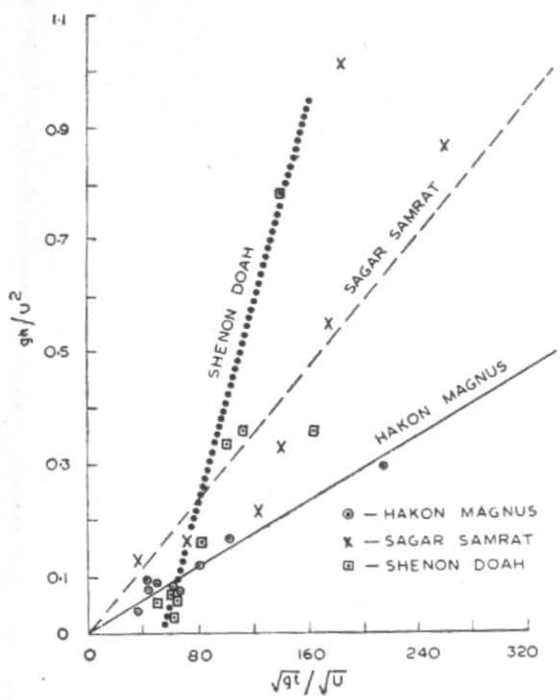

Fig. 5

Taking $U = 18\ U_x$ and combining all the final result is

$$gH / U^2 \propto \sqrt{gt} \,/\, U$$

The results are produced in Fig. 5. It is seen that points corresponding to wind speeds less than 20 kt are not fitting. The linear relationship is obeyed for higher wind values. *Shenon Doah* curve has an intercept in time axis. This can be understood thus : The cyclone is moving NEwards, so to the right sector, direction of cyclone's movement and wind velocity of circulation are same. Hence wave travel direction also must be same. But to the left of the eye, the wind direction and the direction of velocity of system are opposing. To attain steady growth of waves, initially some work is to be done against the momentum component of the system. Till then the wave height increase will not be strictly in accordance with wind speed and time of blow. But after sometime, the wave height increase becomes in phase with wind speed and time. Thus the intercept in axis. However the different values of the slopes for the three sets of observations could not be understood.

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