Wave Study for Tidal Power Project at Gulf of Kachchh

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Synopsis

The paper presents the results of analysis of one year data on waves measured at the Hansthal Creek in the Gulf of Kachchh in connection with the proposed 900 MW tidal power project. The field measurement on waves was done by installing a wave rider buoy. Time series data on waves were recorded on chart paper rolls as well as digital cassette tapes. Data were analyzed using the Tucker's method, zero up-crossing method as well as the spectral method. An attempt to predict design wave height was made using Weibull distribution.

Introduction

Three important areas have been identified as potential sites for developing tidal power projects in India. They are Gulf of Khambhat and Gulf of Kachchh in Gujarat on the west coast and Sunderbans in West Bengal on the east coast (Wilson 1979). At the request of the Central Electricity Authority, New Delhi, the National Institute of Oceanography undertook environmental and sea bed surveys at the proposed tidal power project in the Gulf of Kachchh as a part of the techno-economic feasibility study on a 900 MW tidal power plant across the Hansthal creek. Measurement and evaluation of the wave data forms one of the investigations undertaken by the Institute.

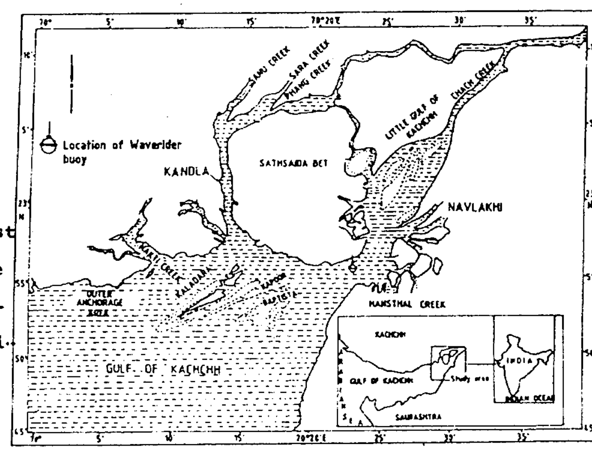

Figure 1: Location Map Indicating Position of Wave Rider Buoy.

Site Description

The Gulf of Kachchh is an east-west indentation in the Gujarat coast of India. The inner gulf is, however, oriented in the northeast-southwest direction. The Gulf of Kachchh presents a complex tidal regime marked by the existence of shoals, channels, inlets, creeks and islands. The innermost part of the gulf has an intricate creek system of which Kandla and Hansthal are very prominent. Figure 1 shows the location of the wave measurement station at which a wave rider buoy was installed and operated by the National Institute of Oceanography, Goa for measuring time series data on waves for about a year. Being a tide-dominant regime, a current velocity of over 2 to 3.5 knots (1.0 to 1.8 m/sec) occurs in the gulf (Sharma and Devasahayam, 1985). The gulf has a tidal range of over 4 m at Kandla and Navlakhi which increases further towards the north.

Equipment and Methods

Wave Rider Buoy

A 90 cm wave rider buoy designed to float and follow the sea surface was moored in the Hansthal creek where the water depth at low tide was about 15 m (Figure 1). The change in vertical acceleration caused as a result of the rise and fall of the moored wave rider is sensed within the buoy housing by a stabilized accelerometer. The water particle displacement is then obtained by twice integrating the acceleration through an electronic circuitry. The wave rider is designed to transmit the information it measures to a recording station located within a distance of 50 km. The D.C. signal analogous to wave height is converted into F.M. square wave amplitude which modulates the transmitter signal at frequencies between 27.5 and 27.75 MHz.

Wave Rider Receiver/Recorder System (WAREP)

WAREP is an instrument which receives and demodulates the F.M. signals from the wave rider buoy and records the time series wave height data on a chart paper roll and simultaneously sends the converted signals to the Digital Magnetic Tape Recorder (DIMA) for recording digitized data at 0.5 sec intervals on a magnetic cassette tape. The programmable clock is generally set to obtain 20 minute records of waves every 3 hours.

Mooring System

The wave rider mooring system used at the Hansthal creek is illustrated in Figure 2.

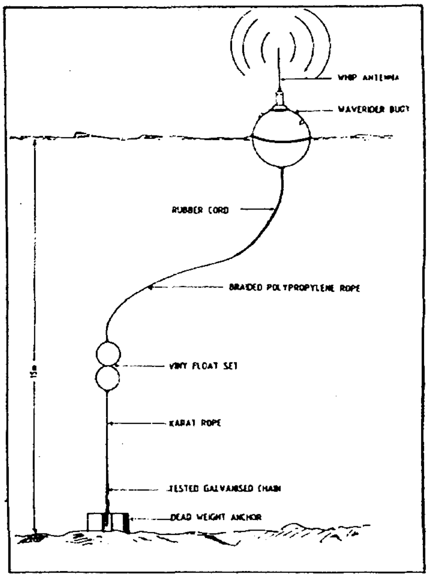

Figure 2: Wave Rider Buoy Mooring System.

The mooring arrangement consisted of a rubber cord of 15 m length, a 20 m long braided polypropelene rope, a set of Viny floats to provide 40 kg buoyancy, a 5 m long Karat rope and a bottom dead weight anchor weighing about 300 kg.

Methods of Data Processing and Analysis

Each 20 minute time series record of waves obtained on chart paper roll was analyzed using Tucker's method (Tucker, 1963). The statistical relationships used are the following:

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

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

Where

m_o = Root mean square deviation of the water surface.

A = Height of the highest crest in each record.

B = Height of the second highest crest in each record.

C = Depth of the lowest trough in each record.

D = Depth of the second lowest trough in each record.

N_z = Number of zero up-crossing waves in each record.

N_c = Number of crests in each record.

H_1 = (A + C) and H_2 = (B + D)

T_z = Zero crossing wave period = $\frac{120}{N_z}$ sec.

Highest value of m_o obtained from equations (1) and (2) above was used for computing the significant wave height, H_s for each record from the statistical relationship:

$$H_s = 4\sqrt{m_o} \quad \ldots (3)$$

Steepness parameter $S = \frac{H_s}{L}$ was computed for each record using the significant wave height, H_s and the wave length, L corresponding to the water depth, d. Spectral width parameters ∈ is computed from the equation

$$e = \left[1 - \left(\frac{N_z}{N_c}\right)^2\right]^{\frac{1}{2}} \quad \ldots (4)$$

Digital data recorded on magnetic cassette tape were analyzed using the software package 'NEPTUN' which takes 2048 data points from each 20 minute record for time series analysis. Fast Fourier Transform (FFT) method was used for computing the periodogram or raw spectrum of the wave record using the equation,

$$S(f) = \frac{1}{N_{fo}} \left[\sum_{j=o}^{j=N-1} x(j)\, e^{-ij\lambda} \right]^2 \quad \ldots (5)$$

where $\left[x(j)\right]_{j=o}^{j=N-1}$ is the time series

$\lambda = \frac{2\pi f}{f_o}$

f = frequency = 0, $\frac{f_o}{N}$, $\frac{2f_o}{N}$, ...

f_o = 2 H_z, sampling frequency and

N = 2048

A smoothed spectrum is computed by taking moving average of 8 spectral estimates of the raw spectrum.

Zero Up-crossing Method

In this method, the waves and their corresponding periods are identified when the time series record crosses the zero level from -ve to +ve values. Statistical wave parameters such as significant wave height, H_s = average of the one-third highest waves in the record; significant wave period, T_s = average period of the one-third highest waves in the record; zero upcrossing period, T_z = average of the zero upcrossing waves etc. were computed. Zero upcrossing method constitutes an integral part of the NEPTUN Software package.

The raw data is subjected to various checks for spikes, steepness, constant signals etc. and the computed results are also subjected to certain checks to have control over the quality of the data. All these checks and controls are also incorporated in the "NEPTUN" Software package.

Results and Discussions

Variation of wave heights, wave periods and spectral width parameter monthwise is presented in Table I.

TABLE - I

Distribution of H_s, T_z, H_{max}, TH_{max} and ϵ

Month and Year	Sig. wave height, Hs in metres.	Zero crossing wave period Tz in sec.	Max. wave height, H_{max} in metres.	Period of Max. wave TH_{max} in sec.	Spectral width parameter ϵ
June 86	0.36-1.40	3.11-7.06	0.60-2.50	3.0-7.0	0.28-0.66
July 86	0.18-1.23	2.50-9.09	0.20-2.10	3.0-6.0	0.26-0.83
Aug. 86	0.07-1.25	2.53-8.11	0.10-2.15	2.0-6.0	0.26-0.88
Sep. 86	0.13-1.01	2.32-5.94	0.20-1.60	2.0-6.0	0.25-0.81
Oct. 86	0.09-1.08	2.82-11.32	0.10-1.80	2.0-6.0	0.26-0.87
Nov. 86	0.06-0.73	3.39-9.52	0.10-1.15	2.0-6.0	0.43-0.93
Dec. 86	0.07-0.70	4.40-9.86	0.10-1.20	2.0-7.0	0.48-0.94
Jan. 87	0.13-0.27	6.22-15.38	0.20-0.45	2.0-6.0	0.37-0.97
Feb. 87	0.13-0.71	3.20-15.19	0.20-1.20	2.0-7.0	0.27-0.95
Mar. 87	0.20-0.98	3.03-9.68	0.30-1.60	2.0-6.0	0.37-0.97
Apr. 87	0.23-2.75	2.61-13.95	0.32-3.75	2.0-7.0	0.34-0.96
May 87	0.22-1.87	2.61-7.50	0.40-3.25	2.0-6.0	0.29-0.84

Wave activity was very low during January and February 87. Highest waves were measured in April 87, the highest significant wave height of 2.75 m was observed on 10 April 87 and the highest wave of 3.75 m was observed on 11 April 87.

Joint distribution of significant wave height Hs and Zero crossing wave period Tz for different months are shown in Figure 3. Dominant characteristics of the significant wave height Hs zero crossing wave period, Tz and wave steepness parameter, $S = \frac{Hs}{Tz^2}$ based on the scatter diagrams of Figure 3 are given in Table II.

TABLE-II

Dominant Wave Parameters

Month and year	Dominant wave height Hs in m	Dominant wave period Tz in sec.	Dominant wave steepness Parameter Hs/Tz^2
June 86	0.5-1.0	4.0-6.0	0.02-0.06
July 86	0.5-1.0	3.0-5.0	0.02-0.06
Aug. 86	0.5-1.0	3.0-5.0	0.03-0.06
Sep. 86	0.5-0.8	3.0-5.0	0.03-0.10
Oct. 86	0.1-0.6	3.0-5.0	0.01-0.06
Nov. 86	0.1-0.50	4.0-5.0	0.005-0.01
Dec. 86	0.1-0.50	5.0-7.0	0.005-0.01
Jan. 87	0.1-0.20	1.4-16.0	0.0025
Feb. 87	0.1-0.5	4.0-5.0	0.005-0.015
Mar. 87	0.5-0.8	4.0-6.0	0.01-0.06
Apr. 87	0.5-2.0	3.0-5.0	0.04-0.10
May 87	0.5-1.5	3.0-4.0	0.05-0.10

Wave steepness parameter Hs/Tz^2 was found to be mostly less than 0.01 from October to March. It ranged most of the time 0.02-0.03 during June, July, August and September and 0.04-0.06 during April and May.

Figure 4 presents cumulative distribution of significant wave height Hs for different months. From this percentage of time by which a particular wave height was exceeded can easily be obtained. Table 3 presents percentage of time, the significant wave height was exceeded Hs = 0.05 m, Hs = 1.0 m, Hs = 1.5 m and Hs = 2.0 m.

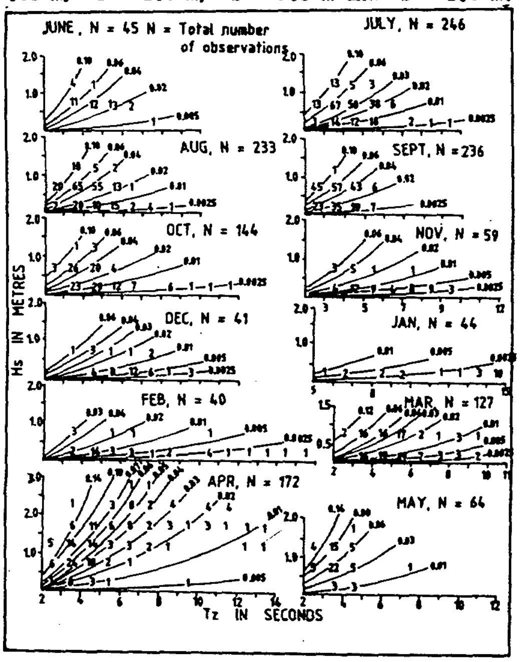

Figure: 3: Joint Distribution of H_s and T_z.

From Table III, it is shown that April 87 experienced roughest sea state whereas January 87 was the calmest month. Highest significant wave height of 2.75 m was observed on 10 April 1987.

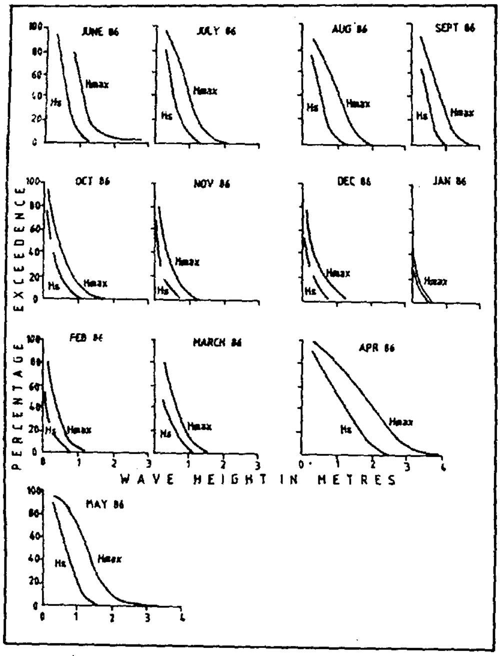

Figure 4: Cumulative Distribution of H_s and H_{max}.

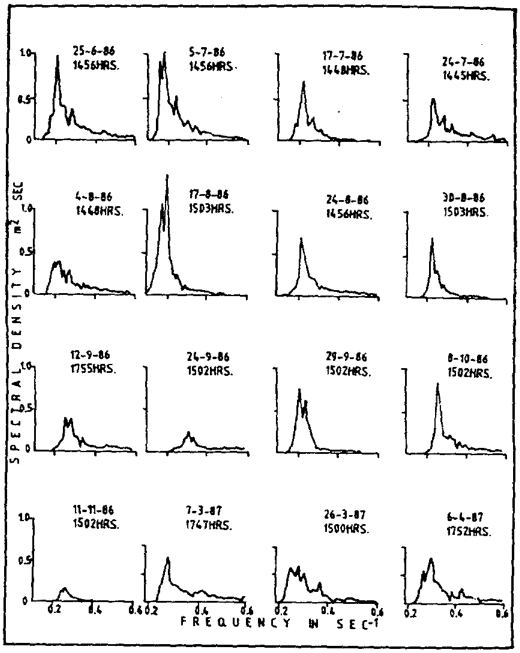

Figure 5: Representative Samples of Observed Wave Spectra.

TABLE_III

Wave Exceedance Percentages

Month and year	Percentage Exceedance of the significant Wave Height			
	Hs=0.5m	Hs=1.0m	Hs=1.5m	Hs=2.0m
June 86	96	10	-	-
July 86	80	10	-	-
Aug. 86	76	11	-	-
Sep. 86	64	1	-	-
Oct. 86	40	3	-	-
Nov. 86	18	-	-	-
Dec. 86	21	-	-	-
Jan. 87	2	-	-	-
Feb. 87	17	-	-	-
Mar. 87	46	1	-	-
Apr. 87	67	57	41	17
May 87	40	22	3	-

Representative samples of computed wave spectra are presented in Figure 5. Comparatively low spectral densities indicate that severe sea state was not experienced at the measurement site for the period of study. In general the spectra are broad banded indicating wide distribution of wave energy in different frequency bands. As the sea was calm, wave heights during January and February 1987 were of less significance.

Design Waves

Measured data available for the site were very limited as the wave measurement programme was undertaken only for about a year. Inspite of this serious limitation an attempt was made to estimate design wave height for different return periods using Weibull distribution. Significant wave heights, Hs are plotted on the Weibull probability paper as shown in Figure 6. Weibull parameters Hc = 0.468 and

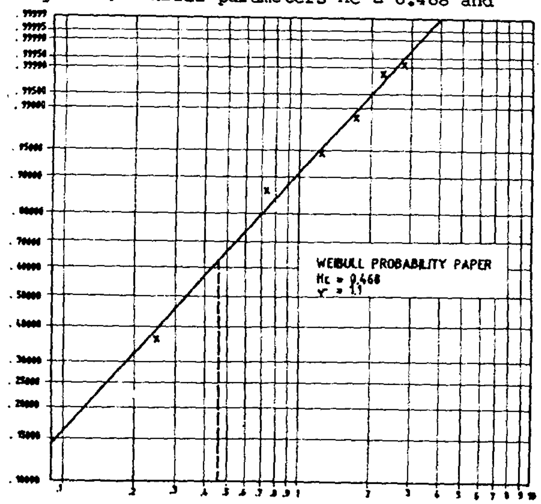

Figure 6: Weibull Distribution of Observed Significant Wave Heights.

γ = 1.1 are obtained from the plot. Design significant wave heights for the return periods of 10, 25, 50, 75 and 100 years are then estimated as 3.67 m , 3.95 m, 4.17 m, 4.29 m and 4.38 m respectively. It is very difficult to determine the reliability of such an estimation as the data base used here is limited to only about year. In general a data base of 5 to 10 years would be required for making such predictions using extreme value statistics.

If the project site is prone to the attack of severe storms and cyclones which is very likely for the region under consideration, it would be essential to obtain wave data for such extreme conditions for estimating design wave heights. It is also to be noted that severe storms or cyclones did not occur during the present measurement programme making it very difficult to use the data for predicting a realistic design wave height.

Conclusions

One year time series data on waves were analysed for various wave parameters and an attempt was made to estimate the design wave heights for different return periods keeping in view the limitation of such an exercise for the site under consideration. The location of the proposed tidal barrier for the tidal power plant is in the inner part of the Gulf of Kachchh and therefore, seems to fairly well protected from waves. However, under extreme storm and cyclone conditions, one can expect severe wave activity in the area. Design wave height to be adopted should take into consideration such occurrences.

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References

1. Mandal, S. and B. U. Nayak (1986), "Wave Prediction techniques - A review", Proc. 3rd Ind. Conf. on Ocean Engg., I.I.T. Bombay, pp J21-32.

2. Nayak, B. U., P. C. Mohan, S. Mandal and S. G. Diwan (1986). "Wave climate studies off Daman on the west coast of India", Proc. 3rd Ind. Conf. on Ocean Engg., I.I.T. Bombay, pp G73-80.

3. Nayak, B. U., S. Mandal and K. Ravi (1986), "Analysis of cyclone waves off Daman, India", Proc. 3rd Ind. Conf. on Ocean Engg., I.I.T., Bombay, pp G91-100.

4. Nayak, B. U., and S. Mandal (1988), "Analysis of waves off Umbergaon, west coast of India", Proc. 3rd Ind. Conf. on Ocean Engg. I.I.T.., Bombay, pp G 101-110.

5. Nayak, B. U., P. Chandramohan and S. Mandal (1987), "Wave measurement and evaluation techniques adopted at Daman on the West coast of India", Int. Conf. on Coastal and Port Engg. in Developing Countries", Beijing, China.

6. Sharma, H. R. and R. Devasahayam (1985). In: 52nd Annual R & D Session, CBIP, Aurangabad.

7. Wagle, B. G. (1979). "Geomorphology of the Gulf of Kutch". Ind. Joul. of Mar. Sc. Vol. 8, pp 123-126.