CHAPTER 3
WAVE RECORDING AND ANALYSIS

The study essentially involved the long-term recording of waves at a shallow water location. A brief description of the location and its coastal environment are given first, followed by a description of the instrumentation and mode of wave recording, in this chapter. The criteria for selection of wave records for analyses, the different types of analyses performed and some preliminary results on wave climate are also dealt with in detail.

3.1. LOCATION

Alleppey (lat.9°29'30"N, long.76°19'10"E) is a small coastal town at the southwest coast of India (Fig.3.1). The coastline is almost straight with a 350° North orientation. The shelf is gently sloping and the isobaths are more or less parallel to the shoreline. The sediment up to a distance of about 80 m from the Mean Water Line (MWL) consists mainly of fine sand, and further offshore - predominantly of clay. The tide here is semi-diurnal and the maximum range is only about 1 m.

A 300 m long pier present at this location provides a convenient platform for carrying out the studies even during the rough monsoon season when the sea is otherwise inaccessible due to high breakers.
Fig. 3.1 Location map.
3.2. WAVE RECORDING SYSTEM

Devices ranging from human eye to sophisticated electronic instruments are used in measuring the ocean surface waves, depending upon the accuracy required. When visual observations are sufficient for the determination of average period or velocity of propagation, instrumental recordings are necessary for the determination of various characteristics of these complex random waves. Obtaining a true measurement of the ocean surface conditions depend on many factors like selection and location of the measuring device, its installation, data control and recording, processing, maintenance of the system, etc.

The three types of wave measuring devices that are commonly employed for the measurement of ocean waves are those measuring (i) from above the sea surface - mainly remote sensing techniques, (ii) at the sea surface and (iii) from below the sea surface.

3.2.1. Selection of Recording System

In general, remote sensing techniques are very expensive and the methods of processing and analysis are yet to be standardized. Surface measuring instruments, especially the accelerometer type buoys give a better representation of the actual sea surface. These are very useful
for the studies like wave growth processes where the energy in the higher frequencies are critical. These are expensive, though not as high as remote sensing, and chances of damage and loss are high. Resistance/capacitance wave staffs and pressure recorders are comparatively cheaper, but require a supporting structure (except for bottom mounted pressure gauges). The wave staffs are more susceptible to wave impacts, leakage, corrosion, fouling and other hazards and require continuous inspection and servicing. Subsurface pressure recorders are suitable particularly for shallow waters since they are almost sheltered from excessive water particle velocities and breaking waves. Also, they are less susceptible to damages by ships, fishing activities, floating debris and corrosion, since no surface penetrating or floating parts are required. They are not affected by tidal variations or storm surges, and on the other hand provide information on mean water level and do not require frequent maintenance. The main disadvantages are that they require signal correction, have restricted frequency response (higher frequencies are filtered out) and are subjected to fouling.

3.2.2. The Recording System Used

In the study of the wave energy spectrum, more attention is paid generally to the energy containing
portion. In the height and period distribution studies the high frequency-filtered data is more appropriate since shorter period waves superimposed near the zero-crossings may lead to erroneous period and height values in the wave-by-wave analysis (usually a filter is applied to eliminate this error). In the present study the wave energy in the higher frequencies are considered insignificant. Hence, a sub-surface pressure recorder is selected to measure the shallow water waves.

The pressure type recorder used consists of a Wave and Tide Telemetering System (Sivadas, 1981), a standard strip chart recorder, a timer and power supply and control units (Fig.3.2). The Wave and Tide Telemetering System comprises of an air-filled stainless steel bellow-type pressure transducer connected by a two-core cable to the shore-based receiving and processing unit which in turn is connected to the strip chart recorder (Fig.3.3). The transducer functions on the principle of proportional variation of electrical inductance. A plunger core is connected to the bellow. With the passage of waves the core moves up and down freely through the centre of an activated coil, in accordance with the movements of the bellow, inducing voltage in the coil proportional to the movements. The bellow and coil are kept inside a protection casing. The signals transmitted by the coil through the 2-core cable is
Fig. 3.2 Schematic diagram of the wave recording system.

Fig. 3.3 View of the wave recording system used.
received in the wave and tide telemeter which processes the signal and transmits to the wave and tide separator. This unit separates the tide and wave components using a low-pass filter. The wave output, in millivolts, is recorded on strip charts. The timer which can be programmed for the starting time and duration of recording, in fact, controls the AC power supply to the recorder. This facilitates the collection of wave records at fixed intervals for the required duration. A unique facility available in the system separates the waves undistorted, unlike some similar systems in which waves are reshaped to its nearest sinusoidal form.

3.2.3. Transducer Installation

The transducer is installed on a pile at the end of the pier at a depth of 5.5 m (Fig.3.4 & 3.5). The transducer projects 1.5 m seaward of the pile (Fig.3.5) to eliminate the possible effects of the piles on the waves being recorded. The attenuation of pressure due to waves increases with the depth of installation of the transducer. Hence it would be better if the transducer can be as close as possible to the water surface, depending upon the lowest tide and maximum depth of wave trough at the location. Taking into consideration of the low tidal range here (about 1 m only) and the maximum depression during the highest wave
Fig. 3.4 Site of wave recording and the pier at Alleppey.

Fig. 3.5 Installation of pressure transducer.
possible, the depth of installation is chosen to be 3.5 m below the Mean Sea Level. Thus the transducer is very close to the sea surface and at the same time will never get exposed. The transducer is protected against deposition of mud, marine fouling and corrosion by covering its open end with a flexible neoprene rubber hose filled with silicon oil (Fig. 3.5). The cable is fastened to the installation mount and taken out through the GI pipe fixed to the pile of the pier, to shield it from the wave forces and vagaries of the marine environment.

3.2.4. Calibration

The system is calibrated in such a way that the output is linear and is 20 mv per meter of wave height. This signal is fed to the chart recorder running at 5 cm/min to give 5 cm deflection per meter of wave height. The calibration was checked periodically at site and in the laboratory. The site checking is done by noting the crest and trough heights against the calibrated pipe to which the transducer is attached and by comparing the wave heights with the ones recorded simultaneously (after applying the corrections towards attenuation of pressure, which will be explained later in this chapter).

The frequency response of the system has been checked for a wide range of height and period conditions (Fig. 3.6).
Fig. 3.6 Frequency response diagram of the wave recorder.
It is found that the response is more than 95% for waves of period greater than 3 seconds and it is nearly 100% for waves of period 5 seconds and more.

3.3. RECORDING PROCEDURE AND SCREENING OF RECORDS

The recordings were carried out for 30 min. at every 3 hrs except during the periods of interruptions due to power failure, instrumental problems or servicing of the system. The predominant wave direction at the recording point was also noted at the site using a Brunton Compass.

From the available records, those with the following defects or limitations are discarded:
- a drift in the mean zero-line due to instrumental problems;
- breaks in the records due to power failure, cable fault, instrumental problems, etc.;
- noise due to power fluctuations, vibration of the transducer due to slackening of the installation; and
- near-straight-line records during very calm seas, particularly during the periods of mud banks.
All other records are considered for analysis.

3.4. PRELIMINARY ANALYSIS (TUCKER-DRAPER METHOD)

A reliable estimate of wave climate statistics can be obtained from the analysis of wave records collected
systematically over a sufficiently long period with a sample of one observation per day (Thompson and Harris, 1972; Baba, 1983; etc.). The records collected during a four year period (1980-1984), sampled at one record per day, is selected for a preliminary analysis. This analysis is carried out using the Tucker-Draper method (Draper, 1967; Silvester, 1974), which is regarded as the simplest of all.

In this method a portion of the record having a length of 720 s without any disturbance is selected for the analysis. The Mean Water Line (MWL) is drawn by fixing it with the eye. The heights of the highest and the second highest crests, A and B respectively, are measured from the MWL. Similarly the depths of the lowest and the second lowest troughs C and D are measured. The number of zero-crossings ($N_z$) and the number of crests ($N_c$) are also counted. From these values the different statistical parameters are estimated as detailed below.

The root mean square wave height ($a_{rms}$) can be computed from the following equations:

$$2a_{rms}/H_1 = 1/(2\ln N_z)^{1/2} \left[1+(0.289/\ln N_z)-(0.247/\ln N_z^2)\right]$$

.....(3.1)

$$2a_{rms}/H_2 = 1/(2\ln N_z)^{1/2} \left[1-(0.211/\ln N_z)-(0.103/\ln N_z^2)\right]$$

.....(3.2)
where $H_1 = A+C$ and $H_2 = B+D$. As per theory, the results from $H_1$ and $H_2$ should be essentially the same. The statistical errors involved in this procedure are of the same order as averaging the highest $1/3$ waves in the record for significant wave height, $H_s$ (Silvester, 1974). In this study $a_{\text{rms}}$ is determined using Eq.3.1. The spectral width parameter ($\varepsilon_w$) is computed from

$$\varepsilon_w^2 = 1 - \left(\frac{N_z}{N_c}\right)^2 \quad \ldots \ldots (3.3)$$

This parameter helps to assess a more accurate proportion of $H_1/10$, $H_s$ and $\bar{H}$. The ratio of these parameters to $a_{\text{rms}}$ are given in the form of tables and nomograms in Silvester (1974).

The average zero-crossing period ($\bar{T}_z$) is given by

$$\bar{T}_z = 720/N_z \quad s \quad \ldots \ldots (3.4)$$

In order to compensate for the attenuation of pressure with depth, correction is applied to the height parameters derived from this analysis using the following relation:

$$H = nH_pcosh\left(\frac{2\pi h}{L}\right)/cosh\left[\left(\frac{2\pi h}{L}\right)(1-z/h)\right] \quad \ldots \ldots (3.5)$$

where $H$ and $H_p$ are the corrected and un-corrected heights and $n$ is the instrument factor, $L$ is the wave length corresponding to $T_z$, $h$ is the water depth and $z$ is the depth at which the transducer is installed.
Values ranging from 1.0 to 1.5 have been assigned to the instrument factor by various researchers (Homma et al., 1966; Bergan et al., 1968; Cizlak and Kowalzki, 1969; Kurian and Baba, 1986; etc.). The value of 1.25 suggested by Dattatri (1973) is used in the present analysis.

3.5. WAVE CLIMATE AT ALLEPPEY

The wave climate at this location is influenced by the southwest monsoon as is the case at any other location along the west coast of India. Following the suggestions of Thomas and Baba (1983) the data is grouped into two seasons - 'rough season' from May to October and 'fair season' from November to April.

3.5.1. Wave Height

The percentage exceedance of $H_{st}$ and $H_{max}$ for the two seasons are presented in Fig.3.7a. From the different percentages of exceedance it is seen that the wave intensity during the rough season is double of that during the other season. When 25, 50 and 75 percent of $H_{st}$ exceed 1.40, 0.95 and 0.62 m respectively during the rough season, it exceed only 0.70, 0.52 and 0.42 m respectively during the fair season. Similar trend is shown by $H_{max}$ also. During the rough season the above percentages of $H_{max}$ exceed 1.90, 1.35 and 0.85 m respectively and during the fair season they
exceed 0.95, 0.72 and 0.58 m. The maximum wave height observed during the rough season is 3.8 m and that during the fair season is 2.0 m. Similarly, the maximum value of $H_{st}$ during the rough and fair seasons are 3.0 and 1.4 m respectively. Eventhough the wave activity is maximum during the month of June, the formation of the mud-bank brings in a few-weeks-long calm sea towards the end of the month.

3.5.2. Zero-Crossing Period

The zero-crossing periods ranged from 6 to 21 s with the prominent periods falling in the range 7-15 s. The frequency, in percentage, for the two seasons are presented in Fig.3.7b. During the rough season the waves are better sorted and are of comparatively shorter periods, the most frequent being 8-9 s, which contribute to 31%. During the other season waves with periods 9-11 s dominate and this contribute to 46% of the distribution.

3.5.3. Wave Direction

Though the wave direction range from 200-320° with respect to north, the majority of waves were confined to a small range of 230-265°. The percentage occurrence of direction of wave approach is presented in Fig.3.7c. The waves are more parallel to the coastline during the rough season. The dominant direction during this season is 245-250° and
Fig. 3.7 Wave climate at Alleppey during fair and rough season:
percentage exceedance of wave heights, $H_s$ and $H_{max}$ (d) and frequency distribution of zero-crossing period (b); direction (c) and spectral width parameter (d).
this contribute to about one-fifth of the total of the season. During this season 50% waves arrive from the direction 245-260° and 83% from 235-265°. During the fair season the waves are more southerly and about one-fifth of them arrive from the direction 235-240°. Waves from 230-245° contribute to 44% and that from 230-255° contribute to 61% during this season.

3.5.4. The Spectral Width

The spectral width parameter ($\gamma_w$) for both the seasons are presented in Fig.4.7.d as percentage occurrence. The values range from 0.5 to 1.0 during both the seasons. However, the average value is less during the rough season. During this season 70% of the values fall in the range 0.6-0.8 and 90% in the range 0.6-0.9. During the fair season about 60% of the values are in the range 0.8-0.9 and 90% in the range 0.7-0.9.

3.5.5. Persistence of Waves and Calm

Persistence diagrams serve as a ready reference to determine the number of times a range of wave conditions (at or above in the case of 'persistence of waves' and at or below in the case of 'persistence of calm') persist for at least for a given length of time. The significant wave heights computed for three-hourly intervals during 1981 are
selected for the preparation of these diagrams. At times of break in the data the wave condition prior to the interruption is assumed for the elapsed time. This appears to be justifiable since the nearshore wave characteristics show near-stationary conditions for durations of the order of a day (Thompson and Harris, 1972; Kurian et al., 1985a, etc.). Persistence of waves and calm are presented for height intervals of 0.25 m (Fig. 3.8a-b). From the diagrams it can be seen that high wave conditions persist for very short durations and low wave conditions persist for long durations at this coast. For example, wave heights ($H_{st}$) at or above 2 m persisting for a day occurred on less than 20 occasions only during a year. It can be inferred easily from these diagrams that if a study requires a minimum wave height of 2.5 m persisting for 100 hrs, it cannot be conducted at this location. Similarly, if wave heights ($H_{st}$) not more than 1 m prevailing for a minimum of 60 hrs is required for a particular study, 95 such occasions are available during a year.

3.5.6. DISCUSSION ON THE WAVE CLIMATE

On an assessment of the distribution of the above parameters it can be seen that the waves during the rough season exhibit certain characteristic features. They are well sorted and arrive from the same generating area, as evidenced from the distribution of periods, directions and
Fig. 3.8. Persistence of (a) waves and (b) calm at Alleppey.
spectral width. The lower periods are indicative of a not-far-away origin of these waves. Evidently these are generated under the influence of the south-west monsoon winds. From the monthly wind speed summary for the Arabian Sea and Northwest Indian Ocean (Boisvert, 1966) it is seen that from May the winds get intensified, the dominant direction being south-west. The intensification continues through June, July and August and the entire Arabian Sea and the North-western Indian Ocean become the wave generating area. Wind speeds of the order of 28 knots and more are reported all over this region. These winds prevail till September and the direction is reversed to northeast by November and continues till March, April and October being the transition periods. During the fair season the waves are poorly sorted as waves generated at different areas arrive at this coast. The larger period waves during this season associated with smaller heights and lesser frequencies of occurrence indicate that these waves are generated at great distances and have undergone different transformation processes like wave-wave and wave-current interactions, shoaling, refraction, diffraction, etc. Incidentally, the prevailing wind in the Arabian Sea and the North-eastern Indian Ocean during this season has low velocities and north-easterly direction, leading to the generation of waves which also contribute to the wave climate.
3.6. DETAILED ANALYSIS

3.6.1. Selection of Records

The wave climate characteristics are found to vary only slightly from year to year during the examined 4 year period. Hence, the wave records collected during a one year period is selected for the detailed analysis of spectral and probabilistic characteristics. Records collected during 1981 are selected, as maximum number of records, with lesser number of disruptions, are available during this year. Thus 287 records, at the rate of one record per day (corresponding to 1200 Hrs), are used for the detailed analysis.

Since the coastal erosion is during the southwest monsoon, a more intensive study of the wave characteristics during this season is also warranted. Hence, an additional 30 three-hourly records collected for one month from mid-May are also utilised for this study.

3.6.2. Spectral Analysis

Two procedures are generally used to estimate the wave spectrum. One is using the data to estimate the covariance function first and then to compute the cosine Fourier transform of the covariance function numerically, in turn to compute the raw spectrum (Blackman and Tukey, 1958). The other uses the Fast Fourier Transform (FFT) computer
algorithm (Cooley and Tukey, 1965) to get the raw spectrum directly from the data. The basic principle of FFT lies in splitting the given time series into two half-series, which is performed many times during the process of computing the Fourier transform. This involves lesser number of arithmetic operations compared to the covariance method, thereby leading to a large reduction in computation time. Both the procedures give the same results except that the covariance method applies an intrinsic smoothing to the spectrum. From the viewpoint of simplicity, computational speed and preservation of information, the FFT method is preferable. The FFT method is applied here to compute the wave spectrum.

The stability and accuracy of the spectral estimates depend on many parameters such as the record length, sampling interval, spectral window used, high/low frequency cut off, etc. (Goda, 1974; Harris, 1974; Baba et al., 1986; Kurian, 1987; etc.).

3.6.2.1. Digitization and processing

The records are digitized manually at 1 s interval, for accuracy and simplicity in digitization, since each cm of the chart paper, on which the waves were recorded, is divided into 6 divisions and the recordings were done on the chart running at a speed of 5 cm/s. In a few cases the
digitization is done at 1.2 s interval, since each cm of the chart paper is divided into 5 divisions in those cases. For the computation of spectral densities, 512 data points each are utilized. This is sufficient to obtain a reasonably stable spectrum (Baba et al., 1986).

Usually the time series digitized at equal time interval is subjected to a trend removal procedure before the spectral analysis. Even in the absence of any trend of significance, as the recording system used in the present study removes the trends, the raw data is subjected to a linear trend removal, which makes the arithmetic mean of the process zero.

3.6.2.2. Spectral window

In order to minimize the distortions in any desired aspect of the spectrum, spectral windows are applied. Even though the spectral windows are many, the most commonly used ones are the 'hanning' and the 'hamming' windows. Though the highest side lobe for the hamming spectral window is about one-third of the height of the highest side lobe for the hanning window, the heights of the side lobes for the latter fall off more rapidly than for the former (Wilson et al., 1974). The hanning window is selected in the present study. The hanning window function for a digitized time series of N points is defined as:
As a consequence of the application of this window all the spectral estimates have to be scaled by the constant factor $8\pi/0.375$ and this is incorporated in the computer programme.

**3.6.2.3. Pressure attenuation**

The pressure spectrum thus computed is subjected to pressure attenuation correction to obtain the surface spectrum using the standard relation (Harris, 1972; Black, 1978; etc.), which is given as

\[
S(f) = \left[ \frac{\cosh (2\pi h/L)}{\cosh [(2\pi h/L)(1-z/h)]} \right]^2 S_p(f) \quad ..(3.7)
\]

Grace (1978) modified this relation by incorporating an empirical correlation factor, $n(f)$, based on wave tank measurements. Since the use of this factor is not yet firmly substantiated and may introduce some uncertainty in the spectral data, as observed by Knowles (1982), it is not included in the present analysis.

**3.6.2.4. Spectral parameters**

In accordance with the frequency response of the recorder and the maximum wave period possible in this region, the low and high frequency cut off are fixed at 0.04 and 0.33 Hz respectively in the computation of moments and
other spectral parameters. The different spectral parameters computed are:

(i) $n$th moment of the spectrum

$$m_n = \int f^n S(f) df$$  \hspace{1cm} \ldots (3.8)

(ii) significant wave height

$$H_{ss} = 4(m_0)^{1/2}$$  \hspace{1cm} \ldots (3.9)

(iii) zero-crossing period

$$T_{m0,2} = (m_0/m_2)^{1/2}$$  \hspace{1cm} \ldots (3.10)

(iv) mean wave period

$$T_{m0,1} = m_0/m_1$$  \hspace{1cm} \ldots (3.11)

(v) mean crest period

$$T_{m2,4} = (m_2/m_4)^{1/2}$$  \hspace{1cm} \ldots (3.12)

(vi) spectral band width parameters

$$\varepsilon_s = (1-m_2^2/m_0m_4)^{1/2}$$  \hspace{1cm} \ldots (3.13)

$$\nu = (m_0m_2/m_1^2-1)^{1/2}$$  \hspace{1cm} \ldots (3.14)

$$\nu' = (1 - m_1^2/m_0m_2)^{1/2}$$  \hspace{1cm} \ldots (3.15)

(vii) spectral peakedness parameter

$$Q_p = 2/m_o^2 \int fS^2(f) df$$  \hspace{1cm} \ldots (3.16)

and (viii) slope of the high frequency side of the spectrum

$$S(f) \propto f^{-m} \quad ; \quad f_m < f < 1.8f_m$$  \hspace{1cm} \ldots (3.17)

3.6.2.5. Smoothing

The wave spectrum obtained from the FFT method of analysis exhibits details much more than that required for
applications like graphical presentation and comparison with theories. The irrelevant details are usually suppressed by applying a smoothing function. The smoothing depends on the type of smoothing applied and the number of spectral lines used. In the comparison of the observed spectrum with theoretical ones a well-smoothed spectrum would be much useful since the theories are developed for single-peaked spectrum only. However, in the present case the prominent peaks are retained to get a clear picture of the actual wave conditions prevailing in the region of study. A weighted averaging method of smoothing (Ou, 1977) is applied here to obtain 33 bands with 16 degrees of freedom, without the low/high frequency cut off, for comparison with the theoretical models and for graphical presentation.

3.6.3. Wave-by-Wave Analysis

In wave-by-wave analysis the zero-crossing method is generally accepted as a standard procedure. In this method, the MWL fixed by the eye, is drawn for the selected length of the record. The individual wave heights and periods can be measured by following two procedures, zero-up-crossing or zero-down-crossing methods. In the zero-up-crossing method, the points where the wave record crosses the MWL in an upward direction is marked and a wave is defined between two successive zero-up-crossings. The height of the wave is the
difference in elevation between the highest crest and the
lowest trough between the two up-crossings and its period is
the time interval between these two crossings. Similarly, in
the zero-down-crossing method a wave is defined as the one
between the two successive zero-down-crossings. The height
and period of the wave is defined as in zero-up-crossing
method. Individual wave heights and periods may differ in
these two methods and hence the estimate of the maximum wave
height in a record also may be different. However, in a
comparative study of the two methods of analysis, no
significant influence of the method is observed in the
height statistics particularly $H_{rms}$ and $H_s$ and in the
probability density distribution (Dattatri, 1985).

In the present investigation, the zero-up-crossing
method of analysis is carried out for the study of the
distributions of wave heights and periods. The heights and
periods of individual waves are derived from the digitized
data using a computer algorithm (Varkey and Gopinathan,
1984). This programme identifies the individual wave by the
zero-up-crossings and measures the maxima and minima and the
corresponding periods. The exact wave height is calculated
from the interpolated crest and trough values using
Stirling's formula (Scarborough, 1966). Necessary
modifications are made in the above algorithm to incorporate
the correction for pressure attenuation as applicable to the location of study and the recording system employed.

In accordance with the frequency response of the recording system (Fig. 3.6) waves with period less than 3 s are scanned out. The higher non-linear effect due to the exponential increase of the pressure attenuation correction factor (Eq. 3.5) in the lower periods are also eliminated by this scanning. However, this removes the lower period tail of the probability density distributions. Since the density and energy in this range are not significant this does not affect the probabilistic characteristics. The different height and period parameters \( (H_{\text{max}}, H_{\text{sw}}, \bar{H}, T_C, T_z \text{ and } T_s) \), spectral width \( (\varepsilon_w) \), steepness, individual and joint distributions of heights and periods are determined from the remaining individual waves.