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Wave Climate Along the Nile Delta Coast

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ABSTRACT

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Directional wave measurements have been carried out at two locations along the Nile Delta coast, and the principal results are reported here. The measurement program commenced in 1985 provides a rational basis for longshore sediment transport and for the design of coastal protection works under extreme wave conditions. Measurement locations at Abu Quir and at Ras el Bar are separated by approximately 190 km. Wave energy conditions have been calculated and characterized on a seasonal basis and for extreme conditions. Due to the prevailing westerly winds, and the relatively limited fetch from the north, the dominant wave direction is from the NW and WNW; whereas, waves from the NNE and NE sectors are limited in magnitude and occur primarily during the summer months. The maximum seasonal significant wave heights at Abu Quir were found to be: 5.5 m, 4.0 m, and 3.3 m for winter, spring and summer, respectively; and at Ras el Bar they were 4.3 m in winter, 2.0 m in spring and 2.6 m in summer. The annual average significant wave height and period were approximately 1.0 m and 6.0 seconds, respectively, at Abu Quir. The corresponding values at Ras el Bar are 0.7 m and 6.0 sec. This smaller wave height at a location with a generally greater fetch has been found to be due to the stronger refraction effects which occur at Ras el Bar. The results of this study have been applied to the design of a number of coastal protection structures and to the computation of longshore sediment transport along the Nile Delta coast. At present, consideration is being given to the construction of a coastal road which may also serve for coastal protection. If this plan is implemented, the wave data will play a critical role in the optimization of the set back and protection elements. The paper presents the analysis results for the return periods of extreme waves and the calculated distribution of longshore sediment transport along the Nile Delta coast.

ADDITIONAL INDEX WORDS: *Directional wave measurements, extreme wave conditions, Nile Delta coast, sediment transport, wave climate, wave breaking.*

INTRODUCTION

Wave action on structures and beaches is the most fundamental environmental phenomenon which the coastal engineer has to deal with. Waves determine the geometry and composition of beaches and significantly influence the planning and design of coastal and offshore structures. They provide the necessary energy that forms beach configuration, sediment sorting on the shoreface, sediment transport, onshore/offshore and/or alongshore. They are responsible for most of the forces acting on coastal and ocean structures (CERC, 1984).

Thus proper understanding and evaluation of the wave climate at a given site is necessary and essential for adequate designing and constructing a coastal or offshore structure. If the wave data are not sufficient either in quantity or quality, as was the case in Egypt, about fifteen years ago, then the engineer has to undertake a wave measurement program and analyzing the wave records for the statistical, spectral and/or directional information that is needed. This paper presents the analyses for the return periods of extreme waves and the calculated distribution of longshore sediment transport along the Nile Delta coast.

DATA COLLECTION AND ANALYSES

Wave data from 1985 to 1990 were collected by Cassette Acquisition System (CAS). Two stations for the measurement of wave energy and direction were installed off the Nile Delta at Abu Quir and Ras el Bar (Figure 1). The CAS system is a portable, self-contained remote recording system for sensing nearshore environmental parameters such as wave energy, wave direction and coastal currents. It consists of an electromagnetic current meter, three pressure sensors, encoder, recorder, cables for interconnections and batteries for power.

At Abu Quir the pressure sensors are situated about 18 km from the shore at 6 m below mean water level and 11.5 m above the sea bed. They are spaced 7 m apart in a triangular array (Figure

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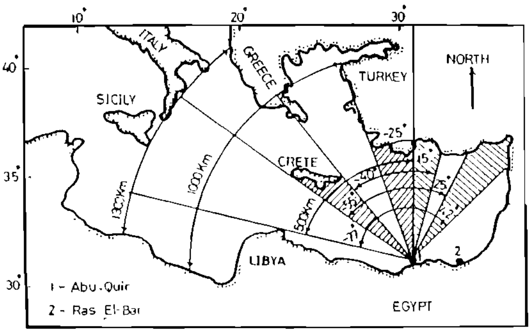

Figure 1. Location of CAS array system.

2a). While at Ras el Bar the sensors are at 6.5 m below MWL and 0.6 m above the bottom. The position of those sensors is shown (Figure 2b). Complete and detailed description of the system is given in BOYD and LOWE (1985). Wave data were recorded for 34.1 minutes, each about 6 hours, 4 times per day. The data are recorded on cassettes and analyzed by the use of the computer, which gives the significant wave height, wave period and wave direction.

The data collected by the three pressure sensors were transferred to the computer through a decoder. Then they were subjected to pre-processing treatment to detect areas of invalid data, based on the following: (1) expected maximum and minimum recorded values for each time series, (2) maximum excursion from the mean, and (3) expected slew rates. Once the magnitude and slew rate checks have been applied, a linear or quadratic interpolation is done across the set of drop out values (spurious points) detected. If the shapes of the valid data at either side of the drop out indicate a local maximum or minimum condition, the quadratic interpolation routine is selected, otherwise the linear interpolation is carried out. The processed time series resulting from the treatment of drop-out is used as input for analysis programs.

Each 34.1 minutes pressure time series was Fourier transformed. The Fourier coefficients of sea surface elevation were obtained by applying the frequency dependent depth correction given by linear wave theory. The total variance $\langle\eta^2\rangle$ of the sea surface displacement η is obtained for each pressure sensor by summing the variance in the frequency range 0.05–0.35 hz. The mean variance of the three pressure sensors is also calculated. The high frequency cut-off was established at wave frequency 0.35 hz.

Each wave event is characterized by three parameters obtained from the wave frequency spectra and their phase differences:

(1) The significant wave height H_s is obtained from the mean of the variance of the three pressure sensors.

(2) The wave period is obtained at the frequency band containing the maximum energy density in the frequency spectrum.

(3) The mean direction, $\alpha(fi)$ for frequency band i, is calculated from the phase difference between the signals of the two sensors expressed in radians by:

$$\alpha(fi) = \sin^{-1}\frac{\theta_i L_i}{2\pi l} \qquad (1)$$

where $L_i = 2\pi/K_i$ is the wave length for a wave frequency f_i: $K = [(2\pi f)^2/g]\tanh Kh$ is the wave number of frequency f_i; g is the gravitational acceleration, l is the distance between the sensors and α is the angle of the wave approach relative to the normal to line separating the sensors.

The phase difference of the wave signals of the two sensors as a function of frequency is obtained from the cross-spectrum analysis. It is related to the real and imaginary parts of the cross spectrum by $\theta = \tan^{-1}(\theta_{12}/C_{12})$ in which θ_{12} is the quadrature part and C_{12} is the co-spectrum.

The present paper is concerned with the wave data at Abu Quir and Ras el Bar. (Table 1) shows the available wave data at the two stations. Different wave windows occurring on the Mediterranean coast of Egypt are present in (Figure 1). The large scale meteorological systems that give rise to the occurrence of waves along the Nile delta coastline have been thoroughly studied and are well presented in UNDP (1978).

The Mediterranean weather is highly seasonal in nature and is strongly related to the large scale pressure systems whose limits overstep the boundaries of the Mediterranean area and extend towards the North Atlantic, Eurasia and Africa. Three seasons with respect to atmospheric circulation patterns have been distinguished by HAMED (1983) which are winter, spring and summer.

The winter season extends from November to March. Storms, associated with moving depressions mainly following a west northwest to east path occur regularly during the winter season. They are the cyclonic type and produce average

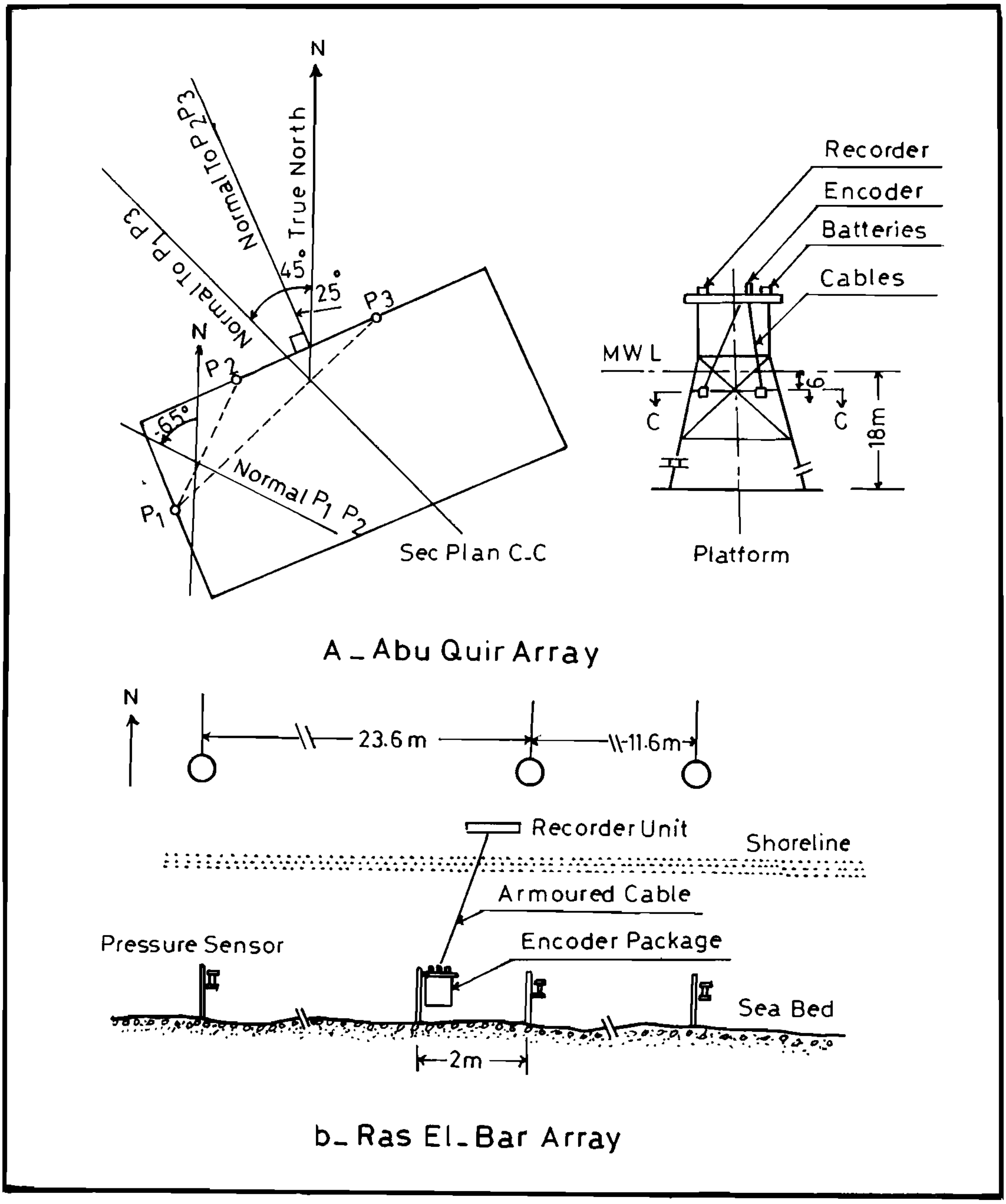

Figure 2. Arrangement of CAS wave directional system.

Table 1. *Number of wave records at Abu Quir and Ras el Bar stations.*

	Year											
	1985		1986		1987		1988		1989		1990	
Month	1*	2**	1	2	1	2	1	2	1	2	1	2
January	—	—	97	59	32	—	35	—	—	45	101	67
February	—	—	76	63	—	—	62	—	—	31	—	—
March	—	—	42	74	35	67	67	—	—	56	—	—
April	—	—	120	—	109	69	96	—	—	—	—	—
May	—	54	88	39	—	6	92	—	36	56	—	—
June	—	113	113	80	—	55	60	59	—	25	—	49
July	—	121	109	49	—	43	100	105	—	27	—	99
August	71	111	118	19	—	20	87	103	59	79	113	—
September	83	112	119	96	78	98	115	100	71	—	92	66
October	56	125	110	117	72	103	91	100	93	—	119	27
November	120	120	94	43	—	88	110	65	63	56	81	76
December	112	98	—	100	96	—	117	55	57	28	67	100

*Wave data collected by CAS by Abu Quir for a period of 46 months
**Wave data collected by CAS at Ras el Bar for a period of 51 months

fetch lengths of about 250 nautical miles and occasionally extend to 600 nautical miles. Such storms are responsible for the generation of the high waves affecting the Egyptian northern shoreline. Spring season extends from April to May, causing strong winds associated with sand storms due to the desert depression. The summer season covers the period from June to September. This period is free from moving depressions with high winds. The surface winds over the eastern Mediterranean blow mainly from the northwest producing swells which reach the Nile Delta coast.

RESULTS AND DISCUSSIONS

It is of fundamental importance that the variation of energy along the coast is determined from the wave climate. To determine this, the wave height, wave period were obtained and presented in histograms for the different seasons for Abu Quir and Ras el Bar (Figure 3). A modal significant wave height of about 0.75 m characterizes the two locations. A modal wave period of about 7–8 sec characterized the winter and summer seasons reducing to 5–6 sec during the spring season at the two locations. Short waves of about 3–4 sec are distinguished at Ras el Bar. Table 2 summarizes these data in terms of percentage of time exceeded of significant wave heights, maximum wave heights and wave periods.

Distribution of wave energy within each wave period interval is represented in Figure 4. The wave energy during winter season is much more severe than the summer season; this has been found also by ELWANY *et al.* (1988). At Ras el Bar the wave energy is less than at Abu Quir; this has been found to be due to the stronger refraction effects which occur at Ras el Bar. The monthly, seasonally and yearly significant wave height and period, as well as the maximum wave height and wave period, are also presented in Figure 5. At Abu Quir maximum significant wave height were found to be 5.5 m, 4.0 m and 3.3 m for winter, spring and summer, respectively, while at Ras el Bar they were 4.3 m in winter, 2.0 m in spring and 2.6 m in summer. The annual average significant wave height and period were approximately 1.0 m and 6.0 seconds, respectively, at Abu Quir. The corresponding values at Ras el Bar are 0.7 m and 6.0 sec. The predominant wave direction is from the NW and WNW; whereas, waves from the NNE and NE sectors are limited in magnitude and occur primarily during the summer months. As an example of the results, the wave rose for Abu Quir is presented in Figure 6.

EXTREME WAVE CONDITIONS

Estimation of extreme waves is necessary in designing marine system when wave forces exceed the critical value of the structure's strength. The prediction of extreme wave heights has been discussed by BORGMAN (1970 and 1973), DATTATRI (1973), ST. DENIS (1975), LIU and MA (1980), OCHI and WHALEN (1980), OCHI (1992). In this paper, the extreme wave conditions are obtained from the joint distribution between significant wave height and wave period.

The number of observations is 3,934 and 3,616 at Abu Quir and Ras el Bar, respectively, during

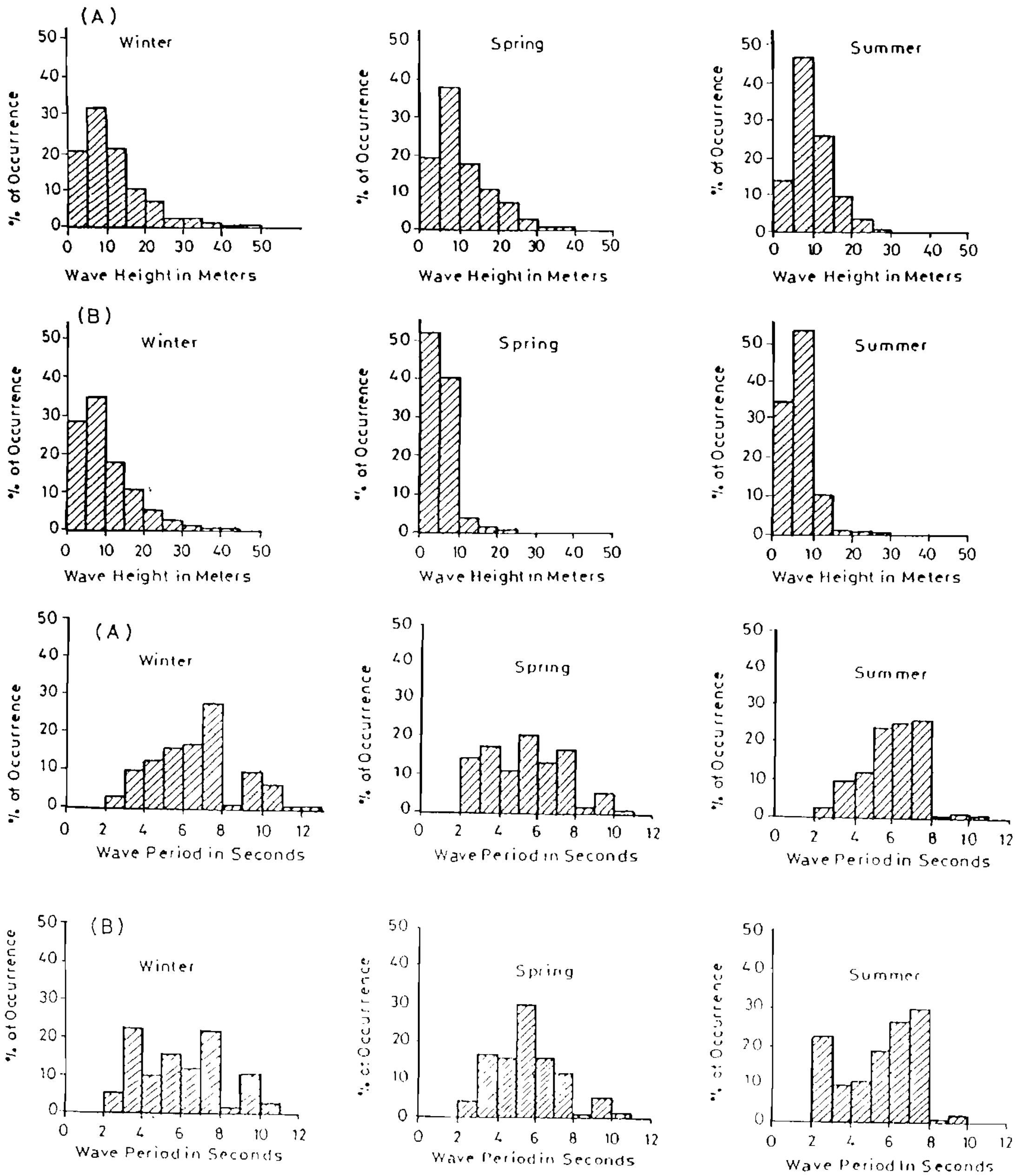

Figure 3a. Histograms of wave height during the different seasons at (A) Abu Quir and (B) Ras el Bar (1985–1990). Figure 3b. Histograms of wave period during the different seasons at (A) Abu Quir and (B) Ras el Bar (1985–1990).

the whole period. The cumulative distribution function of the significant wave height is calculated and plotted on Weibull probability paper.

One method of achieving a precise representation of the data is to express the cumulative distribution function as a combination of an exponential and a power of the wave height (OCHI and WHALEN, 1980).

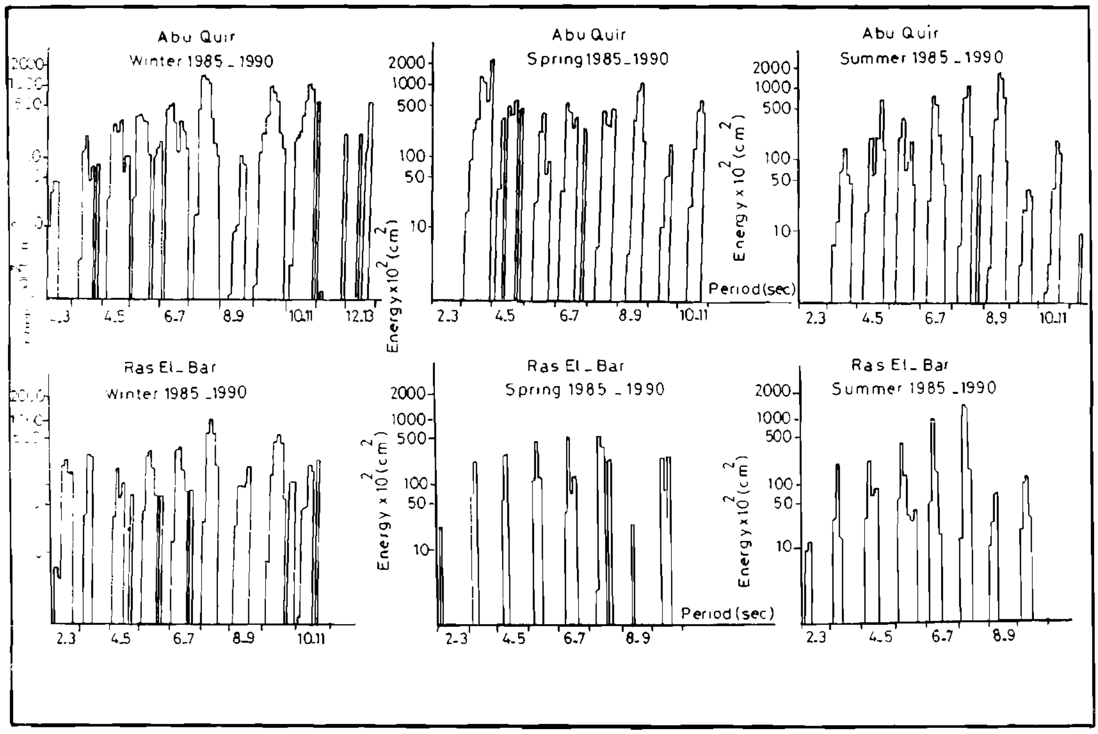

Figure 4. A representative of the wave climate for different seasons. Each column represents the energy and central period for a spectral peak in a wave record.

$$F(x) = 1 - e^{[-\lambda(x-a)]^c} \qquad (2)$$

The parameters λ, a and c are graphically determined from the Weibull probability paper. Once the parameters values are determined, the extreme wave height can be evaluated from the following equation:

$$1 - F(x) = \frac{1}{n} \qquad (3)$$

This equation implies that the probable extreme wave height expected to occur in *n* observations can be evaluated from the known cumulative distribution function and the number of waves involved. Applying the previous method at Abu Quir and Ras el Bar frequency curves were obtained between the wave height and recurrence interval (Figure 7).

LONGSHORE SEDIMENT TRANSPORT

The wave statistics at Abu Quir and Ras el Bar are used to calculate the longshore sediment transport. The breaker wave height is calculated based on the energy conservation method *i.e.*

$$H_o^2 \cos \alpha_o Cg_o = H_b^2 \cos \alpha_b C_b \qquad (4)$$

where

H is the wave height
α is the wave direction
Cg is the group velocity.

Deep water conditions are indicated by the subscripts *o* and the breaking water conditions by the subscript *b*.

The wave recorders are installed at an intermediate water depth h_m. So,

$$H_o^2 \cos \alpha_o Cg_o = H_m^2 \cos \alpha_m Cg_m \qquad (5)$$

when the relative water depth becomes shallow

$$C_b = \sqrt{gh} \qquad (6)$$

where *h* is the water depth.

Assuming spilling breaker

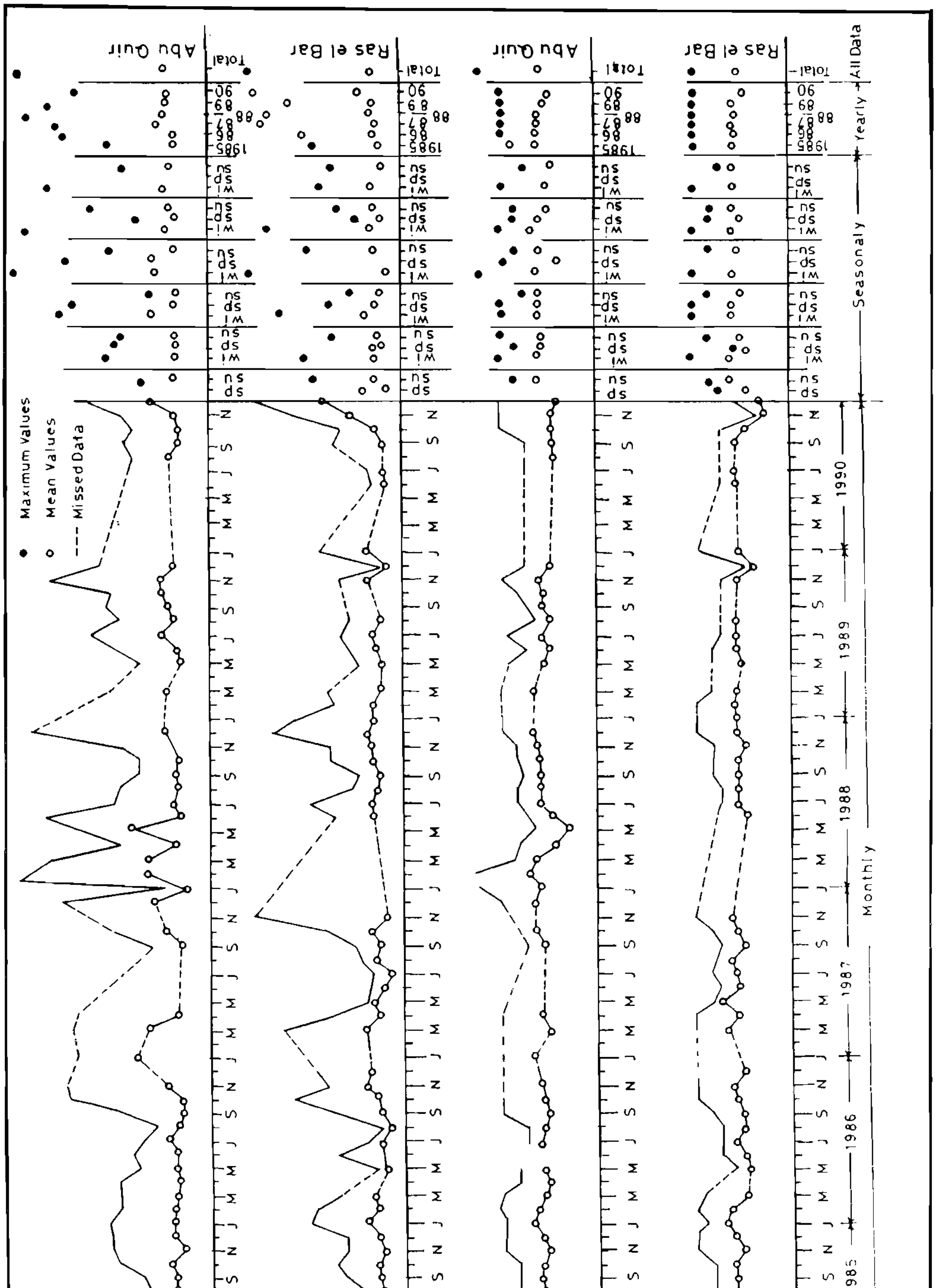

Figure 5. Maximum and mean wave height and wave period for the pe

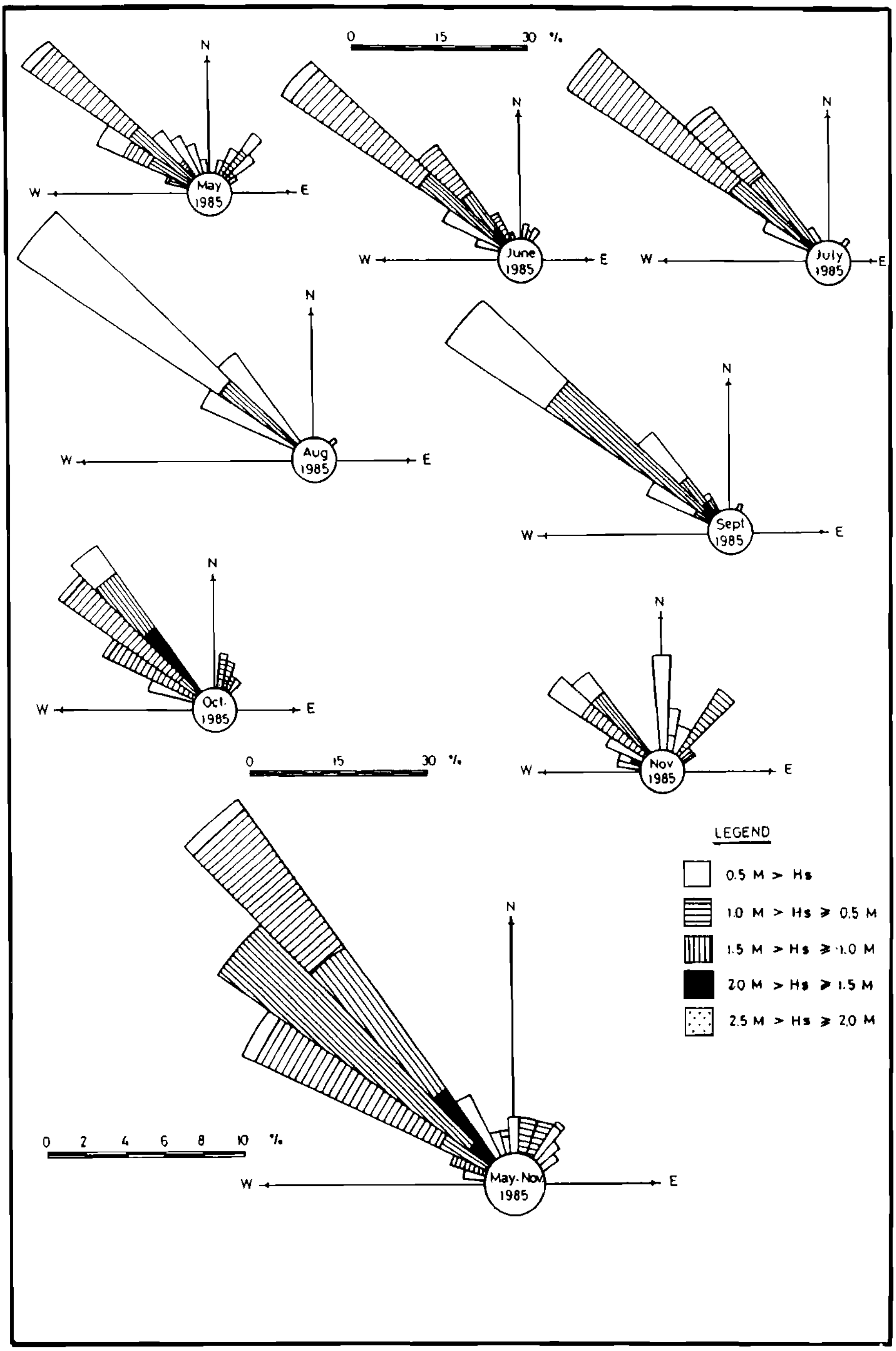

Figure 6. Monthly and yearly wave rose at Ras el Bar (1985).

Table 2. *Frequency of occurrence of waves heights and periods.*

Wave Parameters	% Equal or Exceed	Abu Quir Winter Hs	Abu Quir Winter H max	Abu Quir Spring Hs	Abu Quir Spring H max	Abu Quir Summer Hs	Abu Quir Summer H max	Ras el Bar Winter Hs	Ras el Bar Winter H max	Ras el Bar Spring Hs	Ras el Bar Spring H max	Ras el Bar Summer Hs	Ras el Bar Summer H max
Wave height	80%	0.50	3.00	0.50	1.90	0.60	2.00	0.40	2.50	0.25	0.92	0.30	1.55
	50%	0.98	4.80	0.85	3.00	0.85	2.30	0.80	3.25	0.50	1.30	0.65	1.85
	20%	1.75	5.30	1.70	3.60	1.35	3.00	1.50	4.00	0.80	1.55	0.90	2.35
		Ts	T max	Ts	T max	Ts	T max	Ts	T max	Ts	T max	Ts	T max
Wave period	80%	4.75	10.40	3.35	9.50	4.60	7.60	3.75	11.00	4.00	6.80	4.60	8.10
	50%	6.75	10.70	5.40	9.60	6.10	8.75	5.90	—	5.50	8.00	6.30	9.40
	20%	7.90	11.00	7.25	10.20	7.25	9.90	7.75	—	6.75	10.25	7.40	10.50

Hs and H max are in meters
Ts and T max are in seconds

$$h = \frac{H_b}{K} \qquad (7)$$

where K = 0.78.

From Equ. (4&5)

$$H_b^2 \cos \alpha_b C_b = H_m^2 \cos \alpha_m Cg_m. \qquad (8)$$

Assuming α_b is very small so $\cos \alpha_b \simeq 1$

$$(H_b)^2 = \frac{(H_m)^2 \cos \alpha_m Cg_m}{C_b}$$

$$= \frac{(H_m)^2 \cos \alpha_m Cg_m}{(g/k)^{0.5}(H_b)^{0.5}} \qquad (9)$$

$$H_b = H_m^{0.8} \cos \alpha_m^{0.4} Cg_m^{0.4} K^{0.2}/g^{0.2} \qquad (10)$$

where

$$Cg_m = \frac{C_m}{2}\left(\frac{1 + 2K_m h_m}{\sin h\ 2K_m h_m}\right). \qquad (11)$$

K_m is the wave number = $(2\pi/L_m)$; L_m is the wave length.

Knowing the wave height and wave direction at the measured point, the breaking wave height, and wave direction could be determined.

The longshore transport rate Q_l depends on the longshore component of energy flux (P_l) in the surf zone, CERC (1984)

$$P_l = \frac{\rho g}{16} H_b^2 C_b \sin 2\alpha_b \qquad (12)$$

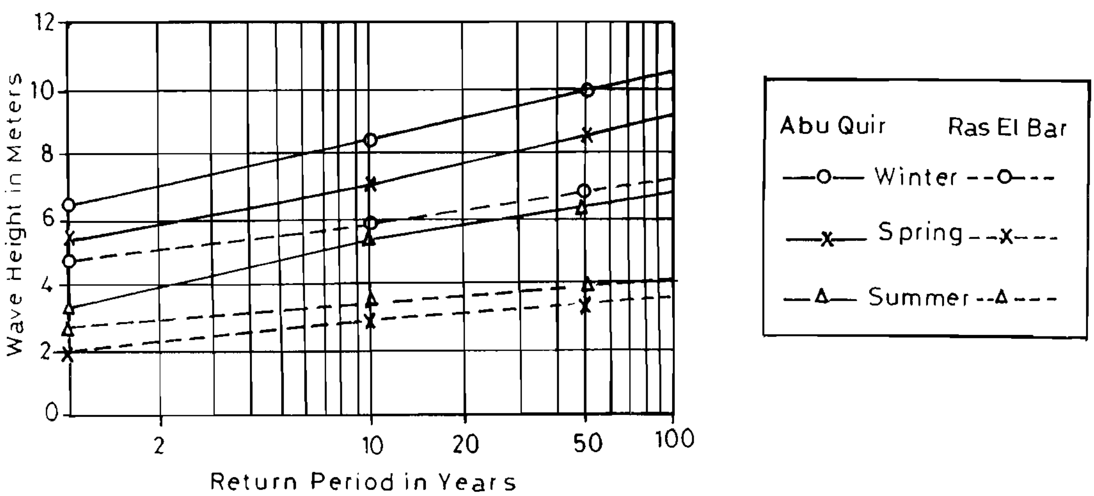

Figure 7. Return periods of storm waves computed from measured data at Abu Quir and Ras el Bar from 1985 through 1990.

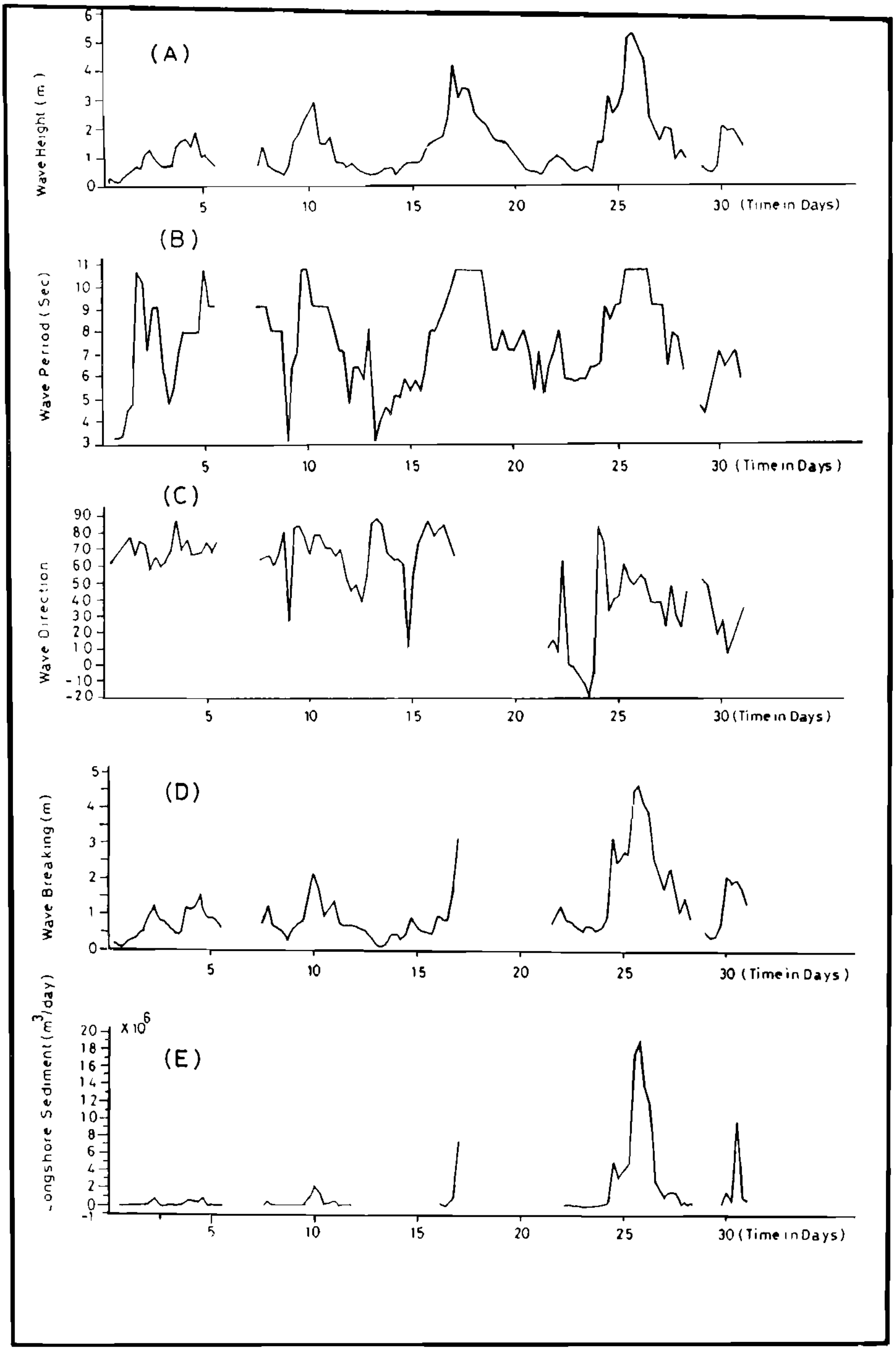

Figure 8. Sample of wave records during December 1988 at Abu Quir (A) Wave height. (B) Wave period. (C) Wave direction. (D) Wave breaking. (E) Longshore sediment.

$$I_l = K_l P_l. \quad (13)$$

K_l is constant equals 0.77 defined by (KOMAR and INMAN, 1970). I_l is the immersed weight of sand transport alongshore.

$$I_l = (\rho_s - \rho)g(1 - a)Q_l. \quad (14)$$

ρ_s and ρ are the sediment and water densities, respectively, a is the porosity of the moving bed. Sample of the results is shown in Figure 8.

CONCLUSIONS

From the study of the wave climate along the Egyptian coast, the following is deduced:

(1) For both the two stations (Abu Quir and Ras el Bar)
   A. Modal significant wave height is about 0.75 m
   B. Modal significant wave period 7–8 sec during winter and summer reducing to 5–6 sec at spring.

(2) At Abu Quir maximum significant wave heights were found to be 5.5 m, 4.0 m and 3.3 m for winter, spring and summer; while at Ras el Bar, they were 4.3 m in winter, 2.0 in spring and 2.6 m in summer.

(3) The annual average significant wave height and period were approximately 1.0 m and 6.0 sec, respectively, at Abu Quir. The corresponding values at Ras el Bar are 0.7 m and 6 sec.

(4) The predominant wave direction is from the NW and WNW; whereas, waves from the NNE and NE sectors are limited in magnitude and occur primarily during the summer months.

(5) The expected extreme wave height which might occur after 50 years was found to be 10 m, 8.5 m and 6.5 m at Abu Quir; while at Ras el Bar it was 7 m, 4 m and 3.5 m during the winter, spring and summer seasons, respectively.

(6) The wave statistics along the Mediterranean coast of Egypt are used to calculate the sediment transport and to study the erosion problem along this coast.

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