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WAVE CLIMATE AND WAVE REFRACTION ALONG MADRAS COAST

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ABSTRACT

Wave climate along Madras coast (lat. 13° 04′N and long. 80° 17′E) for deep and shallow waters have been evaluated and discussed. The bottom topography and the orientation of the coastline seem to have profound influence on the shallow water wave characteristics. Wave refraction diagrams have been constructed for the average wave conditions and the wave energy distribution and the resultant longshore current along the coast have been critically examined.

Key-words : Wave climate, wave refraction, Madras coast.

INTRODUCTION

The waves impinging on a shoreline are those generated either by local winds or by storms at a relatively greater distance from the shorelines. Wind generated sea is a confused mixture of waves of varied wave lengths, heights and periods. Hence the wave characteristics of a wind generated sea can be expressed precisely only in probabilistic form. Sverdrup, Johnson and Fleming (1942) have summarized the characteristics of the ocean waves generated by wind action on the sea surface and later investigations by Pierson, Neumann and James (1955) have led to a better understanding of the wave characteristics, viz., wave height, length, period and velocity, and their inter-relationships with the wind speed and direction, duration and fetch. The wave effects near the shore were studied by Shepard (1963) and Inman, Munk and Balay (1962) who explained the influence of waves on the nearshore sedimentation processes and currents.

When waves approach a shoreline at an angle, the wave velocity and the wave length decrease, while the period remaining the same and the total energy is slightly reduced due to bottom friction but in addition they are bent. The inshore portion of the wave front travels at a lower velocity than the portion in deeper water, consequently the waves swing around and conform to the bottom contours. The result of refraction is a change in height and direction of the waves. The magnitude of the changes in height and direction resulting from wave refraction can be estimated through refraction diagrams. Krumbein (1944) was the first to consider the effect of wave refraction on sediment transportation, in which he states that a wave refraction diagram indicates at least the order of change in wave energy along the coast. The graphical method of construction of wave refraction diagrams are described by Arthur, Munk and Isaac (1952). An excellent review of the progress in the theoretical and practical aspects of the wave refraction diagram is given by Chao (1970). The numerical

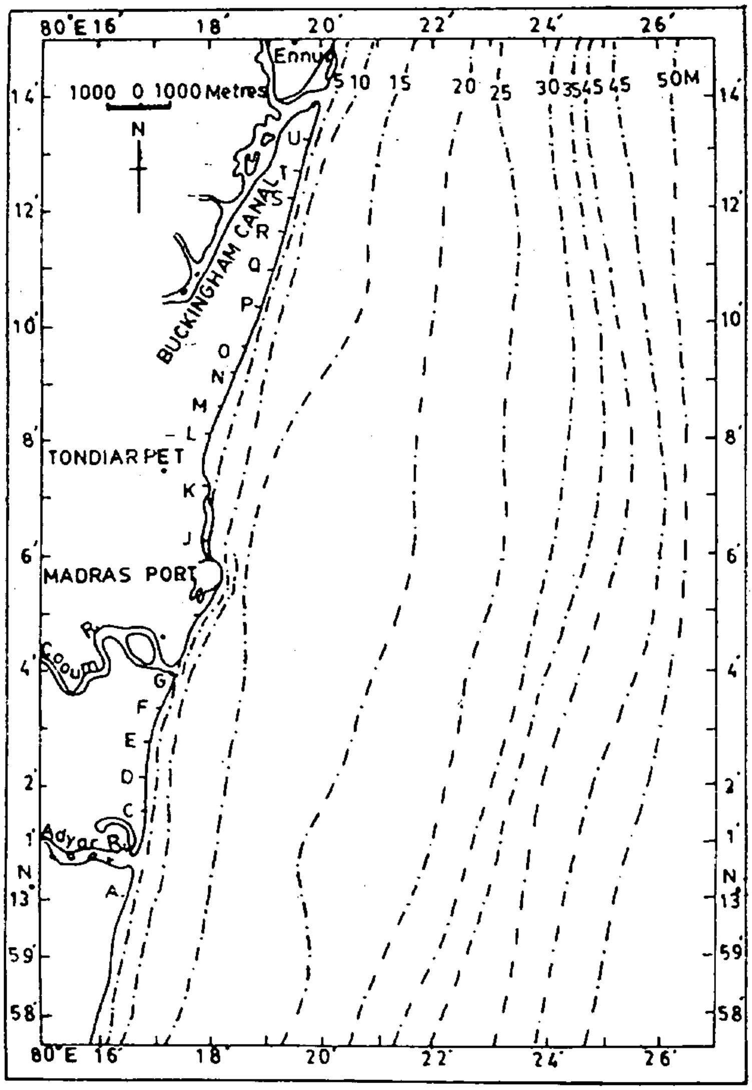

Fig. 1. Station location.

model for the wave refraction analysis is developed by Dobson (1967). His model requires the wave ray to originate in deep water, a condition which is not always practical (or economical) for long period waves.

The area under investigation is a 25 km stretch of the coast near Madras (lat. 13°04′ N; long. 80°17′ E), East coast of India. Madras coast is more or less a straight stretch of land oriented approximately north-south (Fig. 1).

MATERIAL AND METHODS

The wave characteristics (height, period and direction) in deep waters reported by ships plying in the neighbourhood of Madras between latitudes 12° N to 16° N and longitude 80° E to 85° E for the years 1970 to 1979 have

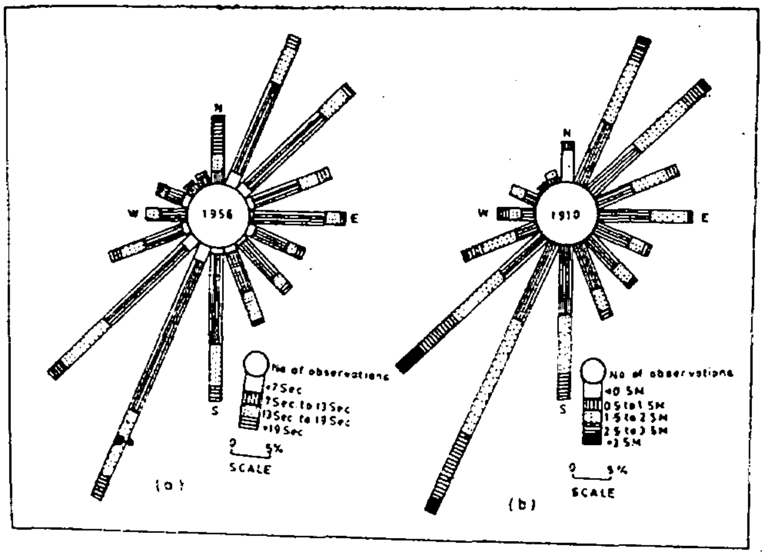

Fig. 2. Yearly wave rose diagram for deep water wave period and wave heights.

been collected from the records of India Meteorological Department. The wave data have been analysed statistically and the frequencies of their occurrence of wave heights and periods from different directions are presented in the form of rose diagrams (Fig. 2). The shallow water wave data from 1970 to 1979 have been analysed and their frequency of occurrence from different directions are presented (Tables I & II).

Wave refraction diagrams have been constructed using the topographic survey chart off Madras, published by the Naval Hydrographic Survey of India (No. 3001). The direction of wave approach at any point is usually given by the direction function 'α' representing the angle between the wave ray at the point and the coast-normal. The value of 'α' may vary along a depth contour depending on the wave refraction pattern. The refraction function 'K_b at the point of wave breaking is given as $(bo/b)^{1/2}$ and varies for different points along the coast. (Where bo is the separation between wave rays in deep water and b is the separation in shallow water at the point of investigation).

DISCUSSION

The mean annual distribution of wave heights and periods from different directions (Fig. 2), during a year indicate that about 48% of the waves come from the directions between south and west with the predominant direction being south southwest. About 29% of the waves come from directions between north and east with the predominant direction being North-northeast. The predominant wave directions in deep water and shallow water are given in Table III. The analyses of the deep and shallow water wave characteristics show that the wave direction, height and period undergo remarkable changes as the waves travel from deep water to shallow water. In deep water, the wave

Table I. Percentage frequency of shallow water wave heights from different directions.

Month \ Wave heights range(m)	< 0.5	0.5 to 1.0	1.0 to 2.0	< 2.0	Total	< 0.5	0.5 to 1.0	1.0 to 2.0	< 2.0	Total
			NE					ENE		
January	—	6.4	4.3	—	10.7	7.8	34.4	19.2	—	61.4
February	—	—	—	—	—	—	7.4	1.4	—	8.8
March	—	—	—	—	—	—	0.8	1.6	—	2.4
April	—	—	—	—	—	—	—	—	—	—
May	2.5	—	—	—	2.5	2.9	1.7	—	—	4.6
June	—	—	—	—	—	—	—	—	—	—
July	—	—	—	—	—	—	—	—	—	—
August	—	—	—	—	—	—	—	—	—	—
September	—	—	—	—	—	—	—	—	—	—
October	4.0	3.4	—	—	7.4	—	8.7	5.5	—	14.2
November	1.1	15.6	10.0	2.5	29.2	—	13.5	15.2	7.8	36.5
December	—	6.3	11.9	—	18.2	—	37.5	21.3	—	58.8
			EAST					ESE		
January	1.4	9.9	5.8	—	17.1	—	10.0	0.8	—	10.8
February	3.0	26.5	5.8	—	35.3	13.2	24.2	4.1	—	41.5
March	—	4.8	1.6	—	6.4	3.2	28.2	—	—	31.4
April	—	—	—	—	—	—	2.0	1.0	—	3.0
May	—	—	—	—	—	0.6	4.7	3.5	—	8.8
June	—	—	—	—	—	—	14.9	10.3	—	25.2
July	—	—	—	—	—	—	1.1	0.6	—	1.7
August	—	—	—	—	—	—	2.5	1.5	—	4.0
September	—	—	—	—	—	—	9.4	2.8	—	12.2
October	—	14.5	4.6	1.2	20.3	—	14.2	—	—	14.2
November	—	20.7	10.7	—	31.4	—	2.1	0.7	—	2.8
December	—	8.8	13.5	0.6	22.9	—	—	—	—	—
			SSE					SE		
January	—	—	—	—	—	—	—	—	—	—
February	—	—	—	—	—	0.8	12.0	1.4	—	14.2
March	6.4	2.4	—	—	8.8	2.4	41.8	6.6	—	50.8
April	3.6	20.5	2.7	—	26.8	1.5	54.4	14.3	—	70.2
May	—	9.9	—	—	9.9	—	51.1	23.1	—	74.2
June	—	10.3	1.2	—	11.5	11.4	42.4	9.4	—	63.2
July	—	9.0	2.8	—	11.8	3.4	64.0	19.0	—	86.4
August	—	4.5	—	—	4.5	12.0	67.7	11.7	—	91.4
September	5.0	5.5	2.2	—	12.7	5.5	62.7	6.8	—	75.0
October	4.0	—	—	—	4.0	2.0	35.1	2.7	—	39.8
November	—	—	—	—	—	—	—	—	—	—
December	—	—	—	—	—	—	—	—	—	—

Table II. Percentage frequency of shallow wave periods from different directions.

Wave period (Sec) / Month	< 8	8	10	12	14	Total	< 8	8	10	12	14	Total
			NE						ENE			
January	—	0.7	3.4	5.5	—	9.6	6.2	40.0	12.4	1.4	—	60.0
February	—	—	—	—	—	—	—	2.9	5.1	0.8	—	8.8
March	—	—	—	—	—	—	—	2.3	—	—	—	2.3
April	—	—	—	—	—	—	—	—	—	—	—	—
May	—	—	—	—	—	—	—	—	4.7	—	—	4.7
June	—	—	—	—	—	—	—	—	—	—	—	—
July	—	—	—	—	—	—	—	—	—	—	—	—
August	—	—	—	—	—	—	—	—	—	—	—	—
September	—	—	—	—	—	—	—	—	—	—	—	—
October	—	—	7.5	0.6	—	8.2	0.6	6.8	5.6	—	—	13.0
November	1.2	11.3	13.6	0.6	—	26.7	6.5	19.2	11.9	1.8	—	39.4
December	—	5.2	12.0	1.0	—	18.2	3.8	36.4	19.2	0.6	—	60.0
			East						ESE			
January	1.4	15.1	3.5	—	—	20.0	—	6.8	3.6	—	—	10.4
February	5.1	23.0	5.2	—	—	33.3	0.8	21.5	21.5	0.7	—	44.5
March	2.3	3.0	—	—	—	5.3	3.0	20.6	7.7	—	—	31.3
April	—	—	—	—	—	—	—	2.5	1.5	—	—	4.0
May	—	—	—	—	—	—	1.2	3.6	2.9	—	—	7.7
June	—	—	—	—	—	—	2.9	9.5	1.8	2.2	—	22.4
July	—	—	—	—	—	—	—	—	2.4	—	—	2.4
August	—	—	—	—	—	—	—	1.5	2.0	0.5	—	4.0
September	—	—	—	—	—	—	—	5.6	0.6	3.9	—	10.0
October	—	15.0	4.8	2.0	0.8	22.6	—	7.7	6.8	—	—	14.5
November	0.6	17.8	11.9	1.2	—	31.5	—	—	2.4	—	—	2.4
December	0.6	14.5	6.7	—	—	21.8	—	—	—	—	—	—
			SSE						SE			
January	—	—	—	—	—	—	—	—	—	—	—	—
February	—	—	—	—	—	—	0.8	6.6	5.2	0.8	—	13.4
March	—	—	6.8	2.4	—	9.2	2.4	30.5	16.7	2.3	—	51.9
April	—	11.2	15.3	0.7	—	27.2	—	35.7	29.6	3.5	—	68.8
May	—	3.2	7.7	—	—	10.9	1.2	28.0	41.0	6.5	—	76.7
June	—	1.6	9.0	0.6	—	11.2	0.6	39.4	22.4	4.0	—	66.4
July	—	5.7	4.5	0.6	—	10.8	—	22.4	50.8	10.8	2.8	86.8
August	—	—	3.6	—	—	3.6	—	30.1	40.2	18.6	3.5	92.4
September	—	2.3	10.6	—	—	12.9	—	35.4	22.0	19.6	—	77.0
October	—	—	4.1	—	—	4.1	—	15.0	15.8	6.8	—	37.6
November	—	—	—	—	—	—	—	—	—	—	—	—
December	—	—	—	—	—	—	—	—	—	—	—	—

Table III. Predominant wave direction in different months.

Month	Deep water wave direction	Shallow water wave direction
January	North-northeast Northeast	East-northeast
February	Northeast	East-southwest
March	East	Southeast
April	South	Southeast
May	South-southwest	Southeast
June	South-southwest	Southeast
July	South-southwest Southwest	Southeast
August	South-southwest	Southeast
September	South-southwest	Southeast
October	South-southwest Southwest	Southeast
November	East-northeast Northeast	East-northeast Northeast
December	Northeast	North-northeast

directions are highly variable from season to season and even from month to month while the direction of wave approach in shallow water is limited to a sector between east-northeast and southeast. From March to October the direction of wave approach remains the same (southeast) in shallow waters. During November, December and January the predominant wave direction in shallow water is east-northeast, while in February it is east-southeast. Thus it is found that all the waves which have a southerly component reach the coast from the southeast and all the waves which have a northely component in deep water reach the coast from the east-northeast. This is due to the wave refraction in shallow water which tends to make the wave rays as nearly normal to the coast as possible depending on the offshore topography.

The wave heights in deep water as well as in shallow water exhibit large changes. The maximum wave heights reported in shallow waters are comparatively higher than those in deep water. The higher period waves observed in deep water are not recorded in shallow waters. Also the lower period waves during the course of travel loss their identity. A striking feature of the shallow water is the dominance of the medium period waves. As a result, periods between 8 and 10 sec are mostly observed throughout the year near coast.

WAVE REFRACTION

Wave refraction diagrams have been constructed for wave period of 8 and 10 sec from four directions namely, northeast, east northeast, east southeast, and southeast (Figs. 3 & 4), since these waves are found to be more fre-

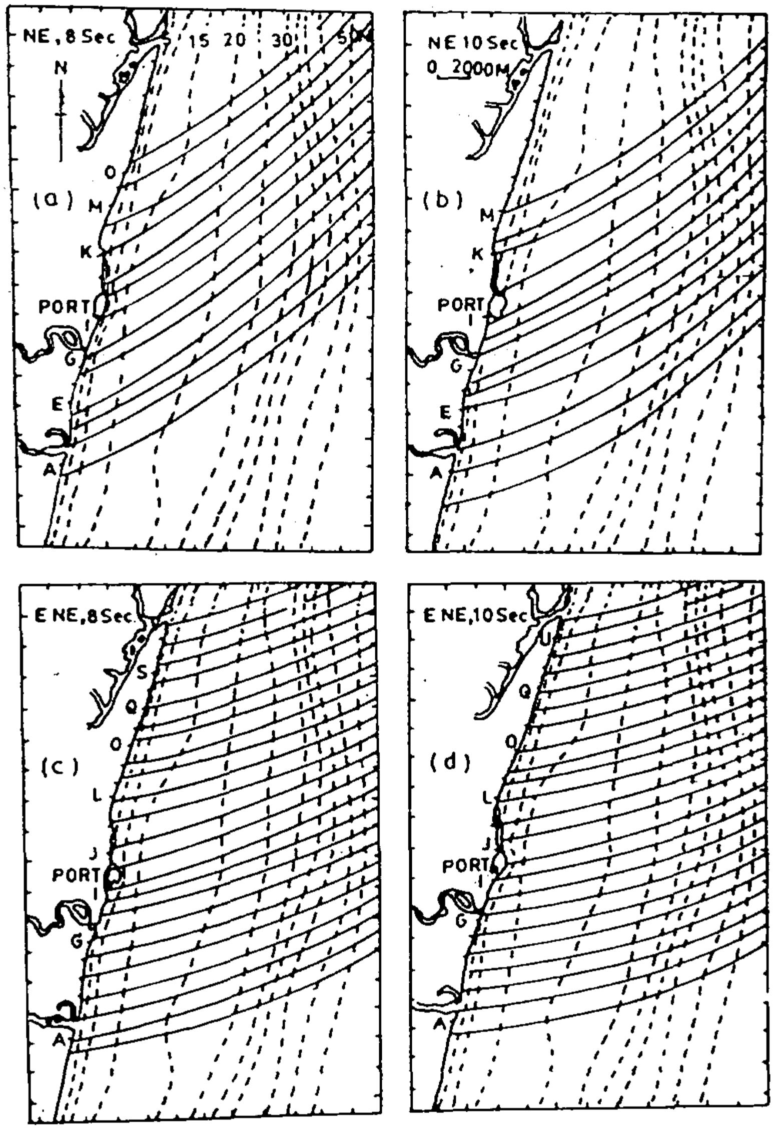

Fig. 3. Refraction diagrams for NE & ENE, directions.

quent near coast as discussed earlier. These diagrams show the wave refraction patterns to the north and south on either side of the port covering a total distance of about 20 km from Adyar river confluence to Ennur. Since the effects of wave refraction vary considerably from one point to another alongshore, it is found convenient to divide the coastal strip into different zones (designed A to V stations from south to north) as shown in the refraction diagrams and the effects of refraction are discussed separately for each zone. The Madras port itself lies between the zones I and J. The refraction function (K_b) and the direction function (α) have been evaluated for each zone and are presented in Table IV.

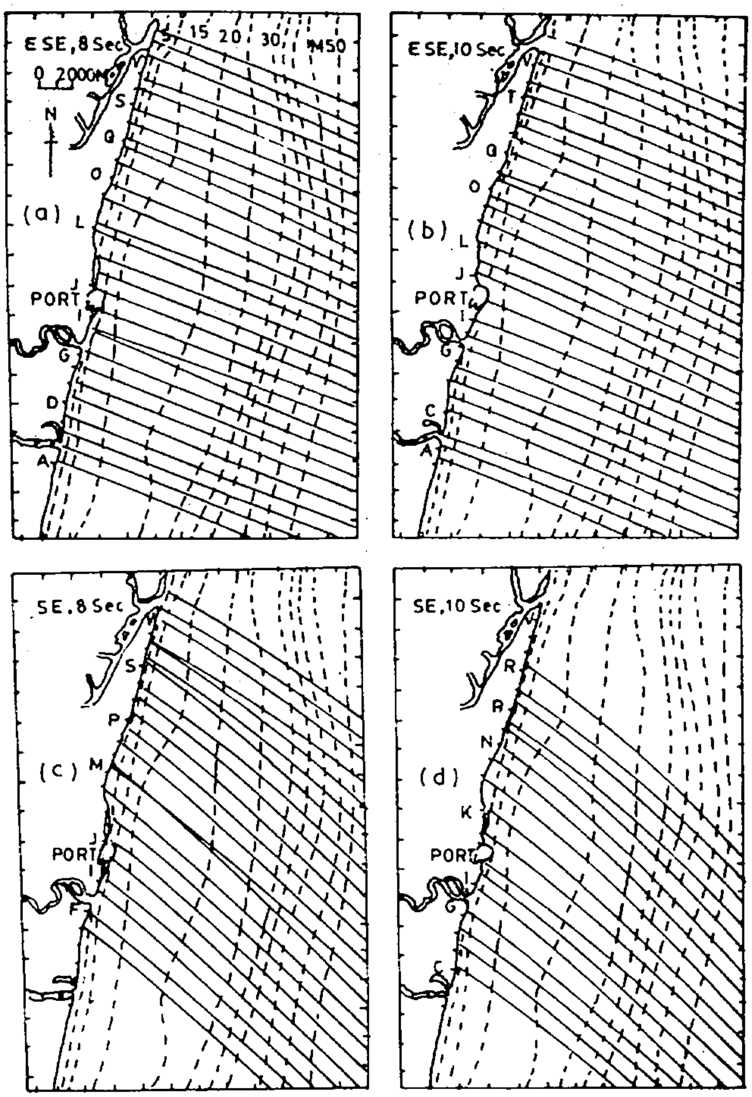

Fig. 4. Refraction diagrams for ESE & SE directions.

Refraction of waves from NE direction: The distribution of wave rays along the coast (Figs. 3A & B) is by no means uniform. The refraction functions are highly variable along the coast as shown in Fig. 5 and do not show any regular pattern. The values of wave heights along the coast also vary accordingly and do not show any regular change from one zone to the other. The shoreline to the south of Madras port that is from A to I shows alternate zones of divergence and convergence with the refraction function varying from a minimum value of 0.74 to a maximum value of 1.03. The wave heights should also show variations along the coast in this area accordingly. The wave refraction diagram indicates the possibility of rip currents between Adyar river confluence and Madras Port. To the north of Madras port there is generally a divergence pattern along the entire shoreline particularly for 8 sec waves. The refrac-

Table IV. Refraction functions (K) and directions (α) along the breaker line for different stations.

Station	NE/8 Sec		NE/10 Sec		ENE/8 Sec		ENE/10 Sec		ESE/8 Sec		ESE/10 Sec		SE/8 Sec		SE/10 Sec	
	α	K	α	K	α	K	α	K	α	K	α	K	α	K	α	K
A	25°	0.83	27°	0.77	17°	1.09	17°	0.89	4°	1.00	7°	1.05	—	—	—	—
B	22°30′	1.03	25°	0.85	16°30′	0.91	14°	0.94	7°30′	1.05	5°	1.18	—	—	—	—
C	22°	1.01	—	0.74	15°	0.92	13°	0.98	10°	0.98	8°	0.85	—	—	22°30′	—
D	28°	—	25°	1.18	18°	0.89	14°	0.92	11°30′	0.92	9°	1.05	—	—	27°	0.96
E	—	0.75	32°	1.09	21°	0.96	12°	0.95	9°	1.00	10°	1.00	22°	—	22°	1.01
F	30°	0.96	35°	—	26°	0.94	25°	0.92	3°30′	1.00	7°	1.07	21°30′	0.96	21°	0.92
G	40°	—	37°	0.82	27°30′	0.89	27°	1.00	5°	0.98	1°	0.91	20°	1.08	19°	0.85
H	—	0.77	30°	1.05	29°	1.07	30°	0.94	2°	1.80	3°	1.00	17°	1.00	17°30′	1.05
I	43°	0.90	38°	0.74	22°30′	1.09	20°	1.03	1°	0.95	2°	0.90	20°	0.91	9°	1.15
J	38°	1.05	37°	0.83	20°	0.91	17°	0.88	4°	1.00	12°	0.89	29°	0.94	19°	0.85
K	21°	0.82	30°	0.74	10°	0.87	17°	0.89	10°	1.00	10°	0.96	20°30′	0.96	22°	0.86
L	25°	0.90	32°30′	1.11	19°	0.95	20°30′	0.96	2°30′	1.35	5°	0.96	18°	0.86	21°	0.89
M	—	0.79	31°	0.81	13°	0.86	21°30′	1.07	9°	0.85	6°	0.95	—	0.83	22°30′	1.03
N	30°	0.89	—	—	20°	1.07	21°	0.92	7°30′	1.03	5°30′	1.18	20°	0.98	21°	1.00
O	32°30′	—	—	—	20°	0.87	23°	0.87	9°	0.90	5°	1.35	19°	0.96	25°	1.25
P	—	—	—	—	22°30′	1.12	22°	0.96	7°	1.00	6°30′	0.89	18°30′	0.98	20°	0.89
Q	—	—	—	—	21°	0.92	22°	0.96	5°	1.03	6°	1.05	19°	1.18	17°	0.85
R	—	—	—	—	20°30′	0.87	20°30′	0.92	2°30′	1.05	3°	1.07	21°	0.87	19°	—
S	—	—	—	—	20°	0.96	19°30′	1.01	4°	0.92	4°30′	0.98	12°	1.70	—	—
T	—	—	—	—	17°	0.94	22°	0.96	3°	1.18	4°	1.03	10°	1.03	—	—
U	—	—	—	—	—	0.92	25°	0.94	4°	0.89	3°	0.94	12°	0.85	—	—
V	—	—	—	—	17°	—	24°	—	4°30′	1.00	2°30′	1.09	10°30′	1.11	—	—

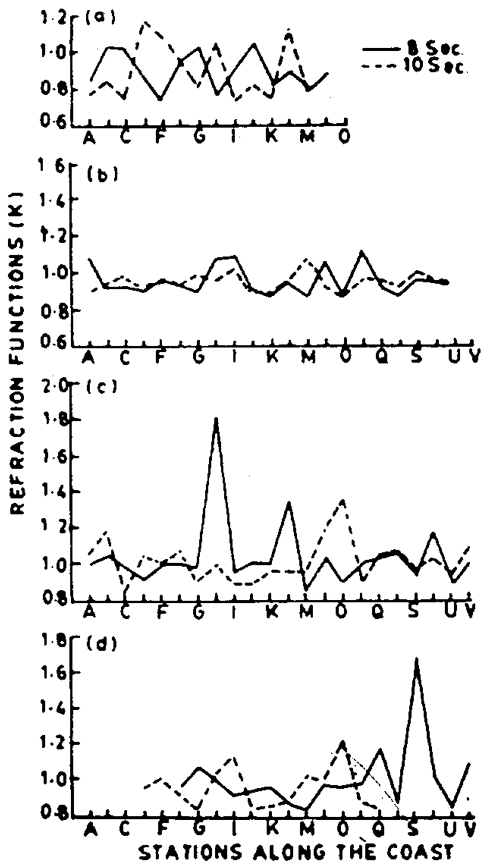

Fig. 5. Variation of refraction function (K) for different zones along the coast (a) NE waves, (b) ENE waves, (c) ESE waves, (d) SE waves.

tion function is generally less than 1.0. Convergence patterns are noticed at zones B and C on the southern side for 8 sec period waves, while the zones of convergence are at D and E for 10 sec waves. At J just to the north of port entrance there is a convergence zone for 8 sec waves and erosion is noticed in this area even during northeast monsoon season. Protection measures have been taken up in this region and a seawall has been constructed to minimise erosion.

The values of direction function ' α ' are fairly large, varying between 21° and 43°. This indicates that the waves break even before the refraction has been completely effected, and strong longshore currents directed southward could exist.

Refraction of waves from ENE direction: The refraction diagrams for waves of 8 and 10 sec period from ENE direction are shown in Fig. 3 C & D. The wave ray distribution to the south of Madras port upto Adyar river confluence indicates more or less uniform distribution of wave energy. The refraction functions are generally less than 1.0 except for zones I and H very near the port where convergence takes place. Slight deposition is possible all along the coast to the south of Madras port during the season when east northeast waves are predominant. The shore to the north of Madras port shows zones of wave convergence at N and P. Except for these two zones the entire coast to the north is safe and stable and a gradual deposition of the beach might take place as a result of these waves. The direction functions vary around 20° giving rise to strong longshore currents directed towards south.

Refraction of waves from ESE direction: The refraction function evaluated from the refraction diagrams for east-southeast waves are shown in Table IV. The values of refraction function are generally less than 1.0 for most of the zones all along the coast. However, a highest refraction of about 1.8 is found at station H for waves of 8 sec period, where there is an intense zone of wave convergence. Heavy breakers appear in this zone when the predominant wave direction is east southeast. To the north of Madras port there is again a zone of convergence at L, where the refraction function is about 1.35 for 8 sec period waves. The direction functions vary between –2° to 12° and the alongshore component of energy is comparatively small. The longshore currents generated by these waves are generally weak and are directed from south to north.

Refraction of waves from SE direction: The refraction diagram for waves of 8 sec and 10 sec periods from southeast are shown in Figs. 4 C & D. The allignment of wave rays to the south of Madras port indicate more or less uniform distribution of wave energy. Near the port entrance there is a zone of divergence particularly for 10 sec period waves. As a result of this the breakers to the south of the port are of small height. The region to the north of Madras port shows zones of wave convergence particularly at O, S, and T. The convergence seen from the diagram. Heavy breakers are witnessed in that region during southwest monsoon season. The beach here is subjected to severe erosion during this season. The refraction function is generally less than 1.0 for 10 sec period waves, except for zone I and O, where the values exceed unity. For 8 sec waves the refraction functions exceed unity to the north of port entrance channel and attain very high values at zones Q and S. The direction function vary between 10° and 29° for 8 sec waves and between 9° and 27° for 10 sec period waves. The average value for the coast is worked out to be about 18° for the southeast waves. As a result, the alongshore component of energy is large and strong longshore currents directed towards south during northeast monsoon season.

Thus the wave refraction studies for the Madras port region reveal that the distribution of wave energy along the coast varies for different waves according to their direction and period. The region between Adyar River and the Madras port (south of the port) shows alternate zones of convergence and divergence for northeast waves and rip currents might be produced here during November and December particularly after a storm period. But for the region north of port there is less chance of danger due to rip currents during the northeast monsoon season. Thus from November to January the longshore currents in the surf zone south of the port are supposed to be strong and directed downcoast. During the same period the longshore currents to the north of the port are supposed to be weak. Wave refraction studies for the southeast waves indicate high breakers and strong currents to the north of Madras port while on the southside of the port the wave heights and longshore currents are comparatively smaller. As a result the northern shore in subjected to severe erosion during the southwest monsoon season.

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