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Littoral Processes along Shoreline from Andhakaranazhi to Azhikode on the Kerala Coast

S S C SHENOI & S PRASANNA KUMAR
Department of Marine Sciences, University of Cochin, Cochin 682 016

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Distribution of wave energy and variations in wave height and direction of longshore currents have been estimated from the wave refraction diagrams for predominant waves approaching the shore. A zone of strong energy concentration for waves of 14 sec period approaching from 240° has been identified near Azhikode. The direction of littoral current is northerly for waves approaching from 220° and 240° whereas it is southerly for waves approaching from 280° and 300°. Probable areas of rip currents have been identified along the shore. More areas of generation of rip currents have been located during southwest monsoon season when wave approach is from 260°. Regions of possible erosion and accretion have been identified. The coastline shows an erosional tendency under the influence of waves approaching from 220° and 240° and an accretional tendency under the influence of waves from 280° and 300°.

The barrier type beaches of Kerala are low and sandy. Along many of these beaches, severe erosion is an annual phenomenon during southwest monsoon season[1]. Wave action is the primary source of energy available in the nearshore zone for various processes involving circulation pattern and sediment transport along these stretches of open coast.

When waves approach a shoreline at an angle to the bottom contours, they undergo refraction whereby they tend to conform to the bottom contour. Oblique approach and variations in the height of the breakers give rise to movement of water parallel to the shore as longshore currents. The associated sediment movement is called longshore drift. The present study attempts to elucidate the distribution of wave energy, longshore currents, rip currents and intensity of erosion and accretion in relation to refraction pattern for waves approaching with different periods and from different directions, along the beaches around Cochin on the Kerala Coast.

Materials and Methods

The area under study is a stretch of about 57 km of shoreline from Azhikode to Andhakaranazhi (Fig.1). Azhikode, where river Periyar opens out into the Arabian Sea, is located at the northern end of the coast under study. The Cochin harbour entrance channel is located midway between Azhikode and Andhakaranazhi. At Andhakaranazhi there is a small seasonal opening which remains open throughout the monsoon season. At Malipuram and Narakkal the shore is usually protected by the presence of mudbanks which form during southwest monsoon season[2]. Considerable stretch of the shoreline, particularly in the region between Fort Cochin and Andhakaranazhi are vulnerable to seasonal erosion[3]. The bottom topography on the northern side of the Cochin harbour channel presents gentle offshore slope, whereas south of the channel, the slope is relatively steep (Fig. 1).

Refraction diagrams have been constructed following the method of Arthur *et al.*[4] using bathymetric charts prepared from the chart No.220 (Naval Hydrographic Office, Dehra Dun, Govt. of India) corrected up to 1971 and updated with recent sounding data. Wave orthogonals are taken at 1.5 km apart in the deep water so that the area under study is covered by about 41 orthogonals. The locations of the shore stations (A-T) are also shown in Fig.1.

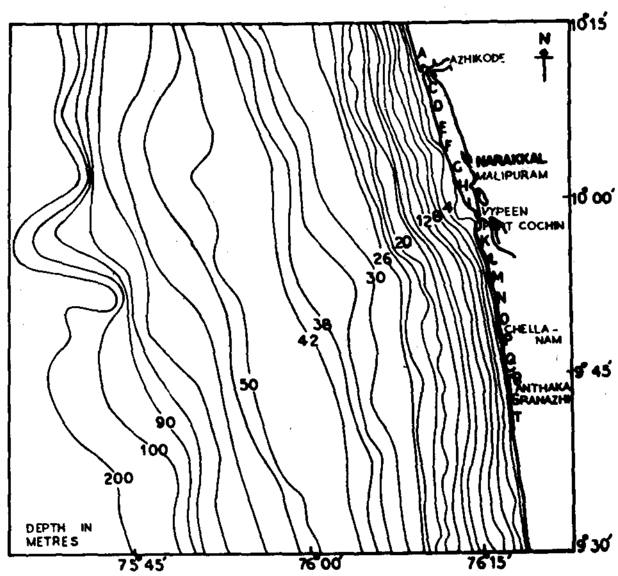

Fig. 1—Bathymetry and sts A to T

From the spacing of the wave orthogonals reaching shallow water, refraction function is calculated using the formula[5],

$$K(f,\theta)^2 = \frac{b_o/b}{\frac{C}{C_o} + \frac{4\pi d}{L_o}\left(\sin h \frac{4\pi d}{L_o} \frac{C_o}{C}\right)^{-1}}$$

where b_o and b are distances of separation of wave rays in deep and shallow water, c_o and c are wave crest speeds in deep and shallow water, d is the shallow water depth and L_o is the deep water wave length.

The ratio of the shallow water and deep water wave heights is given by[6],

$$\frac{H}{H_o} = \left[\frac{L_o}{L}\right]^{\frac{1}{2}} \left[\frac{b_o/b}{1 + \frac{4\pi d/L_o}{\sin h \frac{4\pi d}{L_o}}}\right]^{\frac{1}{2}}$$

Since $L = CT$ and period T is same for a particular wave in deep and shallow water,

$$\frac{H}{H_o} = K^{\frac{1}{2}}$$

Estimation of deep water wave characteristics becomes important for a study like this, because, the results depend mainly on the reliability of the offshore wave data. Data obtained from the visual observations reported by the ships in the neighbourhood of Cochin between lat. 8°30'N to 11°30'N and long. 73°30'E to 76°30'E for 1974 to 1980 have been collected from the Indian Daily Weather Reports. The wave data have been analysed statistically and frequency percentages of occurrence of period and direction are given in Tables 1 and 2 for each month. The orientation of the shoreline along this part of the Kerala coast is in the NNW - SSE direction so that waves approaching the coast between 170° and 350° are of greatest significance in the littoral processes along the shore under study. Refraction diagrams have therefore been prepared for waves of period 6,8,10,12 and 14 sec approaching from 220°, 240°, 260°, 280° and 300°.

Results and Discussion

Refraction functions have been calculated for 20 stations A to T (Fig.2). The ratios of wave heights at 2 m line to the deep water wave height (H/H_o) for all these stations are presented in Table 3. Angle of incidence of the wave ray on the normal to the shore at each of these stations are determined and direction of littoral movement estimated (Fig. 3). The relative increase in the refraction function indicates an area of erosion and decreasing tendency of refraction function between stations indicates a tendency of accretion. Possible areas of erosion and accretion have been qualitatively identified from the refraction function and longshore current directions (Fig.4).

Wave energy distributions along the beach depends on the refraction function (Fig.2). Refraction function values for 6 sec period waves approaching from various angles are generally higher than 1.06 (corresponding to $\frac{b_o}{b} = 1$). For waves of 8 sec period, values of K are generally more than that of 6 sec period waves. For waves of 8 sec period the refraction function shows higher values for angle of approach 220° and lower values for angle of approach 300°. In

Table 1—Monthly Percentage Frequency of Swell Periods Off Cochin

Month	Period (sec)									
	≤5	6	7	8	9	10	11	12	13	≥14
Jan	43.4	19.7	5.3	2.6	1.3	11.8	2.6	2.6	4	6.6
Feb.	53.3	19.5	3.9	3.9	5.2	1.3	0	2.6	6.5	3.9
March	23.3	30	6.7	15	5	3.3	5	8.3	0	3.3
April	44.8	20.9	13.4	14.9	1.5	3	1.5	0	0	0
May	28.9	23.1	14.4	12.5	1.9	2.9	4.8	3.9	2.9	4.8
June	18.7	28	13.1	14	5.6	14.9	0	0	1.9	3.7
July	23.7	19.5	19.5	16.1	7.6	5.9	0.9	0.9	2.5	3.4
Aug.	12.4	24	23.3	16.3	7.0	7.8	5.4	1.6	1.6	0.8
Sept.	24.8	23	20.4	7.1	4.4	6.2	0	1.8	5.3	7.1
Oct.	36.5	22.2	12.7	9.5	9.5	6.4	0	0	0	3.2
Nov.	39	12.9	12.9	9.1	2.6	3.9	2.6	1.3	1.3	14.3
Dec.	59.4	21.7	4.4	5.8	0	2.9	0	0	2.9	2.9

Table 2—Monthly Percentage Frequency of Swell Directions Off Cochin

[Direction of wave approach (Degrees)]

Month	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180
Jan.	2.56	1.28	2.56	3.85	3.85	6.41	—	6.41	3.85	—	2.56	8.97	1.28	1.28	5.12	2.56	—	—
Feb.	2.53	1.27	1.27	3.80	2.53	—	2.53	1.27	1.27	2.53	2.53	—	1.27	5.06	1.27	—	—	3.80
March	3.28	—	1.64	—	—	—	—	—	1.64	—	—	1.64	—	3.28	—	3.28	1.64	4.92
April	3.08	1.54	—	—	—	—	—	—	—	1.54	—	—	—	—	3.08	4.62	3.08	6.15
May	—	—	—	—	—	—	—	—	—	—	2.11	—	1.05	2.11	—	1.05	—	8.42
June	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2.78
July	—	—	—	—	—	—	—	—	—	—	—	—	1.68	—	—	—	—	—
Aug.	—	0.76	—	—	—	—	—	—	—	—	—	—	0.76	—	—	—	—	—
Sept.	—	—	—	—	—	—	—	—	—	—	—	—	—	1.72	—	—	0.86	—
Oct.	3.28	—	—	1.64	—	—	—	—	—	3.28	—	—	3.28	1.64	3.28	1.64	4.92	4.92
Nov.	1.43	1.43	—	—	1.43	1.43	1.43	2.86	1.43	1.43	2.86	1.43	2.86	1.43	1.43	2.86	2.86	7.14
Dec.	4.48	2.99	1.49	8.96	4.48	7.46	2.99	1.49	8.96	2.99	—	4.48	1.49	4.48	1.49	4.48	1.99	4.48

Month	190	200	210	220	230	240	250	260	270	280	290	300	310	320	330	340	350	360
Jan.	—	—	—	—	—	—	—	—	1.28	—	1.28	2.56	3.85	10.26	—	5.12	2.56	19.23
Feb.	—	—	—	—	—	—	—	—	3.80	1.27	—	5.06	13.92	8.86	11.39	8.86	6.33	7.59
March	3.28	—	—	3.28	—	1.64	—	1.64	3.28	—	1.64	14.75	3.28	11.48	8.20	14.75	4.92	6.56
April	3.08	1.54	—	—	—	3.08	—	—	3.08	6.15	3.08	6.15	16.92	10.97	9.23	7.69	3.08	3.08
May	3.16	—	1.05	5.26	4.21	3.16	2.11	7.37	9.47	8.42	8.42	9.47	7.37	4.21	5.26	3.16	2.11	1.05
June	0.93	3.70	—	1.85	2.76	4.62	15.74	6.48	17.59	12.96	10.19	11.11	3.70	2.78	0.93	—	—	—
July	0.84	3.36	—	2.50	4.20	8.40	9.24	8.40	15.96	14.29	8.40	13.45	4.20	2.50	0.84	0.84	0.84	—
Aug.	0.76	3.05	1.53	—	8.39	3.82	8.39	8.39	22.14	19.08	11.45	6.11	3.05	2.29	—	—	—	—
Sept.	1.72	0.86	0.86	2.59	1.72	6.90	6.90	13.79	18.97	15.52	11.21	6.90	2.59	5.17	0.86	—	0.86	—
Oct.	1.64	4.92	6.56	3.28	8.20	8.20	1.64	8.20	8.20	6.56	3.28	1.64	3.28	—	—	3.28	—	3.28
Nov.	1.43	4.29	4.29	2.86	2.86	1.43	4.29	2.86	2.86	2.86	4.29	4.29	5.71	1.43	8.57	7.14	—	—
Dec.	—	1.48	—	—	—	1.49	—	—	—	—	—	5.97	1.49	—	10.45	1.49	5.97	1.49

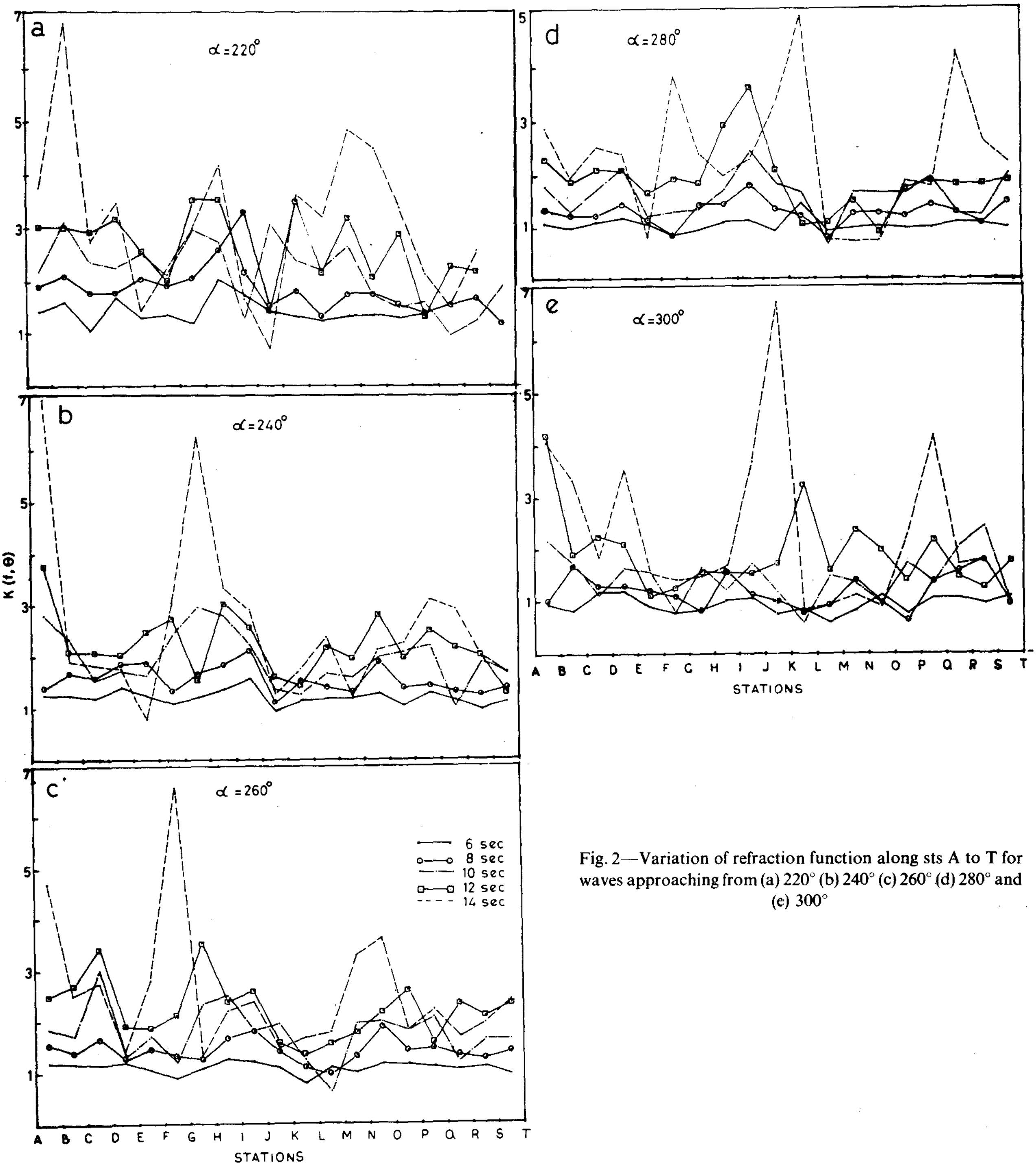

Fig. 2—Variation of refraction function along sts A to T for waves approaching from (a) 220° (b) 240° (c) 260° (d) 280° and (e) 300°

the case of 10 sec waves, the refraction function shows greater values than 1.73 (corresponding to $\frac{b_o}{b}=1$) for 220°, 240° and 260°. The magnitude of refraction shows refraction function lesser than 1.73 for 280° and 300° waves. Waves of 12 sec period approaching the shore from 220° have very high K values especially in the region between A and E, G and I and K and N. Maximum value of refraction function (4.171) has been obtained for 12 sec waves approaching from 300° between sts A and B. Very high K values were obtained at most of the stations for all directions of wave approach with period of 14 sec. Maximum value of refraction function (6.908) is observed between sts A and B for waves approaching from 240° with period 14 sec (Fig. 2a) indicating very high energy concentration in this region. The refraction function values obtained for various stations in this study are higher than those obtained earlier[7], for this stretch of the shoreline, especially for higher periods.

Table 3—Variation of H/H_o for Different Directions of Approach and Periods of Waves

Period, sec	Stations																		
	A-B	B-C	C-D	D-E	E-F	F-G	G-H	H-I	I-J	J-K	K-L	L-M	M-N	N-O	O-P	P-Q	Q-R	R-S	S-T
Direction: 220°																			
6	1.20	1.27	1.05	1.31	1.15	1.18	1.10	1.45	1.33	1.20	1.18	1.13	1.18	1.18	1.15	1.18			
8	1.38	1.46	1.33	1.33	1.43	1.38	1.43	1.62	1.25	1.22	1.36	1.16	1.33	1.33	1.25	1.19	1.25	1.30	1.09
10	1.47	1.77	1.53	1.50	1.58	1.46	1.73	1.66	1.14	1.76	1.38	1.50	1.64	1.32	1.23	1.27	0.99	1.12	1.38
12	1.74	1.74	1.71	1.78	1.60	1.41	1.88	1.88	1.48	1.23	1.88	1.46	1.80	1.44	1.71	1.16	1.52	1.48	
14	1.94	2.61	1.66	1.87	1.20	1.50	1.74	2.06	1.29	0.85	1.91	1.79	2.21	2.13	1.84	1.46	1.24	1.6	
Direction: 240°																			
6	1.13	1.13	1.10	1.20	1.13	1.06	1.12	1.18	1.27	0.97	1.08	1.10	1.10	1.17	1.03	1.15	1.08	0.99	1.05
8	1.19	1.30	1.28	1.34	1.37	1.16	1.30	1.36	1.46	1.06	1.25	1.19	1.16	1.38	1.19	1.22	1.16	1.13	1.19
10	1.66	1.53	1.25	1.32	1,28	1.56	1.72	1.66	1.49	1.18	1.14	1.30	1.27	1.41	1.44	1.47	1.02	1.38	1.32
12	1.94	1.44	1.44	1.43	1.57	1.65	1.25	1.74	1.60	1.27	1.21	1.48	1.41	1.68	1.41	1.58	1.48	1.43	1.41
14	2.63	1.38	1.36	1.34	0.88	1.74	2.49	1.83	1.71	1.15	1.34	1.54	1.12	1.46	1.50	1.76	1.71	1.42	1.31
Direction: 260°																			
6	1.10	1.09	1.08	1.12	1.04	0.96	1.06	1.14	1.12	1.05	0.91	1.05	1.01	1.09	1.08	1.05	1.05	1.06	0.98
8	1.25	1.90	1.30	1.13	1.22	1.16	1.13	1.30	1.36	1.19	1.06	0.99	1.16	1.28	1.13	1.25	1.25	1.03	1.30
10	1.36	1.32	1.74	1.14	1.32	1.10	1.53	1.58	1.35	1.40	1.12	0.81	1.40	1.41	1.35	1.44	1.10	1.28	1.28
12	1.58	1.65	1.86	1.39	1.37	1.46	1.88	1.55	1.61	1.25	1.16	1.25	1.33	1.48	1.61	1.25	1.53	1.44	1.53
14	2.17	1.58	1.66	1.20	1.67	2.56	1.15	1.48	1.54	1.22	1.29	1.34	1.81	1.91	1.34	1.48	1.29	1.40	1.54
Direction: 280°																			
6	1.03	0.98	1.04	1.08	1.03	0.91	0.97	1.04	1.06	0.96	1.20	0.96	0.98	1.01	0.98	0.98	1.04	1.04	0.98
8	1.16	1.10	1.10	1.36	1.06	0.90	1.19	1.19	1.33	1.14	1.10	0.88	1.13	1.13	1.10	1.19	1.13	1.03	1.22
10	1.33	1.14	1.30	1.46	1.08	1.14	1.16	1.30	1.56	1.35	1.28	0.83	1.28	1.128	1.28	1.38	1.14	1.10	1.41
12	1.52	1.35	1.44	1.44	1.27	1.39	1.35	1.71	1.91	1.45	1.02	1'10	1.23	0.94	1.31	1.37	1.27	1.27	1.37
14	1.69	1.38	1.58	1.54	0.88	1.95	1.54	1.40	1.50	1.83	2.21	0.85	0.85	0.85	1.36	1.34	2.07	1.62	1.48
Direction: 300°																			
6	0.97	0.91	1.08	1.08	0.94	0.88	0.90	1.01	1.03	0.88	0.93	0.78	0.91	1.05	0.86	1.04	1.03	0.97	1.04
8	0.99	1.30	1.13	1.13	1.10	1.05	0.90	1.25	1.06	0.99	0.88	0.96	1.19	0.98	0.78	1.19	1.25	1.36	0.92
10	1.47	1.32	1.06	1.28	1.25	0.88	1.28	1.10	1.32	1.08	0.75	1.41	1.18	0.98	1.32	1.18	1.44	1.56	0.99
12	2.04	1.37	1.50	1.44	1.05	1.12	1.25	1.25	1.23	1.31	1.80	1.25	1.55	1.41	1.16	1.48	1.21	1.12	1.33
14	2.01	1.83	1.36	1.87	1.24	1.20	1.20	1.29	1.92	1.59	0.95	0.91	1.06	0.91	1.50	2.04	1.31	1.34	0.95

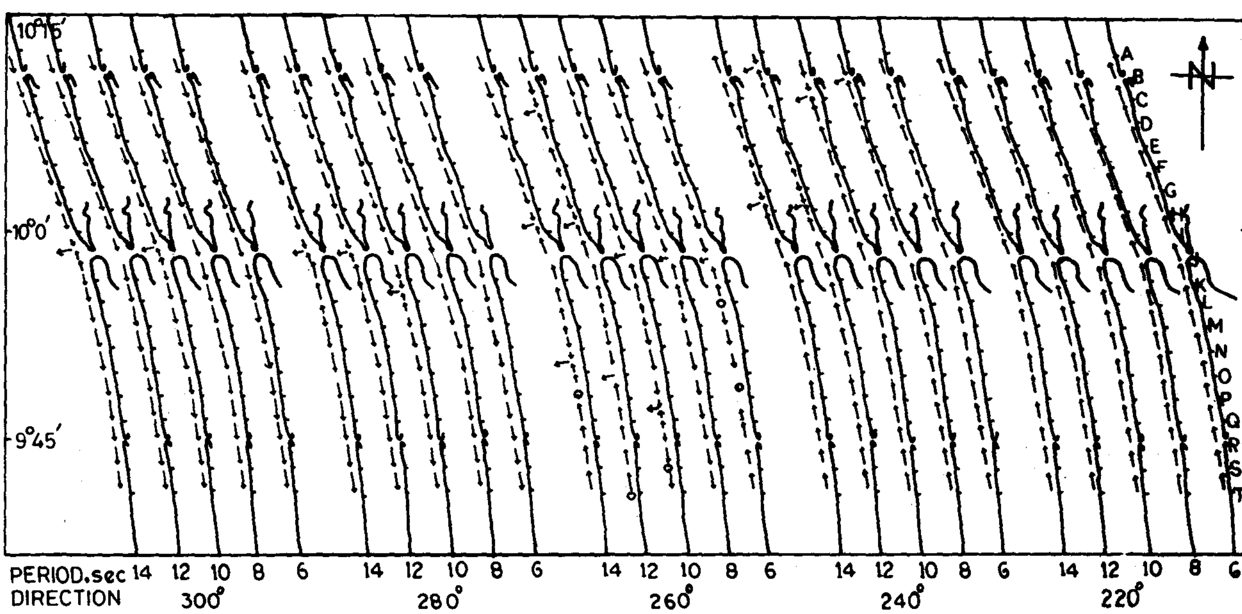

Fig. 3—Direction of littoral transport for different periods and directions of wave approach

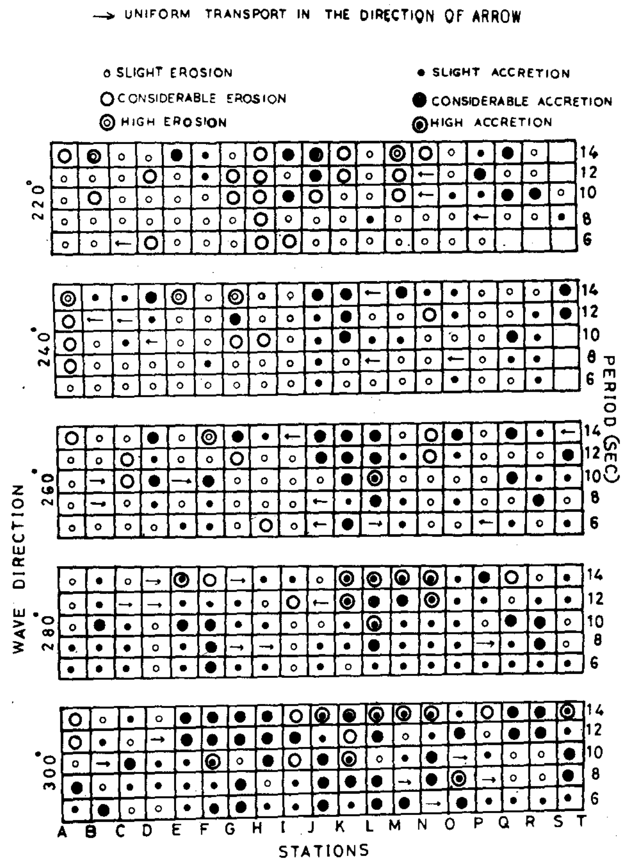

Fig. 4—Intensity of erosion and accretion along shore between Azhikode and Andhakaranazhi for waves of different periods approaching from different directions

The ratio of the wave height at 2 m depth contour to the deep water wave height as evaluated from the refraction functions (Table 2) shows that in some zones of wave energy concentration, wave heights are increased by 2 to 2.6 times the deep water wave heights. However, according to Rayleigh - Boussinesq theory[8], the limiting wave height is given by $H = 0.83\,d$, where H is the wave height at depth d. Those waves that exceed this limit decompose into 2 or more waves and eventually break nearshore[9]. For 6 and 8 sec waves, the shallow water wave heights are less than the limiting wave height 1.66 m. For higher periods, the wave height exceeds this optimum value.

The direction of longshore currents at 2 m depth contours generated by the oblique approach of waves to the coast are presented in Fig.3. The component of wave energy parallel to the shore, generates longshore currents in its direction. It is obvious that waves approaching the coast from the directions 220° and 240° generate currents towards north for almost all the stations except sts A, B, F and G. Waves approaching the coast from 280° and 300° generate currents mostly towards south from Azhikode to Andhakaranazhi. Waves approaching from 260° generate currents varying in direction of flow.

The general direction of longshore currents mainly depends on the direction of waves approaching the coast. For the direction of approach 260°, there is a prominent cell circulation between sts J and K for 6 sec waves, which extends up to st L for 8, 10 and 12 sec waves and further extends up to M for 14 sec waves. Also there is another cell circulation between sts M and O for 12 and 14 sec waves.

Strong but narrow currents in the nearshore zone directed away from the coast termed as rip currents are identified at a number of places (Fig. 3). For waves approaching from 240°, areas between sts A and C and G and H are identified as zones of rip currents. Zones of rip currents have been identified for waves approaching from 260° between sts I and J for 6,8,10 sec waves, between C and D, H and I for 12 sec waves, between sts P and Q for 10 sec waves and between H and I and N and O for 14 sec waves. For waves approaching from 280° rip currents can be expected between sts K and L for 10 sec waves and between I and J for 12 and 14 sec waves. For waves approaching from 300°, rip currents can occur between stations I and J for 10 and 14 sec waves.

Areas vulnerable to erosion and accretion have been identified qualitatively on the basis of refraction function and direction function and presented in Fig.4. Waves approaching the coast from 220° with periods 6 and 8 sec have the tendency to erode the stretch of shore under study, 10 sec waves may bring about considerable erosion except between sts I and J and Q and S. Waves of 12 sec may cause considerable erosion along the coast except between sts J and K and P and Q. Waves of 14 sec cause high erosion between sts B and C and M and N but brings about considerable deposition between sts E and F, I and K and Q and R.

Waves of 6 and 8 sec periods approaching the coast from 240° bring about slight erosion at almost all stations. For 10 sec waves considerable deposition may take place between sts K and L and Q and R, while shore between sts A and B and G and I shows considerable erosion. Waves of 12 sec also bring about slight erosion to the entire coast except areas between G and H, K and L and S and T where considerable accretion occurs. Waves of 14 sec may cause high erosion between sts A and B and G and H while areas between D and F, J and L, M and N and S and T show depositional tendency.

Waves approaching from 260, 280 and 300° show general depositional tendency especially those having periods of 10, 12 and 14 sec. For 260° waves considerable deposition occurs between sts D and E, K and M and Q and S while 280° waves cause considerable deposition between sts E and G, K and O and R and S. Waves of all periods from 6 to 14 sec approaching from 300° cause considerable deposition.

Exceptionally high deposition is brought about by 14 sec waves between J and O, by 10 sec waves between F and G and K and L and by 8 sec waves between O and P.

Thus the areas of erosion and accretion depend primarily on the direction of wave approach, wave period and wave refraction pattern. In general, the entire stretch of coast from Azhikode to Andhakaranazhi suffers erosion under the action of waves approaching from 220° and 240° whereas waves approaching from 280° and 300° cause accretion. The waves approaching from 260° cause accretion and erosion in different parts of the beach and give rise to generation of rip currents at a number of places.

The beach profile surveys carried out at various locations have shown that the beaches of Azhikode, Narakkal and Andhakaranazhi exhibit eroding tendency under the action of southwesterly waves. The beaches at Fort cochin and Malipuram are relatively stable during this period. During southwest monsoon season (June to September) the predominent wave direction is westerly and the entire stretch of the beach shows an eroding tendency. During October to March all the beaches show accreating tendency under the influence of northwesterly waves.

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