

Wave Refraction & Sediment Transport along Kunavaram, East Coast of India

A LALITANANDA PRASAD*, K HANUMANTA RAO, Y VEENADEVI & G R LAKSHMANA RAO

Department of Meteorology and Oceanography, Andhra University, Waltair 530 003

Received 4 January 1980; revised received 27 August 1980

Direction and strength of longshore currents and rate of sediment transport along the Kunavaram beach (lat. $16^{\circ}15'N$, long. $82^{\circ}E$) have been worked out from wave refraction diagrams for waves approaching the shore from E, ESE, SSE and S, and periods 5, 6 and 8 sec using the IMD data obtained during 1971-78. During the NE monsoon the longshore currents have been found to be stronger than those during SW monsoon causing a net annual southerly drift of sediment along this coast.

Wave action is the primary source of energy available in the nearshore zone for various processes. Longshore current combined with the agitating action of the breaking waves, is the primary factor causing movement of sediment along the coast^{1,2}.

The area under investigation is a 25 km stretch of the coast near Kunavaram (lat. $16^{\circ}15'N$, long. $82^{\circ}E$; Fig. 1), about 70 km south of Kakinada. A small creek enters the sea south of Kunavaram. Generally medium to very fine sand is encountered at the bottom up to a depth of 8 m. This paper presents information on the distribution of wave energy and longshore current, and the rate of sediment transport along the Kunavaram coast.

Materials and Methods

Deep water wave characteristics—Swell wave statistics have been obtained from the data on visual observations from ships published in the daily weather reports of the Indian Meteorological Department, for the area between long $81^{\circ}-85^{\circ}E$ and lat $15^{\circ}-19^{\circ}N$, during 1971-78. The deep water wave characteristics have been obtained from these data, and presented in Table 1. It is found that deep water waves approach this region from a general south-southeasterly to southerly direction for a major part of the year (May to November). During the remaining period, the deep water waves approach from an easterly to east-southeasterly direction in general. The predominant wave periods are 5, 6 and 8 sec. During the SW monsoon, waves of 2.5 to 3 m height are sometimes observed in this area.

Wave refraction—Convergence and divergence of wave orthogonals lead to a local increase or decrease in wave energy and wave height^{3,4}.

Wave refraction diagrams have been constructed using the method of Arthur *et al.*⁵ for waves of periods 5, 6 and 8 sec, approaching the coast from E, ESE, SSE and S. Hydrographic chart No: 1711 (NHSI) has been used for drawing the refraction diagrams.

The orthogonals from 10 fm line onwards for waves of periods 6 sec (ESE) and 8 sec (S) are presented in

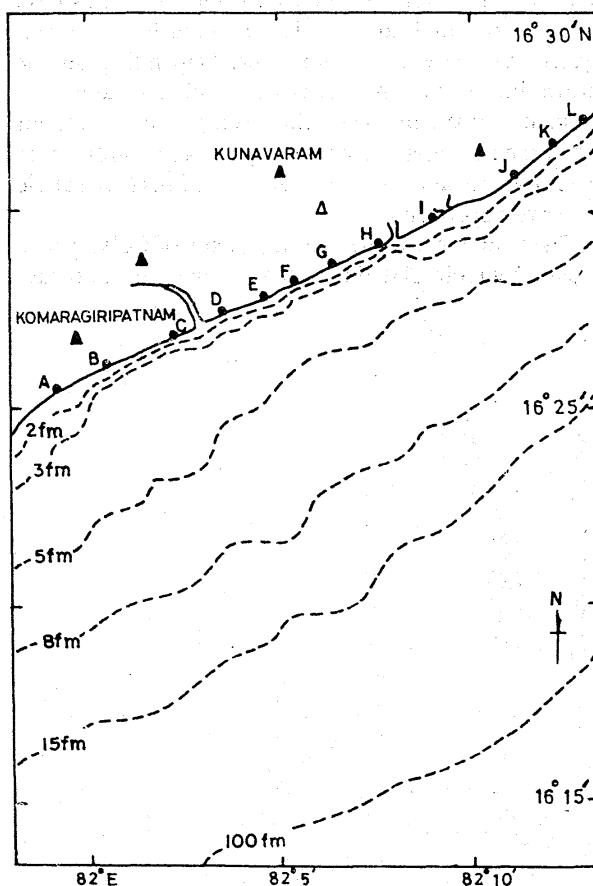


Fig. 1—Station location

*Present address: NIO Regional Centre, Seven Bungalows, Versova, Bombay 400 061.

Table 1—Annual Wave Period Percentage Frequencies for Region along Kunavaram

Period sec	Directions																Total in the year
	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	
5	37.5	36.92	29.48	26.49	33.76	26.3	50.0	23.3	26.6	22.4	21.4	20.9	19.4	—	—	12.5	26.14
6	37.5	15.4	26.92	23.52	25.97	28	18.7	25	23	20	29.4	18.6	33.3	12.3	—	25	25.44
7	—	—	10.25	11.76	6.49	5.2	—	—	8.3	9.4	9.6	16.2	5.5	—	—	12.5	8.09
8	25	7.65	25.64	23.52	27.27	31.6	12.5	28.3	27.3	23.5	20.8	25.6	16.6	10.3	—	25	24.38
9	—	—	—	2.94	5.19	—	—	10	5.6	5.8	1.6	2.3	—	—	—	—	3.44
10	—	—	6.41	11.76	1.29	—	—	3.3	1.4	4.7	2.2	2.3	—	10.3	—	12.5	3.06
11	—	—	—	—	—	—	—	—	1.4	3.6	3.2	2.3	2.7	—	—	—	1.53
12	—	—	—	—	—	—	—	—	1.4	3.5	3.2	2.3	5.5	—	—	—	1.65
13	—	—	1.28	—	—	—	6.3	—	2.7	—	4.3	4.6	5.5	—	—	—	2.12
14	—	—	—	—	—	8.7	—	10	2.1	7.1	4.3	4.6	11.1	8.3	—	—	4.12
Direction total in the year	0.9	1.5	9.2	4	9.07	6.7	3.8	7.1	15.8	10	21.0	5.1	4.2	0.5	—	0.942	

Fig. 2. Figure shows zones of convergence and divergence along 2 fm for these periods and directions. The wave energy will be more where the orthogonals converge and will be less where the orthogonals diverge. The wave heights at 2 fm line are determined using the equation⁵

$$\frac{H}{H_0} = \left[\frac{1}{2} \left(\frac{1}{n} \right) \left(\frac{L_0}{L} \right) \right]^{\frac{1}{2}} \left[\frac{b_0}{b} \right]^{\frac{1}{2}}$$

where $n = \frac{1}{2} \left[1 + \frac{4 \pi d/L}{\sinh 4 \pi d/L} \right]$

where

b_0 is separation between the wave rays in deep water, b separation between the wave rays in shallow water at the point of investigation, H_0 wave height in deep water, H required wave height in shallow water, L_0 wavelength in deep water, L wavelength in shallow water, and d depth of water at the point of investigation (in the present study it is 2 fm).

In the above equation $\left[\frac{b_0}{b} \right]^{\frac{1}{2}}$, generally referred to as

refraction function K , varies along a depth contour. Arbitrary stations marked alphabetically A to L cover the entire beach and the distribution of K at the stations is presented in Fig. 3. The angle α , taken from the refraction diagrams has been superimposed on these graphs. The angle measured towards north and south of the normal to the depth contour is indicated as north and south in the figures.

Longshore currents—The velocity of longshore current along the Kunavaram coast for periods 5, 6 and 8 sec are calculated using the equation⁷

$$v_l = 2.7 u_m \sin \alpha_b \cos \alpha_b - \frac{\pi (2)^{1/2}}{c_f \gamma_b^3}$$

$$\left(1 + \frac{3 \gamma_b^2}{8} - \frac{\gamma_b^2}{4} \cos \alpha_b \right) u_m \frac{\partial H_b}{\partial y}$$

where v_l is resultant longshore current velocity, u_m maximum value of horizontal orbital velocity at the breaker zone given by $\left[\frac{2 E_b}{\rho h_b} \right]^{\frac{1}{2}}$ in which E_b is the energy of breaking waves, h_b water depth at breaking and ρ is density of sea water, α_b direction function at the point of breaking, c_f drag coefficient (taken to be 0.016 from Longuet-Higgins⁸), γ_b a constant that depends on wave height and water depth (0.8 in the present study) and $\frac{\partial H_b}{\partial y}$ longshore variation in breaker heights along the coast.

In the above equation the first part, $2.7 u_m \sin \alpha_b \cos \alpha_b$ represents currents due to oblique wave approach and the other part represents currents that cause alongshore variation in wave height.

Sediment transport—Sediment transport along the coast depends on the strength of the littoral currents produced by the waves in the surfzone. Littoral transport rate has been estimated from wave parameters using the empirical relation⁹

$$I_l = 0.77 (ECn)_b \sin \alpha_b \cos \alpha_b$$

where I_l is the immersed weight transport rate, $(ECn)_b$ is the energy flux of the waves evaluated at the breaker zone and α_b is the breaker angle.

Results and Discussion

From wave refraction diagrams the zones of convergence and divergence of wave energy become apparent. The variation of energy causes reduction of

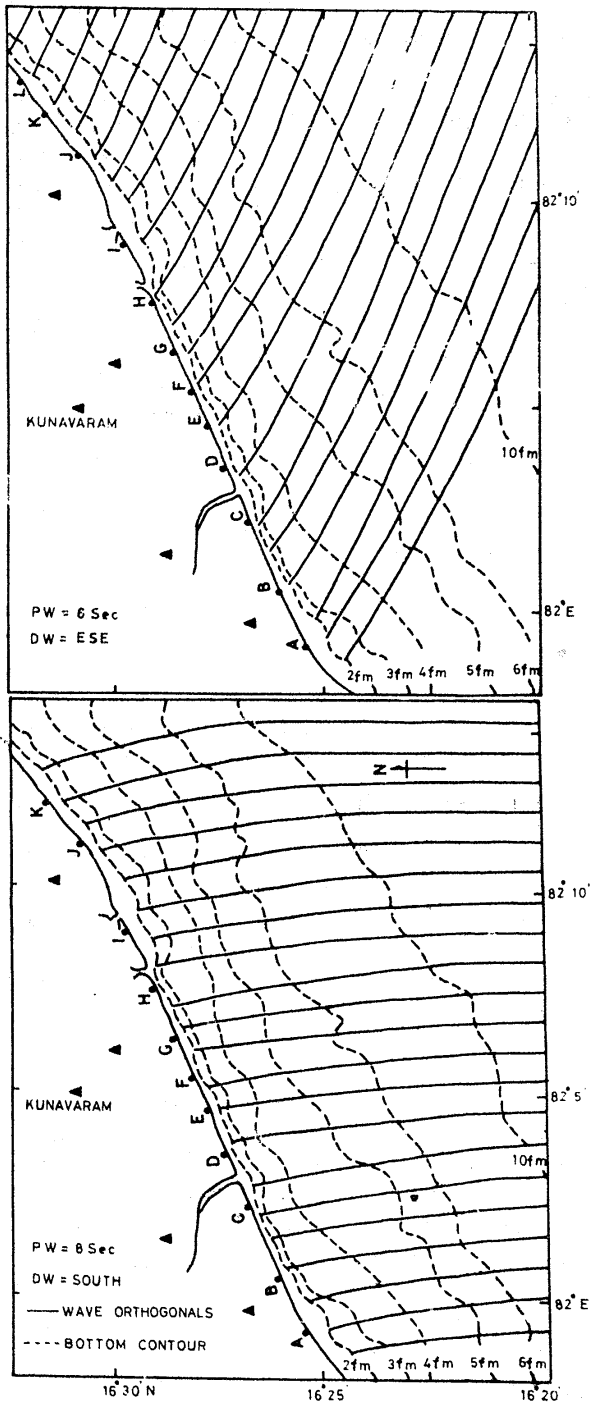


Fig. 2—Wave refraction diagrams for waves from ESE, S directions and periods 6 and 8 sec

wave height in areas of divergence and increase in areas of convergence. From Fig. 3 it can be seen that for waves of all periods from E and ESE the K function is generally < 1 , for many stations. Waves of 8 sec period approaching the shore from E are having a high value (C 1.4) of K at st H. At st H the shallow water wave

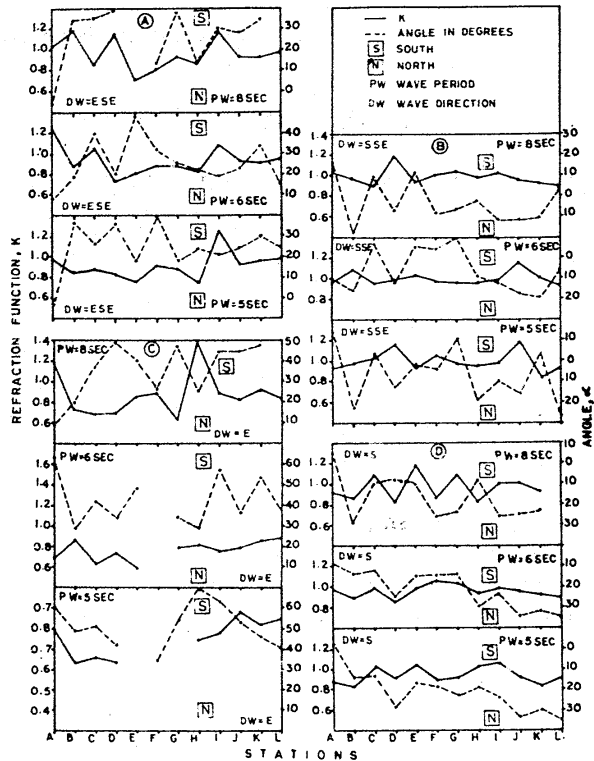


Fig. 3—Refraction function K and angle α at the station for waves of different periods and approaching from ESE(A), SSE (B), E(C) and S(D)

height is about 2 m, i.e. higher than that of deep water wave height (1.5 m). The computed wave heights at 2 fm line for all other stations are presented in Table 2. For waves approaching the shore from SSE and S, the K function is 1 for many stations. Generally convergence zones exist at sts D and G for waves of 5 sec period, at st B for waves of 6 sec period and at sts B and G for waves of 8 sec period approaching from SSE. Maximum increase in wave height is found at sts C, E, G and I for waves of 8 sec period approaching from S. The wave heights of these stations in shallow water are higher than those in deep water. The direction function α varies between 9° and 70° for E, 7° and 40° for ESE direction, 27° to 16° for SSE waves and 35° to 5° for S waves. From wave refraction diagrams it is found that there are certain zones of high energy concentration along the beach.

Longshore currents—The refraction and direction functions obtained from the wave refraction diagrams have been used to estimate the magnitude and direction of longshore currents at different stations. Currents due to waves with periods 5, 6 and 8 sec from E and ESE are maintained mainly by the oblique approach, since the currents are directed towards south all along the coast (Table 3, Fig. 4). Very strong currents of higher order (> 2 m/sec) are observed at all

Table 2—Wave Heights (m) at 2 fm Line for Various Wave Periods in the Direction of Approach

Direction	Stations											
	A	B	C	D	E	F	G	H	I	J	K	L
Period 5 sec												
E	0.94	0.75	0.78	0.75	—	0.69	—	0.88	0.92	1.04	0.96	0.99
ESE	0.98	0.85	0.88	0.83	0.76	0.92	0.88	0.77	1.24	0.94	0.96	0.98
SSE	0.89	0.93	0.98	1.1	0.89	1.01	0.93	0.9	0.92	1.07	0.94	0.91
S	1.19	1.14	1.4	1.24	1.43	1.22	1.24	1.4	1.43	1.24	1.13	1.24
Period 6 sec												
E	0.86	1.09	0.8	0.93	0.76	—	0.98	1.02	0.96	0.98	1.07	1.09
ESE	1.33	0.94	1.13	0.79	0.87	1.05	1.05	1	1.16	1	0.98	1.02
SSE	0.99	1.11	0.97	0.99	1.05	0.99	0.97	0.97	0.99	1.18	1.02	0.93
S	1.42	1.3	1.4	1.2	1.4	1.53	1.5	1.36	1.42	1.39	1.33	1.3
Period 8 sec												
E	1.59	1.05	0.97	0.98	1.2	1.27	0.97	1.99	1.25	1.16	1.3	1.18
ESE	1.2	1.45	1.02	1.4	0.87	0.98	1.13	1.04	1.35	1.13	1.13	1.18
SSE	1.18	1.11	1.03	1.37	1.07	1.15	1.18	1.13	1.17	1.09	1.04	1.03
S	1.53	1.41	1.78	1.31	1.8	1.44	1.8	1.34	1.64	1.64	1.5	—

Table 3—Wave Induced Longshore Currents for Different Stations along the Coast (in m/sec)

Direction	Stations											
	A	B	C	D	E	F	G	H	I	J	K	L
Period 5 sec												
E	1.516	1.925	1.735	1.706	—	1.675	—	1.724	1.967	1.899	1.881	1.891
ESE	1.525	1.784	1.707	1.607	1.643	1.577	1.6	1.886	1.454	1.388	1.273	1.278
SSE	0.519	0.161	0.274	0.205	0.083	0.128	0.189	0.164	0.272	0.854	0.776	0.972
S	0.832	1.091	1.309	1.056	1.181	1.358	1.404	1.282	1.662	1.57	1.713	1.824
Period 6 sec												
E	1.936	1.989	2.039	1.77	2.023	—	1.81	1.832	1.994	1.932	2.185	2.017
ESE	1.565	1.936	1.745	1.586	1.913	1.551	1.501	1.957	1.446	1.552	1.509	1.618
SSE	0.84	0.15	0.039	0.147	0.158	0.133	0.312	0.187	0.547	1.038	0.838	0.775
S	1.425	1.331	1.318	0.942	1.252	1.099	1.311	1.313	1.627	1.91	1.845	1.661
Period 8 sec												
E	1.869	2.191	1.925	2.192	2.352	2.084	1.364	2.374	2.066	2.097	2.045	—
ESE	1.461	2.222	1.33	1.78	—	1.746	1.375	1.804	1.553	1.642	1.677	—
SSE	0.195	0.199	0.056	0.606	0.874	—	0.246	0.18	0.643	1.029	0.604	0.755
S	0.959	1.02	1.121	1	1.643	0.928	1.307	1.185	1.518	1.984	1.653	—

stations except at sts A, C and G, for waves of 8 sec period approaching from the E. For SSE waves, the longshore currents (Fig. 4) appear to be predominantly towards the north, and the average current velocities are comparatively small all along the coast. In SSE direction, the currents for waves of 5 sec period at sts E and H, for waves of 6 sec period at sts B and C and for waves of 8 sec period at sts B, C, D, E and G are directed towards south. These southerly currents are, however, very weak. The longshore currents from the south are directed towards the north at all stations for all wave periods except for waves of 8 sec period at st A.

Currents along the Kunavaram coast seem to be fairly strong during all seasons of the year. During NE monsoon, they are strong and directed towards south.

The study reveals that where waves approach the coast from SSE and S directions during the SW monsoon, the associated littoral current is directed towards the north.

Sediment transport—Momentum from the breaking waves will induce a longshore current by which water, including sediment placed in suspension by the wave breaking, moves along the coast. The distribution of sediment load along the shore depends on the shape of the beach bottom profile, waves, current and material characteristics. An attempt is made to estimate the rate of littoral transport along the Kunavaram beach for different seasons using the empirical formula suggested by Komar⁹. The net longshore movement of the sediment along the beach is the sum of the transport for all the individual wave trains arriving at

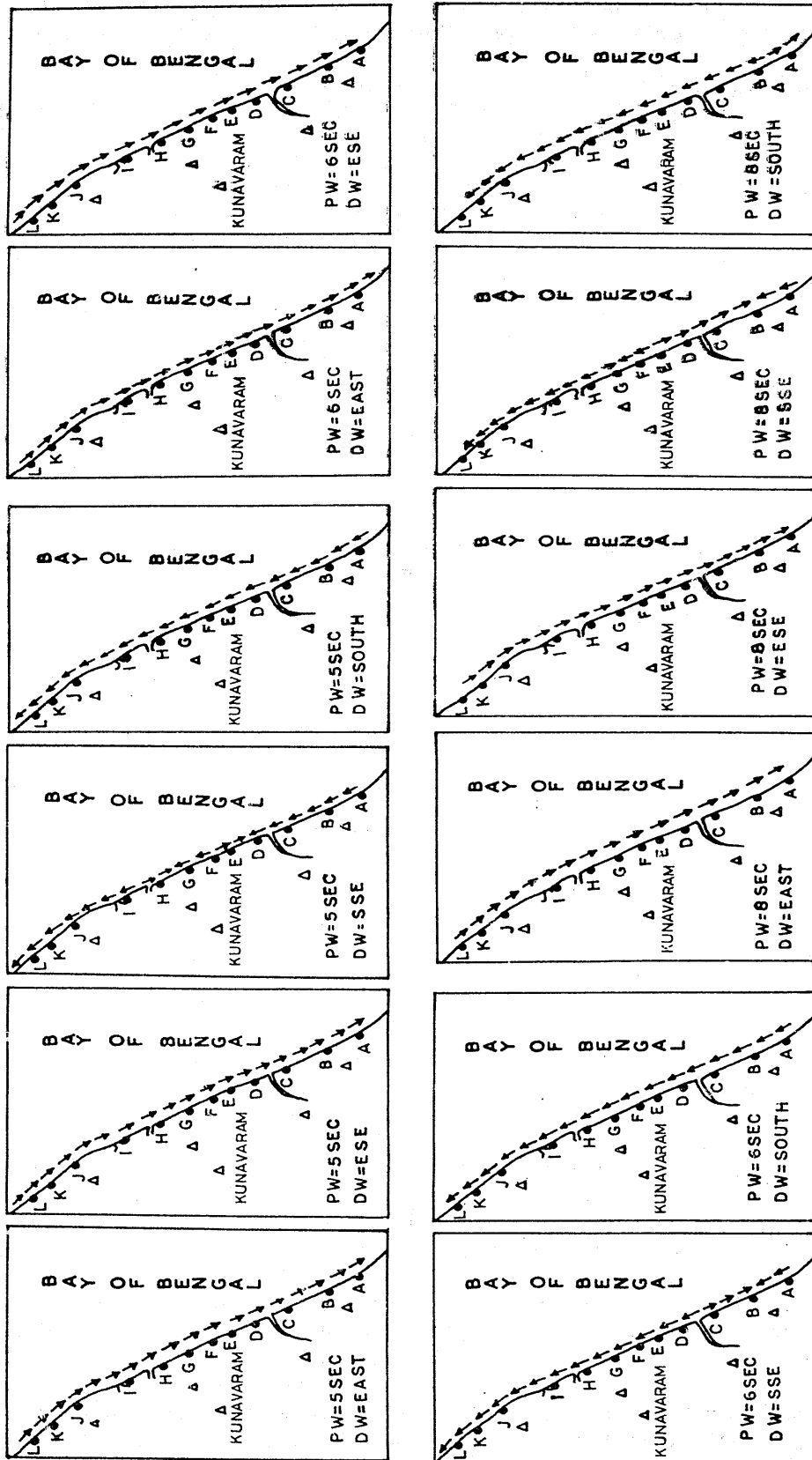


Fig. 4—Direction of longshore currents for waves of different period and directions of approach

Table 4—Littoral Drift (m³/yr) for the Whole Beach during a Year

Direction	Period, sec		
	5	6	8
South	39007	56906	98041
North	32941	44359	48645
Net I*	6066	12547	49396

*To the south direction

the shore from different wave generation areas.

In NE monsoon the deep water wave height is 1.5 m and the littoral currents are southerly. The waves of 8 sec period and direction of 90°, 112° give rise to breaker height of 1.4 m all along the beach except at sts C, D and F leading to erosion. There is no erosion or deposition at sts C, D and F. In SW monsoon the mean deep water wave height is 1.75 m and the predominant wave directions are SSE, S. There is convergence of the littoral currents at sts D, G and B for waves of 5, 6, 8 sec periods approaching from SSE direction. Convergence of littoral currents leads to localization of sediment in suspension resulting in deposition. The 8 sec period waves approaching from south give rise to breaker height of 1.4 m, causing erosion all along the beach.

The net sediment transport along the Kunavaram beach is presented in Table 4. The net littoral drift is towards south. This is due to the currents along the coast. Since the littoral current during NE monsoon is stronger than that during the SW monsoon, there will be a net southerly drift during a year along this part of the coast.

Acknowledgement

The authors thank Sri K. Rupakumar for helpful suggestions and Dr B.S.R. Reddy for going through the manuscript and offering valuable suggestions.

References

- 1 Putnam J A, Munk W H & Traylor M A, *Trans Am Geophys Union*, 30 (1949) 337.
- 2 Sonu C J, *J Geophys Res*, 77 (1972) 3232.
- 3 Shepard F P, *Submarine geology*, (Harper & Row Publishers, New York), 1963.
- 4 Munk W H & Traylor M A, *J Geophys Res*, 55 (1947) 1.
- 5 Arthur R S, Munk W H & Isaacs J D, *Trans Am Geophys union*, 33 (1952) 855.
- 6 Beach Erosion Board, *Corps of Engrs US Dept of Army Washington D C*, 1954 Tech Report 4, 29p.
- 7 Komar P D, *Nearshore sediment dynamics and sedimentation*, (Wiley, New York) 1975, 17.
- 8 Longuet-Higgins M S, *J Geophys Res*, 75 (1970) 6778, 6790.
- 9 Komar P D, *J Geophys Res*, 76 (1971), 713.