

## Wave Refraction & Littoral Currents Off Colva Beach, Goa

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Wave refraction studies have been carried out for waves of different periods approaching the coast at Colva, with directions of approach lying between  $180^\circ$  and  $340^\circ$ , to obtain a qualitative picture of littoral flows along the beach. The refraction function evaluated at an approximate depth of 4 m, indicates amplification of wave heights at certain parts of the coast as the wave period increases. The wave heights are relatively lower for waves approaching from WNW and SW compared to those for waves approaching from WSW and W. The littoral flow is towards the north for deep water waves approaching from SW and towards the south for waves approaching from WNW. The studies show that waves approaching from W and WSW generate onshore - offshore flows and converging and diverging alongshore flows, giving rise to circulation cells in the nearshore regions. The effect of wave refraction pattern and the associated littoral flows on the morphology of the beach has been discussed.

Knowledge of wave refraction pattern and the resulting littoral currents is essential in shoreline and nearshore studies such as beach erosion and accretion, nearshore bottom sediment distribution, littoral drift, movement of sediment in the vicinity of harbours, etc. A study of wave refraction along the Colva beach has been made to investigate the changes that occur in the wave characteristics near the coast as deep water waves of different periods approach the coast from various directions. The refraction function and direction function obtained from the wave refraction diagram have been used to infer the probable direction of littoral currents. The effect of the latter on the beach morphology has been examined through practical observations on the beach and the adjoining waters.

Earlier, Reddy<sup>1</sup> discussed the sediment transport in the vicinity of Mormugao harbour by means of wave refraction studies. Reddy and Varadachari<sup>2</sup> gave a broad picture of the sediment transport along the west coast of India between Cape Comorin and Vengurla based on wave refraction studies, but the information therein is inadequate to have a clear understanding of the littoral flow pattern and the associated sediment transport along the coast of Goa. Later, Murty *et al.*<sup>3</sup> described the littoral and rip current patterns along the Calangute beach based on field observations, while Antony<sup>4</sup> studied the littoral drift in relation to wave refraction along the same beach for specific wave conditions. Gouveia *et al.*<sup>5</sup> dealt with the wave refraction and littoral transport along the coast from Cape Ramas to Karwar, located south of the present area of study. Murty<sup>6</sup> and Veerayya<sup>7</sup> gave detailed accounts on morphology and geological features of the beaches of the Goa region.

### Study Area

The coast of Goa (Fig.1) extends approximately from Loliem Point (lat.  $14^\circ 55' N$  and long.  $73^\circ 03' 10'' E$ ) in the south to Terekhol (lat.  $15^\circ 43' 30'' N$  and long.  $73^\circ 42' E$ ) in the north and it forms part of the central west coast of India. It is bordered by the Western Ghats on the east and the Arabian Sea on the west. The coast trends in a NNW-SSE direction and consists of sandy beaches separated by rocky headlands and river mouths.

The study area (Fig.1) is a 30 km stretch of sandy beach, Colva beach, situated between Betul Point and Cansaulim and extends from the coast to the 50 fm (90 m) contour. In general, the beach foreshore is wide and steep at its extreme ends. It is backed by well developed sand dunes. The beach is composed of medium to fine sand, and moderate to very well sorted sediments. In the nearshore region the 3 fm depth contour shows undulations. Further offshore, the bottom contours run more or less parallel to the shoreline. The sediments in the offshore region of the beach show the presence of sands adjacent to the beach followed by silty sands or sandy silts beyond which clay occurs<sup>7</sup>. A group of islands, generally known as St. George Islands are present in the nearshore region (Fig.1). The river Sal joins the sea to the south of the study area. A number of small streams cut across the beach during the southwest monsoon. The region experiences mixed semi-diurnal tides (range, 2.3 m) in the meso-tidal range.

### Methods

The inputs to the wave refraction studies are bathymetry of the area and the deep water wave

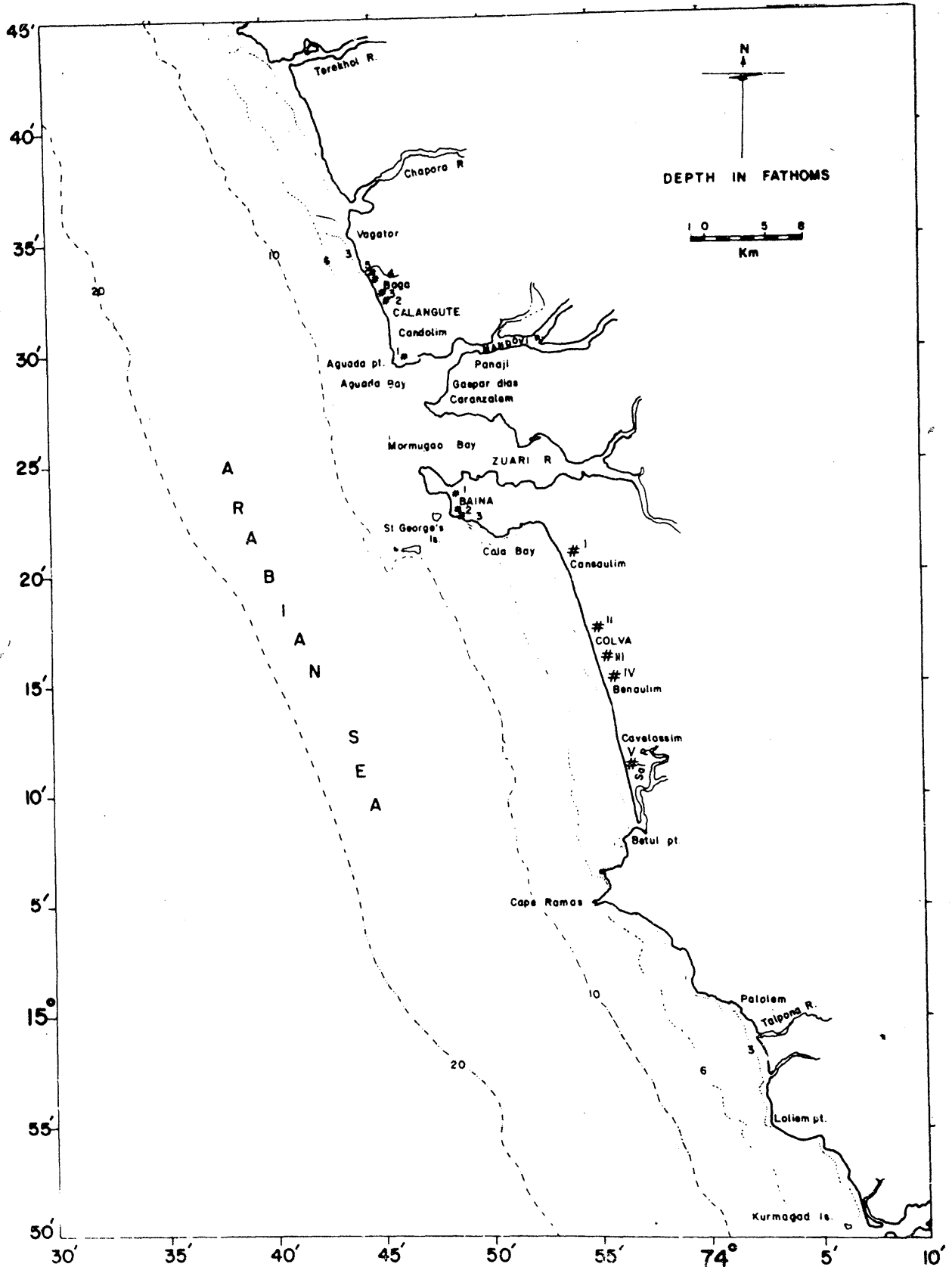


Fig. 1 - General location of study area [≠ Beach profile station]

conditions. For a detailed bathymetry, the bottom topography off Colva beach as given in the British Admiralty Chart No.1509 (corrected up to 1966) has been used.

The initial deep water wave conditions were chosen from an examination of the wave characteristics off the central west coast of India, presented by Veerayya<sup>7</sup>. The directions of wave approach have been arrived at after scrutinizing carefully the exposure of the shoreline for different deep water wave conditions. Wave refraction diagrams have been constructed for waves of periods 5, 6, 8, 10 sec and directions of approach of SW, WSW, W and WNW. The refraction diagrams have been prepared following the method evolved by Arthur *et al.*<sup>8</sup> and discussed in Pierson *et al.*<sup>9</sup>. Eleven stations have been chosen roughly around the 2 fm (4 m) line to cover the region of study. The station locations have been indicated in the figure on the landward part of the shoreline boundary (Fig.2). A

typical wave refraction diagram constructed for a wave of 8 sec period approaching from WSW direction, for the Colva region, is shown in Fig.2. Refraction diagrams for 5, 6, 8, 10 sec period waves from SW, W and WNW, and for 5, 6, 10 sec period waves from WSW direction, have also been constructed.

From the refraction diagrams, the variations in wave heights at the above mentioned stations have been evaluated using the equation<sup>10</sup>:

$$H = H_o K_s K_d$$

where  $H$  is the wave height in shallow water at the point of interest;  $H_o$ , initial deep water wave height;  $K_s$ , shoaling coefficient; and  $K_d$ , refraction coefficient given by  $\sqrt{b_o/b}$  where  $b_o$  and  $b$  are the spacings between adjacent orthogonals in deep water and in shallow water at the point of interest (4 m depth).

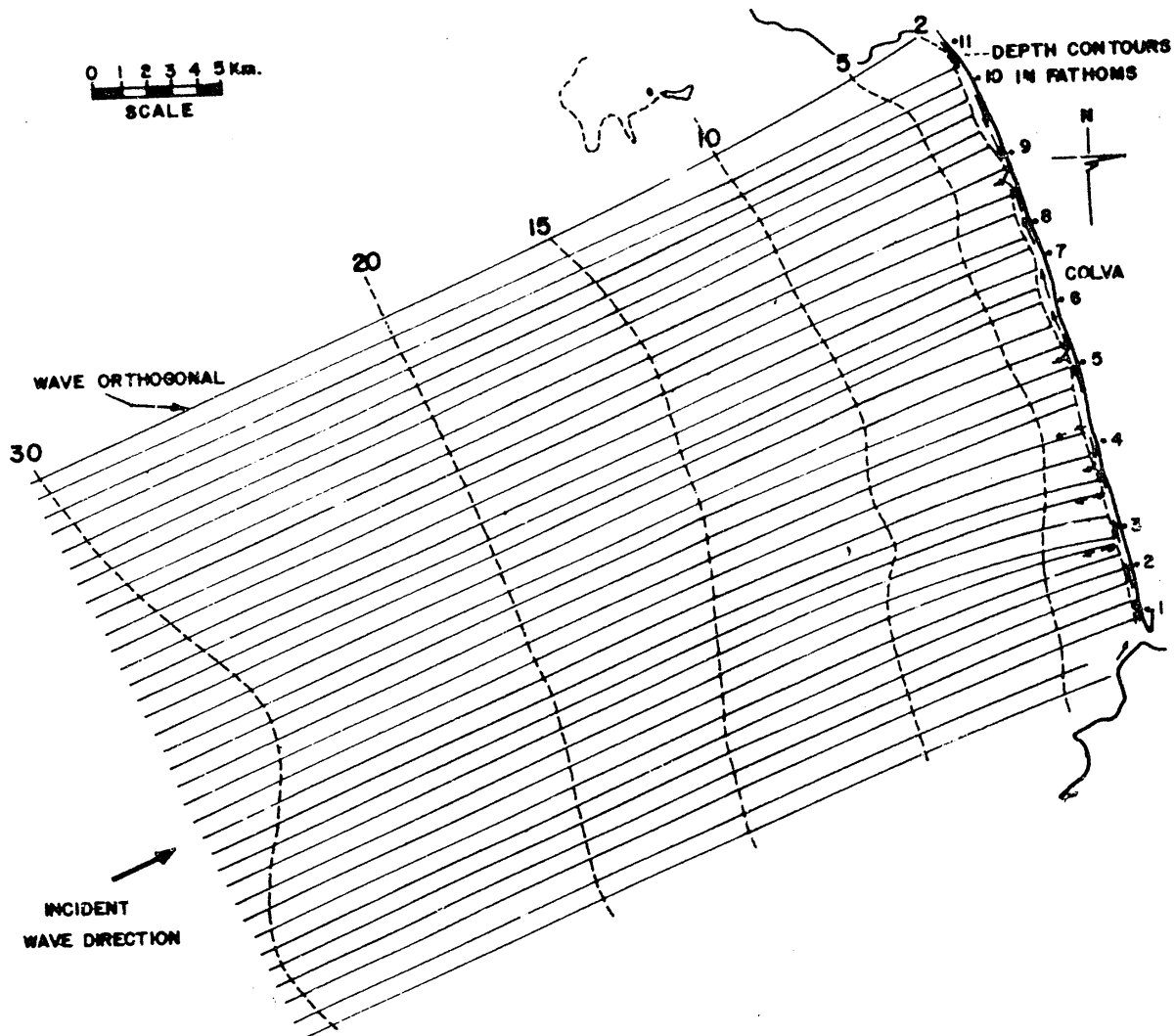


Fig. 2—Wave refraction diagram (WSW, 8 sec) for Colva area [→ Probable direction of littoral flow]

The alongshore variations in wave heights at all the stations for different deep water wave conditions are presented in Table 1. The wave heights presented in the table have been arrived at by assuming unit deep water wave height. The refraction diagrams serve as an index for a qualitative examination of the relative variations in refraction parameters along the shoreline for different deep water wave heights. Figs. 3 to 6 show the probable direction of littoral flows derived from the values of the direction function  $\theta$  obtained from the original refraction diagrams.

### Results and Discussion

Values of the refraction function presented in Table 1 show that in general, the increase in wave height is not significant for waves of 5 and 6 sec periods whereas it is significant for waves of 8 and 10 sec periods, at certain stations. The range of the values of the refraction function increases with increase of wave period for the wave periods under consideration and the highest values of refraction function (and in turn highest wave heights) have been obtained for 10 sec period waves for almost all directions of approach. The wave heights are appreciably more around sts 6 and 7 for the 10 sec period waves.

Values of refraction function are consistently low around st 5 for waves of 5, 6 and 8 sec periods approaching from SW and this reflects apparently low wave energies at this station. This region of low wave energy concentration shifts to st 4 for waves of 10 sec period as indicated by low  $K$  values. The zone of high wave energy concentration identified at st 8 for waves of 5 and 6 sec period approaching from SW shifts towards st 7 for 8 sec period waves and to st 6 for 10 sec period waves (Table 1). For WSW and W directions also the low wave energy region is located around st 5 for different wave periods. The broad features of littoral flow evaluated from the variations in concentrations of wave energies along the coast are indicated in Figs. 3 to 6. Studies on littoral currents carried out in July 1972 (monsoon) by means of fluorescent tracers indicate that convergence in flow pattern occurs between profile sts IV and V (Fig. 7). Littoral currents evaluated from wave refraction pattern for 6 and 8 sec period waves approaching from WSW (which is the predominant direction of approach during monsoon) show convergence at sts 4 and 5 (Fig. 4) which lie between profile sts IV and V (Fig. 7).

The littoral flow is towards north for deep water waves approaching from SW (Fig. 3) and towards south for waves approaching from WNW (Fig. 6). The littoral current pattern is somewhat different for waves approaching from WSW and W. The direction functions for these 2 directions of approach are mostly  $< 5$  for waves of different periods (Table 1) indicating

a near normal approach of these waves at the coastline and a possibility of predominant onshore - offshore flows in the littoral zone.

It is observed that wave heights are higher at some stations and lower at others along the shoreline. This kind of wave height distribution is associated with the formation of zones of convergence of wave energy at stations with higher wave heights and zones of divergence of wave energy at stations of lower wave heights. As a result, water flows from the wave convergence zones to the wave divergence zones giving rise to convergence in longshore currents. The converging water may flow seaward as rip current. These opposing longshore currents together with the seaward flowing rip currents (Figs 4 and 5) form circulation cells<sup>11</sup>. In general, the pattern of opposing longshore currents, onshore - offshore flows, etc. and the associated rip currents for deep water waves approaching from WSW and W that prevails off Colva (Figs 4 and 5) is similar to that off Calangute<sup>7</sup>.

The promontory to the north of the Colva beach and the group of islands in the offshore region shelter the northern part of the Colva coast from the waves that approach the coast from WNW. However, the diffracted waves may affect this sector of the beach.

The effect of wave refraction pattern on the morphological variations of Colva beach have also been examined in relation to the field observations. As part of regular beach surveys along the coast of Goa, 5 beach profile stations were established on the Colva beach (Figs 1 and 7) and beach profiles (sand levels) were measured at fortnightly intervals from Dec. 1969 to Oct. 1973. Simultaneously, visual observations of periods, heights and directions of waves were made and direction and speed of wind measured. Littoral currents were measured following the method of Murty *et al.*<sup>3</sup>.

In general, the beach shows well developed cyclic changes in its topography as well as in sediments during the year. The beach attains its highest sand level with a well developed berm by April/May under the influence of waves approaching from directions in the northerly quadrant. With the onset of the monsoonal wave climate, the beach is subjected to rapid rates of erosion at first followed by slower rates till about August when the beach has the minimum sediment storage. Thereafter, with the changing wave climate the beach recovers to its normal April/May conditions<sup>6,7</sup>.

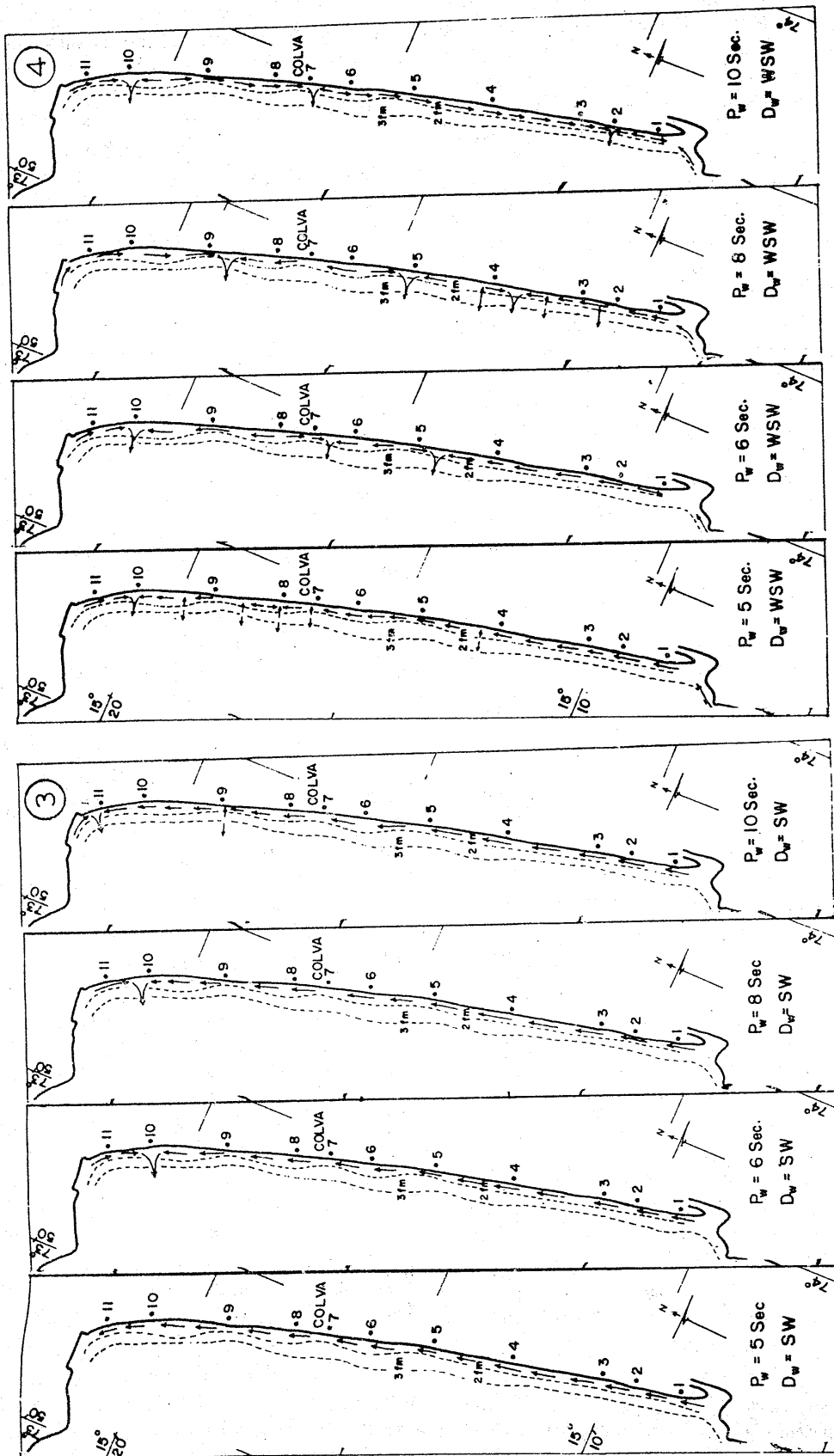
The observed littoral flow is towards up coast (north) during December to April at all profile stations (Fig. 1). In May, profile sts II, III and V record onshore - offshore flows; at times the flow is either northerly or southerly. Profile st I records a northerly flow till about June. During July to October the flow is directed

VEERAYYA *et al.*: WAVE REFRACTION & LITTORAL CURRENTS

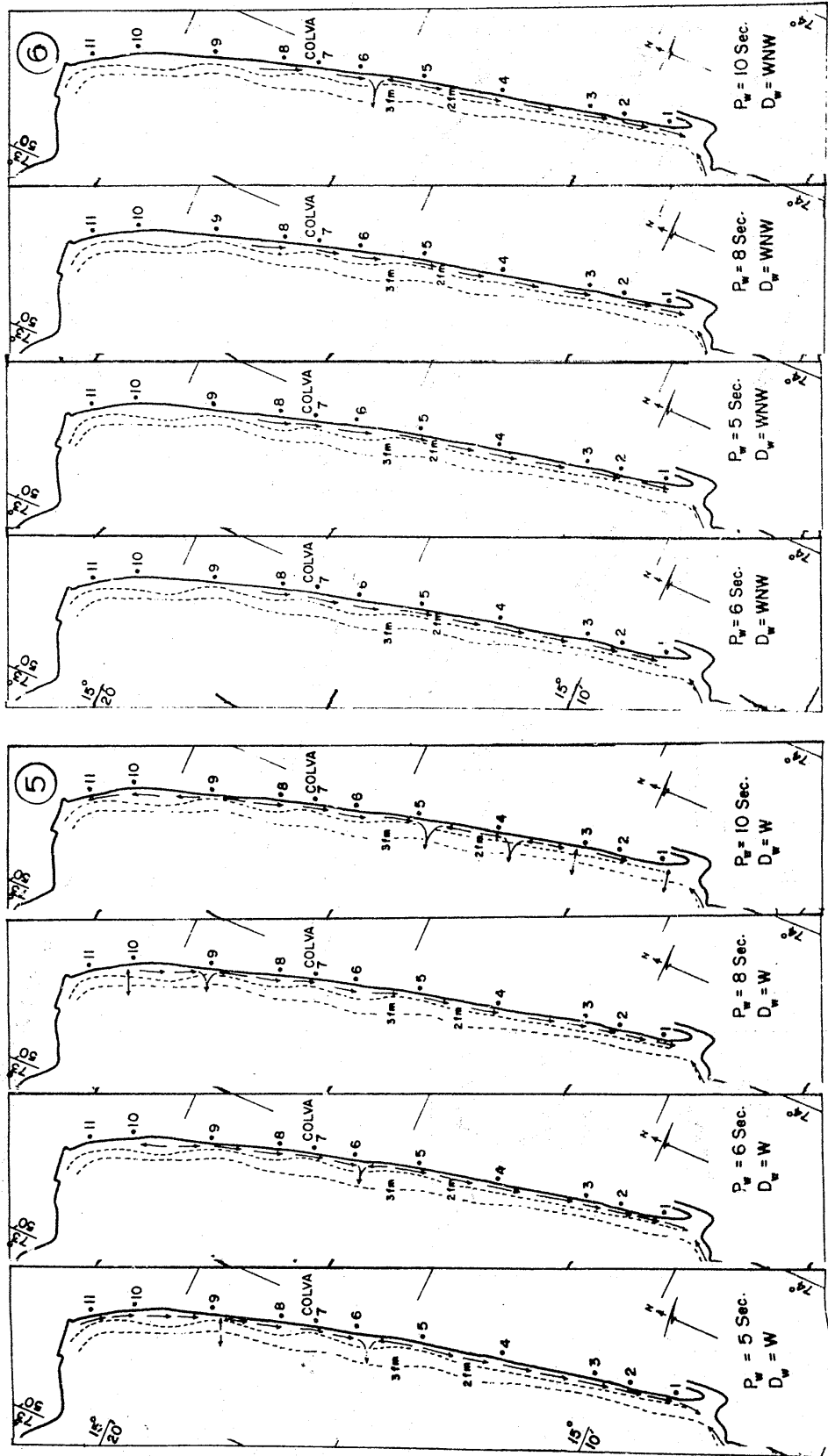
Table 1—Computed Values of Refraction and Direction Functions at the Station Locations Shown in Fig. 2

St	Refraction parameters	Period (sec)							
		5	6	8	10	5	6	8	10
		225 (SW)				247.5 (WSW)			
1	K	0.77	0.87	1.16	0.95	0.86	0.98	1.08	0.81
	$\theta$	18	19	17	12	4	2	9	3
2	K	1.04	0.86	1.12	1.01	1.07	0.93	1.40	1.05
	$\theta$	20	16	15	10	4	3	6	2
3	K	0.94	0.93	1.09	0.89	1.05	0.94	1.06	1.06
	$\theta$	22	16	14	6	3	3	1	0
4	K	1.05	0.83	0.95	0.87	0.98	0.81	0.95	1.04
	$\theta$	20	16	9	8	3	3	-4	3
5	K	0.75	0.79	0.91	1	0.89	0.87	0.88	1.01
	$\theta$	18	13	12	8	4	3	4	1
6	K	0.96	0.82	0.96	1.44	0.96	0.98	1.13	1.14
	$\theta$	22	18	16	10	7	3	6	4
7	K	0.82	0.9	1.06	1.05	1.05	0.83	0.99	1.32
	$\theta$	14	14	14	9	5	2	4	1
8	K	1.14	1.07	0.91	1	1.05	0.94	0.9	1
	$\theta$	14	11	10	10	2	0	2	2
9	K	0.8	1.03	0.81	0.97	0.99	0.9	0.88	0.91
	$\theta$	21	20	6	7	4	3	-6	11
10	K	0.95	0.94	0.83	0.88	1.05	0.85	1.13	0.94
	$\theta$	10	16	13	10	2	5	-3	3
11	K	0.94	0.83	1.08	0.56	0.79	0.73	0.65	0.85
	$\theta$		-2	-2	-1	-6	-5	0	-4
		270 (W)				292.5 (WNW)			
1	K	0.86	0.98	1.08	1.12	0.88	0.73	0.99	0.94
	$\theta$	-4	-2	-2	-8	-24	-16	-18	-15
2	K	0.9	1.03	1.4	1.12	0.93	0.83	0.81	0.72
	$\theta$	-6	-7	-8	-7	-25	-18	-16	-11
3	K	0.89	0.98	0.97	1.12	0.86	0.83	0.81	0.72
	$\theta$	-7	-3	-8	-9	-23	-20	-13	-13
4	K	0.81	0.9	0.97	1.16	0.95	0.69	0.96	0.56
	$\theta$	-5	-3	-5	-5	-21	-17	-10	-12
5	K	0.77	0.94	0.99	1.15	0.74	0.89	0.96	1.1
	$\theta$	-8	0	-4	-3	-18	-10	-10	-9
6	K	0.91	0.82	0.95	0.9	0.86	0.67	1.29	1.18
	$\theta$	0	-4	-8	-13	-21	-16	-12	-3
7	K	0.94	0.93	0.99	1.35	0.86	0.98	0.99	1.15
	$\theta$	-4	0	-5	-2	-20	-18	-14	-5
8	K	0.89	1.05	0.86	1.13	—	0.8	0.77	1.12
	$\theta$	-10	-9	-19	-10	—	-21	-20	-10
9	K	0.89	0.81	0.66	0.76	—	—	—	0.63
	$\theta$	-5	-9	-5	0	—	—	—	-9
10	K	0.78	—	1.11	0.76	—	—	—	—
	$\theta$	-7	—	-1	-6	—	—	—	—
11	K	—	—	—	—	—	—	—	—
	$\theta$	—	—	—	—	—	—	—	—

K = Refraction function;  $\theta$  = Direction function  
 + = northward component; - = southward component



Figs 3 and 4—Wave induced littoral flows along Colva for SW (3) and WSW (4) waves [→ Probable direction of littoral flow]



Figs 5 and 6—Wave induced littoral flow along Colva for W (5) and WNW (6) waves [→ Probable direction of littoral flow]

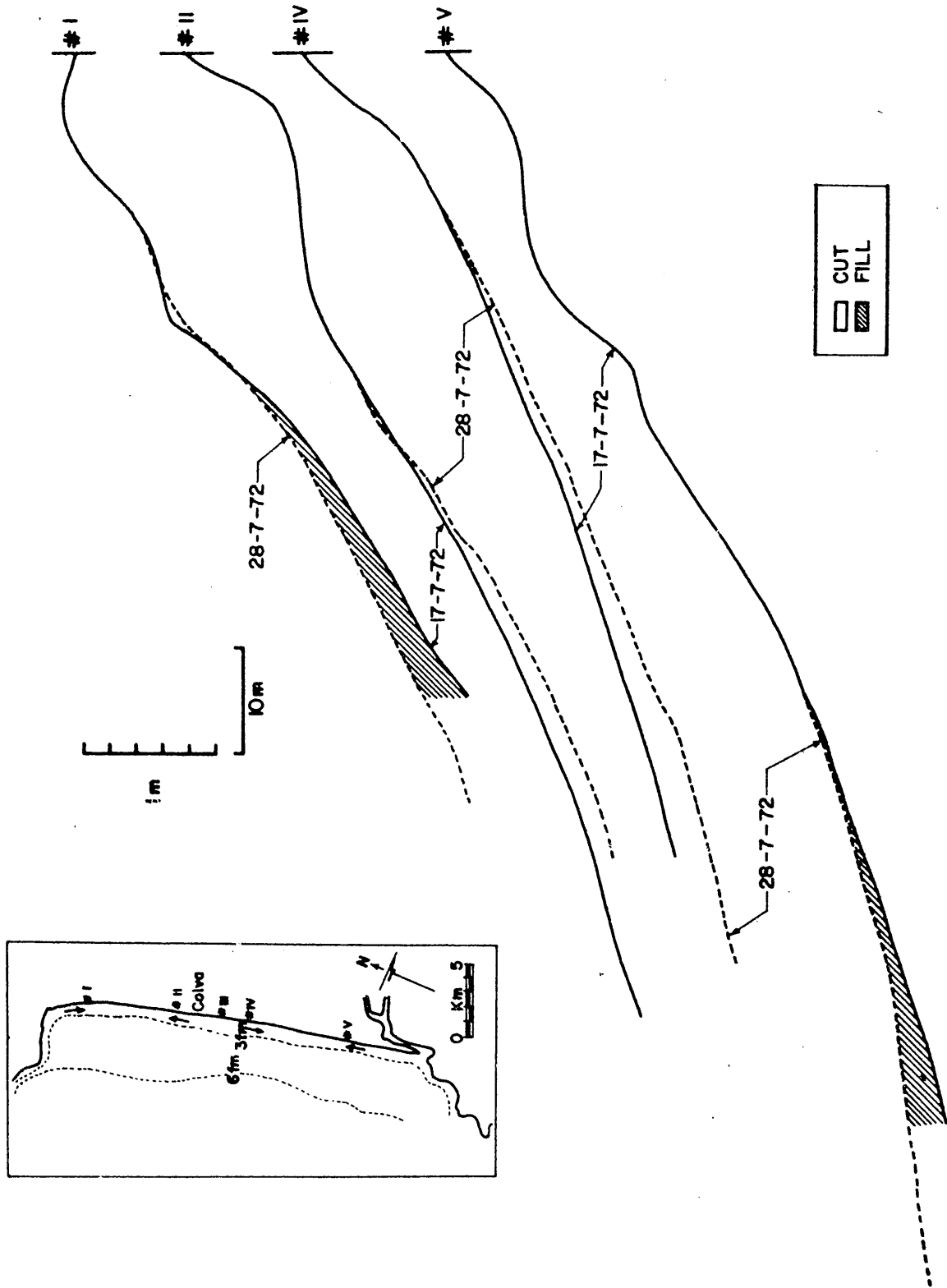


Fig. 7—Typical beach profiles taken during SW monsoon together with observed littoral flows at different profile stations (in inset) along the Colva beach



either southerly or northerly; at times onshore offshore flows prevailed. Profile st II records a southerly flow from August to November. The deduced littoral flow pattern from the wave refraction studies for waves approaching from WSW and W directions presented earlier correlates fairly well with the observed littoral current pattern during the southwest monsoon.

A typical example showing the observed littoral current pattern and the cut and fill of the beach during July 1972 is presented in Fig. 7. The beach at profile sts I and V record accretion while profile sts II and IV show erosion. The littoral flow is southerly at sts I and IV and northerly at sts II and V. These suggest the presence of a zone of converging current pattern between sts IV and V and between II and I. There exists a zone of convergence of wave rays between sts II and III as indicated from the wave refraction studies (Fig. 4). The opposing alongshore currents find their way out as rip currents. As mentioned above, the alongshore flow and the seaward flowing rip currents together with the onshore flows form circulation cells. The sediment that is kept in suspension is trapped in these littoral cells. The sediment that is brought to the converging current zones partly moves alongshore, gets recirculated and feeds the longshore current system by these circulation cells. Depending on the prevailing wave characteristics and the angle of incidence of the breakers, the sediment that is caught up in the cells apart from getting recycled, shifts from place to place as a result of slight variations in the angle of wave approach.

The studies show that the sediments of Colva beach mostly get recirculated between the two promontories,

under the influence of the prevailing currents and the associated circulation pattern in the surf zone.

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