

PHYSICAL CHARACTERISTICS OF THE COASTAL WATERS BETWEEN NAVAPUR AND UMBHARAT, WEST COAST OF INDIA. PART I: CURRENT PATTERN

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ABSTRACT

Surface and bottom current patterns of the coastal waters between Navapur and Umbharat (Maharashtra-Gujarat Industrial Belt) are described in relation to tides and other environmental parameters. The results of the analysis of the frequency distribution and the componential currents showed the extent to which the bimodal currents are induced by tides and are eventually modified by winds and bottom topography. The influence of large river systems has been identified.

Key words: Tides, currents, coastal waters.

INTRODUCTION

The coastal area between Navapur and Umbharat, encompassing a portion of the Maharashtra-Gujarat Industrial Belt has been a scene of intensified activities in recent years owing to the proposal to extend the oil and natural gas pipeline from Bombay High/Bassein oil fields to this region. This naturally leads to the construction of marine structures and possibly to the contamination of the coastal marine environment. But practically no detailed information is available to assess the oceanographic conditions prevailing in these waters. The lack of baseline data could partly be due to the operational difficulties arising from extreme tides, currents, winds and waves in addition to the navigational hazards typical of this region. In 1978, National Institute of Oceanography studied for the first time the physical, chemical and biological characteristics of these coastal waters to help build up the much-needed data for the effective management of the environment (NIO, 1979). This paper describes the results of the analysis of the current data collected during the course of the multidisciplinary investigation conducted for over a year from January 1978.

DESCRIPTION OF THE AREA

The coastline between Tarapur (Maharashtra) and Hajira (Gujarat) roughly runs in a north-south direction for about 150 km with a concave curvature near Tithal (Fig. 1). The southern part of the coast is fringed with rock outcrops. The portion of the coast north of Daman is very muddy. A number of creeks, rivers and rivulets have broken the entire coastline. The major rivers are Damanganga,

Kolak, Par, Ambika, Purna, Mindola and Tapti. Navigation in these coastal waters is very difficult owing to the shoals, bights, reefs, rocks, etc. (Admiralty, 1961). River-mouth bars and shoals with very strong currents often make the entry to the sea and back to the river extremely dangerous. The tide runs up through the river mouths and the creeks; and floods a large part of the low-lying areas and salt marshes.

In the area of study, the tides are semi-diurnal with significant daily inequality. The tidal streams generally set northward during the flood and southward during the ebb of the tidal cycle. The range of the tide is large in general and in the northern section in particular. Consequently the currents in the nearshore waters are very strong. They are bimodal.

The winds are seasonal and pick up a considerable speed at times. Strong winds blow from southwest during May-July. The wind speed may exceed 60 kmph during cyclones.

Maximum air temperature is experienced during April to June along the Maharashtra coast and during March to May along the Gujarat coast. The coldest months are January and February.

METHOD OF THE STUDY

The present study was carried out in five regions over a stretch of about 150 km between Navapur and Umbharat. The field observations on currents were made at the surface, mid-depth and near-bottom levels over tidal cycle using NIO-made rotor induction current meter, Toho Dentan current meter and LYNX current meter, from a vessel anchored at a water depth of 10-20 m off Navapur, Umbergaon, Daman, Tithal and Umbharat (Fig. 1). The observations off Navapur, Daman and Umbharat covered pre-monsoon, monsoon (Southwest) and post-monsoon seasons during the period, January 1978 to January 1979. Observations off Tithal and Umbergaon were carried out during the pre-monsoon and post-monsoon periods respectively. The results are summarised in Table I, and the representative current patterns are given in Figs. 2-4

In some cases the onshore-offshore and alongshore components of the currents were computed and are presented in Figs. 5-11. The observed wind velocities were also resolved into components and their variation over complete tidal cycles are shown in these diagrams. The frequency distributions of the current speeds and directions (surface, mid-depth and near-bottom) over a tidal cycle at Navapur, Daman and Umbharat were worked out and are shown in Figs. 12-14. The most frequent current directions and the most frequent current speeds during different seasons were identified separately and are presented in Table II. For the sake of comparison the most frequent individual current speeds with their respective directions (modal current velocity) were singled out and are given in Table III.

Tides were recorded at Akkarpatti (Navapur), Nani Daman (Daman), Umar-sadi (Tithal) and Machiwada (Umbharat) (Fig. 1). These tidal measurements were conducted for more than 30 days continuously during the comparatively calm season (pre-monsoon). Water level observations were made visually using graduated poles. Summary of the tidal information is given in Tables IV & V.

Table I. Summary of current speeds (in cm s⁻¹).

	Daman		Navapur		Umbergaon		Umbarhat		Tithal							
	Spring Max Min	Neap Max Min	Spring Max Min	Neap Max Min	Spring Max Min	Neap Max Min	Spring Max Min	Neap Max Min	Spring Max Min	Neap Max Min						
Pre-monsoon																
Surface	150	0	90	25	125	5	80	10	160	5	140	10	135	0	90	10
Mid-depth	150	0	78	25	135	5	80	0	160	5	140	10	145	10	80	10
Near-bottom	140	0	86	22	165	0	60	5	160	10	140	8	150	10	60	0
Monsoon																
Surface	80	30	160	40	100	20	140	20	110	20	120	15	110	30	120	10
Mid-depth	80	20	160	30	90	30	120	15	110	30	120	10	100	20	120	10
Near-bottom	60	20	160	20	90	20	120	10	100	20	120	10	100	20	120	10
Post-monsoon																
Surface	147	16	112	26	148	0	122	0	146	5	125	16	168	36	122	10
Mid-depth	134	13	102	28	134	0	104	14	125	0	120	16	148	48	116	12
Near-bottom	134	0	84	31	122	0	101	21	138	12	116	7	148	35	115	12

RESULTS AND DISCUSSION

Tidal Currents

A general analysis indicated that the tidal currents followed the configuration of the respective coastlines. However, the influence of creeks and rivers in the vicinity of the stations was perceptible. The currents also followed the tidal rhythm at all the stations (Figs. 2-4). The time of occurrence of minimum current speed was around ± 1 hr 30 min from the time of occurrence of high water or low water. Though the tidal effects dominated, the local current pattern was found to be modified by the variation in wind, waves and general coastal circulation. The deviation from the normal tidal current pattern was of the order of 30 cm s^{-1} . Surface-to-bottom variation in the speed was not very pronounced.

During the flood tide, the peak in the surface current tends to occur nearly an hour ahead of the peak in the bottom currents along this coast (Figs. 2-4). During the ebb, the time of occurrence of the maximum bottom currents was found to lead that of the peak surface current by about an hour. However, on many occasions, no marked lag or lead was noticed. A difference of ± 30 degrees was

Table II. Most frequent current directions and speeds

	Station	Pre-monsoon		Monsoon		Post-monsoon	
		Direction Range (deg)	Speed Range (cm s^{-1})	Direction Range (deg)	Speed Range (cm s^{-1})	Direction Range (deg)	Speed Range (cm s^{-1})
Surface	Daman	016-045	26-45 46-65	196-225	26-45 46-65	016-045 196-225	86-105
	Navapur	166-195 346-015 015-045	26-45	016-045	26-45 46-65	166-195	46-65
	Umbergaon					196-225	86-105
	Umbharat	345-015	26-45 106-125	166-65	46-65	166-195	46-65 66-85
	Tithal	016-045	46-65				
Mid-depth	Daman	016-045	26-45	346-025 196-225	26-45 46-65	016-045	26-45
	Navapur	166-195 346-015 016-045	26-45	046-075	46-65	166-195	46-65
	Umbergaon					196-225	66-85
	Umbharat	346-015	66-85	196-225	26-45	166-195	46-65
	Tithal	196-225	26-45	346-015			
Near-bottom	Daman	016-045	26-45	196-225	26-45	016-045	46-65 86-105
	Navapur	166-195	26-45	196-225	26-45	166-195	66-85
	Umbergaon					166-195	46-65
	Umbharat	196-225 346-015	106-125	196-225	46-65	346-015 166-195	26-45 105-125
	Tithal	016-045	26-45				

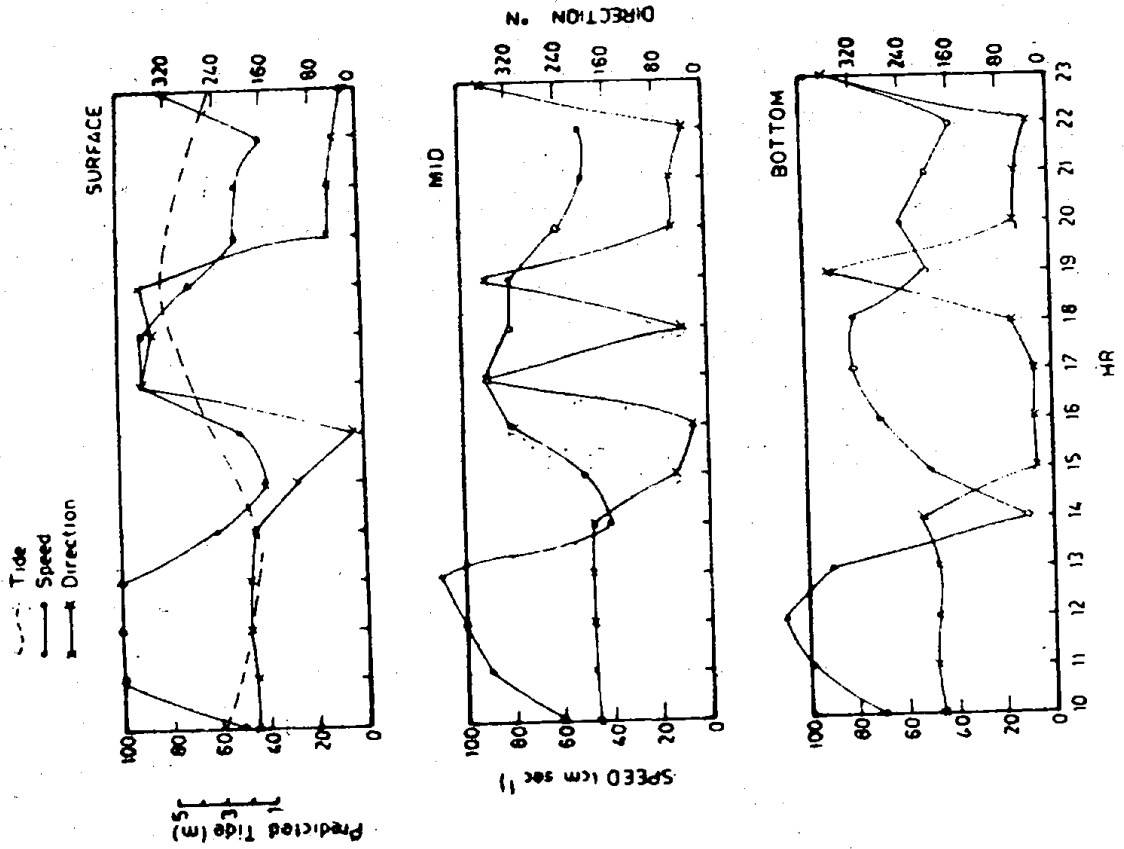


Fig. 4. Tidal Current Pattern (Umbharat, 24.8.78)

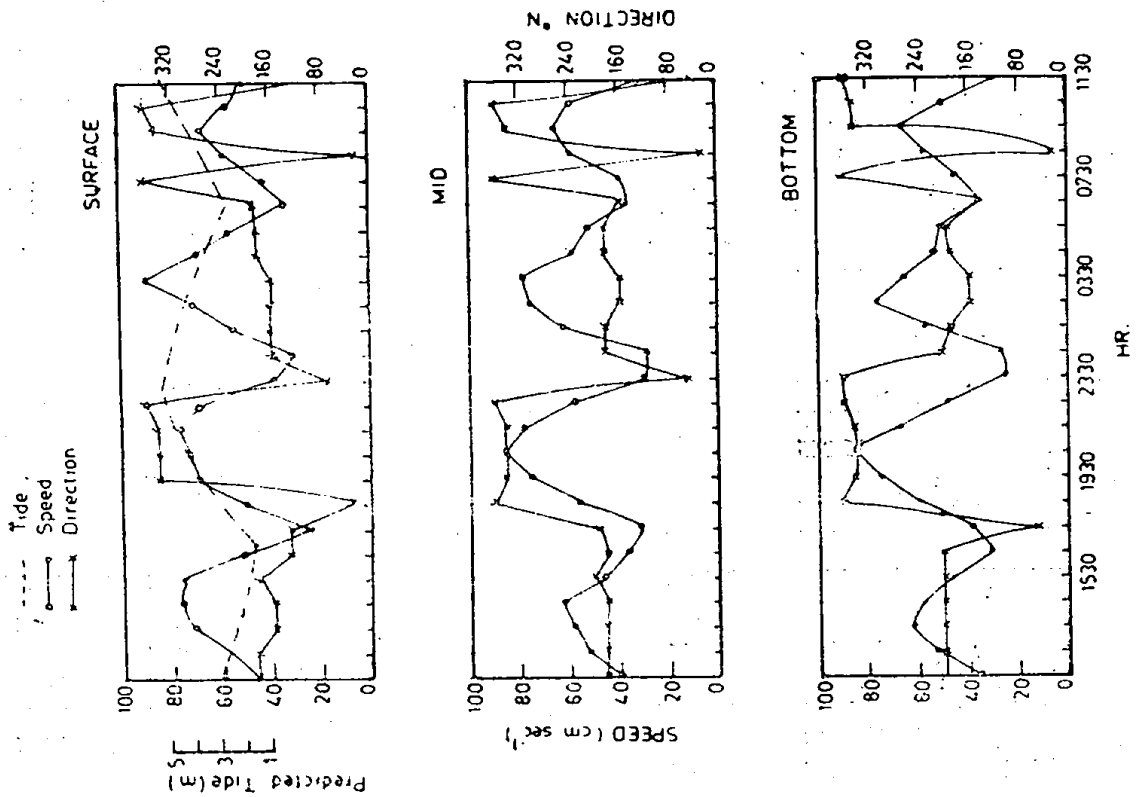


Fig. 3. Tidal Current Pattern (Daman, 4/5.3.78)

observed between the directions of the surface and bottom peak currents during flood tide. The ebb currents followed the same direction mostly. The surface currents were generally stronger than the bottom currents by 10 to 40 cm s⁻¹, though significant exceptions were noticed.

The tidal currents off Navapur were found to be directed towards north-northeast during the flood and towards south during the ebb (Fig. 2). The onshore component was prominent at the surface. The slack period of the currents lasted for an hour when the tidal reversal took place.

Off Daman, the flood currents set towards northwest both at the surface and along the bottom (Fig. 3) whereas ebb currents were directed towards south and southwest respectively. The effect of the proximity of the Damanganga river might have modified the tidal currents. The tidal reversal caused the currents to slacken for an hour.

At Tithal, the flood currents were directed towards north at the surface and towards north-northwest at the bottom. The ebb currents set in the south-southwest direction both at the surface and the bottom at the same time. Associated with the change in the phase of the tide, the currents slackened for about an hour.

The flood currents were observed to set in north-northwest direction off Umbharat (Fig. 4). The ebb currents were found to flow towards south-southeast. The slack period lasted for about an hour.

Table I shows that the currents intensified at Navapur during the monsoon season. At Umbharat the currents were comparatively weaker during this period.

Table III. Modal current velocity*.

Station	Pre-monsoon (Jan-Apr)		Monsoon (May-Sep)		Post-monsoon (Oct-Dec)		
	Direction (Deg)	Speed (cm s ⁻¹)	Direction (Deg)	Speed (cm s ⁻¹)	Direction (Deg)	Speed (cm s ⁻¹)	
Surface	Navapur	180	35	030	35	180	55
	Umbergaon	—	—	—	—	360	95
	Daman	030	55	210	75	030	95
	Tithal	030	55	—	—	—	—
	Umbharat	360	75	180	95	180	55
Mid-depth	Navapur	180	35	060	35	180	55
	Umbergaon	—	—	—	—	180	93
	Daman	030	35	360	55	030	55
	Tithal	210	55	—	—	—	—
	Umbharat	360	95	180	95	180	55
Bottom	Navapur	180	35	210	35	180	75
	Umbergaon	—	—	—	—	180	95
	Daman	210	35	210	55	030	55
	Tithal	030	35	—	—	—	—
	Umbharat	360	115	210	55	360	115

* Most frequent individual currents with respective average direction and speed.

Frequency distribution of currents

Frequency distribution analysis of currents over a tidal cycle, presented in Figs. 12-14, revealed that in one tidal cycle the most frequent directions and speeds of the currents at Daman were the same (150° to 210° , and $45-85 \text{ cm s}^{-1}$) from surface to bottom. At Navapur a deviation of about 150 degrees was noted

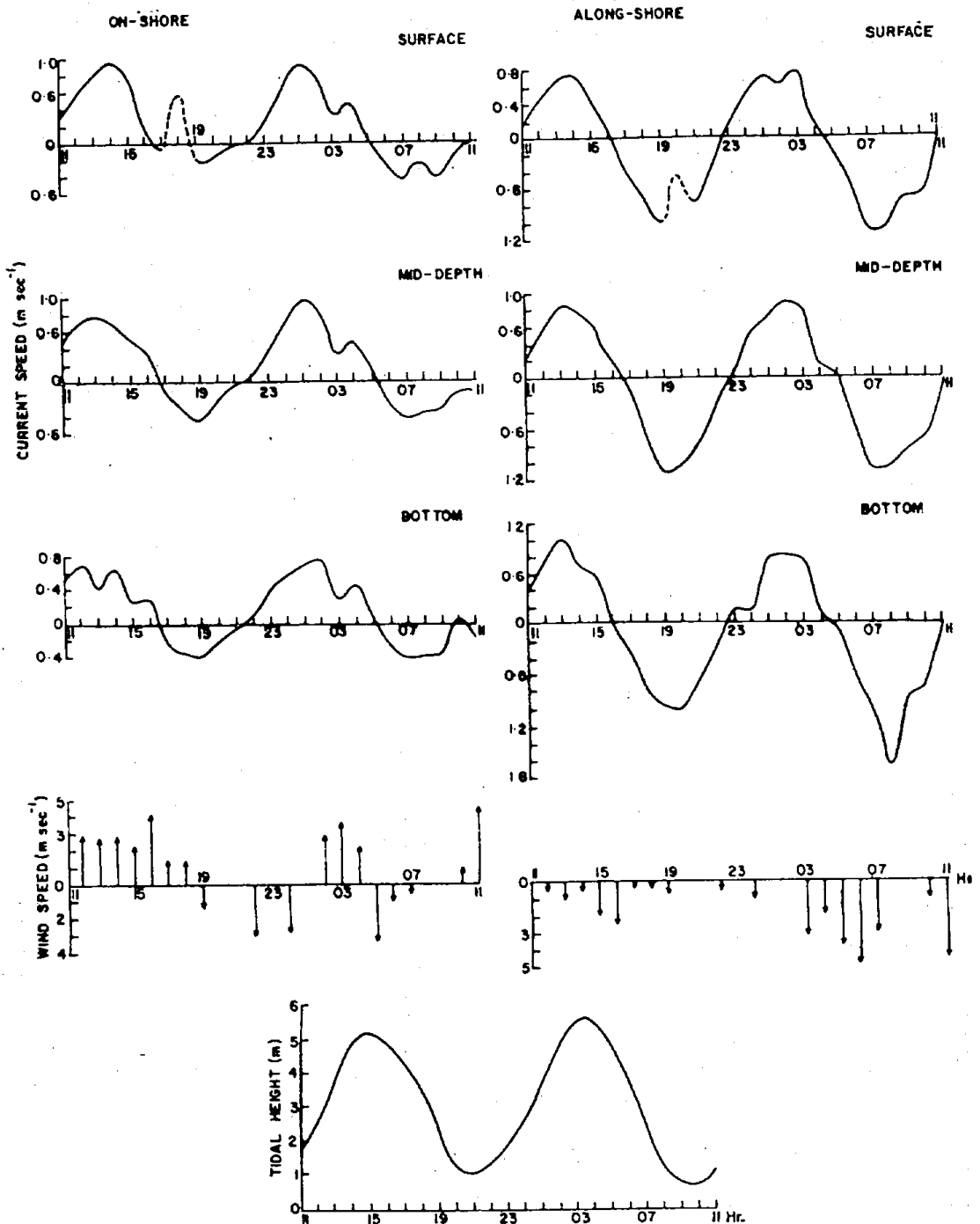


Fig. 5. Componential Currents (Navapur, 25/26.2.78)

in the direction of the currents from surface to bottom. The speeds of the mid-depth currents were high compared to the speeds of the surface and bottom currents. This could possibly be due to the interaction of the wind induced currents at the surface. At Umbharat too there was a deviation of about 150 degrees between the surface and bottom currents while the current speeds were approximately uniform (45-65 cm s⁻¹) from the surface to the bottom.

Table IV. Tidal information.

	Time difference w.r.t. Bombay		High Tide		Low Tide		Observed Tidal Range(m)		Average Ratio of Tidal Range w.r.t. Bombay	
	Observed	Predicted	Observed	Predicted	Observed	Predicted	Spring	Neap	Observed	Predicted
Navapur	(+) 1 hr 02 min	(+) 1 hr 23 min	(+) 8 hr 23 min	(+) 1 hr 16 min	5.35	2.1	1.19	1.09		
Daman	—	(+) 2 hr 27 min	(+) 2 hr 58 min	(+) 3 hr 32 min	5.45	2.9	1.41	1.35		
Tithal	—	(+) 2 hr 50 min	—	(+) 3 hr 27 min	4.6	1.2	—	1.56		
Umbharat	(-) 2 hr 25 min	(-) 1 hr 51 min	(-) 2 hr 27 min	(-) 1 hr 03 min	6.7	2.5	0.63	0.57		

* Time difference and tidal ratio w.r.t. Bhavnagar.

Note: Tidal Stations: Akkarpatti (Navapur), Nani Daman (Daman), Umarsadi (Tithal), Machiwada (Umbharat).

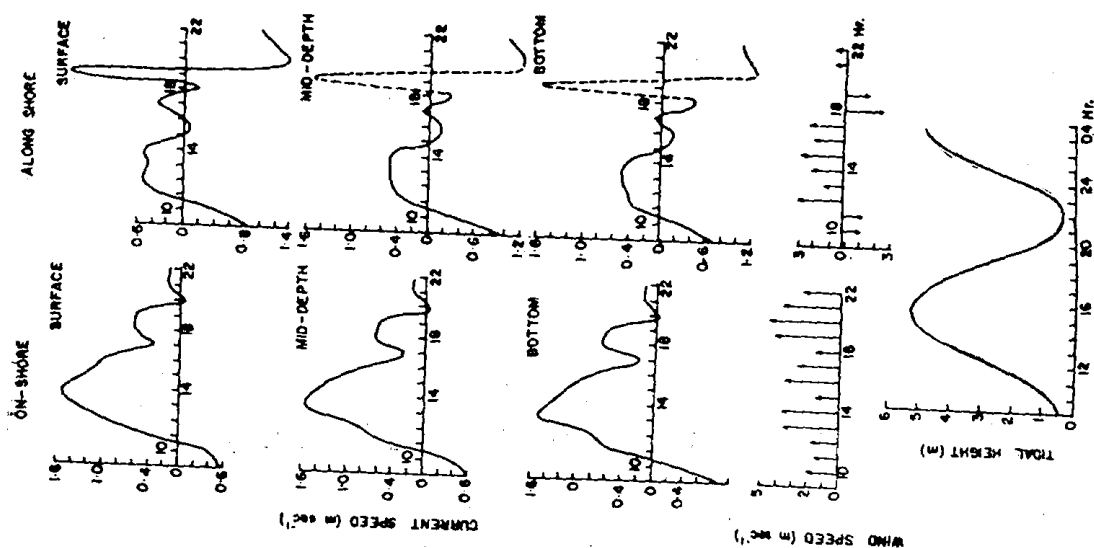


Fig. 6. Componential Currents (Navapur, 21.8.78)

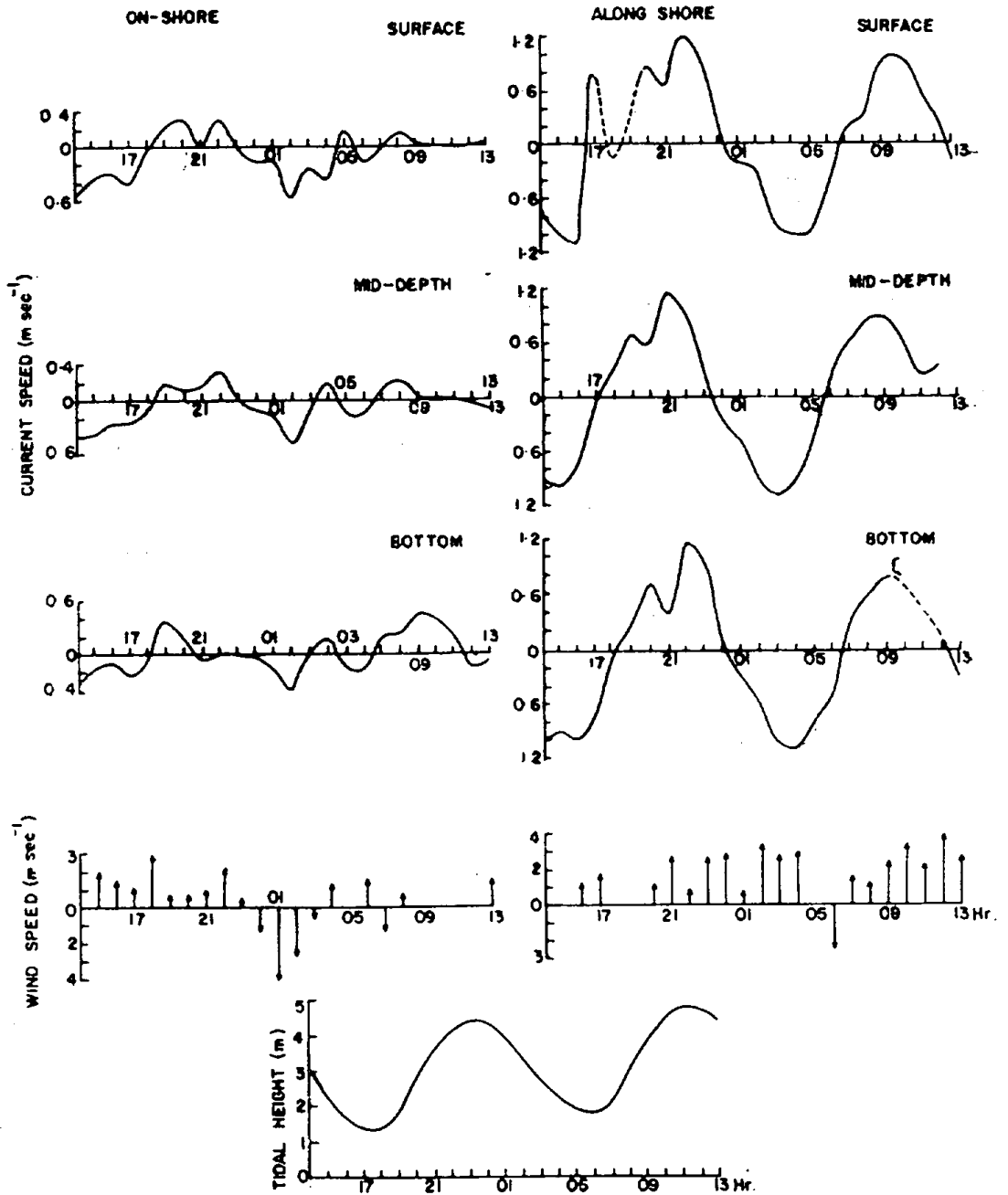


Fig. 7. Componential Currents (Umbergaon, 10/11.11.78)

Table V. Observed tidal periods.

Station	Average Flood Period	Average Ebb Period
Navapur	6 hrs 7 min	6 hrs 12 min
Daman	5 hrs 21 min	6 hrs 27 min
Umbharat	5 hrs 39 min	6 hrs 32 min

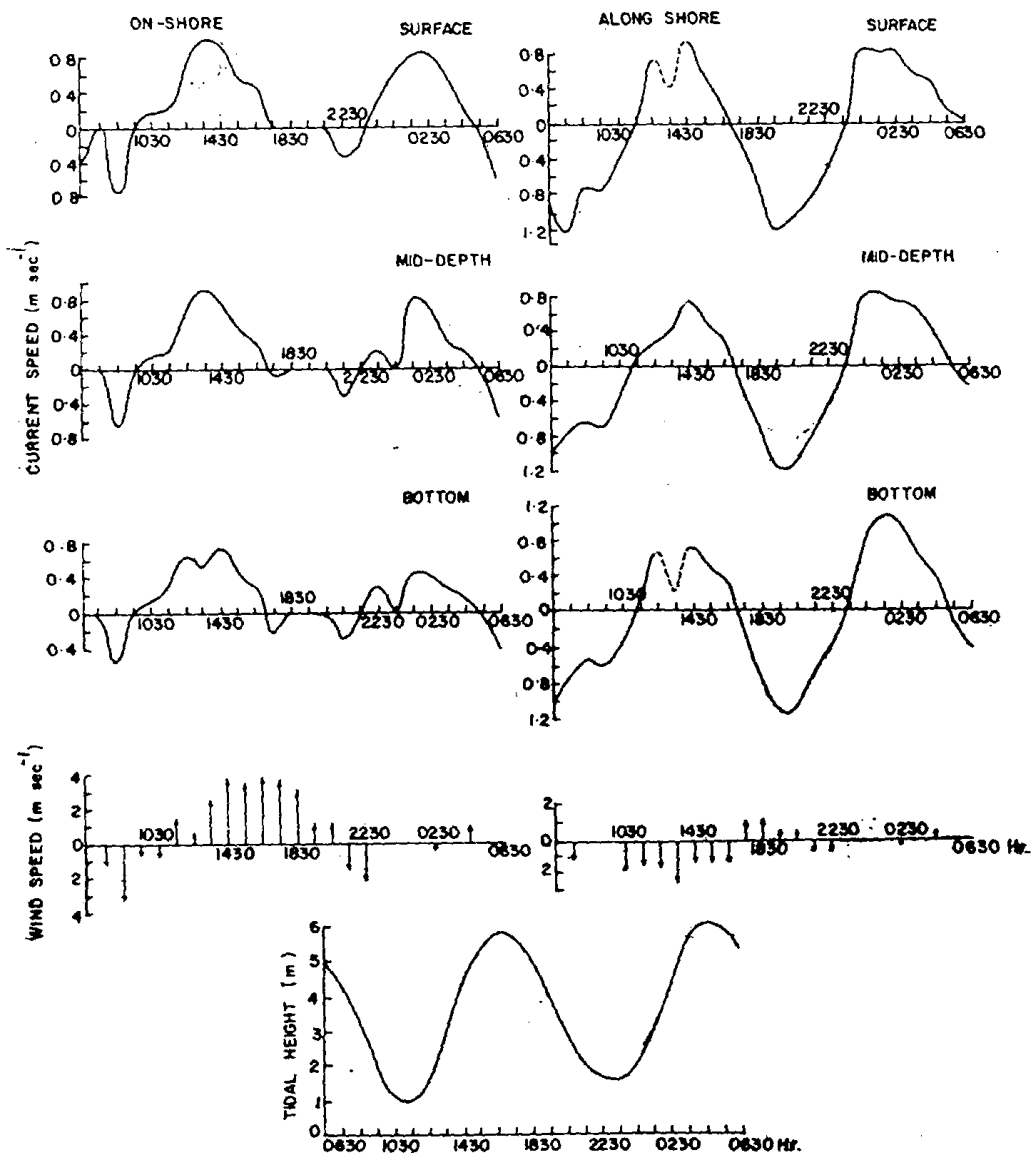


Fig. 8. Componential Currents (Daman, 26/27.2.78)

It could be seen from Table II that the currents reversed during the south-west monsoon with reference to the pre-monsoon conditions in this area. This shift of about 180 degrees in direction was perceivable throughout the vertical water column. During the post-monsoon period the currents were found to take generally the pre-monsoon course. The station off Navapur, however, appeared to exhibit somewhat different pattern which might be due to some peculiar combination of wind and tide regimes and the orientation of the depth contours.

Table III presents more details. Both at the surface and the bottom, intensification of currents could be noted at Navapur during the post-monsoon period, at Daman during the monsoon and post-monsoon period, and at Umbharat during the monsoon. The speed of the bottom currents was higher at Navapur during the

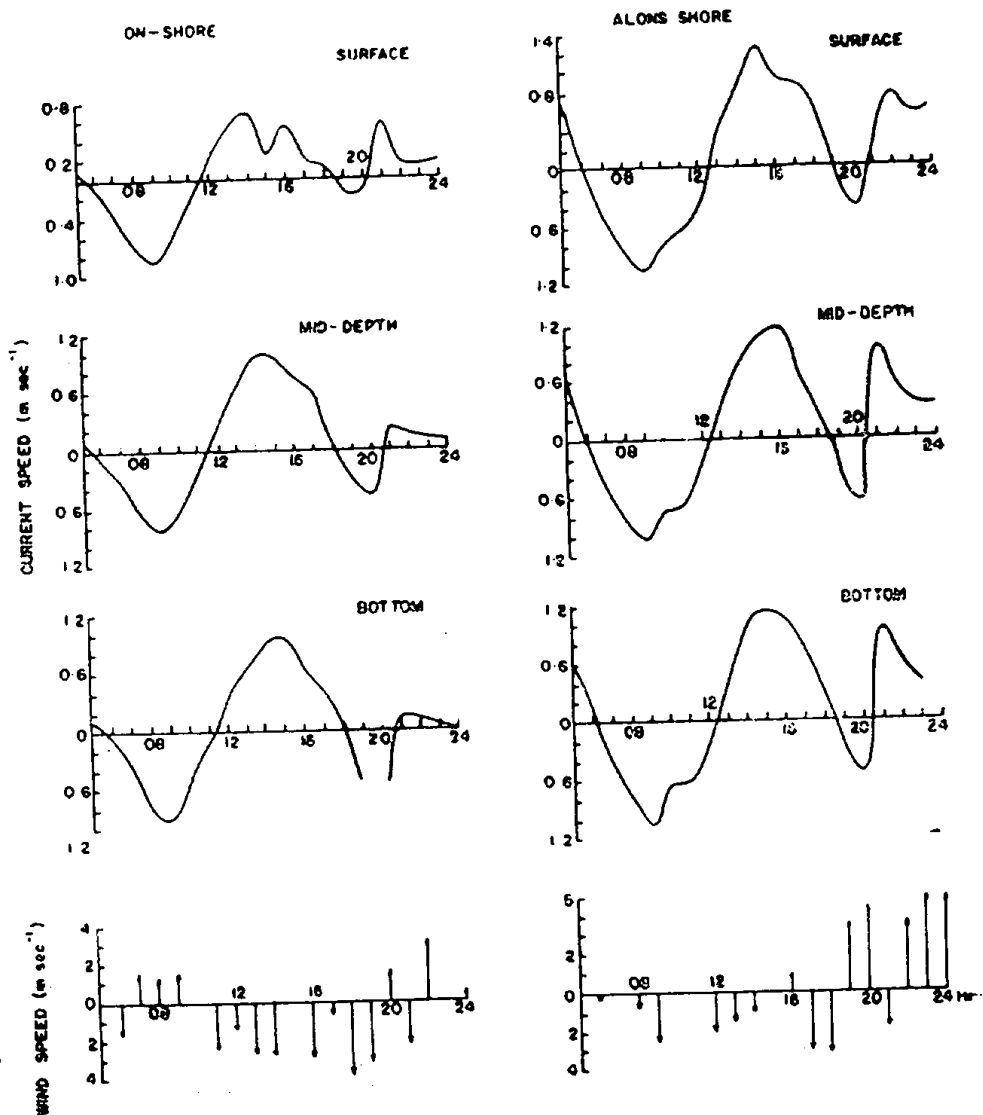


Fig. 9. Componential Currents (Tithal, 28/29.3.78)

monsoon period and at Umbharat during the pre-monsoon and post-monsoon periods. A shift of 30-180 degrees from the surface to the bottom, in the most frequent current direction was observed at Navapur during the monsoon, at Daman during the pre-monsoon and monsoon, and at Umbharat during the monsoon and post-monsoon periods.

Onshore/offshore and alongshore components

During the pre-monsoon period at Navapur, the onshore component was greater than the offshore component. Also the southward component was generally greater than the northward component (Fig. 5). At Tithal and Umbharat (Figs. 9 & 10 respectively) the onshore component was found to be smaller than the offshore component.

During the monsoon period, the current pattern was remarkably modified by strong gusty sea breeze at Navapur. In general, the onshore component was conspicuous (Fig. 6).

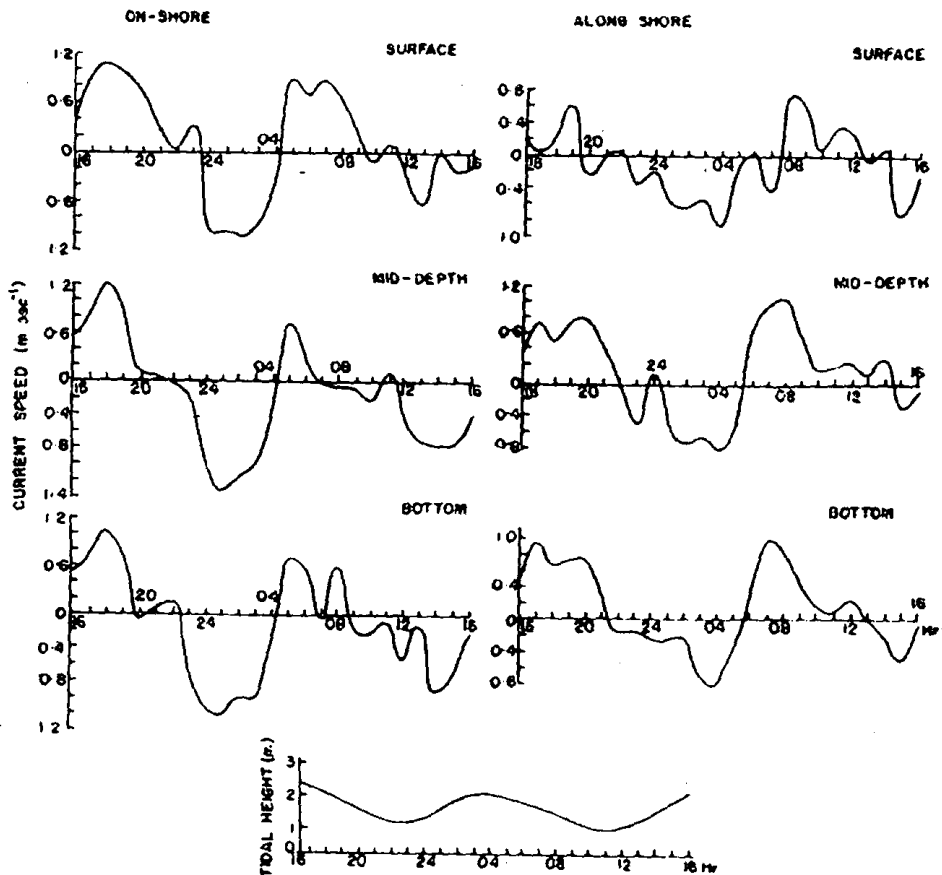


Fig. 10. Componential Currents (Umbharat, 29/30.4.78)

During the post-monsoon period, it was noticed that the alongshore components were considerably greater than the components perpendicular to the coast at Umbhergaon and Umbharat (Figs. 7 & 11 respectively). At Umbhergaon the on-shore components were less than the offshore components whereas at Umbharat they were fairly comparable at both the stations.

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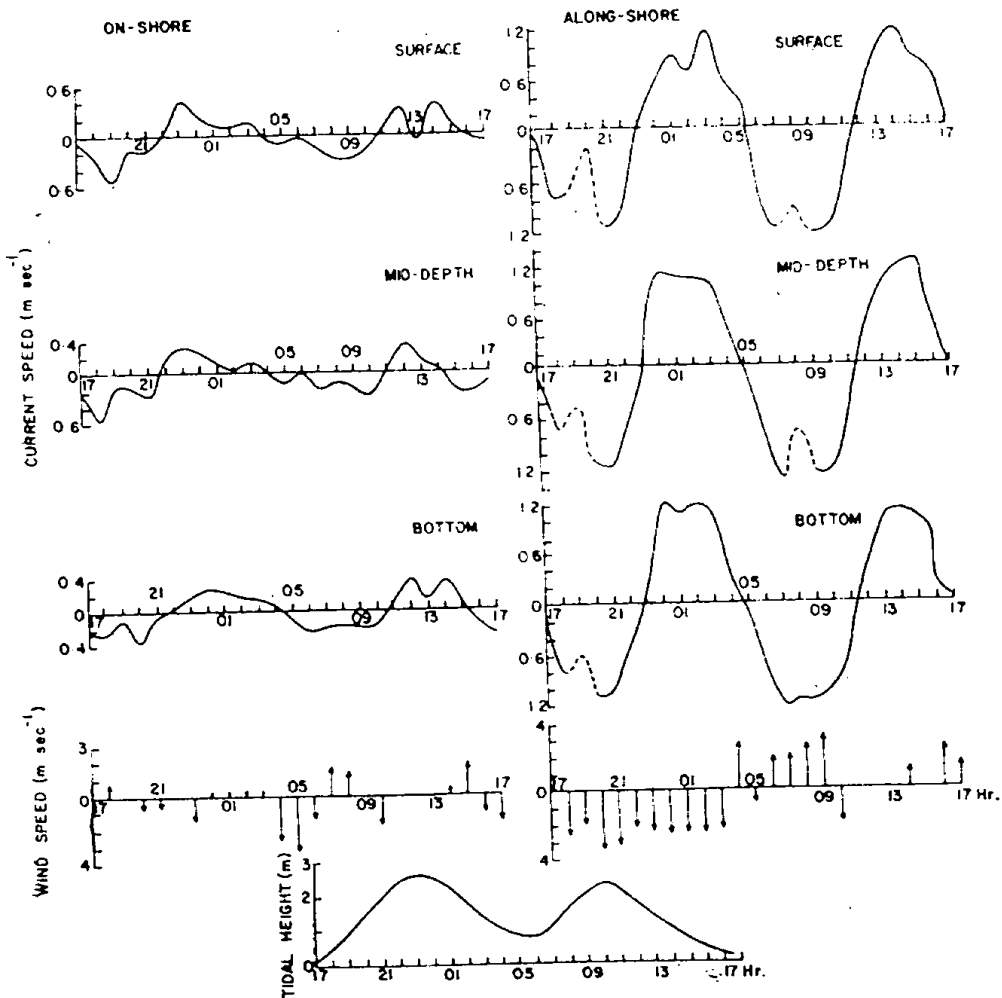


Fig. 11. Componential Currents (Umbharat, 15/16.11.78)

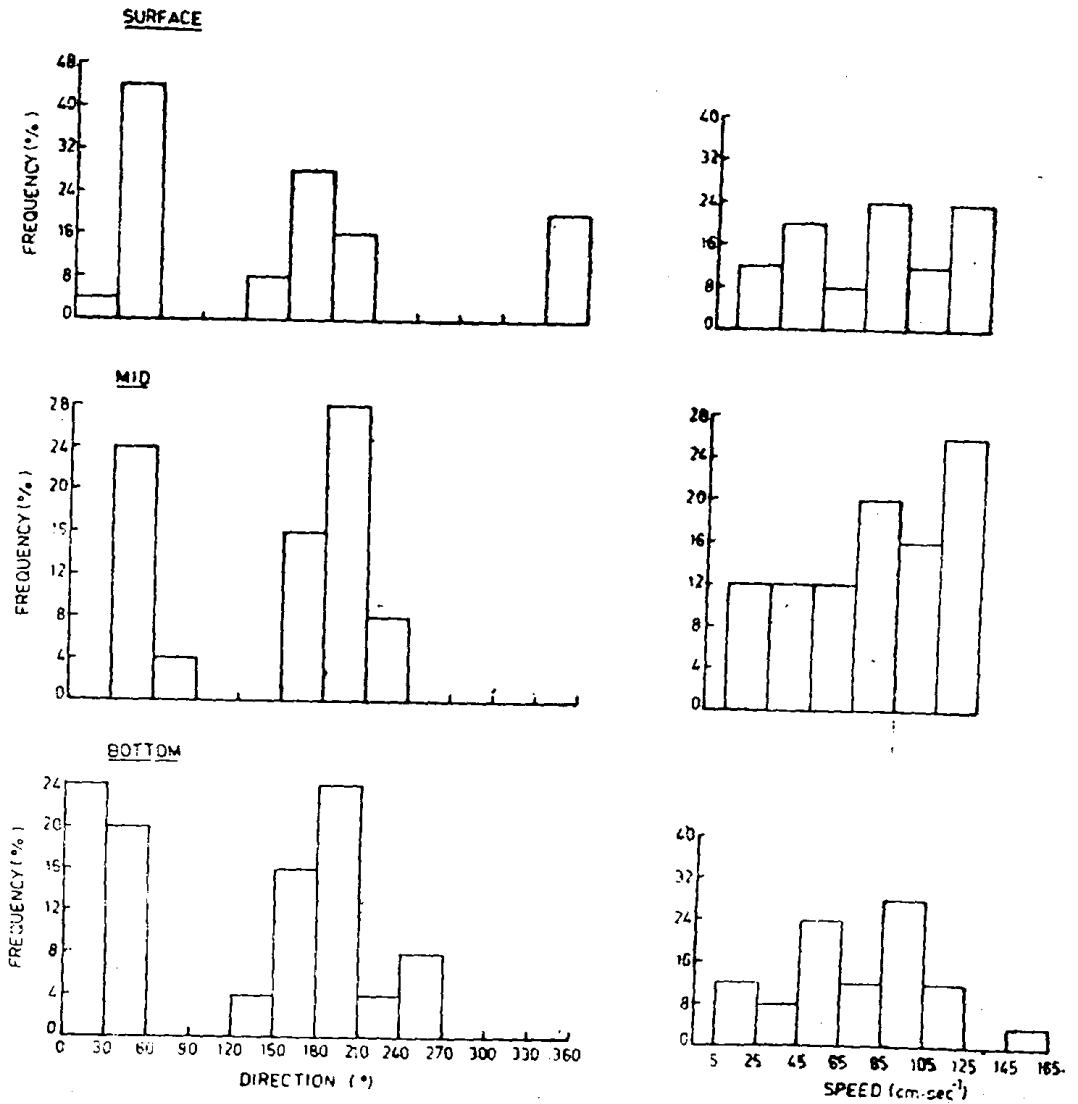


Fig. 12. Frequency Distribution of Currents over a Tidal Cycle (Navapur, 25/26.2.78)

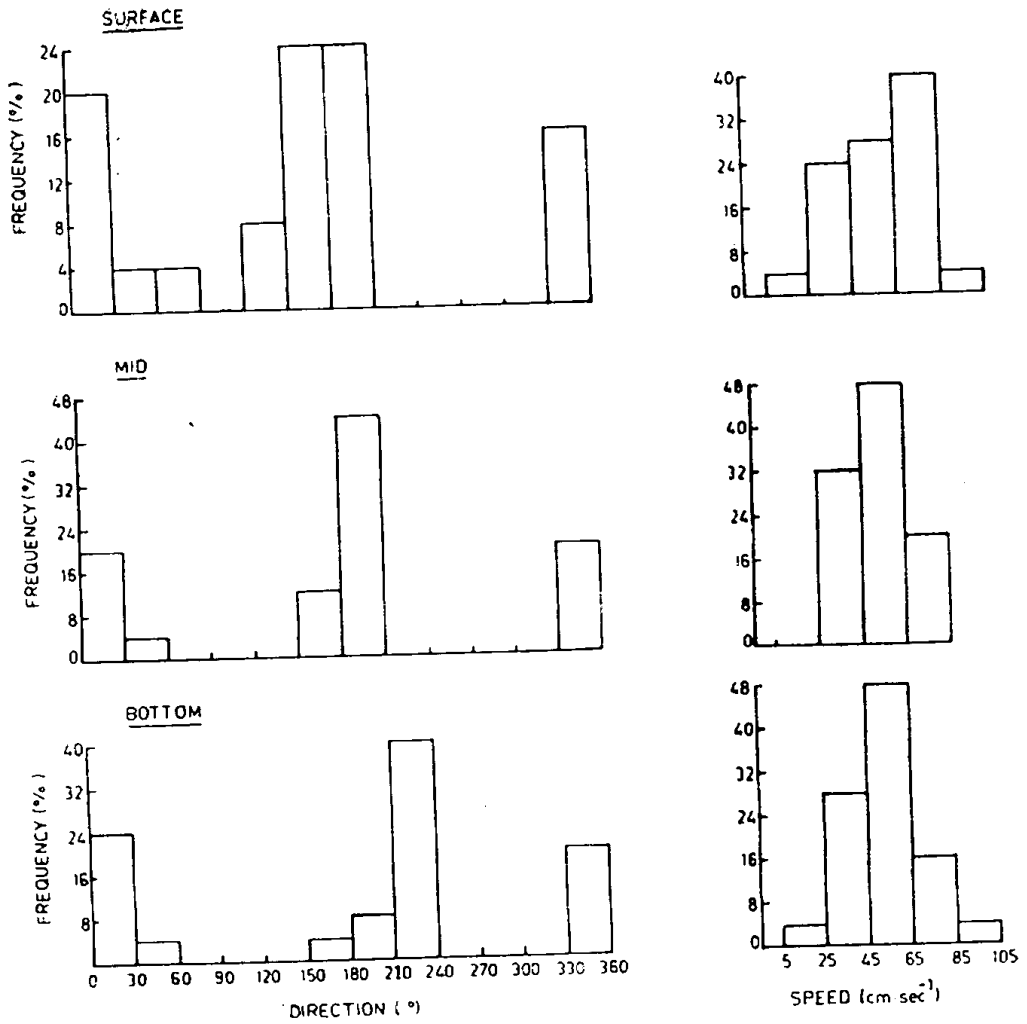


Fig. 13. Frequency Distribution of Currents over a Tidal Cycle (Daman, 4/5.3.78)

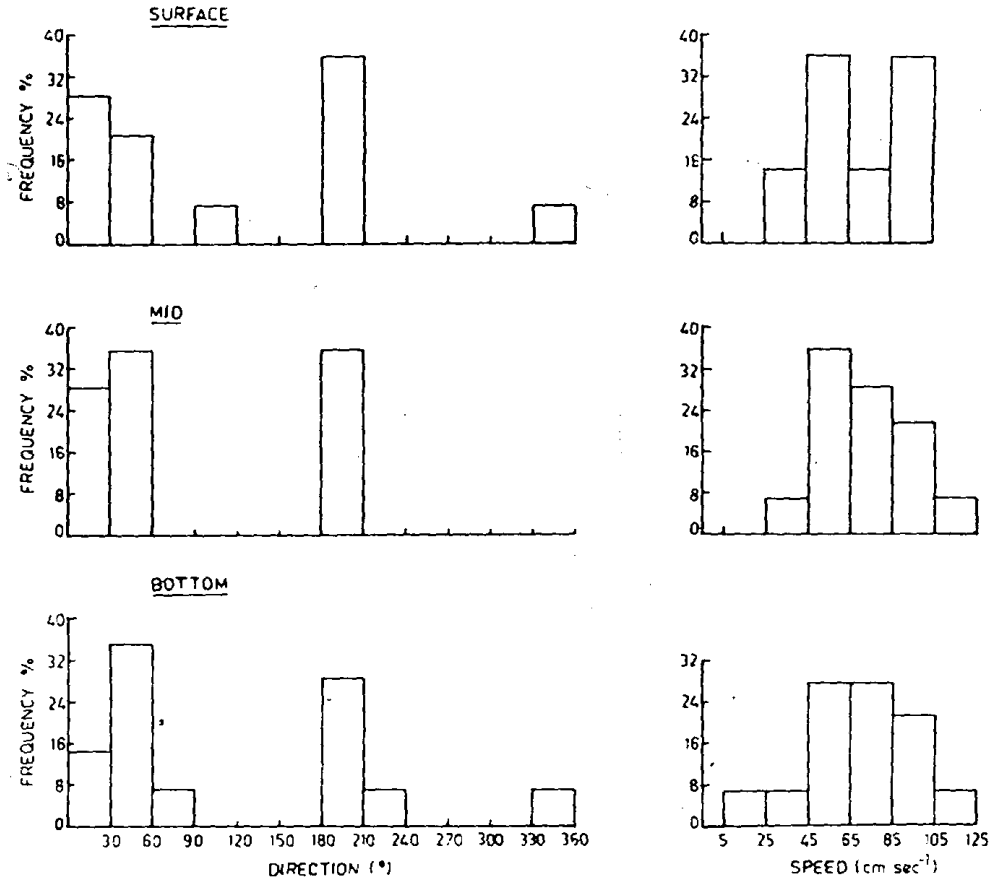


Fig. 14. Frequency Distribution of Currents over a Tidal Cycle (Umbharat, 24.8.78)

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