

Beach Morphological Variations over Micro-time Scales

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Nature and magnitude of beach changes over short periods have been studied at Calangute and Miramar in relation to tide, ground water level and relevant oceanographic and meteorological factors. Alternating zones of accretion and erosion moving up and down the beach face with breakers, locations of which alternately shift landward and seaward with the rise and fall of tide are observed. The ground water table shows an oscillation with tide with a time lag of about 1 hr. When the ground water table cuts across the beach face, erosion processes become prominent. Short-term erosion and accretion patterns are discussed in terms of the short-crested wind waves and low long period swells prevailing in different seasons. During the periods of cusp formation, variations in the profiles show anomalous behaviour. The differences in grain-size distribution of the sediments of these 2 beaches are attributed to the available wave energies at these 2 locations.

The beach profile at a place at any time is the net result of variations in beach topography over time scales varying from a few seconds to 1 yr or more preceding the time of observation. The observed variations in the beach topography are the integrated effects of various process variables (waves, tides, winds, ground water, etc.) in different time scales. An understanding of the nature of these process variables and their effects in the above time scales should enable one to reconstruct the beach profiles at least qualitatively.

Studies¹⁻⁹ on the beach topography in micro-time scales are largely limited to a single tidal cycle or to a set of tidal cycles in a particular season over a few years.

In this paper, studies carried out over micro-time scales of the beach topographies at Calangute and Miramar, representing high and low wave energy environments respectively, under different seasonal and tidal conditions are presented.

Description of Area

Calangute and Miramar (Fig. 1) differ significantly in their environmental set up. The beach at Calangute with a backshore width of 15 to 20 m has sediments in the size limits of gravel to fine sands¹⁰ and is exposed to the wave action directly. Miramar, a relatively small sandy beach, is protected by two headlands—Aguada and Cabo Raj—and from direct wave influence by a submerged bar, Aguada bar¹¹. This beach has a backshore width of 10 to 15 m, with its foreshore sloping between 10° and 5°. The sediments are in medium to fine sand size class.

Materials and Methods

Iron rods (~ 0.5 cm diam.) were planted at 5 m intervals along the profile transect up to the breaker

zone. Topographic variations at these points were monitored at 30 min intervals. The first set of observations forms the base profile for each survey. Environmental variables such as winds, waves, breakers, ground water table fluctuations and littoral currents, were also recorded simultaneously.

Longshore current direction and speed were measured by timing the movement of the centre of a patch of Rhodamine B fluorescent dye in the surf zone. The dye releases were made twice and the mean times for their passage over 10 m distances determined. During various surveys the measurements of longshore

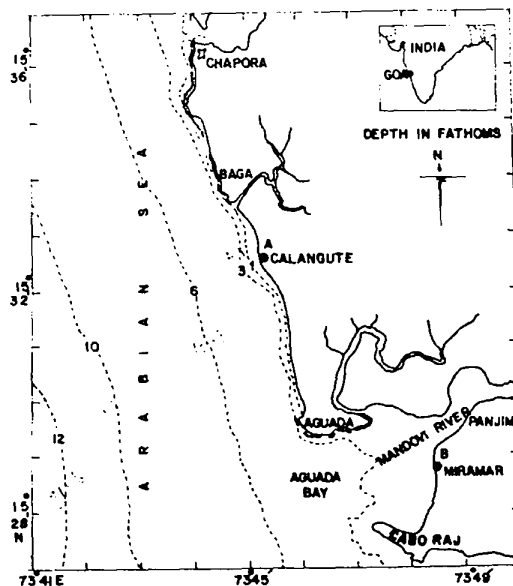


Fig. 1—Station locations

drift were found to be highly variable. The dye patch not only moved upcoast and downcoast but also offshore and onshore. The current directions (Figs 2 to 10) should, therefore, be viewed as the most probable directions. It may be noted that the arrows in these figures are not to scale. Whenever the current directions could not be thoroughly established, the current directions were not shown in the figures but mentioned in the text.

In the initial surveys, the level of the ground water table was measured from a well close to the transect and during subsequent surveys, it was monitored at 30 min intervals during the observation period, from a well dug on the beach near the transect, with a graduated pole.

As waves break farther offshore in rows (multiple breaking) and only visual estimates of these were made, they were not included in the figures. The breaker heights presented in Figs 2 - 10 are the means of 10

breakers observed over a period centred around the observation time and hence they may be considered as representative.

For the Calangute region, the surveys were conducted under spring tide conditions during the monsoon (CS₁ and CS₂), postmonsoon (CS₃) and winter (CS₄). Two surveys (CN₁ and CN₂) were conducted under neap tide conditions respectively during September and November 1970. One survey CC₁ was conducted when the beach at this location showed cusp formations. For the Miramar region, 2 surveys (MS₁ and MN₁) were conducted during the monsoon to represent spring and neap tide conditions respectively.

Results

Calangute Region

Spring tide conditions—Survey CS₁ : During the period of observation, winds were mostly from W and

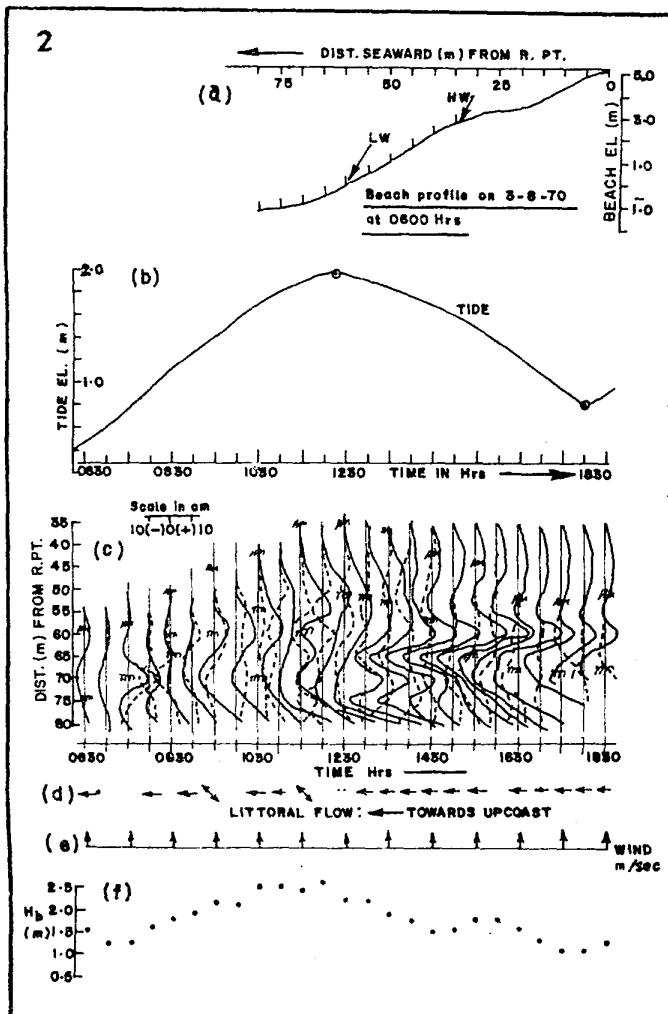


Fig. 2—Micro variations over a tidal cycle on 3.8.70 (CS₁) [In (a): Base profile of the beach, LW - Low water and HW - High water; (b)—, tide curve; --- GWT, ground water table; (c)—, changes in foreshore elevation and ---, changes that have taken place in the preceding 30 min; landward limit of breakers and maximum reach of swash; (d) observed littoral currents, upcoast (northward) and downcoast (southward); (e) winds \uparrow onshore and \downarrow offshore; (f) breaker height]

WSW and waves with dominant periods of 9 and 10 sec approached from WNW and WSW (Fig. 2). The breaker (mostly spilling) heights varied from 1 to 2 m. They often showed an increase with rising tide. The dye experiments indicated in general, southerly littoral flows, except during the rapid rise of water level when onshore and offshore tendencies prevailed.

Nearly 35 m of the beach came under the influence of wave activity as the water level varied with the tide. The topographic changes during the period of survey at different points along the transect are shown in Table 1. During the rising stage of the tide, the upper reaches of the beach showed depositional tendencies (Fig. 2). This process continued till about the time of high water. During the falling stage of the tide, erosion was noticed from the upper reaches of the foreshore. The net result (Table 1) was an alternating pattern of deposition and erosion along the entire transect. The points on the extreme landward side (40 m) experienced accretion and during the falling stage of the tide, the beach, at this point retained its deposit. Further, on either side of the breakpoint accretion was generally noticed while erosion was observed in the vicinity of breakers. The maximum change (-22 cm) was at 70 m point around 1630 hrs (Fig. 2). After the high water, well developed ripples on the beach face were observed shifting gradually seaward. The changes in elevation along the transects indicated alternating deposition and erosion which were seen to shift with the temporal still water level (Fig. 2).

Survey CS₂ : During this survey, the waves approached with a predominant period of 10 sec. Long period swell waves of 20 sec period from SW were observed from noon onwards. Though the spilling breakers prevailed during this survey also, the breaker heights were greater (up to 3.5 m) and showed much larger variation. The direction of the littoral currents showed a higher degree of variability. The wind speeds, however, were low compared to those during the earlier survey.

A thin surficial deposit was noticed at the swash reach (Fig. 3) as in survey CS₁. The zone of breakers coincided with deep cuts in the beach face. At the time of high water all points from 40 m onwards showed a decrease in elevation, the maximum being 12.5 cm at 60 m (Table 1).

At low water, the 60 m point showed an increase in elevation of +5.5 cm. Thus, this point gained a deposit of 18 cm from high to low water. A step feature migrating up and down the beach with the tide was observed during this survey in contrast to the ripples observed in the earlier survey.

Survey CS₃ : Fig. 4 shows the response of the beach during postmonsoon under spring tide conditions. At high water, deposition (+5 cm) at the upper reaches

(55 m to 60 m) and cut in the lower foreshore (70 m) were observed (Table 1). The lower foreshore beyond 80 m showed deposition towards the end of the survey.

Survey CS₄ : This survey represents winter monsoon conditions. The tide range was 1.3 m. The waves approached from WNW and NW directions with periods from 10 to 14 sec. The breaker heights were significantly low (0.3 to 0.75 m). The littoral flows were very weak. As a result of the changes in the temporal water level, the width of the breaker zone indicated variation of about 35 m (Fig. 5). The swash and back wash velocities were relatively low.

The elevation changes at high water (Fig. 5 and Table 1) indicated alternate accretion and erosion from the upper to lower foreshore. At low water, all the affected points on the beach except that at 60 m showed erosion features.

Neap tide conditions—Survey CN₁ : The beach response under transitional conditions soon after the southwest monsoon was studied. At the beginning of the survey, offshore winds of 1 to 2 m/sec up to 0900 hrs and onshore winds (sea breeze) later with speeds up to 6 m/sec were observed. The wave periods ranged from 9 to 12 sec and the waves approached from W and WSW. The breaker heights varied from < 0.5 to > 1.5 m and showed a decrease from 1030 hrs. The littoral flow was quite weak (about 10 cm/sec) and it was directed southward up to 0830 hrs and again from 1100 hrs. It was alternating between south and north between 0830 and 1030 hrs.

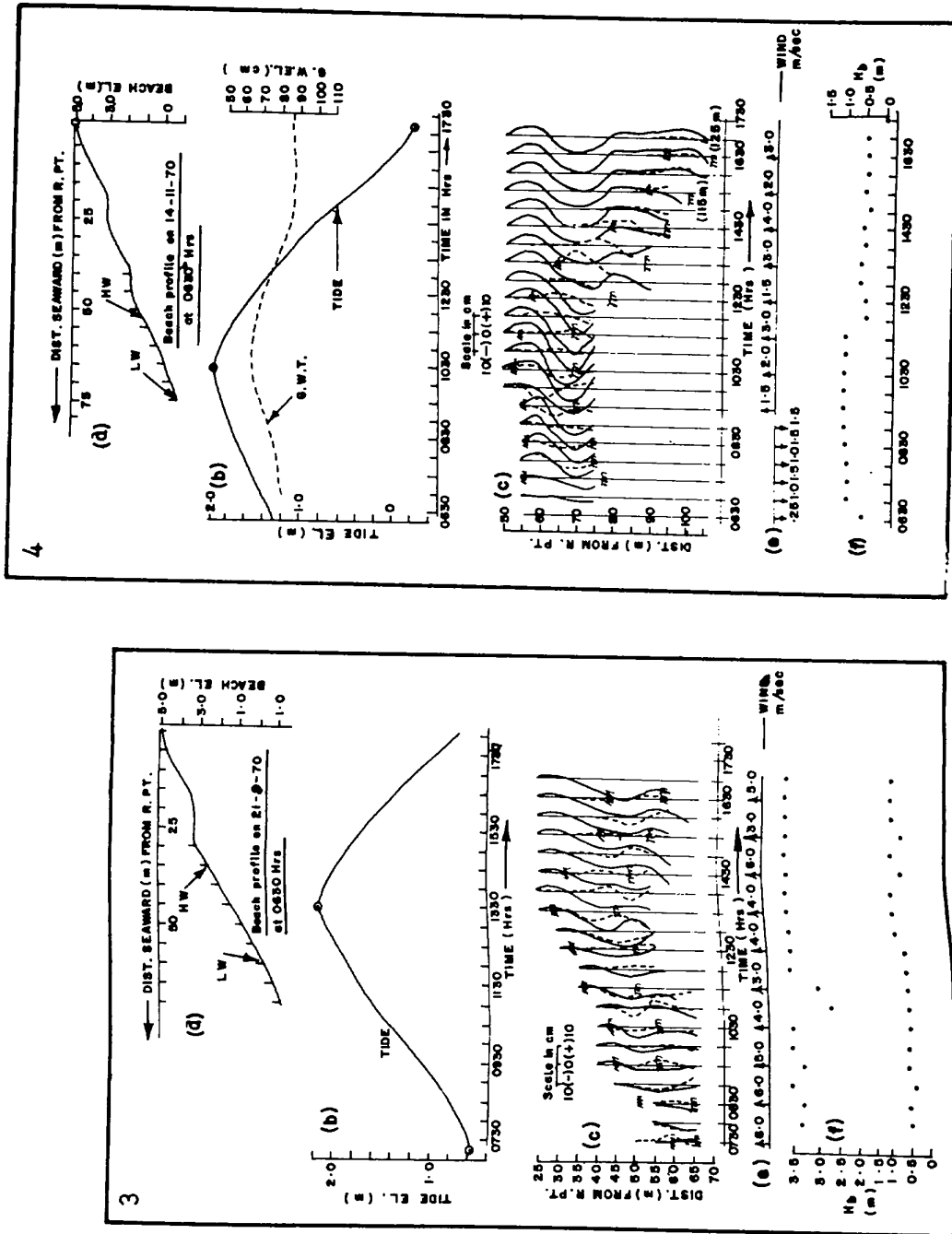
About 10 m of the beach (Fig. 6) was under the influence of waves and tides. The ground water table fluctuated about 10 cm and varied with the tide. The net change that occurred from the base profile by the end of the survey was of the order of -5 cm at 55 m point and a maximum cut of about 8 cm at 65 m point where breaking activity was confined. The net effect was loss of material from the beach face.

Survey CN₂ : During this survey, the breakers ranged from 0.25 to 1 m (Fig. 7). Both spilling and plunging breakers were observed. The littoral flows were directed towards the south up to 1400 hrs and later to north. The winds changed from offshore to onshore around this time. Associated with these features, the net change observed was deposition in the upper reaches and erosion at the lower reaches of the foreshore.

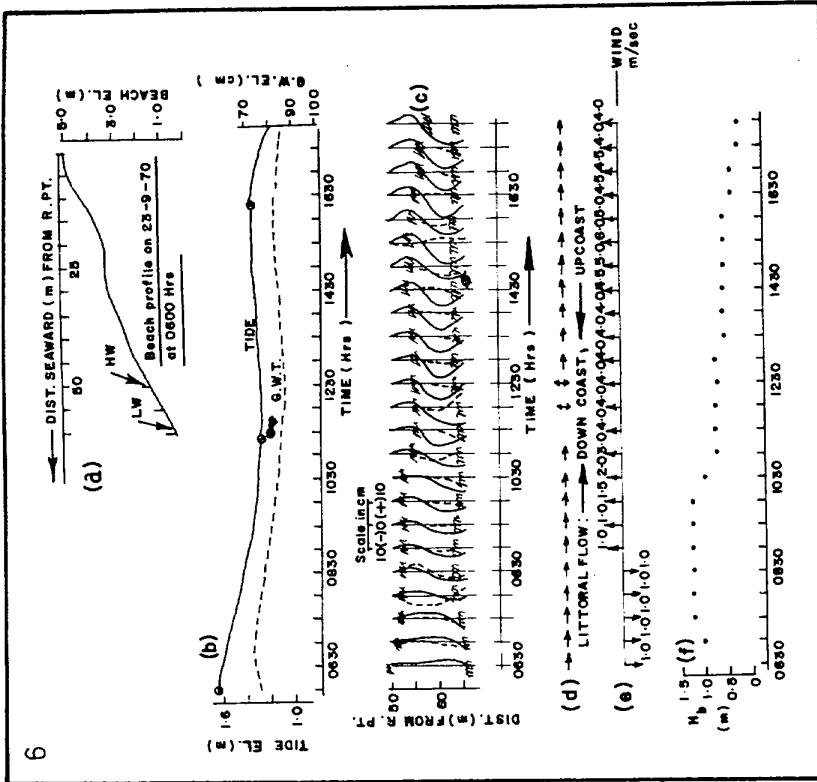
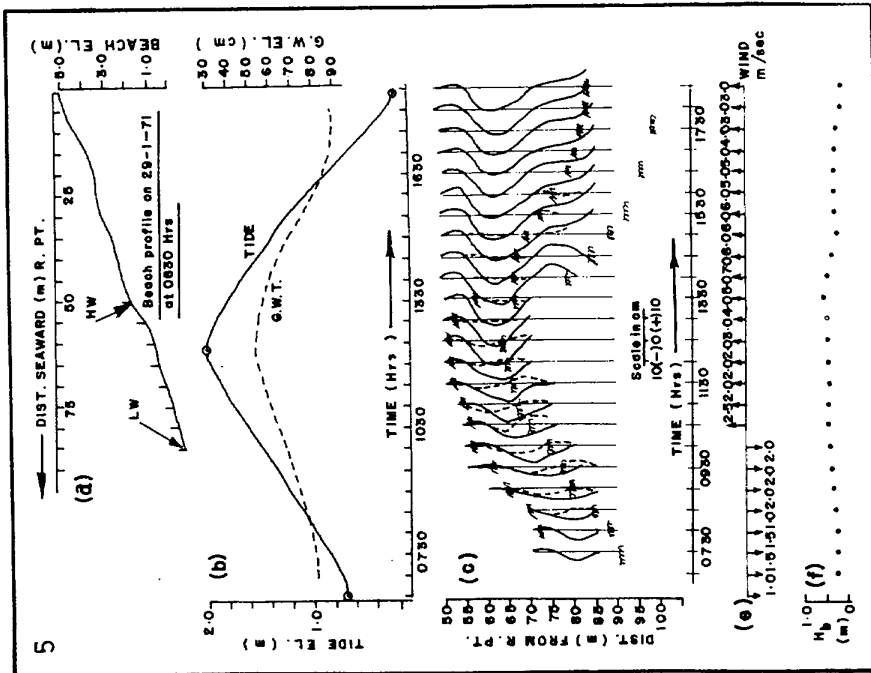
Profile variation in-relation to cusp formations - Survey CC₁ : Immediately after the survey CN₁, the development of a cusp was observed. This survey was immediately conducted to study the micro variations (Fig. 8) associated with the cusp formation. The range of the tide was 1.15 m. Long period swells with periods up to 16 sec approached from the west. Breaker heights varied from 0.5 to 1 m and showed an increasing

Table 1—Changes in Net Elevations (in cm) on the Beach at Various Points Along the Transect

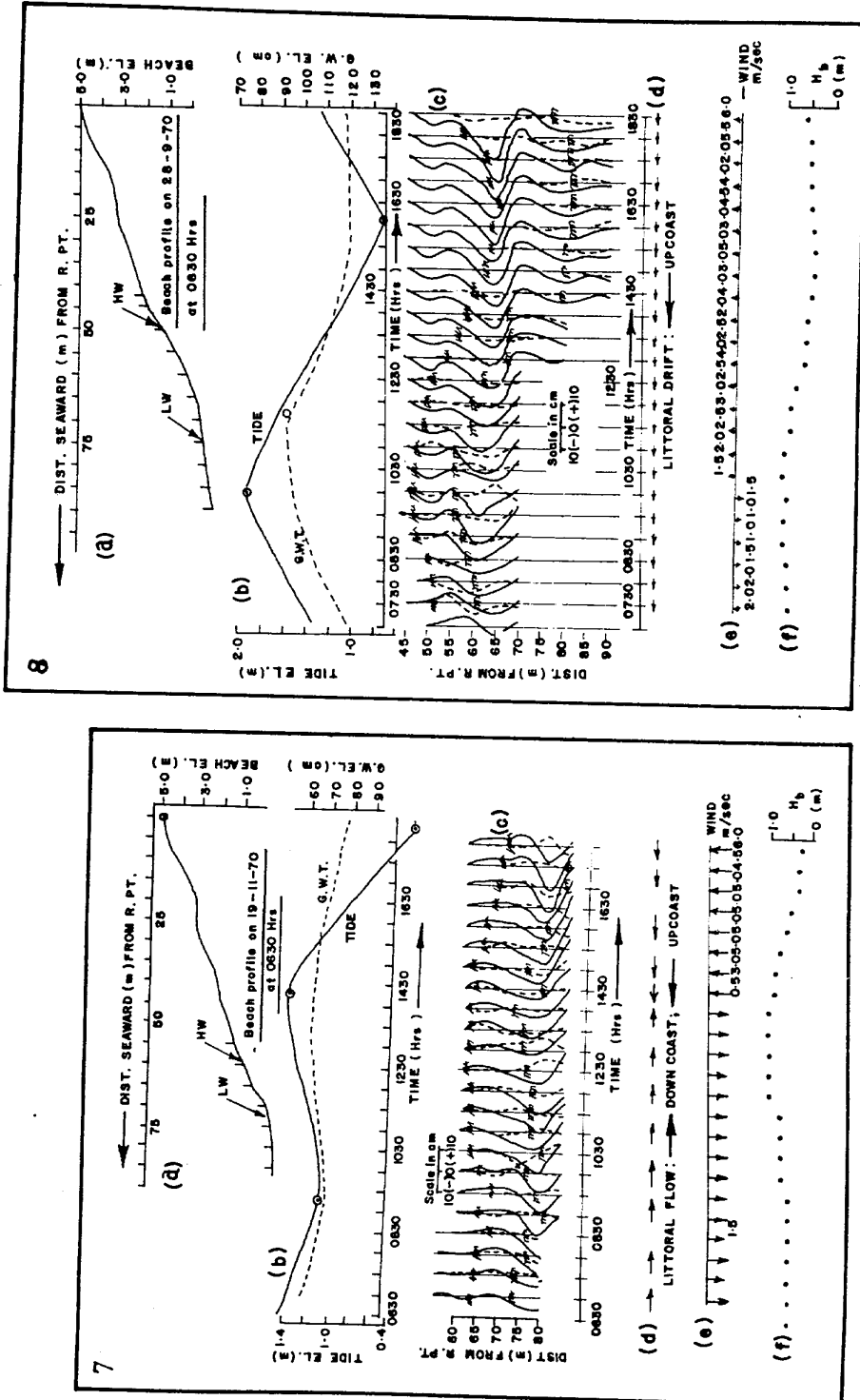
Time (hrs IST)	Distance from reference point (m)												
	25	30	35	40	45	50	55	60	65	70	75	80	85
HW (1230) from base													
LW (1800) from HW													
Net change (0630-1830)													
				3.8.70 (CS ₁)									
			+ 0.5	+ 5.5	+ 10.8	+ 12.5	+ 8.5						
			+ 3	- 1.5	- 11.5	- 15	- 2.5	- 10.3	- 10				
			+ 3.5	+ 4	- 1.5	- 2.5	+ 6	- 10.3	- 10				
HW (1400) from base				21.8.70 (CS ₂)									
at 1700 from base				- 8	- 7.3	- 7.3	- 8.8	- 12.5	- 8	- 6			
			+ 3	- 3	- 3.8	+ 3	+ 5.5	+ 4	+ 3				
HW (1100) from base				14.11.70 (CS ₃)									
at 1700 from HW													
net (from 0630 to 1700)							+ 5	+ 3	- 16.8	- 16.8	- 6.7		
							+ 0.5	+ 1.5	+ 10.3	+ 7.3	- 1		
							+ 5.5	+ 4.5	- 6.5	- 9.5	- 7.7		
HW (1230) from base				29.1.71 (CS ₄)									
LW (1800) from HW													
net (from 0700 to 1800)							+ 2.5	- 11	- 10	+ 1	+ 3.8	+ 4	+ 11
							- 0.5	+ 0.7	- 0.7	- 3	+ 3.8	+ 4	+ 11
							+ 2	- 10.3	- 10.7	- 2	+ 3.8	+ 4	+ 11
HW (1630) from LW				23.9.70 (CN ₁)									
LW (1100) from base													
net (from 0600 to 1800)							+ 2.5	- 3.8	- 0.5				
							+ 2	- 4.5	- 4.5				
							+ 4.5	- 8.3	- 8				
HW (1430) from LW				19.11.70 (CN ₂)									
LW (0930) from base													
net (from 0630 to 1830)													
							+ 2	- 3	- 5	+ 1	- 6	+ 6	+ 9
							+ 1	+ 2	- 12.8	+ 2.5	- 1	- 10	- 1
							+ 3	+ 2	- 21.8	+ 3	- 4.5	- 9	- 1
HW (1000) from base				28.9.70 (CC ₁)									
LW (1630) from HW													
net (from 0630 to 1830)							- 5.5	+ 0.8	- 10.8	- 5	+ 1		
							+ 0.5	- 2.3	+ 1.1	- 12.8	+ 2.5		
							- 5	- 1.5	- 12.5	- 21.8	+ 3		
from 0630 to HW				16.9.70 (MS ₁)									
from 1100 to 1630													
net (0630 to 1630)							- 6.5		- 3		+ 5		
							+ 3.5	+ 7	+ 6	+ 10.5	+ 7.5		
							- 15.5	- 5.5	+ 3	+ 10.5	+ 12.5		
							+ 7.5	+ 7	+ 3	+ 10.5	+ 12.5		
from 0630 to 0830				28.7.70 (MN ₁)									
from 0830 to 1330													
from 1330 to 1800							+ 1	- 1.5	- 2	+ 1	+ 4		
							+ 1.5	+ 3	+ 4.5	+ 2	+ 2.5	- 1	
							-	+ 2	- 1.5	- 1	- 6.5	+ 1	



Figs. 3 and 4— Micro variations over a tidal cycle (3) on 21.8:70 (CS₂) and (4) on 14.11:70 (CS₃) (details same as in Fig. 2)



Figs 5 and 6—Micro variations over a tidal cycle (5) on 29.1.71 (CS₄) and (6) on 23.9.70 (CN₁) (details same as in Fig. 2)



Figs 7 and 8—Micro variations over a tidal cycle (7) on 19.11.70 (CN₂) and (8) on 28.9.70 (CC₁) (details same as in Fig. 2)

tendency to be in phase with the tide. The wind speeds ranged from 1 to 2.5 m/sec till mid-day and later increased up to 6 m/sec. In the early morning hours, winds were offshore while during the rest of the time they were onshore. The littoral currents were directed to the south with offshore components. The breakers were mostly of spilling type. The ground water table varied with the tide with a lag of about 1.5 to 2 hr. The net changes from the base profile over a period of 12 hr are shown in Table 1.

The zone of variation of the ground water table was active between 45 and 50 m from the reference point while the low and high water marks were located at 75 and 50 m respectively.

Initially, the upper foreshore showed deposition which decreased later and the 0830 hrs profile showed erosion with its maximum located at 60 m point. All these curves up to that time showed a tendency for deposition beyond 70 m from the reference point. As the water level rises fast, a slight increase in the breaker heights was also seen. During the earlier stages, when the breaker heights were low, with the rising tide, the maximum erosion coincided with the zone of breakers.

In relation to the base profile, the curve for 0700 hrs shows the deposition from 50 to 60 m from the reference point and that for 0730 hrs has a similar pattern though the zone of deposition moves slightly landward. The 0800 hrs profile shows that most of the surficial deposit is removed while the entire profile for 0830 hrs shows erosion. A closer examination of this figure shows that the landward-most breakers which are located at 60 m from the reference point are probably responsible for this pattern. When the waves are about to break, the water suction and associated drag on the bottom causes removal of material from the landward side of the breaker. This process appears to be responsible for erosion noticed in the 0830 hrs profile. Around the time of slack high water, the landward-most breakers are located at 55 m from the reference point and multiple breaking within an interval of about 10 to 15 m prevails. The beach profiles at this time indicate considerable erosion. Due to the increased turbulence associated with the increase in breaker heights at the time of flood tide, the bottom material is churned up more and kept in suspension and is transported onshore, offshore and alongshore, by the advection-diffusion processes. At the landward most breaking point suction of water causes erosion in the upper reaches leading to a temporary deposition close to the breaking point on the seaward side. With the falling tide, the breaker zone is shifted further seaward (Fig. 8) and even though multiple breaking is observed, it is more or less ineffective. The slight deposition seen around 55 m between 0900 and 1000 hrs is eroded by suction process. By 1100 hrs the entire

profile shows a net erosion. Thereafter this zone is out of reach of the breakers and swash. The ground water table at 45 and 50 m from the reference point may have also contributed to erosion in the upper reaches. During the time of low water, the observations could be extended up to 90 m from the reference point and as seen from Fig. 8, the breakers are located at 80 m and a slow erosion is in evidence at this point. At 70 m, a gradual tendency for deposition can be seen. This material would have been brought from 80 m point.

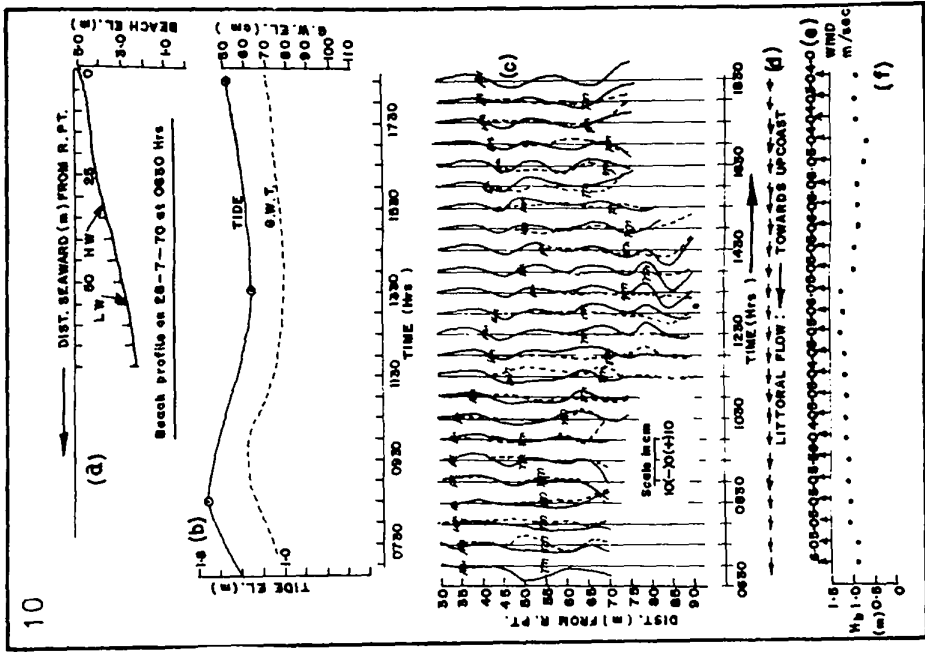
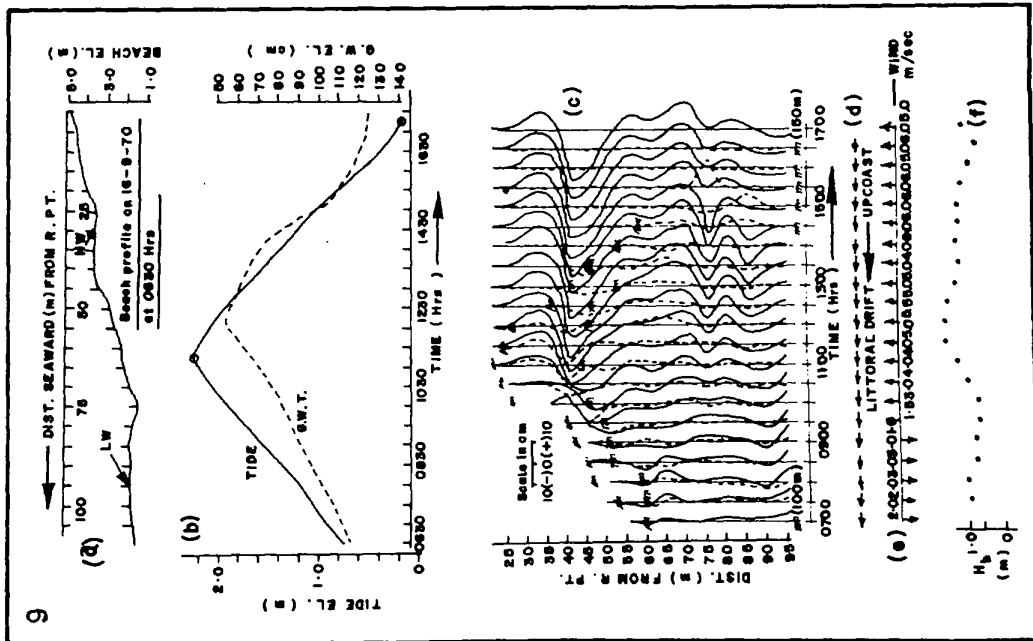
Miramar Region

Spring tide conditions—Survey MS₁ : This survey revealed the response of the beach under transitional environmental conditions. Weak land breeze prevailed up to 0900 hrs beyond which sea breeze with speeds up to 6 m/sec persisted till the end of the observations. Waves with periods varying from 9 to 15 sec and predominant periods around 12 sec approached mostly normal to the shore. The associated breakers, mostly of spilling type, with heights as much as 1.5 m were observed (Fig. 9). An increase in breaker heights with rise in temporal water level was also found. Direction of littoral flows was northerly. The ground water table fluctuated by about 60 cm and showed a time lag of 1.5 hrs at high water.

About 40 m width of the beach was subjected to wave activity during the course of the survey. Fig. 9 shows depositional features at the extreme landward reaches of the beach face during the rising phase of the tide. The quantity deposited during the rising phase remained undisturbed during the falling stage of the tide. At 40 m point, the vertical variation was maximum (25 cm cut, Table 1). Removal of material at the reaches close to the final break point and deposition on either side of it was recorded. The beach face presented migratory rippled topography after the high water stage.

Neap tide conditions—Survey MN₁ : The survey presents the nature of beach variations under neap tide conditions. The range of the tide was 40 cm. Winds were onshore all through the survey with maximum speed of 6 m/sec. Waves with periods 12, 14 and 15 sec approached from the west. Multiple breaking in 9 rows occurred with heights up to 1.25 m. The littoral flows indicated movement in a northerly direction. The ground water level fluctuations were about 15 cm.

The elevation changes (Fig. 10) showed alternate increase and decrease in deposition at the time of high water while the upper beach face experienced a thin deposit. The deposition/erosion feature shifted seaward during the falling tide. The points seaward of 60 m from the reference point presented depositional tendency. The maximum changes were 20 cm cut at 40 m point at high water and 9.5 cm deposition at 65 m



Figs 9 and 10 Micro variations over a tidal cycle (9) on 16.9.70 (MS₁) and (10) on 28.7.70 (MN₁) (details same as in Fig. 2)

point at low water (Table 1). The beach presented rippled topography all through the survey.

Discussion

Studies on beach topographic variations at Calangute¹² show that the beach attains minimum sediment storage during July/August, and in the neighbourhood of the present section, the mean rates of erosion are of the order of $1.7 \text{ m}^3/\text{day}/\text{unit}$ width of the beach up to the mean low water. The maximum rate of erosion, which occurs during the onset of monsoon can be much higher. Surveys CS₁ and CS₂ which refer to August, show only $0.4 \text{ m}^3/\text{day}/\text{unit}$ width of the beach. November and January surveys (CS₃ and CS₄) show deposition in the lower foreshore, as against erosion during the August surveys and this feature is clearly due to variations in the environmental parameters. From the middle of September, the monsoon withdraws from this region and after a period of transition, northeast monsoon conditions prevail. Associated with this, the low and long period swell waves approach the shoreline as tail ends up to about November. From November onwards the low and short period swell waves dominate. The local seas associated with the land and sea breezes during this period, though present, are not as strong as those during the southwest monsoon. The predominant swell directions are from WNW and NW. During the November survey (CS₃) the wave directions show considerable variation from WSW to NW, while during the January survey (CS₄), the wave approach is consistently from WNW (wave periods - 10 to 14 sec). On both the occasions, the breaker heights are low compared to those during August surveys. Associated with these low, long period swell waves, the beach shows a depositional tendency, the first signs of which can be seen in the lower foreshore.

The ground water table during the monsoon months cuts across the beach in the foreshore region. This may partly contribute to erosion during the monsoon as suggested by Emery and Foster¹. By November, the ground water table is found at much lower levels and its effects are not of much consequence in the erosion processes of the foreshore region.

The 2 surveys under the neap tide conditions, CN₁ and CN₂, reveal deposition on the upper and erosion on the lower foreshore. The stretch of beach under the influence of wave activity is very narrow and the breakers do not show much shift as in surveys CS₁ to CS₄. Thus, these 2 surveys reveal that the zone of maximum erosion is located close to the breaker zone. The various curves in Figs 6 and 7 show that 2 processes are at work. If the breaker is a plunger, just

before breaking, considerable drag on the bottom occurs on the landward side of the breaker and the bottom material shifts towards the breaker. The continuous activity of this type at the same location results in erosion slightly landward of the breakers. On the other hand if the breakers are of spilling type, the bottom material from the breaker zone is pushed up, thereby causing erosion at the breaker and deposition at the upper foreshore. The surveys CS₁ to CS₄ reveal a shift of the zones of erosion and deposition with the tide, which is clearly a result of shifts in the breaker zone. Thus, one may expect removal of material from the beach face from neap to spring tide, during the monsoon months associated with the higher wave activity. During the rest of the year, the entire beach face experiences a net deposition pattern under the general influence of low long period swell waves.

At Miramar, the changes observed during the spring and neap tide conditions are similar to those observed at Calangute. However, the order of magnitude of these changes is considerably low ($0.2 \text{ m}^3/\text{day}/\text{unit}$ width of the beach). This is due to the fact that the beach at Miramar is a sheltered one and as such it falls under low wave energy environment. A detailed study of the nature of the sediments in this area¹¹ shows that moderately well sorted and medium sands are present on the beach surface during this period¹² while at Calangute, coarse to medium sand class size material with considerably greater percentage of very coarse sands have been found¹⁰. These differences are partly due to the variations in the wave energy at these localities.

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