BEACH-SURF ZONE MORPHODYNAMICS ALONG A WAVE-DOMINATED COAST

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CERTIFICATE

This is to certify that this Thesis is an authentic record of research work carried out by Mr. K.V. Thomas under my supervision and guidance in the Centre for Earth Science Studies for Ph.D. Degree of the Cochin University of Science and Technology and no part of it has previously formed the basis for the award of any other degree in any University.

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CONTENTS

PREFACE

Beach is a very dynamic system which forms the boundary between the land and the sea. A high concentration of human activities due to its commercial and recreational potentials enhance the importance of this zone. Its is natural that efforts are being made in different parts of the world to understand the various processes that sustain this system. But the complexities of the forces acting on this zone make the investigations difficult. However, knowledge of the processes and their effects on beaches are steadily growing.

Beach erosion is one of the most spectacular landform changes by which a beach may disappear within a short duration of a few days. A clear understanding of the forces acting on this beach and its response are the basic requirements for a successful design of coastal protective structures. Many parts of the southwest coast of India are seriously affected by beach erosion. Construction of shore protective structures are highly expensive along this wave-dominated coast. Failures of these protective structures are a great loss to the State's exchequer. These failures are mainly due to the lack of accurate knowledge of the processes that lead to erosion. Physical and theoretical model studies of nearshore processes too are impeded due to inadequate information on these processes. The present investigation is an effort to fill these gaps in information by studying the various morphodynamic processes that are active along this coast.

Waves are the fundamental force operative on the beach. Hence the wave climate is studied in detail. The role of surf zone and shoreline rhythmic features in the processes of erosion-accretion along this coast is highlighted for the first time. Erosion in the embayments of giant cusps can create very serious problems. It is also highlighted that the formation of beach cusps is an important stage in berm building. Such information brought out from the present investigation will definitely be useful in selecting the design parameters for coastal protection measures. This will also help in developing a successful model for beach and nearshore processes.

The thesis comprises of seven chapters. The first chapter is an introduction to the present study. A detailed review of the studies on beach and nearshore processes is given in chapter two. Methods of data collection and analysis are described in chapter three. Chapter four discusses the wave climate based on diurnal, monthly and yearly variations in wave characteristics. Breaker characteristics and longshore currents are also discussed in this chapter. Beach and surf zone morphologies are detailed in the fifth chapter. Morphodynamic response of beach-surf zone system to changing wave energy is described in the sixth chapter. Six morphodynamic states in a beach erosion-accretion cycle are also identified and given in chapter six.

Parts of this thesis are included in the following published papers.

Thomas, K.V., 1988. Waves and nearshore processes in relation to beach development at Valiathura. In: Ocean Waves and Beach Processes (Ed: M.Baba and N.P.Kurian), Centre for Earth Science Studies, Trivandrum, pp.47-66.

Thomas, K.V., 1989. Wave-beach interaction. In: Ocean Wave Studies and Applications (Ed: M.Baba and T.S.S.Hameed), Centre for Earth Science Studies, Trivandrum, pp.81-91.

Thomas, K.V. and Baba, M., 1983. Wave climate off Valiathura, Trivandrum. Mahasagar - Bull. natn. Inst. Oceanogr., 16 (4), pp.415-421.

Thomas, K.V. and Baba, M., 1986. Berm development on a monsoon influenced microtidal beach. Sedimentology, 33, pp.537- 546.

Thomas, K.V., Baba, M. and Harish, C.M., 1986. Wave groupiness in long-travelled swell. J. Wat. Port Coastal and Ocean Engng., ASCE, 112, pp. 498-511.

A list of publications by the author in the related fields are given at the end as Appendix I.

LIST OF SYMBOLS

a_i	incident wave amplitude near the break point
d	water depth
g	acceleration due to gravity
H	wave height
H_b	breaker height
$\bar{H}$	mean wave height
H_s	significant wave height
h_c	depth of bar crest from MWL
h_t	depth of bar trough from MWL
k	instrument factor
L	wavelength
L_e	edge wave wavelength
Q_p	spectral peakedness
T	wave period
T_i	incident wave period
T_e	edge wave period
T_p	spectral peak period
$Tm_{o,1}$	period estimate from 0th and 1st moment
$Tm_{o,2}$	period estimate from 0th and 2nd moment
x_c	distance of the bar crest from shoreline
β	beach slope
γ	critical point of breaking
γ_{HH}	correlation co-efficient between successive wave heights
ϵ	surf scaling parameter
ϵ_w	spectral width parameter
ϵ_b	surf scaling parameter of beach face
ϵ_s	surf scaling parameter of inshore
ϵ_{bar}	surf scaling parameter of offshore side of bar
λ_c	cusp wavelength

CHAPTER I

INTRODUCTION

The southwest coast of India is thickly populated and economically vital due to its rich fisheries and mineral deposits. There are major plans to exploit the high tourism potential of this coast. Moreover this part is of great strategic importance to the country due to its proximity to the Indian Ocean. Many parts of this coast, however, are affected by severe erosion and coastal protective structures are being constructed at a staggering cost of rupees 70 to 80 lakhs per kilometre. In the light of the great importance of this coast and the high cost to protect it planners, engineers, scientists and social organisations have strongly pleaded for a comprehensive coastal zone management programme for this coast. Detailed understanding of the various coastal processes is essential for formulating such a management programme. In order to understand the coastal processes it is necessary to define the different terms used to explain it.

1.1 Beach, Nearshore Zone and Coast

The beach, which is most important among these terms, forms one of the most dynamic and complex systems of the coastal environment. The earth's three major constituents, i.e. the land, the ocean and the atmosphere meet at this unique interface. This is also a zone of dissipation of ocean energy.

The beach is defined as 'an accumulation of unconsolidated sediment extending shoreward from the mean low-tide line to some physiographic change such as a sea cliff or dune field, or to the point where permanent vegetation is established (US Army, 1984). But according to Komar (1976) this definition has a drawback that it does not include any portion that is permanently under water, where many of the important processes which are responsible for beach morphological changes occur. And hence it is appropriate to have a more inclusive definition, encompassing the underwater portion of the coastal environment. In the present study the latter definition (given below) of beach is preferred.

Figure 1.1 illustrates the cross section of the beach, otherwise called the profile and other related terminologies. The definitions of these terms are in close conformity with those given in Komar (1976). In this, the beach consists of a backshore, a foreshore and an inshore. Foreshore is the sloping portion of the beach profile lying between the upper limit of wave swash, i.e. wave uprush, at high tide and the low water mark of the wave backwash at low tide. Backshore is the zone of the beach profile extending landward from the foreshore to the point, where permanent vegetation is established. The part of the beach profile extending seaward from the foreshore to just beyond the breaker zone forms the inshore.

The nearshore zone (Fig.1.2) encompasses the swash zone, surf zone and breaker zone. Swash zone is the portion of foreshore which is alternately covered by the swash or uprush and exposed by the backwash. Breaker zone is the region in which the waves arriving from the offshore reach instability condition and break. Surf zone extends from the inner breakers to the swash zone. The boundary demarcating the breaker zone and the surf zone, in practice, is used more loosely than indicated above.

'Coast' is the region extending landward of the backshore which includes sea cliff, marine terraces, dune fields

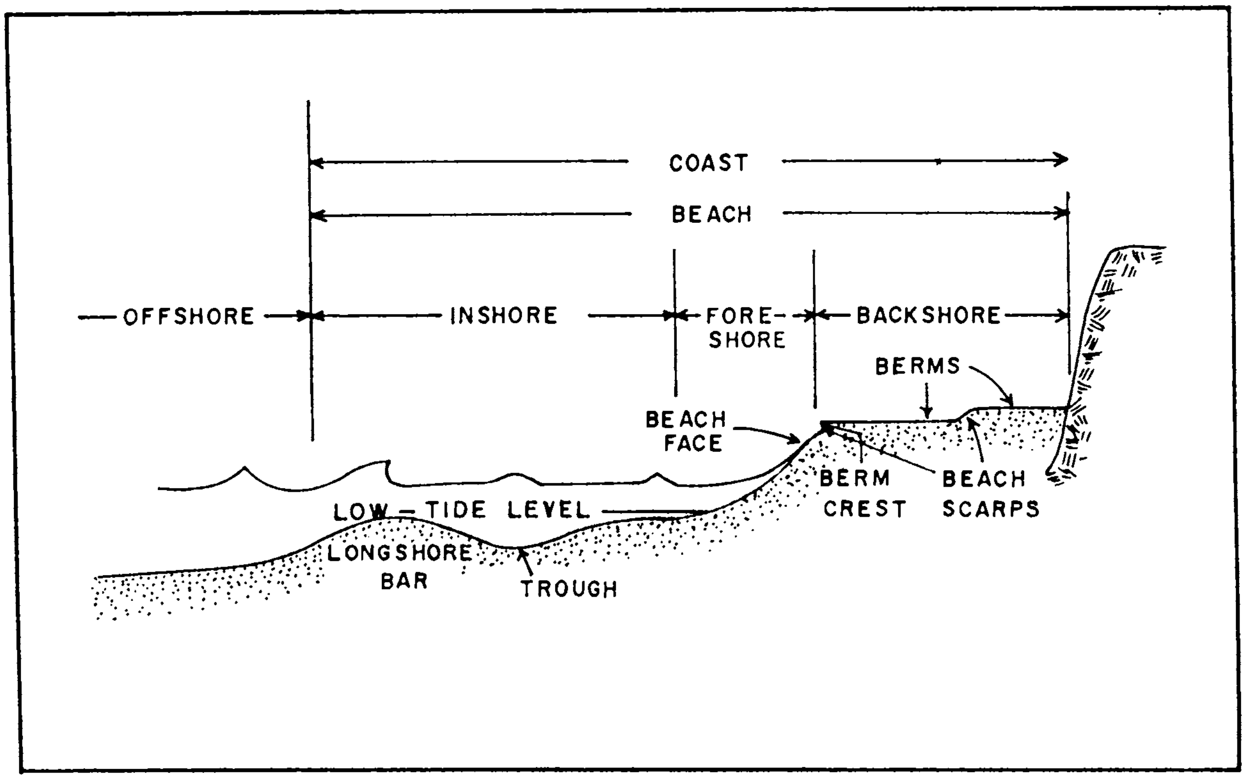

Fig.1.1 Definition sketch of beach profile and other related features.

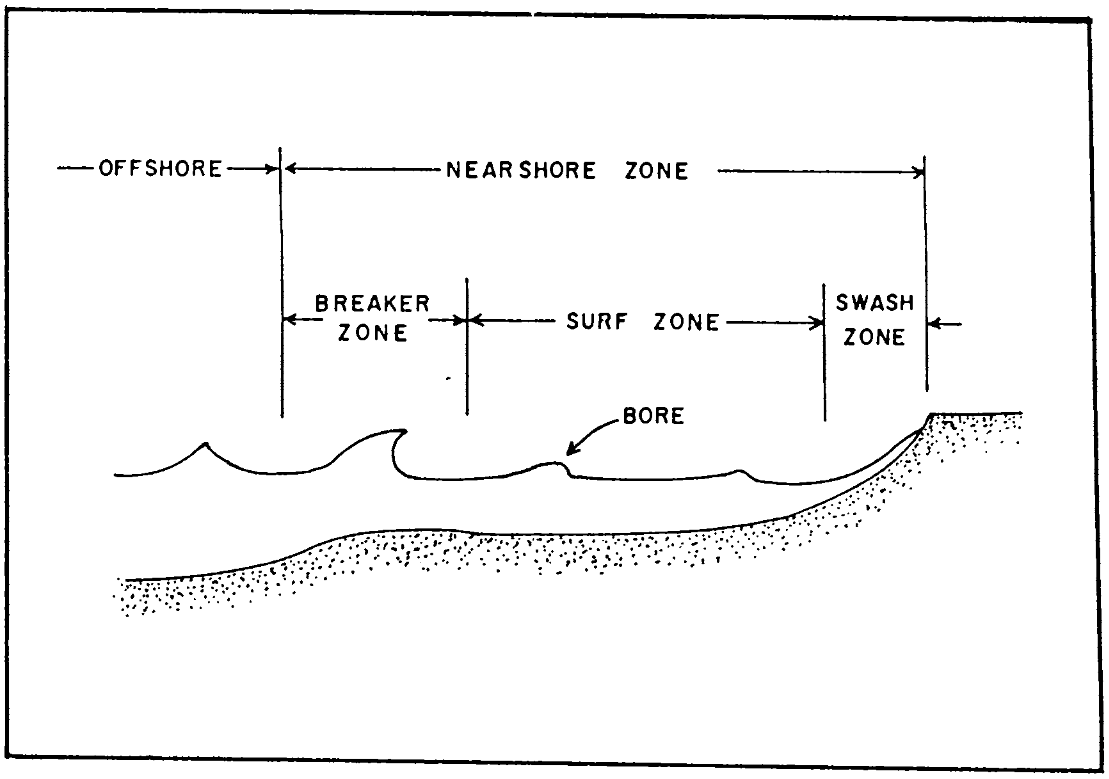

Fig.1.2 Definition sketch of nearshore zone and other related features.

and so on and its shoreward limit is very indefinite. In practice, this term coast is used more loosely sometimes including the beach and nearshore. Since various nearshore processes are, to a large extent, responsible for different coastal morphological features, the latter definition of the coast, which also includes the beach becomes more meaningful. Hence this definition of the coast is preferred in the present study. The other terms illustrated in Figs.1.1 and 1.2 are defined as follows:

Beach face: The sloping section of the beach profile below the berm which is normally exposed to the action of wave swash.

Beach scarp: An almost vertical escarpment notched into the beach profile by wave action.

Berm: A nearly horizontal portion of backshore formed by the deposition of sediment by wave action.

Berm crest: It is the seaward limit of the berm.

Longshore bar: A ridge of sand running roughly parallel to the shoreline.

Longshore trough: An elongated depression extending parallel to and between the shoreline and any longshore bars that are present.

Offshore: The comparatively flat portion of the beach profile extending seaward from beyond the breaker zone (inshore) to the edge of the continental shelf.

Shoreline: This is the line of demarcation between water and the exposed beach.

1.2 Wave/Tide - Dominated Coasts

The principal source of energy into the beach and nearshore zone that causes major beach morphological changes is waves. Tidal ranges determine the stretch of the beach that comes under wave attack in addition to the influence of tidal currents on beach processes. Since waves and tides are the two major physical processes acting on the coast, it is possible to identify different types of coasts on the basis of the relative importance of waves and tides. Davies (1964 & 1980) and Hayes (1975 & 1979) pioneered the classification of coasts as wave-dominated or tide-dominated. Davies (1964) considered three major categories of coasts: microtidal (< 2 m), mesotidal (2-4 m) and macrotidal (> 4 m). Hayes (1975, 1979) modified the Davies' classification (Fig.1.3). In this classification, the microtidal coast has a tidal range of less than 1 m and waves are the dominant physical processes here. The low-mesotidal coast has a tidal range of 1-2 m. It is a coast of mixed tidal and wave energy but with waves dominating. The high-mesotidal coast has tidal ranges of 2.0-3.5 m. This also is a mixed energy coast but tides are dominant. The low-macrotidal coast has tidal ranges of 3.5-5.0 m and macrotidal has ranges greater than 5 m. These coasts are characterised by pronounced influence of strong tidal currents.

This classification is based largely on coasts with low to moderate wave energy. Davis and Hayes (1984) found that these classifications are over-simplified and they cited numerous exceptions to these general rules. The relative effects of waves and tides are of extreme importance. It is possible to have wave-dominated coasts with virtually any tidal range and it is likewise possible to have tide-dominated coasts even with very small tidal ranges. Hence there

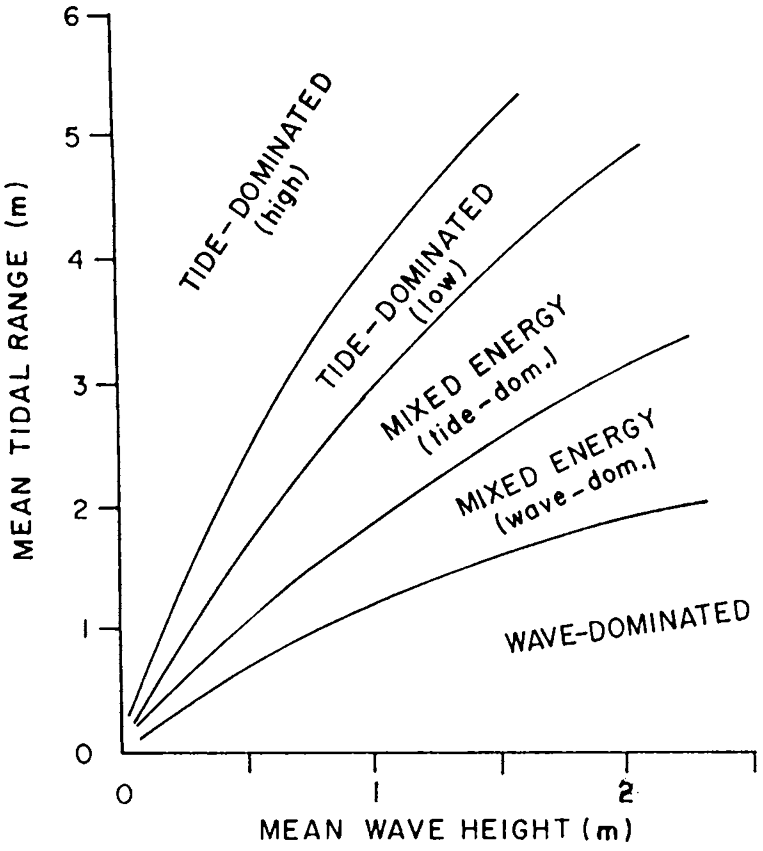

Fig.1.3 Definition of wave/tide-dominated coasts with respect to mean tidal range and mean wave height.

is no need to relate tidal ranges to coastal morphotypes. The most spectacular changes in beach morphology in response to the forcing parameters occur on wave-dominated sandy coasts (Short and Hesp, 1982). To determine whether a coast or beach is wave-dominated, the important relationship is that wave energy overwhelms tidal energy and in so doing, a characteristic morphology is produced. In a comprehensive review of wave-dominated coastal environments Heward (1981) also expresses a similar opinion that 'wave-dominated beaches are those where wave action causes significant sediment transport'. The morphology of a wave-dominated coast is characterised by elongate and shore-parallel sediment bodies.

Along certain coasts, wind energy can cause substantial changes in beach morphology. Again the relative importance of wind energy compared to wave or tidal energies in producing morphological changes is to be considered in determining whether the coast is wind-dominated.

1.3 Beach Erosion and Accretion

Beach sediments continuously respond to the ever changing environmental forces. A net loss of beach sediment results in erosion while a net gain causes beach accretion. Waves, tides, currents, winds and man are the major factors responsible for such modifications on a short time scale, while the slow sea level changes cause them on a longer time scale. Short-term, seasonal changes which occur in response to seasonal variations in the wave field like monsoonal wave climate are the most evident among these beach changes. Short-period storm waves cause spectacular beach erosion which may reach its peak within hours. Long-period waves (swell waves) cause beach accretion.

Waves undergo transformation as they travel from open ocean to the nearshore zone. As a result, waves steepen and orbital velocities increase. At some critical point near the shore waves become unstable and break. Turbulence within the breaker zone helps sediments to be in suspension. Wave-induced currents cause transport of beach sediments both alongshore and in the onshore-offshore direction. Longshore transport is parallel to the shoreline while onshore-offshore transport is normal to it.

Along a wave-dominated coast onshore-offshore sediment transport is more important and generally little net longshore drift is found here during an erosion-accretion sequence (Silvester, 1974). Onshore-offshore sediment transport alone can cause drastic changes in the beach configuration of such coasts (Vemulakonda, et al.,1985). Consequently the study of onshore-offshore transport becomes very important especially along wave-dominated sandy coasts.

Recent studies have shown that nearshore processes are more complex and dependent on more factors than earlier thought to be (Wright and Short, 1984, Wright, et al., 1987; Sallenger and Holman, 1987; Holman and Bowen, 1982; Bowen and Huntley, 1984). Simultaneous observations of the forcing factors and the resultant nearshore morphologies are required for a proper understanding of the different mechanisms in the nearshore zone that cause beach erosion-accretion. This requirement was not adequately met in most of the earlier studies in this field. There is a paucity of reliable field data, probably due to the difficulties in obtaining them from the nearshore environment. Thus taking up more and more field oriented investigations along the beach and nearshore zone becomes imperative to comprehend and tackle the problems of erosion-accretion.

1.4 Location of Study

The area selected for the present study is a beach at Valiathura along the Trivandrum coast (Fig.1.4). This forms part of an almost northwest-southeast trending, approximately 40 km long straight stretch of coast between the rocky headland at Kovalam in the south-east and the lateritic cliffs of Varkala in the north-west. The study site is flanked by two inlets, each approximately 7 km north-west and south-east. The offshore part has nearly straight, parallel contours and the shelf has an average width of 45 km. The inner shelf (<30 m contour) is relatively steep with a gradient of about 0.01 and the outer shelf is gentle with a gradient of about 0.002.

This is a microtidal beach with a maximum tidal range of about 1 m (Survey of India, 1980). The interference on beach processes by man-made structures is also minimum. A 220 m long pier is the only man-made structure on the beach. Seawalls have been constructed southeast of the study site. A frontal beach has been provided for these seawalls which reduces considerably the impact of seawalls on beach processes (Baba and Thomas, 1987). In addition to the microtidal range, the presence of straight, shore-parallel sediment bodies like berm crests and longshore bars along this coast (Baba et al.,1982) is also indicative of the dominance of waves in controlling nearshore processes of this coast. Thus this beach becomes an ideal site to study the beach and surf zone processes along a wave-dominated coast.

1.5 Objectives of the Present Study

Coastal protective designs have to take into account the actual information on beach and nearshore processes for them to be effective. Similarly the reasons behind the

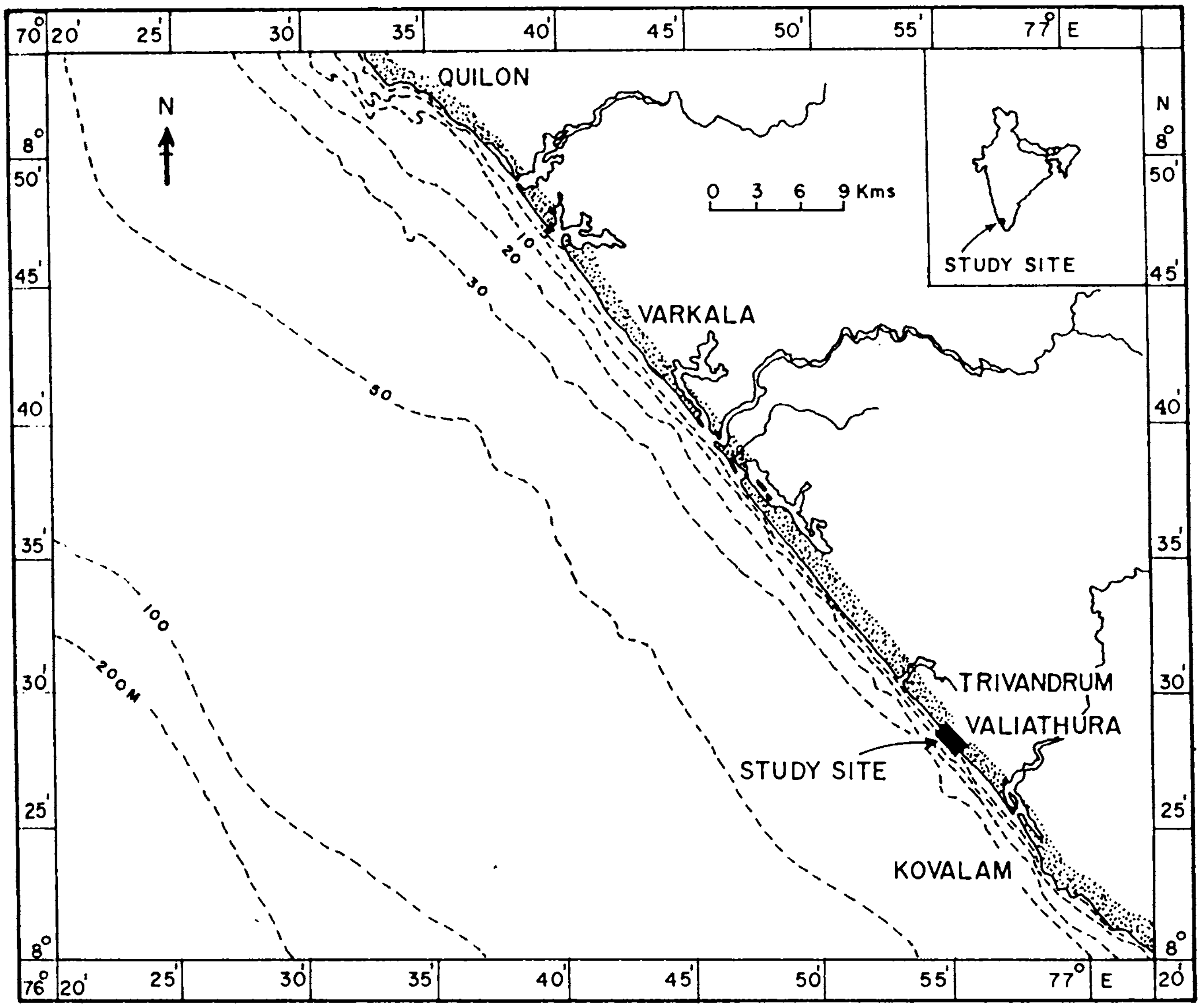

Fig.1.4 Location map of present study.

failure of the coastal protective structures in some parts of our coast haunts the coastal engineering community. The idea that a wide beach is a better coastal protective structure is gaining ground now-a-days (Baba and Thomas, 1987). Beach nourishment is also becoming an effective method of coastal protection. Implementation of such schemes are usually based on physical and numerical model studies. An understanding of the various coastal processes is essential in modelling this system.

Coastal wave climate can differ considerably both temporally and spatially (Thompson, 1977; Baba, et al., 1987). A similar variation may be noticed in many of the other coastal environmental parameters. Hence most coastal morphodynamic studies are usually site specific or time dependent (Short and Hesp, 1982). So each investigation in this field is important as it provides a link in the understanding of the network of interactions that control the coastal zone.

The different processes in the beach, which is inclusive of the nearshore zone, characterised by complex fluid motions and fluid-sediment interactions, are not fully understood. Field observations are usually hampered by a very hostile nearshore environment. Hence there is a lack of reliable field observations on the various nearshore processes. An attempt is made here to understand the changes in beach and surf zone morphology in response to the changing environmental conditions. This is based on simultaneous observations of the beach morphological features, surf zone processes and the waves.

CHAPTER 2

WAVES IN THE NEARSHORE AND BEACH PROCESSES - A REVIEW

2.1. Waves in the Nearshore

Wave is the major force controlling the morphodynamic features of the nearshore zone. Knowledge of wave climate is important for planning coastal operations, designing coastal structures, estimating coastal sediment transport, etc. Wave field varies with seasons. Since the coastal wave climate is influenced by bottom topography, coastal exposure to sea/ ocean and local currents, it can also differ considerably with locations. A detailed knowledge of the nearshore waves at the site thus becomes fundamental to the study of the response of beach and nearshore morphology to the changing wave climate.

Waves are generated due to the energy transferred to water surface by winds blowing over the oceans. Waves behave differently in different depth zones termed as deep water, intermediate water and shallow water. These depth zones are defined by the ratio d/L, where d is the water depth and L is the deep water wave length. A commonly accepted limit of the 'deep water' is a water depth greater than one-half the deep-water wave length, i.e. $d > L/2$. 'Intermediate water' is the region where $1/20 < d/L < 1/2$ and in 'shallow water' d/L is $< 1/20$. Some workers prefer to have $d/L > 1/4$ as the limit of deep water (Komar, 1976). As the waves enter shallow water from deep water they undergo various transformations due to the influence of the bottom starting from a depth approximately one-half the deep water wavelength and become significant at one-fourth the deep water wavelength. The processes that cause these transformations are shoaling, refraction, diffraction, reflection and breaking.

2.1.1 Shoaling

Wave shoaling causes a progressive decrease in group velocity and wave length and an increase in wave height as the waves travel through shallow water. The wave period is not affected. Initially there is a small decrease in wave height in intermediate water depths which is then followed by a rapid increase in wave height as the wave progresses further towards lesser depths. A corresponding variation in wave steepness, i.e. an initial drop in steepness below the deep water value followed by a rapid increase, is also observed. A point is reached, as the waves move further onshore, when they become over-steepened and unstable. Finally they break.

2.1.2 Refraction

As the waves propagate through shallow water, they are subject to refraction, a process that causes a change in the direction of wave travel in such a way that the crests tend to become parallel to the depth contours. Wave refraction can cause either a spreading out or a convergence of wave energy. Irregular bottom topography can cause waves to be refracted in a complex way to cause alongshore variations in wave height and energy (Komar, 1976). Refraction causes wave energy concentration on headlands, thus increasing the wave heights. The reverse is true in embayments. Energy concentration or dispersion along a coast can cause beach sediment transport (Reddy and Varadachari, 1972).

2.1.3 Breaking

Waves break near the shore at a depth approximately equal to the wave height. Breaking occurs when the particle velocity of the crest exceeds the phase velocity.

Four types of breakers have been identified by Galvin (1968) - spilling, plunging, collapsing and surging (Fig. 2.1). In spilling breakers the wave gradually peaks until the crest becomes unstable and spills down as 'white caps' (bubbles and foam). In plunging breakers the shoreward face of the waves becomes vertical. The wave then curls over and plunges as an intact mass of water. Surging breakers peak up and then surge up the beach face. Collapsing breakers come in between plunging and surging types. Here the breakers peak up as if to plunge and then collapse onto the beach face. In general, spilling breakers tend to occur on beaches of very low slope with steep waves. Plunging waves are associated with steeper beaches and waves of intermediate steepness. Collapsing and surging breakers occur on high-gradient beaches with waves of low steepness (Wiegel, 1964; Galvin, 1968).

A critical point of breaking was proposed theoretically by McCowan (1894) as $\gamma = (H/d) = 0.78$ where H is the wave height at depth d. This has been the most universally accepted value since the field confirmation by Sverdrup and Munk (1946) on ocean beaches with very low gradient. Some of the other theoretical values suggested for γ are 1.0 (Rayleigh, 1876), 1.03 (Packham, 1952), 0.73 (Liatone, 1959) and 0.83 (Lenau, 1966). In their laboratory experiments Ippen and Kulin (1955) got as high a value as 2.8 for γ when the bottom slope was 0.065. Their study has shown that the value of γ depend on the bottom slope and indicated that γ would not reduce to 0.78 until slopes become gentler than 0.007. The breaking criteria proposed by Ostendorf and Madson

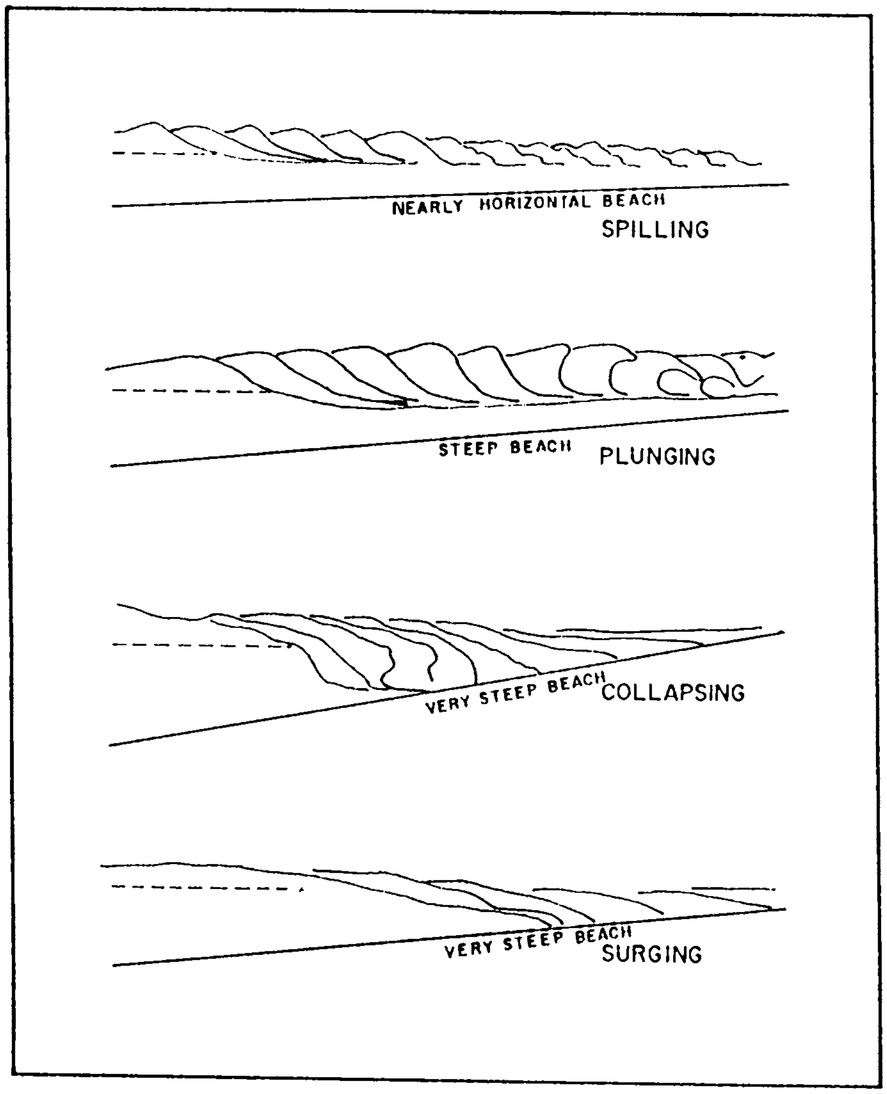

Fig.2.1 The four types of breaking waves on beaches.

(1979) and Sunamura (1983) take into account the effect of beach slope.

2.1.4 Diffraction

In the diffraction process wave energy is transferred laterally along the wave crest from where it is high to where it is low. It is most noticeable in the vicinity of breakwaters, headlands, etc.

2.1.5 Reflection

Part of the incident wave energy on beaches gets reflected and the amount of reflection depends on wave and beach characteristics. Guza and Bowen (1975) and Guza and Inman (1975) have defined a surf scaling parameter denoted by ϵ as a measure of beach reflectivity. It is given by

$$\epsilon = a_i \omega^2 / g \tan^2 \beta$$

where a_i is the incident wave amplitude near the break point, $\omega = 2\pi/T$ where T is the wave period, g is acceleration due to gravity and $\tan\beta$ is beach or inshore slope. These studies have also shown that breaker characteristics, run-up amplitude and the degree of inshore resonance are dependent on beach reflectivity.

2.1.6 Infragravity waves in the surf zone

The importance of infragravity waves in the frequency band of 0.05 to 0.005 Hz in modifying beach and nearshore processes has been well recognised (Holman, 1981; Holman and Bowen, 1984; Guza and Thornton, 1982). Infragravity energy is not limited by wave breaking but rather becomes increasingly important close to the shoreline as offshore wave energy increases (Suhayada, 1974; Wright et al.,1982; Holman and Sallenger, 1985). In contrast, the energy of incident waves in the frequency band of about 1 to 0.05 Hz is limited by breaking and decreases with depth independent of offshore wave energy (Thornton and Guza, 1983; Vincent, 1985; Sallenger and Holman, 1985). As a consequence, close to the shoreline, infragravity wave energy can dominate the energy of the incident waves (Sallenger and Holman, 1987).

Infragravity waves in the surf zone can be in the form of either edge waves or in the form of leaky waves (Sallenger and Holman, 1987). Edge waves are free surface gravity waves which propagate alongshore and their energy is trapped in the nearshore by refraction. Leaky waves are incident waves reflected at the shoreline forming a standing wave pattern with the reflected wave radiating energy to the offshore. The amplitude of edge waves decay exponentially offshore and vary sinusoidally alongshore close to the shoreline. Figure 2.2 shows the cross-shore behaviour of edge waves of modes n = 0,1,2,3 and leaky waves plotted in terms of a nondimensional offshore distance.

It is believed that edge waves are behind the formation of several types of beach morphological features and cell circulation patterns (eg. Wright et al., 1979; Wright and Short, 1984; Guza and Inman, 1975; Holman, 1981; Holman and Bowen, 1982). A progressive edge wave could form a linear, shore-parallel bar, whereas an edge wave standing in the longshore could form a crescentic bar (Bowen and Inman, 1971; Holman and Bowen, 1982). Similarly, a leaky wave could set up bars at nodes or antinodes of the standing wave motion (Carter et al., 1973; Bowen, 1980). The formation of beach cusps has also been attributed to the presence of edge

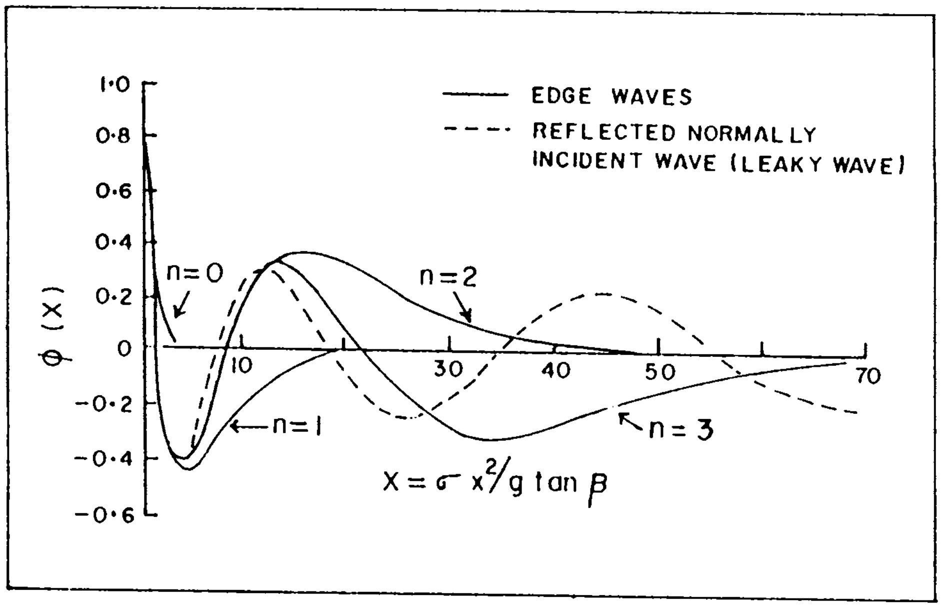

Fig.2.2 Cross-shore behaviour of edge waves (mode 0 to 3) and leaky waves plotted in terms of a non-dimensional offshore distance.

waves in the surf zone (eg. Sallenger, 1979; Inman and Guza, 1982; Seymour and Aubrey, 1985).

Both synchronous (edge wave period, T_e = incident wave period, T_i) and subharmonic ($T_e = 2T_i$) edge waves have been observed in laboratory and field experiments (Huntley and Bowen, 1975; Wright et al., 1979). The most commonly used edge wave solutions to the equations of motion are given by Eckart (1951) and Ursell (1952). They consist of a set of edge wave modes described by an integer modal number. The wavelength L_e , of an edge wave is given by (Ursell, 1952):

$$L_e = \frac{g}{2\pi} T_e^2 \, \mathrm{Sin}\,(2n+1)\beta$$

where g is the acceleration due to gravity, n is the modal number and β is the beach slope.

2.1.7 Sea and swell waves

The term 'sea' is used for waves which are in the process of generation. They are still under the influence of the wind. Sea waves are complex and confused and are characterised by many periods.

Once the waves leave the area of generation, they no longer receive energy from the wind. As they travel across the wide expanse of ocean, they sort themselves out by period and thereby become more regular. The crest becomes rounded and long. Such near-regular waves are known as swells.

2.1.7 Group of waves

Visual observations show that ocean surface waves commonly occur in packets or groups. The waves tend to be more regular (in terms of more or less equal wave heights and periods) within a group. It is now recognised that coastal and ocean structures may be more sensitive to such a succession of high waves than to a single large wave (Burcharth, 1979).

The role played by incident wave groups in generating short-term morphodynamic responses along beaches have been examined by Wright et al. (1985, 1987). The degree of groupiness may be expected to affect significantly the total amount of energy dissipated in the surf zone. There are also field evidences suggesting the possible influence on nearshore infragravity waves of the low frequency fluctuations associated with wave group trains (Sand, 1982; Symonds, et al., 1982; Wright et al., 1987). The studies by Shi and Larsen (1984) have revealed the effect of the groupy wave train on onshore/offshore exchange of sediment. They have suggested a possible seaward sediment-transporting mechanism by groupy wave trains.

2.1.8 Wave spectrum

Spectral analysis presents the energy density (energy per unit frequency) for each frequency or period. Wave spectrum is thus the best tool to identify the frequencies at which wave energy is distributed. The total energy in each individual wave train can be obtained by summing the energy densities under its peak. Various wave parameters like significant wave height, significant period, etc. can be computed from the spectral moments. Wave spectrum, in addition to providing information on the energy content at different frequencies, reveals the occurrence of sea, swell and other wave trains at a given location (Thompson, 1974).

The energy levels of primary incident waves and secondary waves like infragravity waves which have specific roles in beach and nearshore processes can be differentiated from the spectrum (Greenwood and Sherman, 1984).

2.2 Nearshore Currents

The nearshore currents, i.e. currents in the nearshore zone are important in effecting beach and nearshore sediment transport and are mainly wave induced. Broadly they can be categorised into two, namely, cell circulation and longshore currents. Very often a combination of these two systems are observed.

2.2.1 Cell circulation

The slow mass transport, the feeding longshore currents, and the rip currents taken together form a cell circulation system in the nearshore zone (Shepard and Inman, 1950). Cell circulation is shown schematically in Fig.2.3. Rip currents are strong and narrow currents that flow seaward from the surf zone. They disintegrate beyond the breaker zone. The cell circulation depends primarily on the existence of alongshore variations in breaker heights. This can be due to wave refraction or due to the interaction of incoming waves with edge waves (Bowen and Inman, 1969). The interaction or combination of the incoming and edge waves produces alternately high and low breakers along the shoreline and therefore gives rise to a regular pattern of circulation cells with evenly spaced rip currents. Irregular bottom topography with longshore bars cut by troughs can also maintain nearshore cell circulation system in the absence of longshore variations in breaker heights (Sonu, 1972).

2.2.2 Longshore currents

Longshore currents discussed here are those due to an oblique wave approach. They are different from the feeder currents associated with cell circulation. A number of theories have been proposed to describe the longshore currents formed when waves break at an angle to the shoreline (eg. Longuet-Higgins, 1970a,b; Komar, 1976; US Army, 1984; Basco, 1983; Chandramohan and Rao, 1984; Hameed et al., 1986). The model suggested by Putnam et al. (1949) based on radiation stress concepts, further modified by Komar (1976), is the most sound in describing the generation of these currents (Hameed et al., 1986).

2.3 Beach Sediment Transport

Beach changes occur only when a spatial difference in net sediment transport rate exists. These changes are generated by nearshore waves and the resultant currents. Sediment transport may be in the form of bed load or suspended load. Komar (1976) has opined that suspended load transport is much less than bed load transport, possibly less than 10% of the total. But Kraus and Dean (1987) found that the suspended load was dominant throughout the surf zone under 0.5-1.5 m breaking wave heights on a beach of average grain size. It is convenient to distinguish between two orthogonal modes of sediment transport - longshore and onshore-offshore transport - in the study of nearshore sediment movement. Longshore transport is defined as sediment transport parallel to the beach, while onshore-offshore transport is defined as the transport across the beach.

2.3.1 Longshore transport

Longshore currents are the main causative force for longshore transport. Severe consequences due to longshore transport are manifested only when the natural movement of sediment is obstructed through the construction of jetties, breakwaters, groins, etc. Generally there is a seasonal change in the direction of longshore transport depending on the seasonal pattern of the wave climate regime.

Models based on empirical considerations have been proposed to estimate the rate of longshore sediment transport by various authors (eg. Watts, 1953; Caldwell, 1956; Savage, 1959; Inman and Bagnold, 1963; Komar and Inman, 1970) which have produced satisfactory results (Komar, 1976). The most successful of these models relates the immersed-weight transport rate to the longshore component of the wave energy flux (Komar, 1976).

2.3.2 Onshore-offshore transport

Sediment transport normal to the shoreline, i.e. onshore-offshore transport, is the result of the internal flow field associated with wave motion. This cross-shore transport is responsible for most of the beach and surf zone morphological features along a wave dominated coast (Silvester, 1974). Usually onshore-offshore transport is of a smaller scale compared to longshore transport. However, although the gross longshore transport of sediment is very large at any point in the surf zone, the net transport causing a deficit or surplus of sediment on the beach is usually fairly small. On the other hand, though the gross onshore-offshore transport of sediment is small, the deficit or surplus can be equal to the gross over shorter periods of time (Galvin, 1983; Swain and Houston, 1984). For example, consider the case of a severe monsoonal storm wave attack causing an offshore movement of beach sediment to form a longshore bar. Although the total amount of sediment that moves to the bar may be small compared to the gross littoral transport, most of the sediment transported to the longshore bar should be due to sediment eroded from the beach and transported by offshore movement. With the recession of the storm, onshore transport brings most of the sediment back to the beach and the beach almost attains its pre-storm configuration. Thus the onshore-offshore transport is mostly seasonal and cyclic. But the amplitude of beach recession may vary depending on the various forcing parameters. Large scale variations in this amplitude may cause much embarrassment to planners. The southwest coast of India is such a region where monsoonal wave climate causes seasonal and cyclic beach erosion due to cross-shore transport (Murthy and Varadachari, 1980; Varma, et al.,1981; Baba et al.,1982)

2.4 Beach profiles

Onshore-offshore beach sediment transport is better demonstrated by beach profile changes. Beach profiles describe the cross-section of the beach. Broadly, beach profiles are characterised by two types, namely normal profile (berm profile or summer profile) and storm profile (bar profile or winter profile) (Fig.2.4). Normal profile is associated with a fully developed beach with a wide berm while storm profile is associated with an eroded beach usually with a longshore bar in the surf zone. Normally wave dominated beaches undergo a cyclic change from a normal profile to a storm profile and then back to the normal profile, responding to the changes in the wave climate. Corresponding to different stages in this cycle, Raman and Erattupuzha (1972) and Sunamura and Horikawa (1974) have

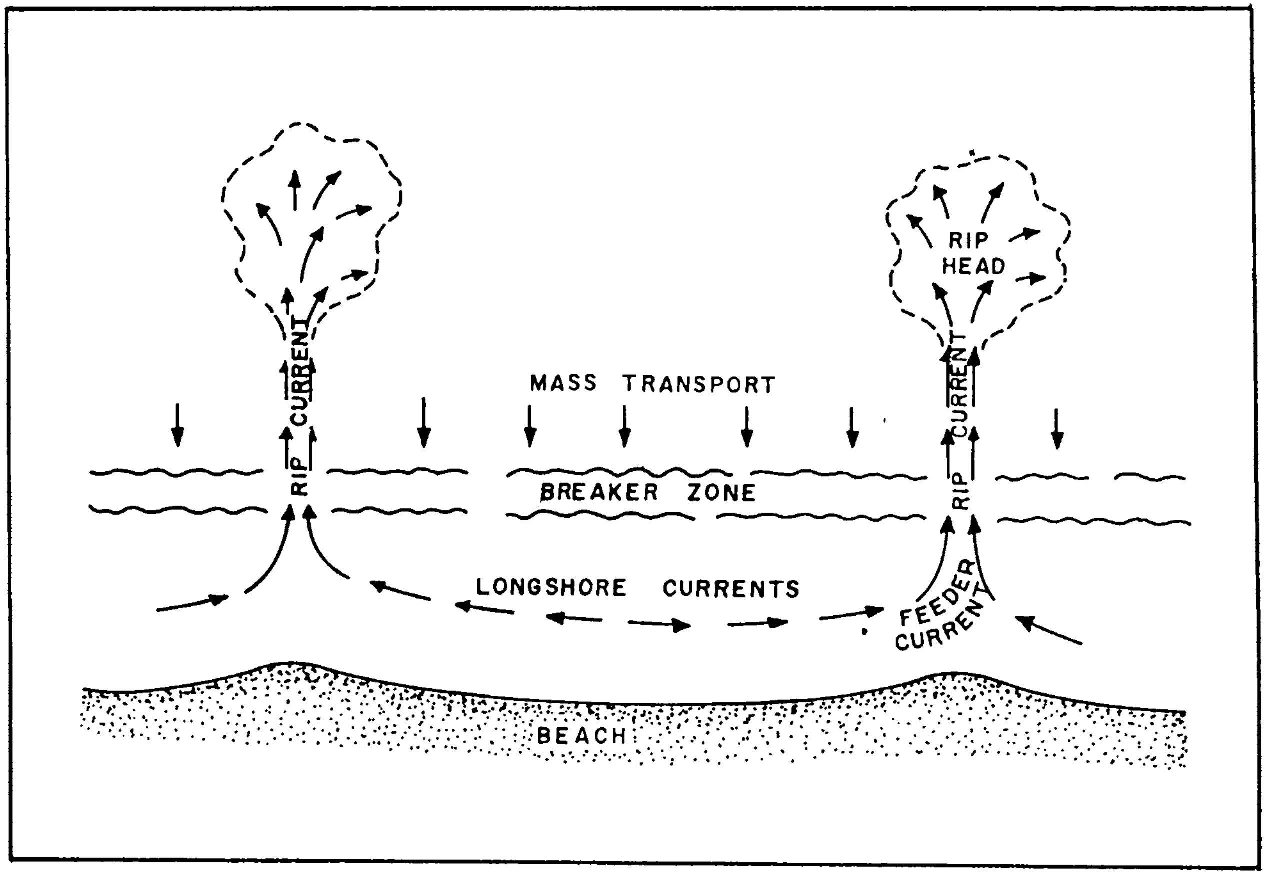

Fig.2.3 Cell circulation consisting of longshore currents, rip currents and mass transport.

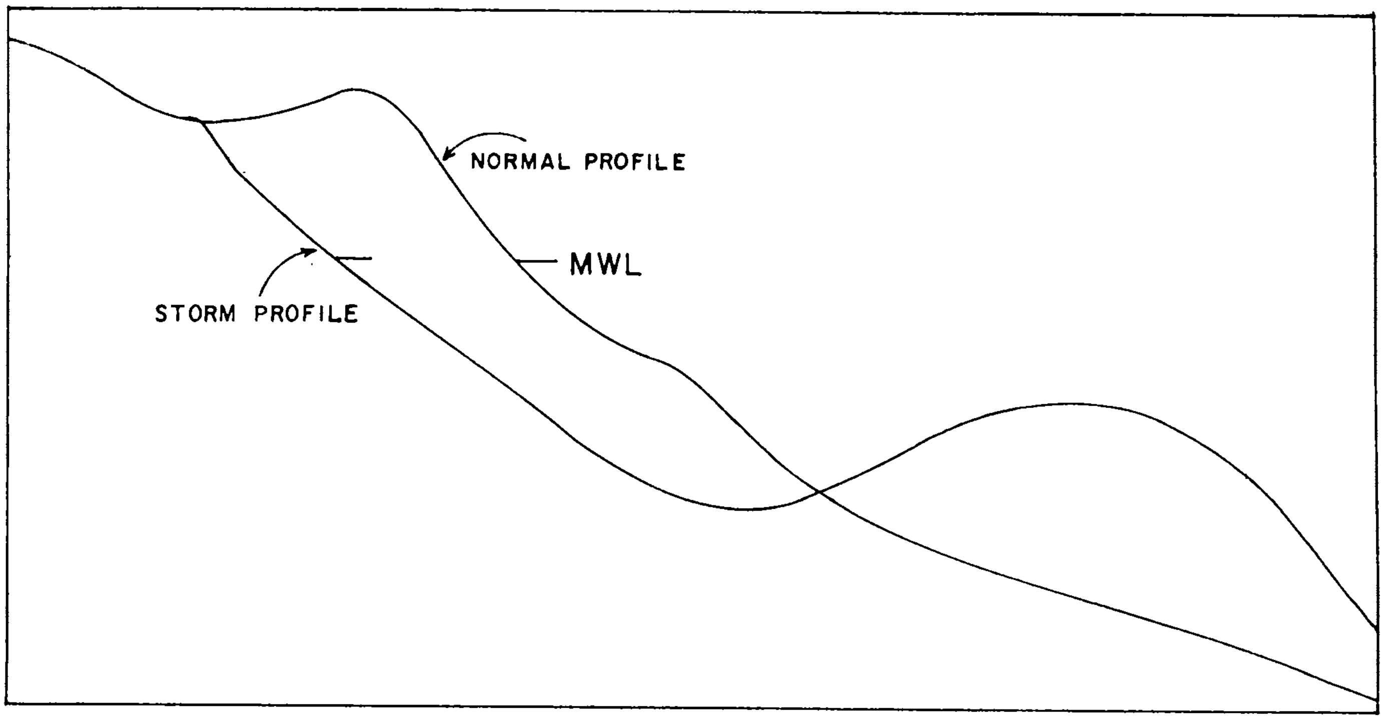

Fig.2.4 Storm and normal beach profiles.

described three types of beach profiles. They are (a) Type I - a shoreline retrogresses and sand accumulates in the offshore zone, (b) Type II - a shoreline advances and sand accumulates in offshore zone, (c) Type III - a shoreline progrades and no sand deposition takes place offshore.

An equilibrium profile is an important concept in the study of beach profile changes (Dean, 1990). This concept was introduced by Inman and Bagnold (1963). It is defined as 'the profile (depth as a function of distance offshore) which would eventually be attained when a nearshore area with a particular set of environmental characteristics (eg. sand size, slope etc.) is acted upon by a given set of environmental forces (eg. waves, currents and tides). The equilibrium concept implies that the profile has ceased to vary with time and the driving force is constant' (Aubrey et al., 1976). Sediment movement still occurs but the net transport is zero.

2.5 Modelling of Beach Processes

Since field measurements of beach profiles and simultaneous wave observations are difficult, most of the work towards modelling the nearshore environment has been done in the laboratory. Scaling natural ocean processes to a laboratory wave tank encounters with many difficulties. The complexity of the oceanic motions and fluid-sediment interactions makes it difficult to determine the most important parameters to be used in scale models (Noda, 1971). The studies carried out identified wave steepness (eg. Johnson, 1949; Watts, 1953; Scott, 1954; Saville, 1957; Kemp, 1960), absolute period (eg. Kemp, 1960; Sitarz, 1963), absolute height (eg. Sitarz, 1963; Shepard, 1950; Aubrey, 1978), sediment type (eg. Nayak, 1971; Swart, 1974), sediment fall velocity (Zwamborn and Van Wyk, 1969; Dean, 1973) and initial profile characteristics (Hattori and Kawamata, 1980; Sunamura and Horikawa, 1974; Iwagaki and Noda, 1962; Swart, 1974) as the major parameters that define the type of the profile.

A different means of studying beach profile variability using the method of eigenfunction representation was presented by Nordstrom and Inman (1975). Studies by Winant et al. (1975), Winant and Aubrey (1976), Aubrey (1978), etc. confirmed the usefulness of this method of empirical eigenfunctions in analysing beach profile data. The three eigenfunctions associated with the three largest eigenvalues, viz. the mean beach function, the bar-berm function and the terrace function, can describe over 99.75% of the variability in data (Aubrey et al., 1976).

Most of the above studies were qualitative and were successful only in giving the type of profile and to identify whether erosion or accretion takes place. A numerical model that can be used for reliable quantitative prediction is still at large.

A partially successful attempt on quantifying the offshore transport of sediments due to beach erosion was made by Swart (1974, 1976) based on empirical equations. By considering many small and full scale tests of profile development under wave attack, Swart was able to develop equations that determine the form and position of the equilibrium profile and the quantum of offshore sediment transport for different incident wave climates. This was further modified to include the effect of oblique wave approach on offshore transport. Swart's concepts were extended (Swain and Houston, 1983, 1984; Swain, 1984; Vemulakonda et al.,

1985) to allow the model to accommodate a variable datum (time-varying tide), a variable wave climate and onshore transport.

Although a substantial number of models have been proposed for qualitative and quantitative assessment of the beach, very little has been done to validate these models under realistic field conditions, primarily due to the lack of suitable data sets. Seymour and King (1982) tested eight different models and found that none of the models was capable of predicting more than a third of total beach volume variability. All these eight models and a few other models were again tested by Seymour (1986) against field data from Santa Barbara, Scripps beach and Virginia and found that the model of Swart (1976) offers some real promise for predicting the complete profile excursion. Baba, et al.(1988) has field tested a combined model, which takes into account the longshore drift (Komar, 1983b) and offshore drift (Swart, 1974) and found this model fairly successful in predicting short-term erosion and estimating the shoreline position along the southwest coast of India. Another model proposed and field tested on the U.S. west coast by Larson (1988) and Larson et al. (1990) satisfactorily describes the erosional phase of a storm event, though the recovery phase is not well described.

A successful model for the prediction of three dimensional beach changes is yet to be developed. A few conceptual models have been proposed by different researchers (Short, 1979; Wright and Short, 1983; Wright et al., 1979, 1986; Horikawa, 1988) and these try to explain the complexities involved in beach evolution. Conceptual models presented by Wright et al. (1979, 1986) and Wright and Short (1984) describe different types of beaches on the Australian coast as dissipative, reflective and four intermediate stages taking into account of beach reflectivity, wave energy dissipation, breaker type, the influence of beach and surf zone morphologies and infragravity waves. Synthesising the results from various studies Horikawa (1988) has suggested an eight-stage three dimensional conceptual model. In order to understand the three dimensional model there is a need for a clear definition of the various coastal morphological features.

2.6 Beach Morphological Features

The prominent beach morphological features are berm, beach face, longshore bar, beach cusp, rhythmic topography and giant cusps. Waves play a major role in their formation. Once they form, the nearshore wave climate is very much influenced by these morphological features. Thus the interaction of the incoming waves and the resultant nearshore processes with the nearshore morphology, i.e. beach morphodynamics, is the basis of many nearshore processes.

2.6.1 Berm

A study into the mechanism of berm development gives an insight into the mode of beach accretion and shoreline advancement (Hine, 1979; Baba et al., 1982). The berm of a beach is a depositional coastal morphological feature resulting from the onshore transport of sediments. It is defined as 'a nearly horizontal part of the beach on backshore formed by the deposition of material by wave action (US Army, 1984). It is also defined as a linear sand body that occurs parallel to the shore on the landward portion of the beach profile. It has a triangular cross-section with a horizontal to slightly landward dipping top surface (berm top) and a more steeply dipping seaward surface - beach face

(Coastal Research Group, 1969). Berm is associated with 'swell' profiles and develops during the transition from a storm profile to a swell profile (Bascom, 1954). The general profile of the berm in different environments has been studied by various researchers (King and Williams, 1949, Hayes, 1969, 1972; Hayes and Boothroyd, 1969; Davis et al., 1972; Davis and Fox, 1975; Owens and Forbel, 1977; Hine and Boothroyd, 1978; and Hine, 1979). Hine (1979) has identified three different mechanisms of berm development and resulting beach growth, viz. (1) neap berm development, (2) swash-bar welding and (3) berm ridge development, each found along distinct zones of a mesotidal barrier spit.

The presence of a berm is not always apparent on a fine-sand beach, while distinct berms with sharp berm crests are best developed on medium to coarse-sand beaches with moderate to high energy wave climate (Komar, 1976). Bagnold (1940) suggested that the berm elevation is directly proportional to the wave height and the proportionality constant is dependent on the grain size. He found that berm elevation is equal to bH where b is a proportionality constant and H is the wave height.

2.6.2 Beach face

Beach face (foreshore) is the sloping section of the beach profile which is normally exposed to the action of wave swash (Komar, 1976). The slope of the beach face is governed by the asymmetry of the intensity of swash and the resulting asymmetry of the onshore-offshore sand transport. Due to water percolation into the beach face and frictional drag on the swash, the return backwash tends to be weaker than the shoreward uprush. This moves sediment onshore until a slope is built up in which gravity supports the backwash and offshore sand transport. When the same amount of sediment is transported landward as is moved seaward, the beach face slope becomes constant and is in a state of dynamic equilibrium.

The slope of the beach face is governed mainly by the sediment properties and the nearshore wave climate. An increase in the slope is observed with an increase in grain size (Bascom, 1951; Wiegel, 1964; Dubois, 1972). For a given grain size, high energies (high wave heights) produce lower beach slope (King, 1972). Rector (1954) and Harrison (1969) also established an inverse relationship between the beach face slope and the wave steepness.

Wright et al. (1979) and Wright and Short (1984) found that the beach slope plays an important role in determining the reflectivity of the beach face. The degree of beach reflectivity is important in various nearshore processes like wave breaking, edge waves, etc.

2.6.3 Longshore bar

A bar is a submerged or subaerial embankment of sand, gravel or other unconsolidated material built on the seafloor in shallow water by waves and currents. It is called a longshore bar if it runs roughly parallel to the shoreline (US Army, 1984). When beach sediment is shifted offshore it generally gets deposited to form a longshore bar with a trough on its shoreward side. Breaking waves comprise the most important element in longshore bar formation, because the breakers control the offshore positions of bars, their sizes and depths of occurrence (Evans, 1940; Keulegan, 1948; King and Williams, 1949; Shepard, 1950). The larger the waves, the deeper the resulting longshore bars and troughs.

Plunging breakers are found to be more conducive to bar and trough development than spilling breakers (Shepard, 1950; Miller, 1976). Multiple bars may be observed where the nearshore slope is small. Bar formation has also been attributed to the presence of infragravity edge waves in the surf zone (Sallenger and Holman, 1987; Bowen and Inman, 1971; Holman and Bowen, 1982). A leaky wave could also set up bars at nodes or antinodes of the standing wave motion (Carter et al., 1973; Bowen, 1980; Lau and Travis, 1973). The onshore and offshore migration of these bars in response to the changing wave climate is important in the formation of various nearshore features.

In many wave dominated coastal environments, the nearshore is characterised by one or more bars. In some cases they remain as stable bathymetric configurations throughout the annual cycle of wave climate (Greenwood and Davidson-Arnott, 1975). In some other cases these bars are seasonal. A sand bar forms in the surf zone as a temporal sediment reservoir when storm waves transport beach material offshore causing beach erosion. Post-storm waves gradually move the sand bar onshore. The bar eventually welds onto the beach face (Hayes, 1972; Greenwood and Davidson-Arnott, 1975; Owens and Forbel, 1977; Fox and Davis, 1978; Hine, 1979).

The bar is very effective in dissipating wave energy in the nearshore zone (Keulegan, 1948). Wave energy is lost when waves cross nearshore bars. This 'breakwater' effect (Davis, 1978) is important over a wide range of coastal geomorphological studies since beach profile form is closely related to the energy dissipation mode (King, 1972; Komar, 1976). Field measurements by Carter and Balsille (1983) indicate that where bar-breaking occurs, between 78 and 99% of wave energy may be dissipated from individual waves. This is an important condition in designing coastal protective structures. The presence of bars can cause multipeakedness in wave spectrum (Thompson, 1980). Run-up spectra and associated sediment transport get modified in the presence of bar-broken waves (Swart, 1974; Sutherland et al., 1976).

2.6.4 Rhythmic Features

On many occasions beach and surf zone exhibit different crescentic formations (Fig.2.5), named as beach cusps, sand waves, shoreline rhythms, rhythmic topographies or giant cusps by different researchers (Bruun, 1955; Bakker, 1968; Hom-ma and Sonu, 1963; Zenkovich, 1967; Dolan, 1971). These features occur more commonly as a series of such forms with a fairly uniform spacing, the horizontal distance between them varying from less than 10 cm to 1500 m (Johnson, 1919; Evans, 1938; Dolan, 1971; Komar, 1973).

The rhythmic shoreline features are generally classified based on their spacing. Beach cusps are considered to have smaller spacing (Dolan and Ferm, 1968; Dolan et al., 1974) while sand waves, rhythmic topographies and giant cusps have larger spacing (Komar, 1976). A classification based on their associated offshore morphology is more logical according to Komar (1976). He prefers to group the rhythmic shoreline features into two, i.e. beach cusps and rhythmic topography. Beach cusps commonly exist as simple ridges or mounds of sediment stretching down the beach face (Fig.2.5a). In contrast, rhythmic topography consists of a series of crescentic bars, or a regular pattern of longshore bars separated by rip currents or a combination of the two (Fig.2.5b,c,d). Giant cusps are also included in rhythmic topography. Beach cusps are primarily a subaerial feature, while offshore morphology within the surf zone and sometimes even beyond the breaker zone is of greater importance in

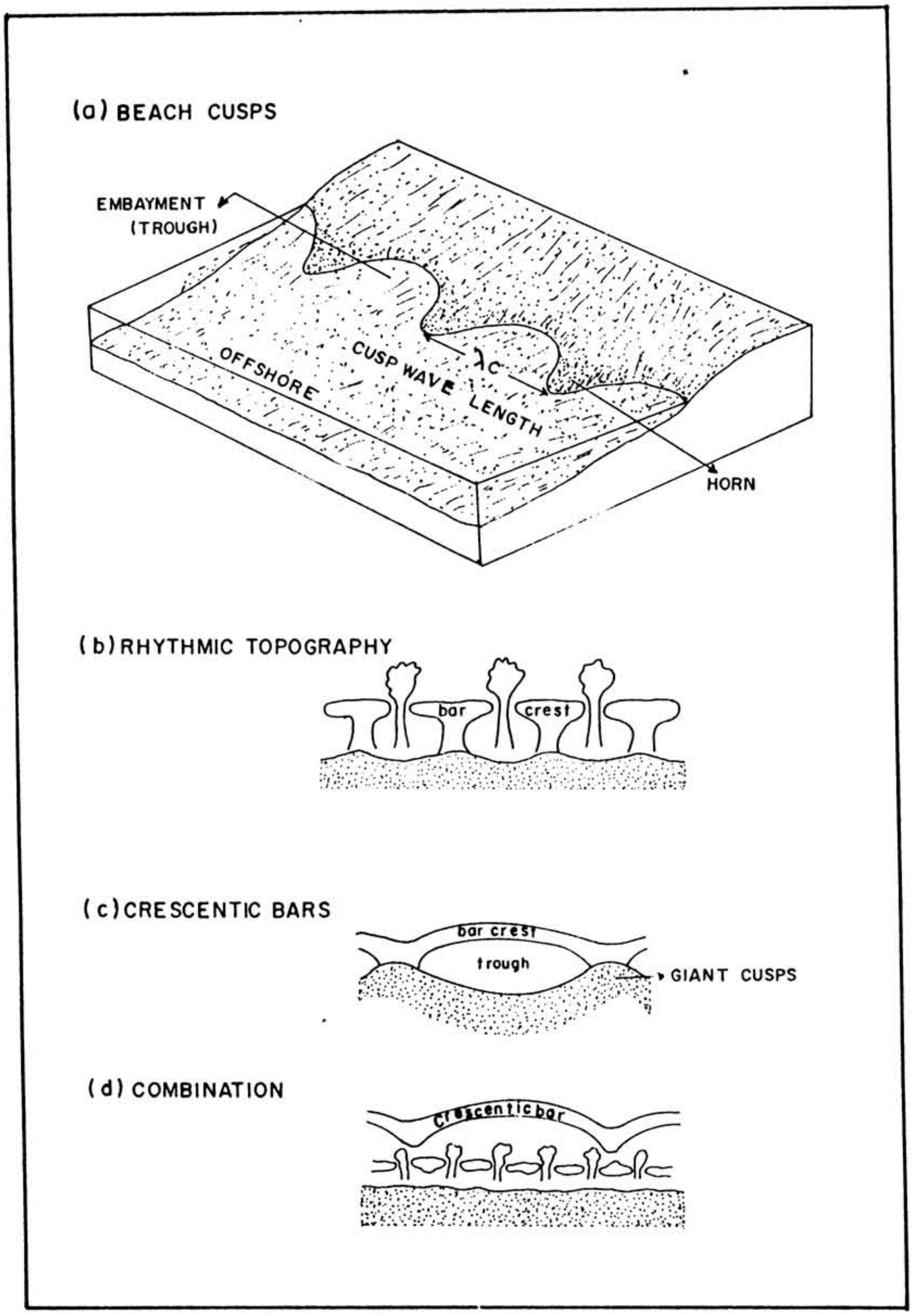

Fig.2.5 Various types of coastal rhythmic formations.

rhythmic topography. In general, the spacings of cusps associated with rhythmic topography is larger than the spacings of beach cusps. The nomenclature suggested by Komar (1976) is followed in the present study.

2.6.4.1 Beach cusps: Beach cusps are associated with the onshore-offshore movement of beach sediments. Cuspated forms have been attributed to accretional processes by Branner (1900), Kuenen (1948), Hayes and Boothroyd (1969), Komar (1971), Sanders et al. (1976) and Guza and Bowen (1981). According to Johnson (1910), Rivas (1957) and Smith and Dolan (1960), erosional processes are responsible for the formation of cusps. Otvos (1964), Gorycki (1973) and Guza and Inman (1975) found that cusps can form during accretional or erosional processes. The study of beach cusps thus becomes important in understanding beach and nearshore processes.

Beach cusps can form in any type of beach sediment (Russel and McIntyre, 1965). Beach cusp formation is most favourable when waves approach normal to the beach (Longuet-Higgins and Parkin, 1962). But Otvos (1964) maintains that wave direction is irrelevant. Several theories have been proposed for the origin of cusps (eg. Johnson, 1919; Kuenen, 1948; Russel and McIntyre, 1965). These, however, are not capable of explaining the formation of cusps and its uniform spacing satisfactorily (Komar, 1976).

Some of the recent studies suggest cusps to be the response of beaches to trapped waves like edge waves (eg. Bowen and Inman, 1969; Sallenger, 1979; Inman and Guza, 1982; Seymour and Aubrey, 1985). The interaction between swash (due to incoming waves) and edge waves produces a systematic variation in run-up heights and this helps the formation of beach cusps at regular intervals. Guza and Inman (1975) has suggested that the longshore spacings of beach cusps are of the same scale of the wavelengths of subharmonic or synchronous edge waves.

2.6.4.2 Rhythmic topography: Rhythmic topography consists of a series of crescentic bars, or a regular pattern of longshore bars separated by rip current troughs, or a combination of the two (Komar, 1976). These features are explained in Fig. 2.5b. A major portion of the rhythmic topographies are under water. Associated large-scale cuspated feature may be present along the shoreline.

Instances of the slow migration of rhythmic topographies in the longshore direction have been reported by Egorove, (1951), Bruun (1955) and Dolan (1971). The importance of migrating rhythmic topography on local beach erosion has been pointed out by Dolan (1971). He also showed that intense erosion may occur at the embayments of rhythmic topographies. He has also attributed the failure of coastal protective structures in that area to a lack of consideration of the changes in profile due to longshore movements of rhythmic topography.

Bowen and Inman (1971) have suggested that the velocity fields associated with edge waves may be behind the formation of rhythmic topographies. The alongshore length scales of rhythmic topographies were coinciding with one-half the wavelength of edge wave modes of $n = 1$ or 2. Further studies by Huntley and Bowen (1973) have supported this.

2.7 Earlier Studies of Waves and Beach Processes at Trivandrum

Some information on wave characteristics of this coast is available from studies of Swamy et al. (1979), Baba et al. (1983, 1987), Joseph et al., (1984), Baba and Harish (1985,1986), Harish and Baba (1986), Baba (1987) and Kurian (1988). Kurian (1988) have studied the transformation of deep water waves to shallow water using refraction models and found that deep water waves are least affected in the southern region of the southwest coast as they propagate to the shallow water. Baba and Harish (1986) provide some information on wave spectrum along this coast. They found that the main peak is at the higher frequencies during the monsoon and there is a shift to the lower frequencies during the rest of the year. Baba and Harish (1986), Baba et al. (1983, 1987) and Baba (1987) found that the wave energy at Trivandrum is always high compared to other stations along the Kerala coast. None of these studies document breaker characteristics in detail except Baba et al., (1982) where breaker characteristics are given for a limited period. Features like wave groupiness and infragravity waves in the surf zone have not received the required attention in the earlier studies. Some information on wave groupiness along the southwest coast is available in Namboothiri (1985) for Vizhinjam and Dattatri (1983) for Mangalore.

Kerala Public Works Department (PWD) has been carrying out observations on beach processes and nearshore waves for the past few years as part of the coastal erosion studies along the Kerala coast (PWD, 1986). The frequency of these observations is once every month at a spatial interval of 1 km, covering the entire Kerala coast. Beach profiling and visual estimates of wave height and period constituted the main part of these observations. Observations at such a large temporal and spatial interval can give only a gross nature of beach erosion-accretion processes. More specific and detailed studies along this coast were conducted by National Institute of Oceanography (1977), Murthy (1977), Murthy and Varadachari (1980), Varma et al. (1981), Baba et al. (1982) and Machado (1985). These studies have attributed beach erosion-accretion mainly to the prevailing wave climate and wave-induced longshore transport. Significant onshore-offshore transport has also been noticed in some of these studies. Murthy and Varadachari (1980) believed that backwash and circulation cells in the surf zone (rip currents) are also contributing significantly towards beach erosion during southwest monsoon. The influence of beach and surf zone morphological features on beach characteristics has not been adequately understood in any of the above studies.

2.8 Summary

The processes that influence beach and surf zone system are complex and interrelated. The mechanism of onshore-offshore transport is less understood than that of longshore transport. On wave-dominated coasts, onshore-offshore transport alone can contribute to substantial changes in beach morphology. The role of surf zone morphologies, surf zone infragravity waves and wave groups, in effecting beach erosion-accretion has received the attention of researchers recently. However, these have to be investigated under different environmental conditions. The various studies that were conducted along the southwest coast of India could give only a gross picture of the processes that take place in the beach-surf zone system. This was mainly due to the large temporal and spatial intervals of observations. Most of the previous studies also lacked simultaneous observations of the different beach processes and the driving mechanisms.

2.9 Present Study

For a proper understanding of the processes controlling beach evolution and also for their modelling there is a need for a detailed field investigation. An attempt is made in this study to address the beach erosion/accretion problem in a different perspective by including the following aspects:

(i) A detailed study of beach and surf zone characteristics at a smaller spatial and temporal interval is undertaken. Nearshore wave records are obtained simultaneously with the observations on surf zone and beach processes. Breaker characteristics are also studied in detail.

(ii) An attempt is made to identify the dominant mode of sediment transport. Beach and surf zone morphologies which influence the beach erosion-accretion processes along this coast are also examined.

(iii) The effects of surf zone infragravity waves in modifying the beach and surf zone processes are looked into.

(iv) Finally an attempt is made to develop a conceptual model describing different stages of beach erosion-accretion processes.

CHAPTER 3

METHODS OF DATA COLLECTION AND ANALYSIS

Field observations are carried out using the facilities available in the coastal laboratory of the Centre for Earth Science Studies at Valiathura. Nearshore wave characteristics, breaker characteristics, beach profiles, three dimensional-beach morphological features and littoral currents are measured in the field.

3.1 Area of Study

A one kilometre stretch of the beach at Valiathura is selected for field observations (Fig.3.1). The facility of a pier of 220 m length is available in the study area. Six stations are selected for regular observations along this one kilometre stretch.

3.2 Nearshore Waves

A pressure-type wave and tide telemetering system (Baba and Kurian, 1988) is used for recording shallow water waves. The transducer is kept 3 m below water level at the end of the pier. It is mounted about 2 m away from the pier pile facing the sea to minimise the effect of the pier on the wave data. The signals are transmitted to a paper chart recorder through a two-core cable. The mean depth at the site of installation is 5.5 m. The depth varies between 5 and 6 m depending on the changes in bottom topography and tide level. The frequency response of the system is greater than 95% for wave periods greater than 3 s. It is nearly 100% for periods above 5 s (Baba and Kurian, 1988). Three to five wave records are taken at three hour intervals for 30

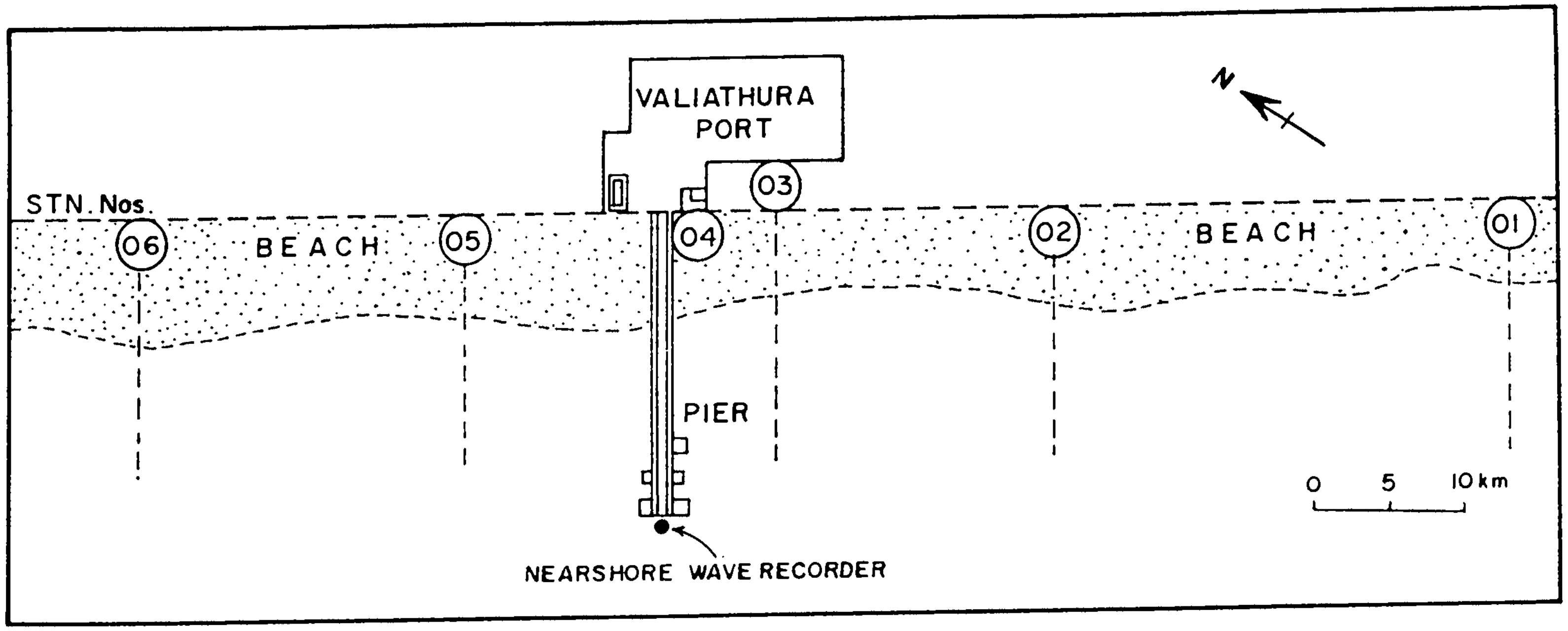

Fig.3.1 Station locations.

min between 0600 and 1800 hrs.

The swell wave direction at the recording point is taken every day using a Brunton compass. When the sea waves dominate their direction is also noted.

3.3 Breaker Observations

Breaker observations are made every day from the pier. For this, a calibrated lead line is used. The height between ten consecutive significant breaker crests and troughs are taken and the average is reported as the significant breaker height (hereafter used as breaker height). While measuring the breaker heights precautions are taken to minimise probable errors. The main sources of error are: (1) slanting of the lead line due to displacement of lead at the wave crest from the vertical and (2) calibration and measurement inaccuracies of the line. The first is minimised by fast operations. The lead line is tagged at 10 cm interval and the calibration is checked periodically to overcome the latter. Further fractions are noted using a measuring scale with an accuracy of 1 cm. The average period of 10 consecutive significant breakers is noted as the breaker period. When there is a disruption in the wave recording due to malfunctioning of the installation or transducer, nearshore wave data is also collected using this method from the end of the pier. The breaker direction is measured using a Brunton compass. The breaker depth and the distance of the dominant breaker line from the shoreline are also measured. Breaker types are identified using Galvin's (1968) criteria.

3.4 Beach Profile Measurement

Beach profiles at all the locations except the pier stations are taken upto the breakers from fixed bench marks using a dumpy level and staff. During severe wave conditions the seaward extend of the profile is further limited. During monsoon profiles are taken twice a week and during fair season once every week. The profiles are taken during low tide to get maximum exposure of the beach. The position of berm crest is noted and the height of scarp is measured whenever it is present while measuring the beach profiles.

At the pier the profiles are extended to the end of the pier which is well beyond the breakerline during fair season and most part of the rough season. The breakerline is at the pier end during peak monsoon. The profiles are taken from the pier using a calibrated lead line. Earlier studies by Shepard (1950), Sonu (1973) and Noble (1978) justify the use of pier for nearshore observations. A recent study by Miller et al. (1983) noticed significant effects especially for small scale, high frequency changes. The pier effect on beach and nearshore processes is a function of pile diameter, its spacing and pier length (Miller et al., 1983). A much smaller impact is expected in the present case since the pier length is about one-third and the spacing between adjacent piles is almost double and the pier diameter is about half that of the CERC pier used by Miller et al. (1983). They suggested that major nearshore changes like movement of nearshore bars could be resolved using pier data and that the wave data collected using instruments attached to the pier is comparable to the data collected away from it. A conscious attempt is made during the present study to minimise the effect of scouring near the piles of the pier on profile measurement by selecting the profile point midway between the adjacent piles. Also, measurements are taken 1 m laterally from the pier. Inaccuracies in profile measurement using lead line can occur due to: (1) inaccuracies in the calibration of the lead line, (2) the displacement of the lead due to mass transport under waves and (3) submergence of the lead line into bottom sediment. The first error is minimised as in the case of breaker measurements. The displacement of the lead due to wave activity is reduced by making measurements during the passage of the wave trough and by speeding up the operations. The last error is minimised by marking the position of the lead line instantaneously as the lead touches bottom.

The beach being a wave-dominated (Baba et al., 1983), and microtidal (Survey of India, 1980), the effect of tidal fluctuations on beach profiles is not significant

3.5 Longshore Current Measurements

The longshore currents at all the stations were measured using neutrally buoyant plastic bottles. The alongshore distance travelled by these floats is fixed using ranging rods and measuring tapes. The time elapsed is noted and the speed computed. The direction is also observed. The presence of cell circulation systems is noted. Rip currents (spacing and offshore extent) are estimated visually.

3.6 Beach Sediment Analysis

Sediment samples are collected from the berm and beach face. Size analysis is carried out using standard sieves and weight percentage of each size was estimated as per standard procedures (US Army, 1984).

3.7 Three Dimensional Morphological Forms

The data on occurrence of giant cusps and beach cusps are collected whenever they appeared. Horizontal spacing of 3 to 5 adjacent cusp horns are measured using measuring tapes. Its average is taken as cusp wavelength (Fig.3.2). Horn-trough relief is measured using a dumpy level and staff. Height of scarps in the embayments of giant cusps are measured. The inclination of cusp axis is noted.

Information on longshore bars at the pier station is available from the profile measurements. The position of longshore bars are estimated from breaker line and breaker type observations at all other stations. The nature of crescentic bars are assessed from the position and type of breakers at various locations. An idea about the crescentic bars and their migration is also obtained indirectly from the observations of activities of fishermen.

3.8 Wave Record Analysis

Records without defects like systematic drift in zero mean line, noise due to power fluctuation or vibration of transducers, etc. are selected for analysis. Tucker and spectral methods were used for analysis. The method recommended by Tucker (1963) and modified by Silvester (1974) is used for the former.

Spectral analysis is carried out using Fast Fourier Transform (FFT) method (Baba and Kurian, 1988). Records of approximately 17 min duration is digitized at an interval of 1.2 s. Spectral parameters like H_s, $\bar{T}$, and T_p are also computed from spectral estimates.

The heights obtained from pressure records are corrected for pressure attenuation with depth (Draper, 1970). As per the small amplitude theory, corrected surface wave

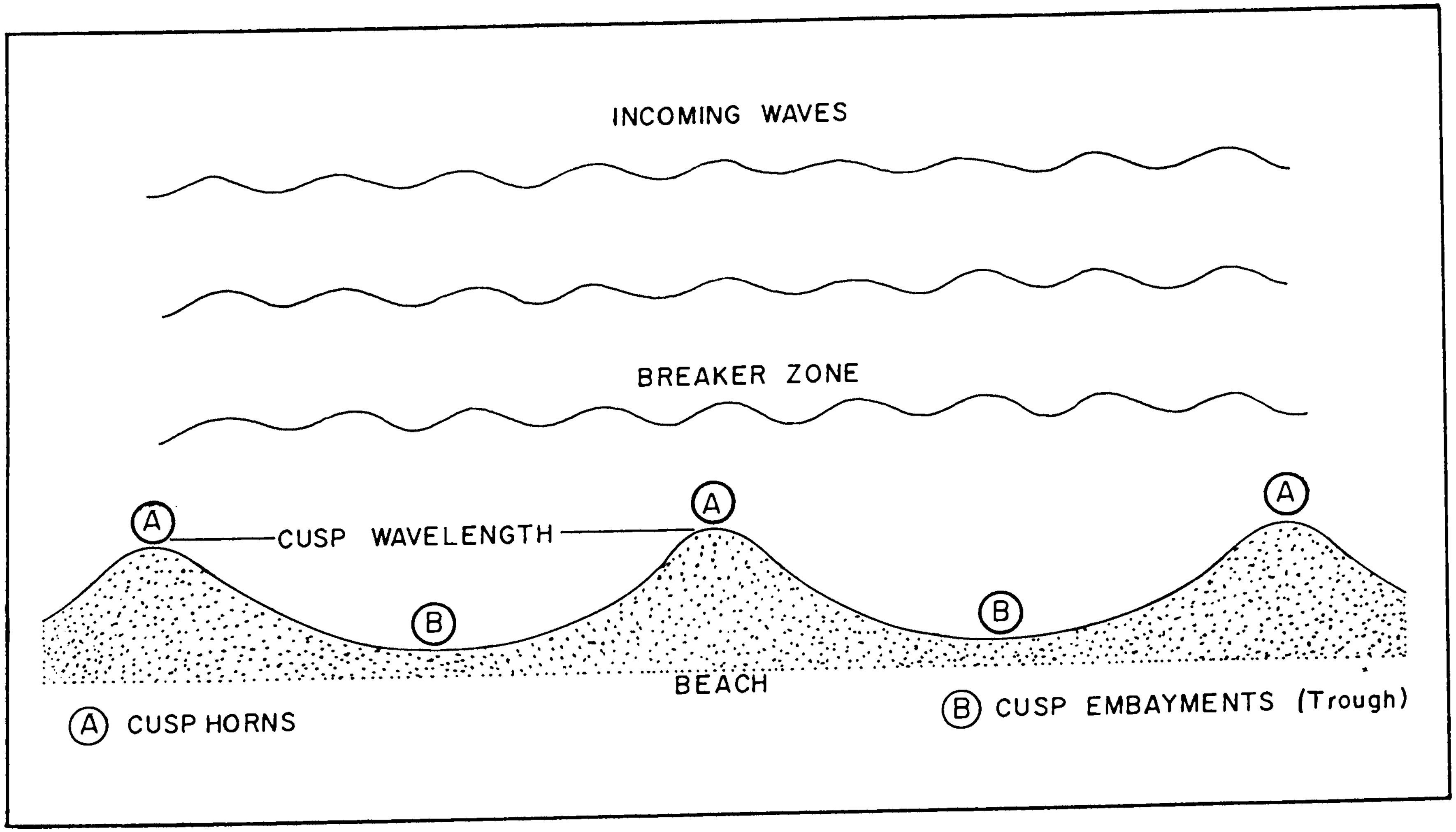

Fig.3.2 Cusp characteristics.

height is obtained from

$$H = kH' \cosh (2\pi d/L)/\cosh [(2\pi d/L)(1- z/d)] \qquad (3.1)$$

where H' is the wave height obtained from pressure record, d is the depth at installation, L is the wave length at depth d, z is the depth of the transducer from MWL and k is an instrumentation factor usually taken as an average of all reported values, i.e. 1.25 (Dattatri, 1973). Similarly the surface spectrum is obtained from the pressure spectrum using the method suggested by Black (1978).

Wave groupiness is estimated using the method of runs and runlengths. A run occurs when wave height exceeds a critical height like the significant wave height or the mean wave height (Goda, 1976). Runlength is the number of consecutive waves in the run that exceed the critical height. Groupiness is also indicated by the correlation co-efficient between successive wave heights, $\gamma_{HH}(n)$, at different lag numbers, n, which is calculated using the relationship suggested by Goda (1976):

$$\gamma_{HH}(n) = \frac{1}{\sigma_H^2 (N_0 - n)} \sum_{i=1}^{N_0 - n} (H_i - \bar{H})(H_{i+n} - \bar{H}) \qquad (3.2)$$

in which σ_H denotes the standard deviation of wave heights, N_z is the number of zero up-crossings in a record and $\bar{H}$ is the mean wave height.

3.9 Estimation of Edge Wave Parameters

Direct field observations of edge waves are difficult and hence they are studied indirectly using beach cusps (Seymour and Aubrey, 1985). This approach becomes possible due to the recent findings that the alongshore spacings of rhythmic shoreline features are closely related to edge wave wavelengths. Inman and Guza (1982) has shown that cusp wavelength, λ_c, and edge wave wavelength, L_e, are related by

$$\lambda_c = L_e/2 \tag{3.3}$$

and

$$\lambda_c = L_e \tag{3.4}$$

for subharmonic and synchronous edge waves respectively. For subharmonic edge waves, the edge wave period, T_e is equal to twice the incident wave period, T_i ; i.e.

$$T_e = 2T_i \tag{3.5}$$

In the case of synchronous edge waves

$$T_e = T_i \tag{3.6}$$

The edge wave disperson relation suggested by Ursell (1952) gives

$$L_e = (g/2\pi)T_e^2 /\sin (2n+1)\beta \tag{3.7}$$

where n is the edge wave mode number, β is the beach slope, g is the acceleration due to gravity and T_e is the edge wave period. The probable edge wave lengths can be estimated using the above three equations.

The cross-shore scaling of longshore bars (distance to the bar crest, x_c) produced by standing waves in the cross-shore direction (either leaky or edge waves) is determined by the relationship (Bowen, 1980):

$$x_c = \chi g T_{in}^2 / 4\pi^2 \qquad (3.8)$$

where T_{in} is the infragravity wave period, χ is a constant equal to 3.5 for deposition at a node of the standing wave. The period of the probable infragravity wave in the surf zone can be estimated from this. Holman and Bowen (1982) found that the longshore length scale of crescentic bars is one-half the edge wave wavelength. This is also utilised in the computations of edge wave periods.

CHAPTER 4

NEARSHORE ENVIRONMENT

Waves, breakers, currents and sediments are the most recognised and visible factors that influence the beach and surf zone processes. Observed charecteristics of these parameters are discussed in this chapter. Though tides are also important in beach processes, their role is insignificant compared to the above factors in the case of a microtidal beach.

4.1 Nearshore Waves

Waves being the main source of input energy into the beach-surf zone system, a detailed study of the waves is necessary to understand the processes involved in this system. The major weather systems that influence the waves off the Trivandrum coast are the monsoons - both southwest and northeast. Wave data for one year is examined in detail to understand the important nearshore wave characteristics. Five years data is further used to study the long-term wave climatic features. Three-hourly, daily, monthly, seasonal and yearly variations in the wave characteristics are examined.

4.1.1 Three-hourly and daily variations

The response of surf zone morphological features to changing wave conditions are at a very rapid time scale (Sallenger et al., 1985). This necessitates a close look into short term changes (eg. three-hourly and daily variations) in wave characteristics.

Diurnal variations in the two major wave parameters, significant wave height, H_s and zero-crossing period, T_z are given in Table 4.1. It is seen that these wave parameters, in general, do not show any significant change over an interval of 3 hours over a day. However, due to local winds which usually become stronger in the evenings, a slightly decreasing trend in wave periods is observed around that time. During the onset of a disturbance like a storm, significant changes may be noticed even at a small interval of three hours. Changes in wave height and period during such an occasion are also given in Table 4.1 (set no.5). As the storm approaches, an increase in wave height with a slight decrease in wave period is observed.

Daily variations in H_s, H_{max}, T_z and wave steepness are given in Fig.4.1. Since there is no considerable variation in wave charecteristics, except during the rare storms, wave observations at 1200 hrs on each day is used for this purpose. It is observed that there is diurnal variations in wave charecteristics through out the year. The range of variations in T_z is large during January to May (Fig.4.1a). Short and long period waves are observed during these months. Long period swells are usually between 10 to 15 s. Short spells of low period swells with periods between 7 to 9 s also occur during these months. Long period swells are sometimes overshadowed by short period sea waves when local winds are strong. The period of these sea waves sometimes falls to a value as low as 4 s.

During June-July the range of daily variations in T_z is usually between 6 and 10 s. During August-September this range increases. This pattern continues through October, November and December when T_z is between 5 and 14 s. Short

Table 4.1 Diurnal variations in H_s and T_z

Sl.No.	Date	Time (hrs)	H_s (m)	T_z (s)
1	06.01.81	0900	0.60	8.7
		0935	0.83	8.0
		1230	0.86	9.4
		1500	0.68	9.0
		1800	0.86	8.6
2	27.02.81	0600	0.80	9.9
		9000	0.83	10.1
		1200	1.00	10.9
		1500	1.00	7.6
		1800	0.82	7.2
3	21.03..81	0900	0.76	9.0
		1240	0.86	7.6
		1500	0.77	7.6
		1800	0.80	7.6
4	10.04.81	0900	1.13	8.6
		1200	1.38	9.9
		1500	1.12	8.3
5	17.05.81	0945	1.61	8.1
		1223	1.66	7.9
		1315	1.73	7.7
		1600	1.68	7.4
		1915	2.21	7.4
		2215	2.59	8.1
6	23.05.81	0930	3.39	9.5
		1240	3.35	10.3
		1500	3.24	10.1
7	05.06.81	0905	3.78	8.4
		1200	3.23	7.8
		1500	3.53	7.7
		1750	3.68	8.0
8	31.08.81	1000	2.58	8.8
		1200	2.34	9.7
		1500	2.32	8.7
		1800	2.60	9.0
9	09.09.81	0845	3.27	10.6
		1200	3.47	10.3
		1445	3.46	10.4
		1800	3.39	9.2
10	27.11.81	0900	0.67	9.4
		1200	0.82	9.7
		1500	0.88	10.3
		1750	0.76	10.1
11	26.12.81	0900	0.56	10.4
		1200	0.55	9.9
		1500	0.68	9.7
		1700	0.65	9.7

spells of low period waves occur during these months also.

The range of daily variations in H_s (Fig.4.1b) during January to March is least while it is maximum during June to October. Calm periods of a few days are observed during June-August. These occurrences of calm periods are due to the breaks in the monsoon. H_s may fall to as low a value as 1.0 m during these calm periods. Duration of these calm periods depends on the duration of monsoon breaks. During September-October the frequencies of occurrence of spells of high and medium-to-low waves are almost equal. Daily variations during November-December show the occurrence of high waves on a few days.

Exceptionally high waves ($H_s > 2$ m) are observed on a few days usually during the first half of April. The wave heights are comparatively low on the other days of this period. These high waves are found to be occurring every year. These waves are characterised by long periods and in some years even waves with zero-crossing period of 17 s have been observed.

Maximum wave heights occurring on each day also show similar variations (Fig.4.1c). The observed maximum wave height of 6.02 m is recorded in September. Some of the values recorded during June are slightly underestimated since waves broke seaward of the recording site on a few occasions during this period. The maximum height recorded are higher than the expected depth-limited wave height ($H = 0.78d$) at the site of recording. As has been pointed out in Chapter 2, the depth-limited wave height depends on the slope of the beach and wave heights larger than $H = 0.78d$ is possible. There are a few days with comparatively high waves during calm periods. Low wave heights may also occur on some days during rough periods.

During May to October wave steepness oscillates between 0.015 and 0.07 (Fig.4.1d). Largest wave steepness is observed in June. It is usually < 0.02 during November to March.

There is no significant daily variations in the wave direction, especially that of swell. Only seasonal variations are distinguishable. This is due to the fact that these observations are from the nearshore where the waves arrive after refraction.

4.1.2 Monthly variations

A more systematic pattern of variations is observed when monthly changes are considered. A detailed monthwise analysis of one year's wave data is given here which will facilitate a better interpretation of seasonal changes in beach characteristics.

4.1.2.1 Significant wave height: Waves are generally high during the months of May to October and they are low during the rest of the year (Fig.4.2). Significant wave heights (H_s) are always greater than 1.0 m during May to October. The maximum value of H_s recorded is 4.2 m in June. The 50% exceedance limit is above 3 m during June. It is above 2 m during August, September and October. A decrease in significant wave height is noticed during July and the 50% exceedance limit of H_s is only about 1.8 m during this month. This is due to a comparatively long break in the monsoon in that particular year of study.

During November to April the 50% exceedance level is

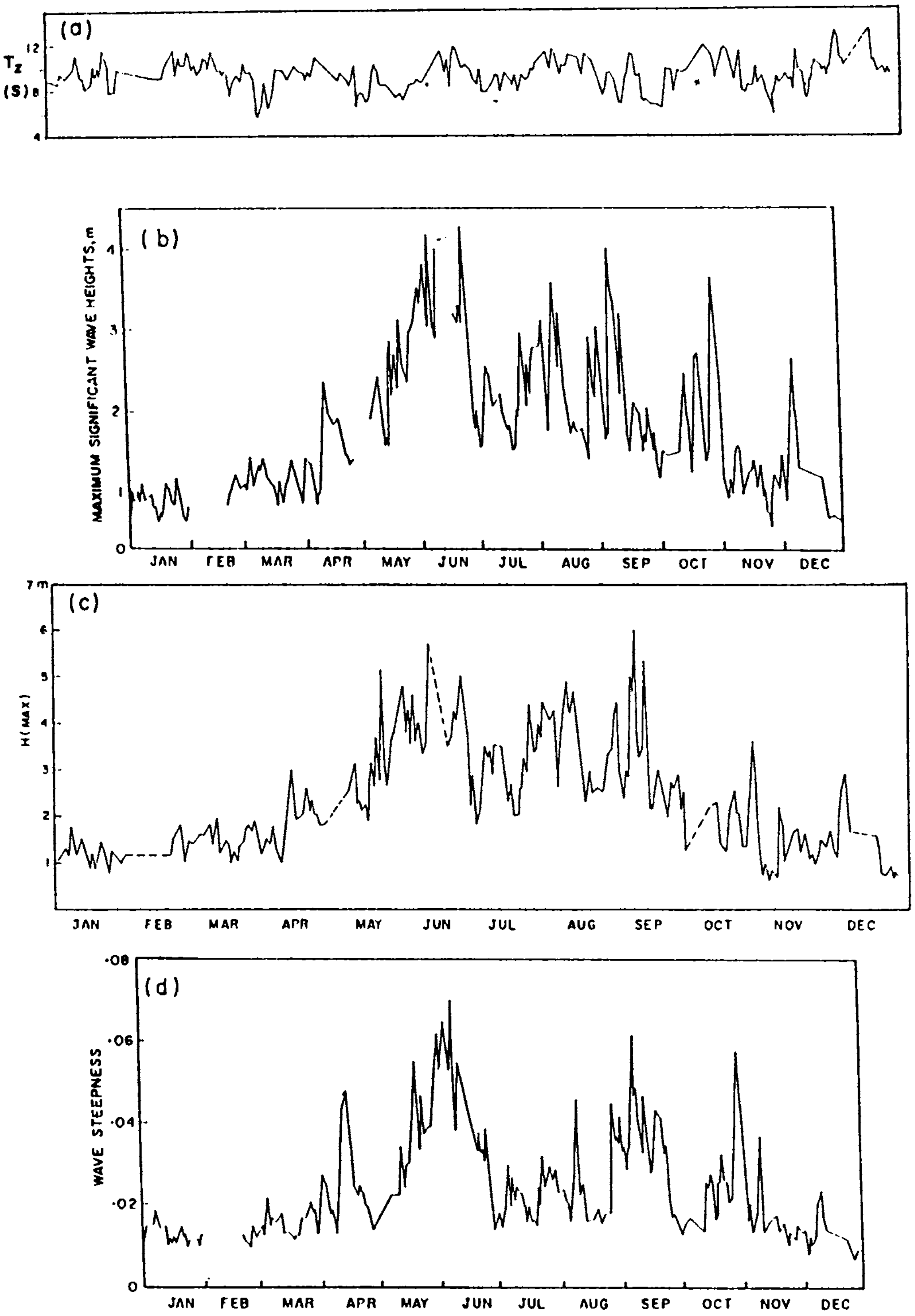

Fig.4.1 Daily variations in (a) T_z, (b) H_s, (c) H_{max} and (d) wave steepness.

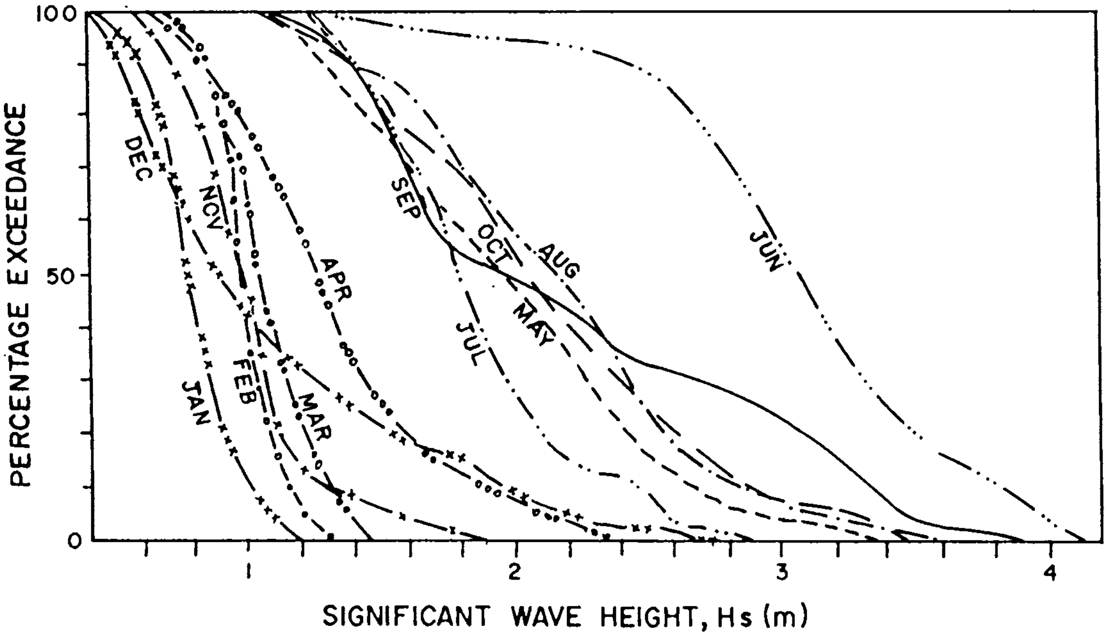

Fig.4.2 Monthly variations in percentage exceedance of H_s for one year.

between 0.8 and 1.3 m. The maximum H_s observed during this period is 2.8 m in December. From January to March the significant wave height never exceeds 1.5 m. During December and April 20 to 25% of the time the value of H_s exceeds 1.5 m.

4.1.2.2 Wave period: Zero-crossing period (T_z) usually varies between 6 and 15 s during a year. The percentage occurrence of T_z is given in Fig.4.3. It shows a wide spectrum of periods during all the months. Short period waves between 6 to 10 s become prominent in June and July. These are associated with the initial stages of southwest monsoon wave activity. Long period swells ($>$ 10 s) become dominant as is seen during the months of August to October. During November to May a combination of long period swells ($>$ 10 s) and short period locally generated sea waves (4 to 7 s) produce a wide spectrum of wave periods.

4.1.2.3 Wave direction (α): As stated earlier the observations are made from the nearshore where the waves arrive after refraction and hence the range of wave directions is limited. Two prominent wave directions, one between 190 and 210°N and the other between 250 and 270°N are observed here (Fig.4.4). During October to May waves are mostly from 190 to 210°N. From January to May sea waves from 250 to 290°N are also observed. With the onset of monsoon, i.e. during June and July waves from 250 to 270°N become prominent. A wider range of directions, i.e. from 190 to 270°N is observed during August-September.

4.1.2.4 Scatter diagrams: The scatter between H_s and T_z is given in Fig.4.5. Lines of equal steepness are superimposed on the scatter diagram of H_s and T_z.

A wide range of wave steepness (between 0.01 and 0.07)

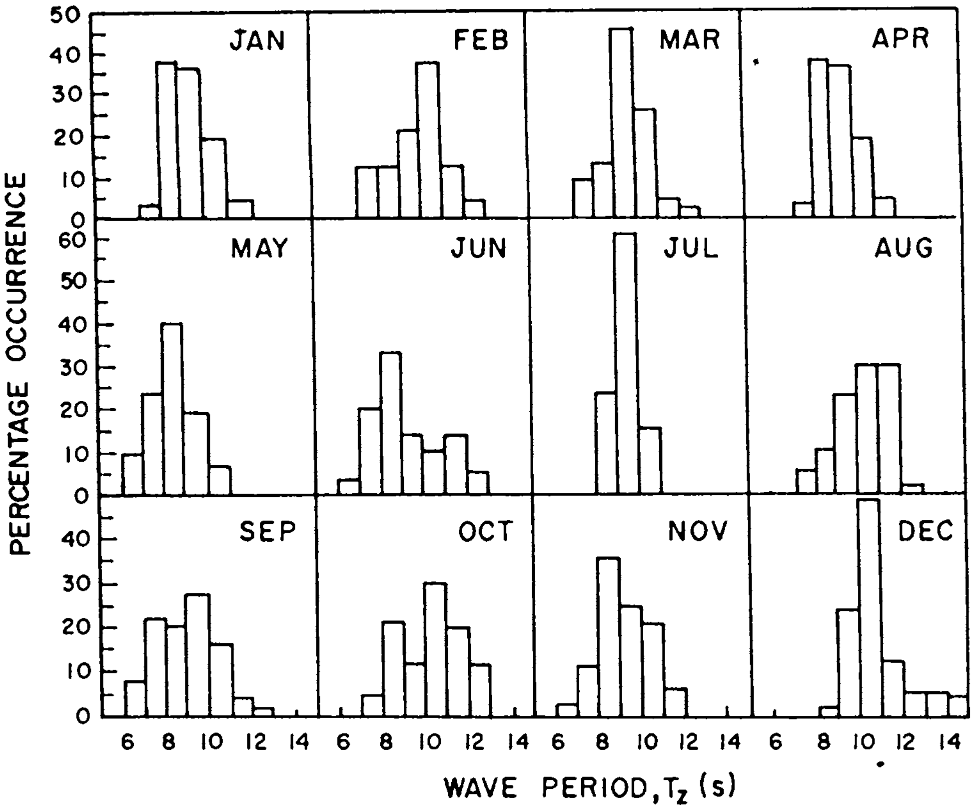

Fig.4.3 Percentage occurrence of T_z .

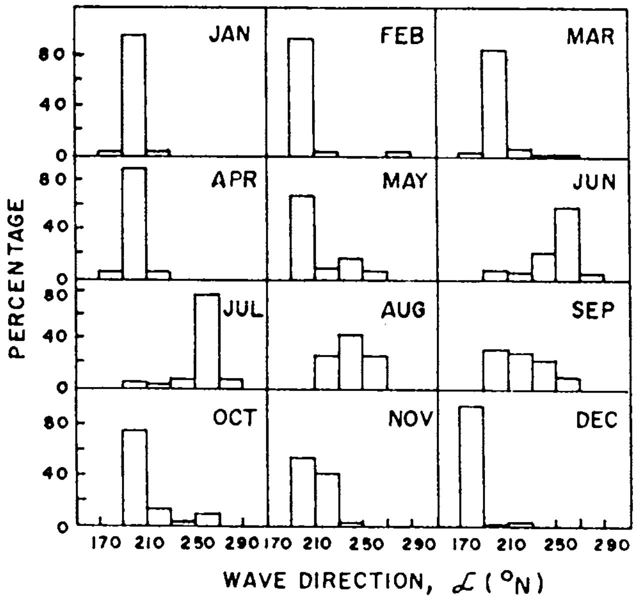

Fig.4.4 Monthly variations in wave direction ($\propto$).

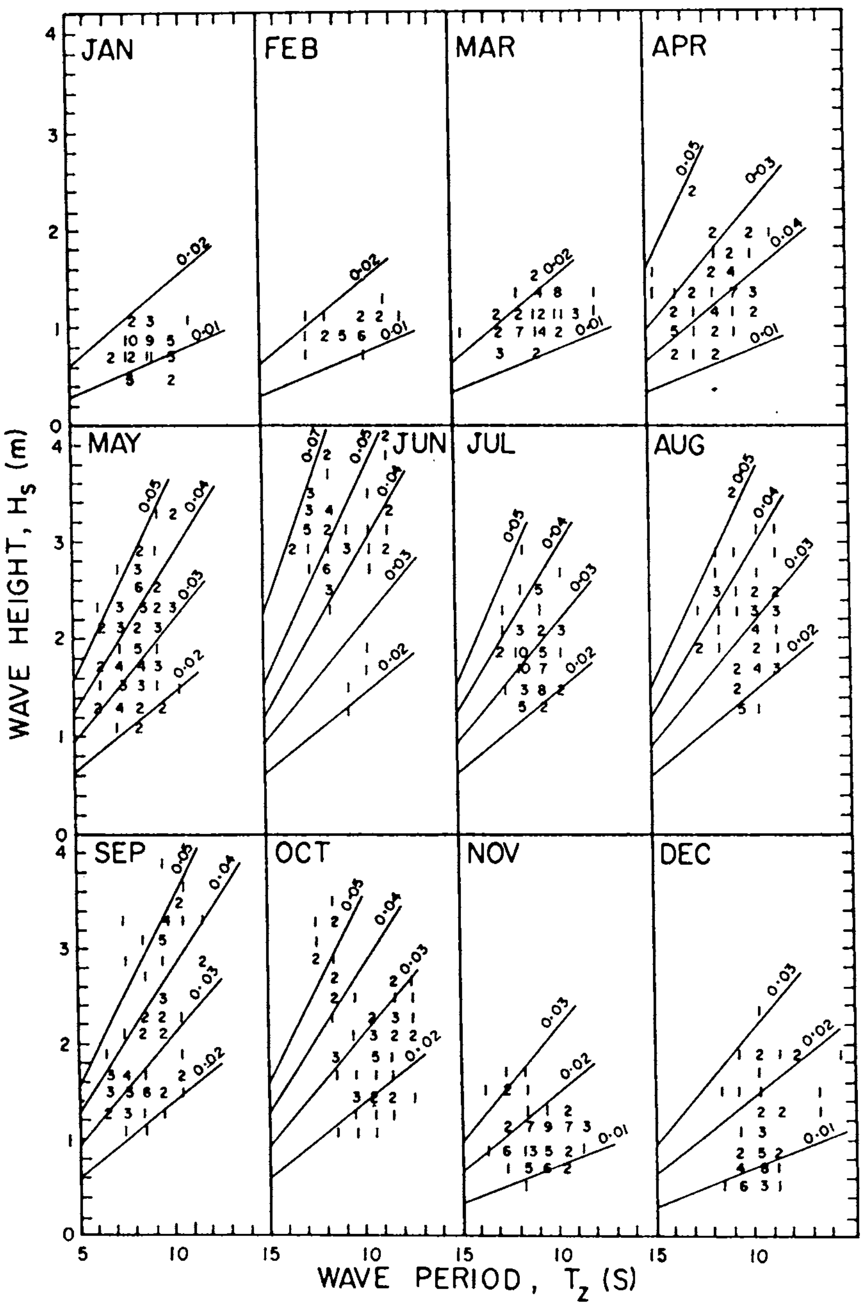

Fig.4.5 Scatter diagram of H_s and T_z .

occur during May to October. Maximum steepness is observed during June which coincides with the onset of monsoon. Steepness becomes as high as 0.07 during this period. Steep waves occur till October. A fall in wave steepness is observed whenever there is a break in monsoon as is seen during July. During November to April the wave steepness is usually less than 0.03. It is mostly less than 0.02 during January, February and March. Since monthly variations in wave direction are limited, scatter diagram between (α and T_z) and (α and H_s) is given only for the whole year (Fig.4.6). Low wave heights are mainly from 190 to 210°N. High waves are either from 190 to 210°N or from 230 to 270°N with the latter dominating. The longest period waves ($>$ 12 s) observed are from 190 to 210°N. Short period waves come from a wide range of directions, i.e. 190 to 270°N.

4.1.2.5 Spectral width parameter: Monthly percentage occurrence of spectral width parameter is given in Fig.4.7. It varies between 0.6 and 1.0. According to general assumption (Tucker, 1963), ϵ_W values indicate the dominance of sea or storm waves. But it is observed that, on many occasions, even when the wave climate is dominated by swells, the spectral width parameter is quite high here. This shows that this parameter may not be reliable especially in the coastal waters. This conforms to the observations of Goda (1974), Holmes (1982) and Rao (1988).

4.1.3 Wave Climate Based on Long-Term Observations

Wave characteristics will show variations every year depending on the variations in the meteorological factors responsible for wave generation. For example, the observed values of H_{max} every month on each year, given in Table 4.2 indicate that the wave characteristics show yearly varia-

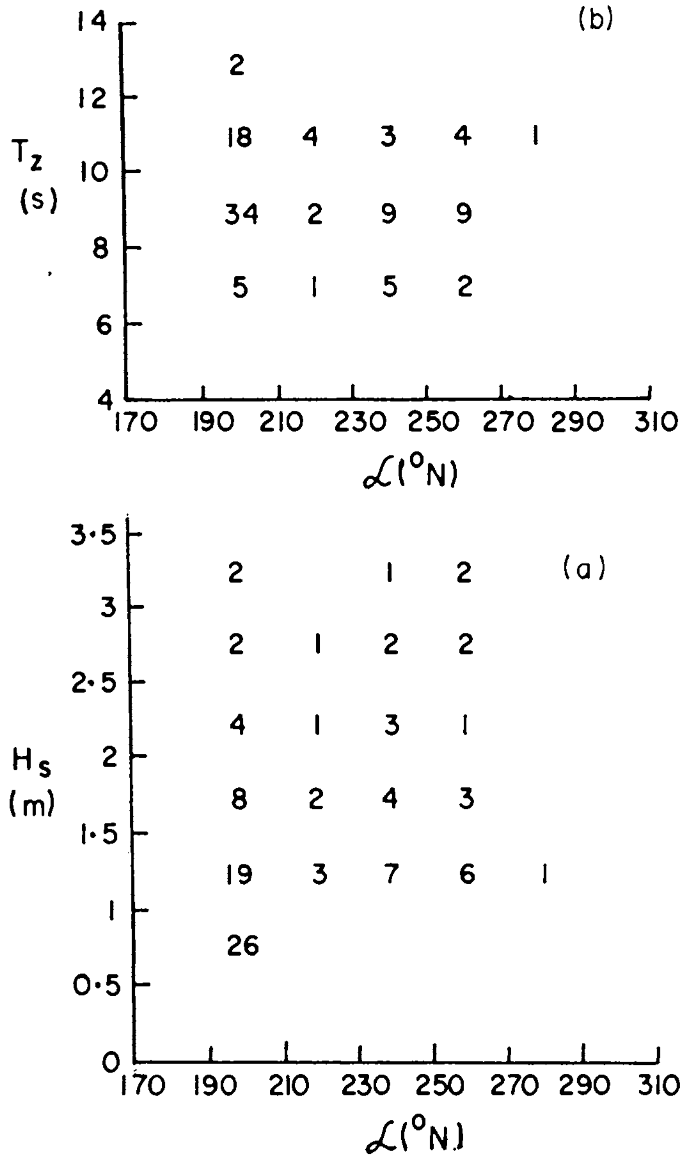

Fig.4.6 Scatter diagram of (H_s & α) and (T_z & α).

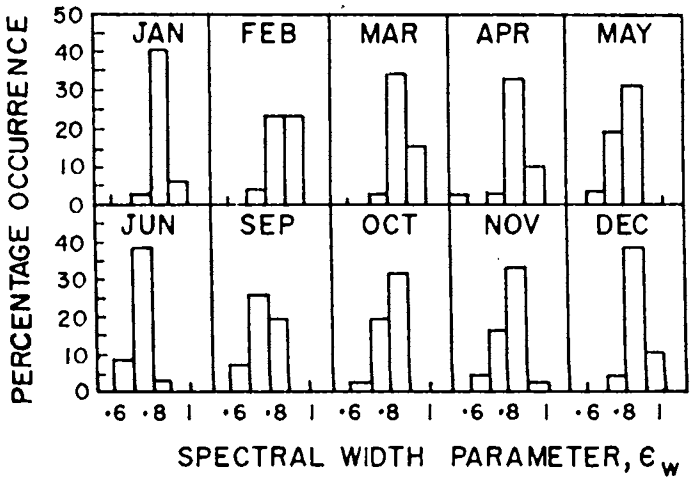

Fig.4.7 Monthly percentage occurrence of spectral width parameter (ϵ_w).

tions. Wave activity may be vigorous in some years as in 1981. The Table also shows that the pattern of variations in H_{max} is more or less similar every year. For a detailed understanding of the effects of long-term variations on the wave characteristics, the different wave parameters for each month averaged over five years are presented here. These are also presented for the two distinct seasons, i.e. rough (May to October) and fair (November to April).

Table 4.2 Monthly maximum of H_{max} (m)

Month	1980	1981	1982	1983	1984
Jan	2.77	1.90	1.73	+	1.55
Feb	+	1.82	2.13	1.06	1.86
Mar	+	1.93	2.08	2.78	2.66
Apr	+	2.97	2.41	2.83	3.71
May	1.18	5.13	2.49	3.74	3.21
Jun	4.50*	5.57	3.59	4.81	4.37
Jul	+	3.70	3.61	4.96	4.09
Aug	+	4.40	3.57	4.14	2.89
Sep	+	6.02	3.57	3.92	3.12
Oct	3.39	3.56	3.01	3.19	4.15
Nov	2.94	2.18	+	2.63	4.10
Dec	1.99	2.93	+	1.58	1.98

*: visual observation; + : no data.

4.1.3.1 Wave height: The percentage exceedance of H_s is given in Fig.4.8. The significant wave heights are always greater than 0.5 m. The fair season has a 50% exceedance level at 0.95 m while during the rough season it is 1.75 m. Five year data shows that the pattern of variations in H_s and H_{max} are more or less similar to the pattern observed for one year.

The 50% H_{max} exceedance levels are 1.4 m and 2.6 m for fair and rough seasons respectively (Fig.4.9). These are 3.3, 3.0, 2.9 and 2.6 m during June, July, August and Sep-

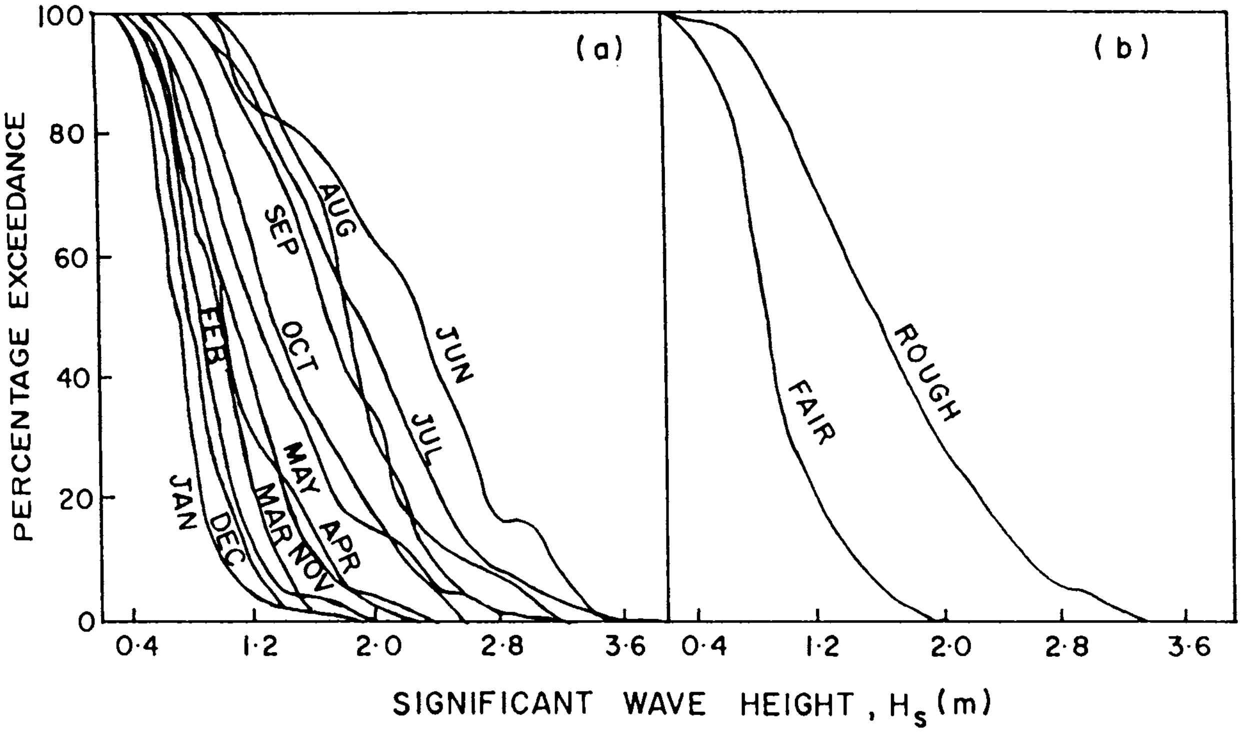

Fig.4.8 Percentage exceedance of H_s for five years: (a) for every month and (b) for fair and rough weather.

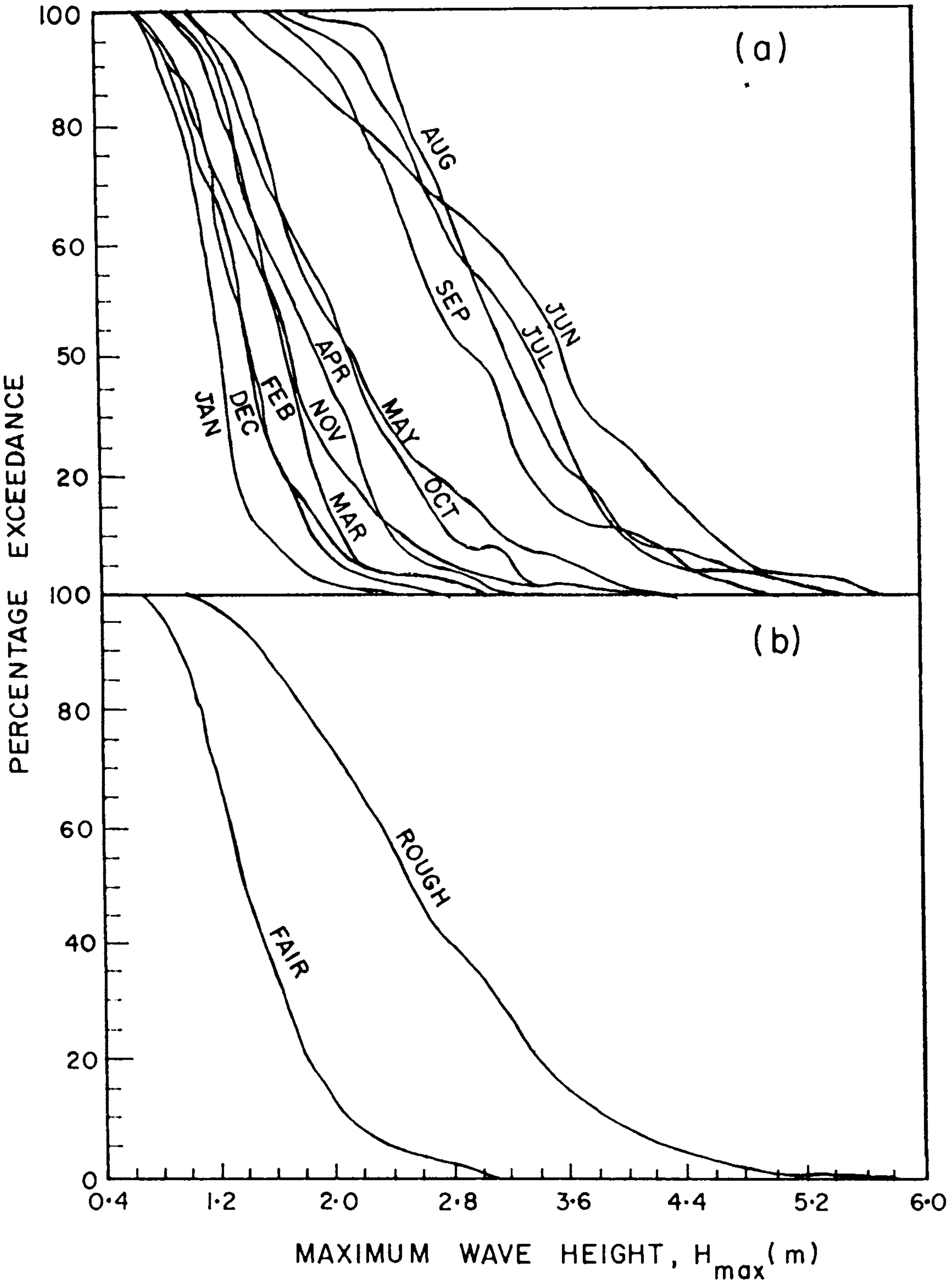

Fig.4.9 Percentage exceedance of H_{max} for five years: (a) for every month and (b) for fair and rough weather.

tember respectively. More than 50% of the observed H_{max} are above 1.8 m during October and May. H_{max} exceeded 1 m more than 70% of the time even during the fair season.

4.1.3.2 Wave period: Long-term observations show that the zero-crossing wave periods vary between 5 and 18 s (Fig.4.10). Long period waves (10-16 s) dominate during October to May. But short period ($<$ 6 s) locally generated sea waves during January-February are, probably, causing a decrease in the observed wave period. On many occasions, long period swells from 180 to 210°N during these months are overshadowed by these short period sea waves from 250 to 280°N. Period characteristics based on both short (one year) and long (five year) term data exhibit more or less similar trends. With the onset of monsoon in June, the wave period decreases ($<$ 10 s). The generation area of these monsoon waves extends to the nearshore region. Towards the end of monsoon, i.e. during August-September a shift towards longer periods is observed indicating the arrival of swells.

4.1.3.3 Wave direction: As has been discussed earlier only seasonal variations in the wave direction are significant. The trend observed in the long-term data is similar to the one year data presented earlier.

4.1.3.4 Scatter diagram: The scatter diagrams for (H_s, T_z), (T_z, α) and (H_s, α) are presented in Fig.4.11. Wave steepness is low (usually $<$ 0.03) during fair season. A wider range of wave steepness is observed during rough season when steepness up to 0.07 occur. This is in confirmity with the one year observations. The scatter diagram between (T_z and α) and (H_s and α) for rough season shows two peaks - one between 190 and 220°N and the other between 230 and 270°N. The first includes mostly the long period, high waves to-

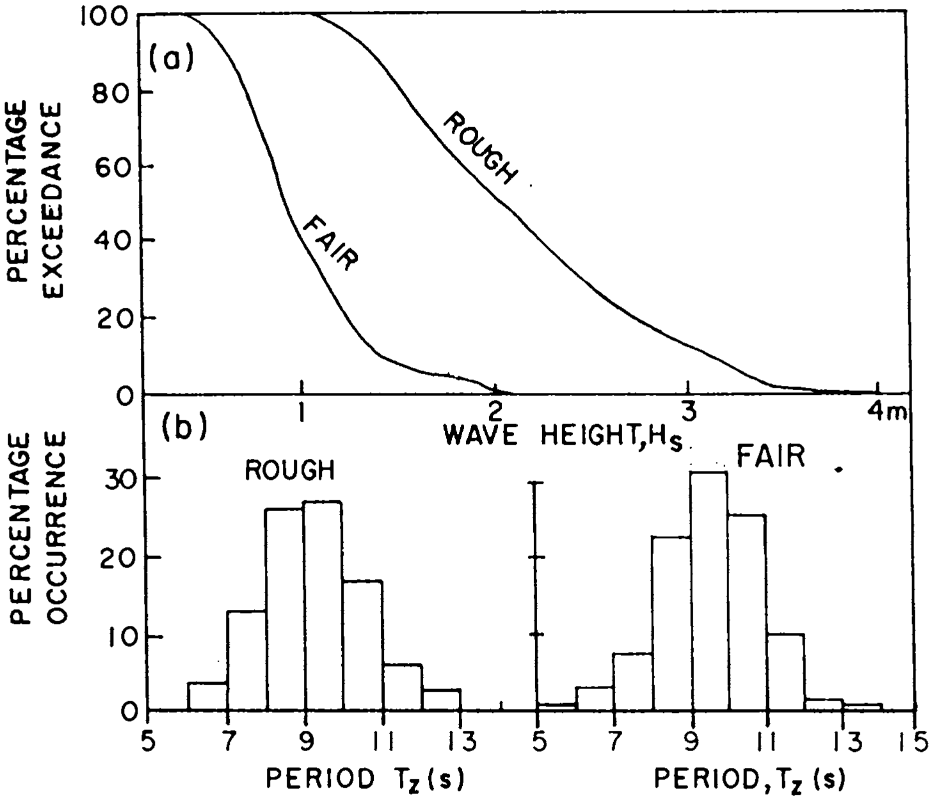

Fig.4.10 Rough and fair weather distribution of T for five years: (a) percentage exceedance, (b) percentage occurrence.

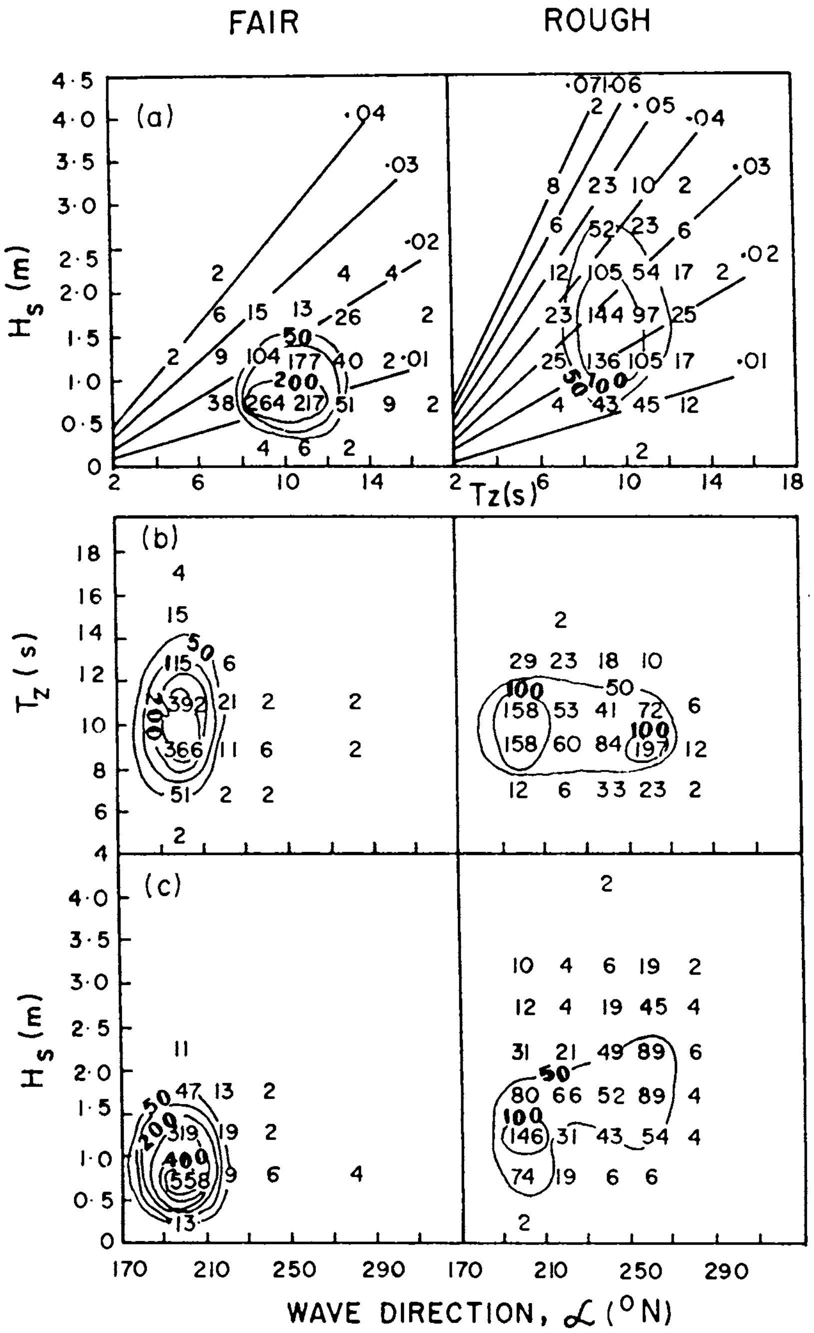

Fig.4.11 Scatter diagram of (H_s, T_z), (T_z, α) and (H_s, α) for 5 years.

wards the latter half of the rough season and also in May. The second group consists mainly of the monsoonal waves during June, July and August.

It becomes evident from the above discussions that the wave climatic changes are significant during different seasons in a year and these are repeated every year almost in an identical fashion. Wave activity becomes severe during the rough season which includes the southwest monsoon and post-southwest monsoon periods. The northeast monsoon is normally weak along this coast and can be catogorised under fair season. Waves during fair season are characterised by low wave heights (<1.5 m), long period (mostly between 8 and 14 s) and low steepness (<0.03) and they are mainly from 190 to 210°N. A wider range is observed in all the wave characteristics during the rough season. This is mainly because of the breaks, extending to a period of 1 to 2 weeks,in the severity of wave activity during the monsoon season. The occurrences of calm spells during rough season and high waves during fair season have already been mentioned while discussing the daily variations in wave characteristics.

The two seasons - rough and fair - represent two distinct wave energy regimes. The rough season with a 50% H_s exceedance level at 1.75 m belongs to a high energy regime while the fair season having a 50% exceedance level at 0.95 m may be considered as a moderate energy regime. In this context it may be noted that Wright et al. (1979) has included some Australian beaches where the significant wave heights exceed 1.5 m for 50% of time in the high energy wave regime. Similar classifications are also used by Short and Hesp (1982) and Short (1984).

4.1.4 Spectral Characteristics

Different parameters obtained from spectral estimates are given in Table 4.3. Corresponding spectra are plotted in Figs.4.12. The 0th moment of the spectrum (m_0) is a measure of the energy level and its value is mostly in the range between 0.01 and 0.4 m^2. The high values of m_0 (> 0.1 m^2) indicating high energy conditions observed during the rough conditions associated with southwest monsoon season. The spectral peak is observed usually at a period between 11 and 16 s before the onset of monsoon wave conditions. With the onset of monsoon the period of spectral peak shifts to lower values (mostly between 7 and 12 s). The peak spectral density varies from 0.4 m^2s during low wave activity to 7.5 m^2s during the rough monsoon conditions.

Table 4.3 Characteristics of the monthly average spectra

Month	H_s	T_p	$T_{mo,1}$	$T_{mo,2}$	ϵ_w	ν	Q_p
Jan	0.60	11.6	8.6	7.5	0.81	0.54	2.4
Feb	0.73	14.3	9.4	8.3	0.83	0.56	3.0
Mar	0.81	12.0	8.8	7.6	0.83	0.57	2.2
Apr	1.12	10.4	8.1	7.0	0.81	0.56	2.4
May	1.07	13.7	9.3	7.9	0.84	0.62	2.3
Jun	1.82	11.0	6.8	6.0	0.75	0.54	1.7
Jul	2.03	10.4	7.6	6.8	0.77	0.50	2.1
Aug	1.53	11.2	7.4	6.7	0.74	0.47	2.2
Sep	1.63	7.5	7.3	6.7	0.72	0.43	3.1
Oct	0.82	9.0	8.5	7.5	0.79	0.53	2.4
Nov	0.88	12.5	10.1	8.9	0.84	0.53	2.5
Dec	0.71	15.0	8.8	7.9	0.79	0.50	2.1

The spectra are usually multi-peaked. Secondary peaks generally occur on the high frequency side of the primary peak. This indicates that the primary peak is in the swell region and the secondary peaks are in the sea region. Since

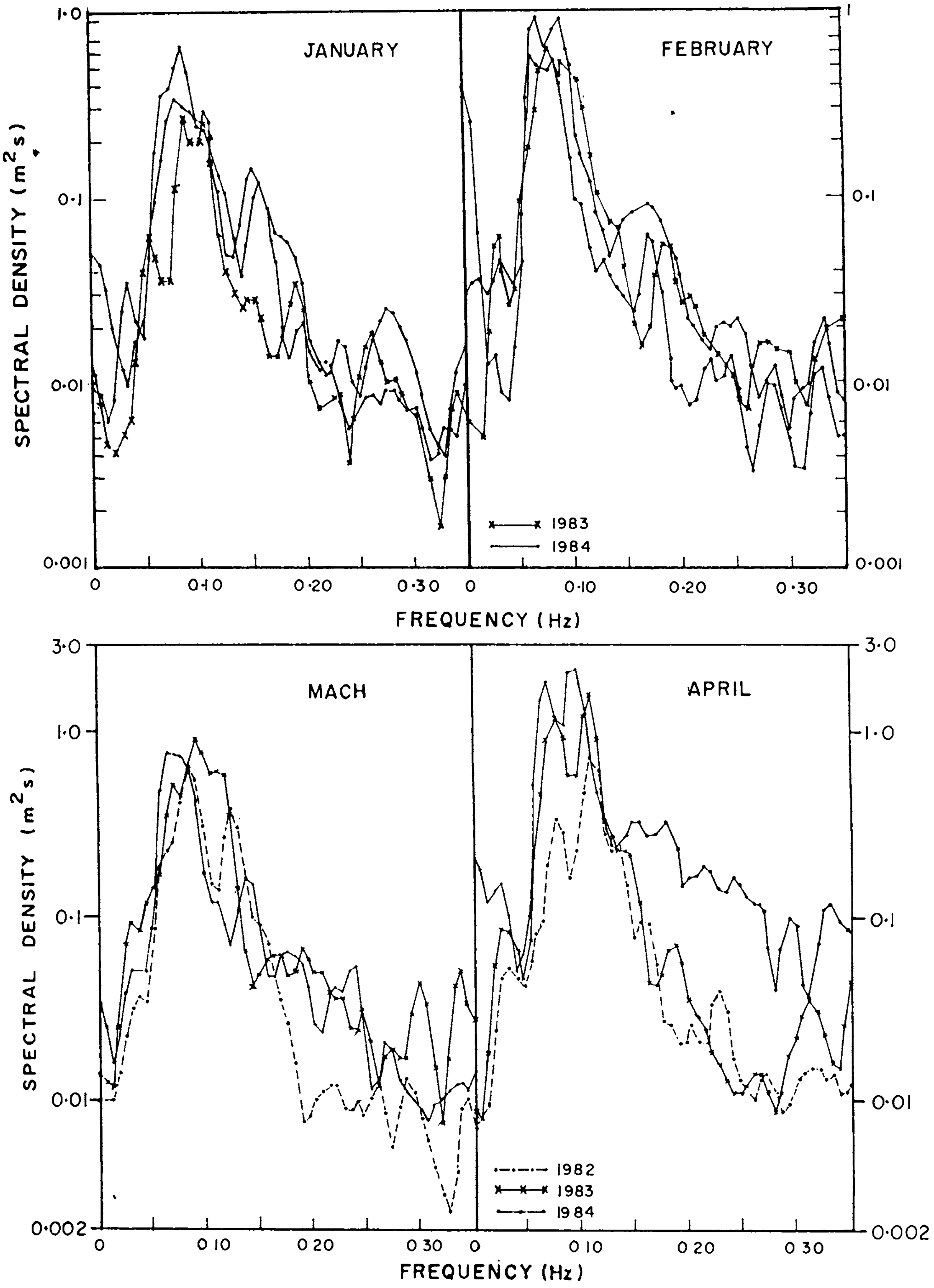

Fig.4.12 Monthly wave spectra.

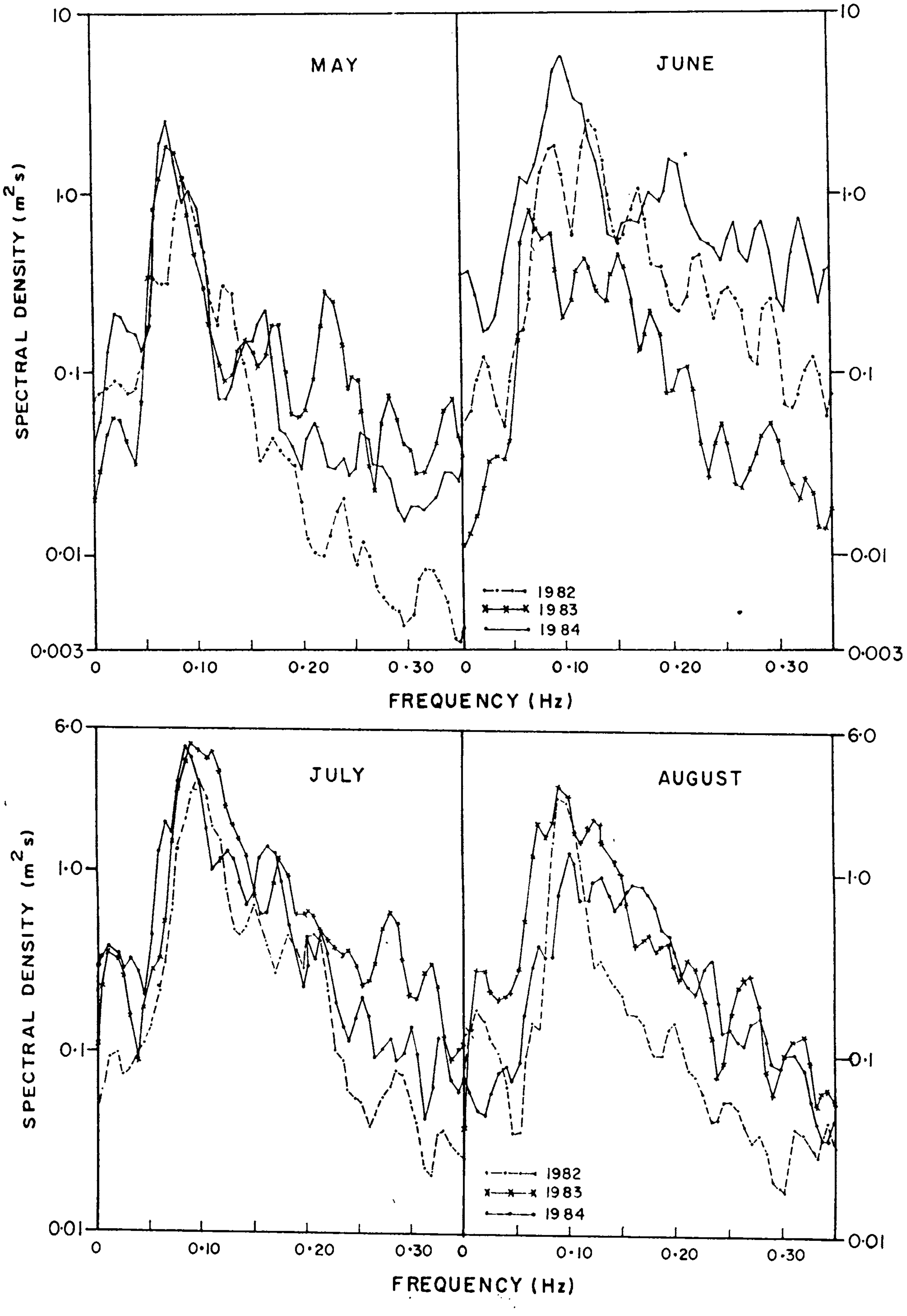

Fig.4.12 Continued

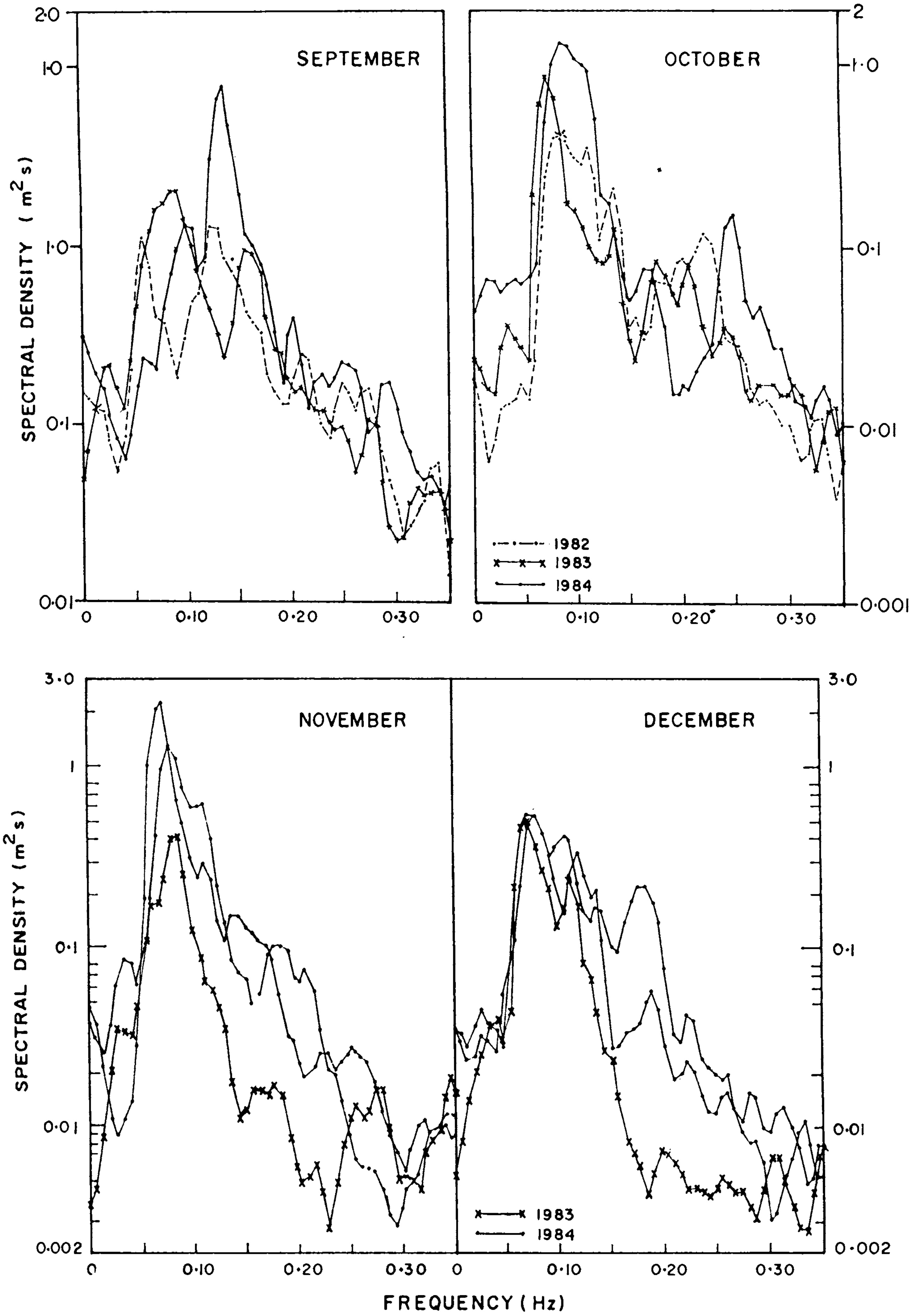

Fig.4.12 Continued.

most of the secondary peaks are to the high frequency side of the main peak, this spectra can be considered to be swell-dominated. Since the period of the primary peak decreases, the difference between the primary peak period and the secondary peak period narrows down during monsoon. There are also a few occasions when the secondary peak is on the low frequency side of the main peak indicating wind-dominated conditions.

Multi-peakedness of the spectrum may be due to the presence of different wave trains (Bretschneider, 1964; Goda, 1974) or may be attributed to the transfer of energy from the main peak to the higher harmonics due to shallow water effects (Lee and Black, 1978 and Thompson, 1980). Here, the energy in the higher frequency side shows a sharp increase during monsoon. The growth of high frequency secondary peaks with the roughening of the sea associated with monsoonal waves indicate the transfer of wind energy due to wind-wave interaction. Hence Kurian (1988) has concluded that the multiple peaks in the spectrum of this coast are due to separate wave trains, i.e. sea and swell.

The spectral peakedness parameter is usually between 2 and 5. Generally lower values are observed during the monsoon months. The slope of the high frequency side of the spectrum shows a wide range of values from about 0 to 5. Slope is low for the high energy monsoonal conditions indicating the presence of more energy on the high frequency side. The spectral estimates, too, lead to the conclusion that the wave climate along this coast is swell-dominated and is characterised by moderate to high energy waves.

4.1.5 Wave groups

Wave groupiness is a process in which high waves occur in groups followed by low waves.Wave groups may cause considerable nearshore water set-up and higher run-up on the beach resulting in the flooding of the coastal region (Symonds et al., 1982). This may cause large scale damages to coastal properties. Wave groups also have the potential to generate infragravity waves in the surf zone which play an important role in beach and surf zone morphodynamics. The occurrence of wave groups along the southwest coast of India has been noticed by Dattatri (1983), and Namboothiri (1985). A typical swell dominated wave condition is examined here to indicate the extent of groupiness along this coast.

The wave records are subjected to wave-by-wave zero-upcrossing analysis and the individual heights and periods are obtained. The mean wave height, $\bar{H}$ and the significant wave height, H_s are calculated. Heights of individual waves and the number of waves exceeding the mean height, $\bar{H}$, and the significant height, H_s , are given in Fig.4.13a.

The longest run identified contains 6 waves for H greater than H_s and 16 waves for H greater than $\bar{H}$. This is indicative of fairly high groupiness. The correlation coefficient between successive wave heights at different lag numbers, n, ie. $\gamma_{HH}(n)$ are given in Fig.4.13b, for a few records. This is found to be large and in some cases significant correlation is evident upto five waves apart. It implies that wave groupiness is a parameter to be considered in the study of beach processes along this coast.

4.2 Breakers

Breakers influence various beach and surf zone processes like the mode of transport, the quantum of wave energy

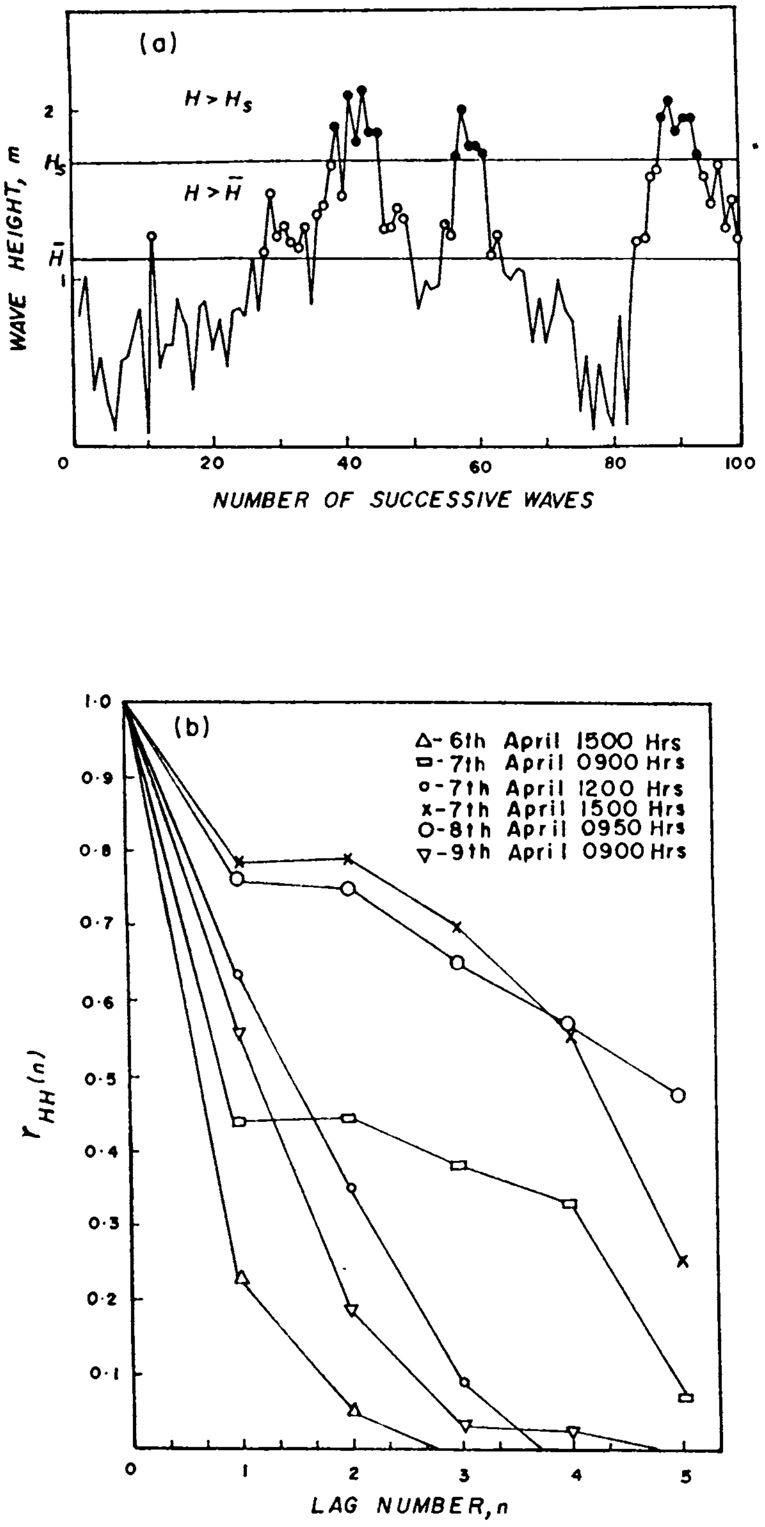

Fig.4.13 (a) Sequence of individual wave heights exceeding H_s and $\bar{H}$; (b) Correlation between successive wave heights for different lag numbers.

dissipation, the width of the surf zone, etc. Variations in breaker characteristics more or less follow the pattern of wave climatic changes. Height, period, direction and type of the breakers during one year are given in Fig.4.14. Here breaker height implies significant breaker height.

Breaker heights are usually between 0.6 and 1.0 m during January to March. The maximum breaker heights are less than 2 m during these months. Breaker heights increase since then. Breaker heights observed during April and May is between 1 and 2 m. The breaker period during January to May are between 9 and 12 s. On many days during these months breakers due to locally generated sea waves with periods between 4 and 7 s are also present. These breakers sometimes overshadow the breakers due to long period, low swells. The direction of approach of the breakers due to long period, low swells are mostly between 210 to 225 °N while the locally generated breakers have a direction between 230 and 240°N. The breakers are surging, collapsing or plunging, with the former two dominating during January to March. They become mostly plunging or collapsing during April. In May, most of the breakers are plunging.

The increase in breaker heights observed since April reaches a maximum with the onset of southwest monsoon in June. Breaker heights are between 1.5 and 3.5 m. A decrease in breaker period also occurs. Period is between 7.5 and 12 s. Breakers are plunging or spilling with the former dominating. Breaker direction changes to 235 to 240°N.

Breaker heights continue to be high during July, August and September. Heights vary between 1 and 2.4 m. It may be pointed out that lulls in breaker activity with a duration of few days are noticed during these months corre-

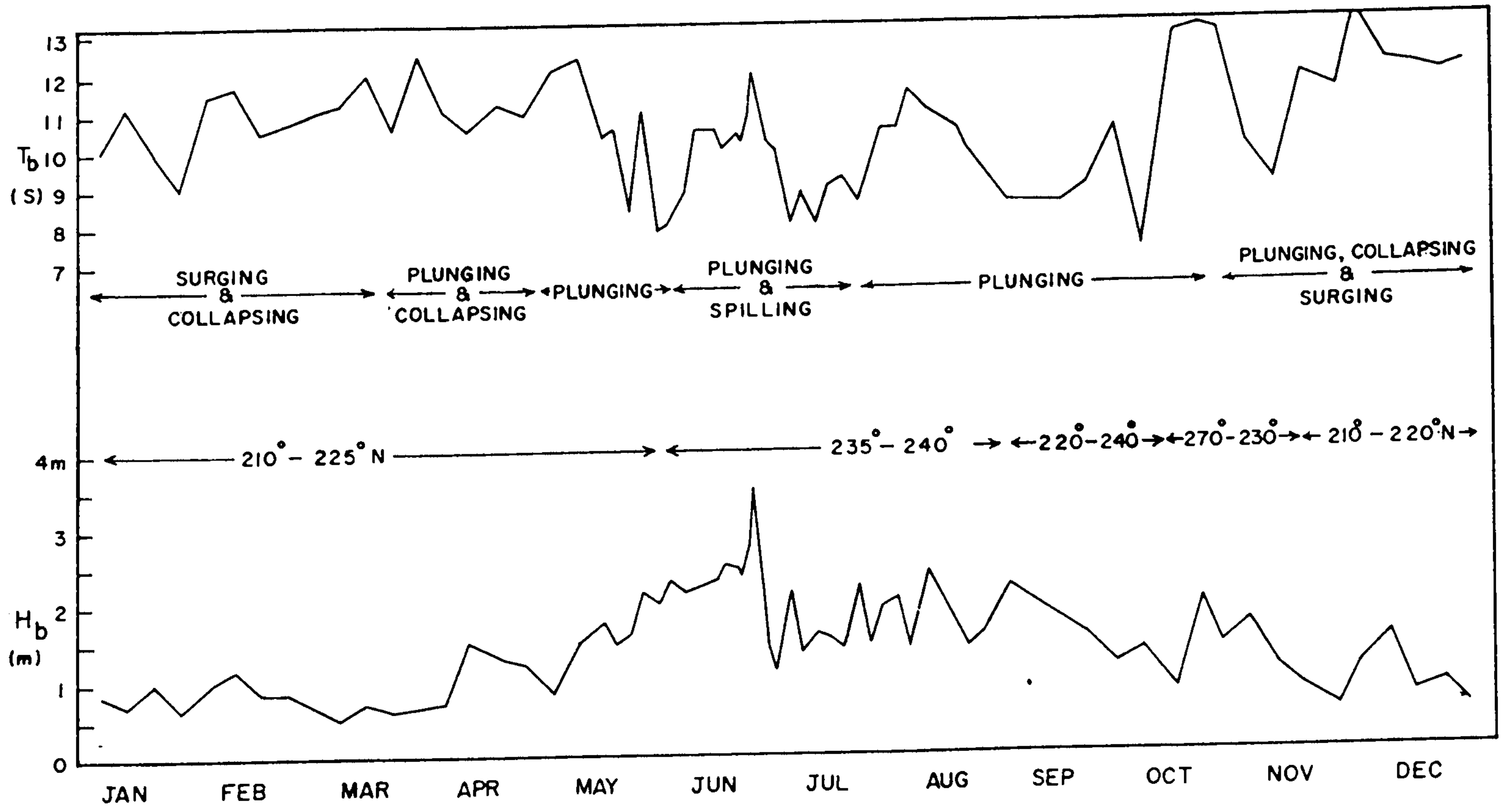

Fig.4.14 Monthly breaker characteristics.

sponding to the breaks in the monsoon. The periods are low (between 8 and 10.5 s) during July while it shows an increase in August (9.5 to 11.5 s). Breakers are plunging or spilling during July while they are plunging during August and September.Breaker directions continue to be between 235 and 240°N in July-August while it is between 220 and 240°N during September.

Breaker heights are between 0.8 and 2 m in October. A few spells of high breakers are also observed. The maximum observed height is 3 m. The periods are between 7 and 13 s. Breaker direction shifts to 210 to 230°N. Plunging breakers dominate.

Breakers are low during November and December. Heights vary between 0.5 to 1.7 m. Occasional spells of high breaker activity also occur during this period. Maximum breaker heights observed are 2.3 and 2.7 m respectively. Breaker periods are usually large (10.5 to 13.5 s). Breaker directions between 210 and 240°N are observed. 210 to 220°N are the dominating directions. Breakers are plunging, collapsing and surging during these months.

Breaker characteristics based on long term (5 years) observations are summarised in Table 4.4. It gives the monthwise break-up of breaker parameters averaged for 1980-84 period. The general trends in the monthly or seasonal breaker climatic changes, obtained from the analysis of one year data, remain almost the same for longterm (5 years) data. The highest breakers are observed during June-September. The period of breakers are less during these months. Breaker periods are high during October, March and April (11 to 12 s). Breaker direction is between 210 and 225°N except during June-August, when the direction is between 230 and

240°N.The most dominant breaker type is plunging during April to October while surging or collapsing breakers dominate during November to March.

The observed breaker characteristics are not exactly compatible with the corresponding wave climate presented earlier. This discrepancy is mainly due to the fact that the wave climate is presented based on daily observations while the breaker climate is presented based on weekly or biweekly observations.

Table 4.4 Breaker Characteristics (Average for 1980-'84)

Month	*Maximum height (m)	Average height (m)	Period (s)	Direction (°N)	Dominant Types
Jan	1.60	0.80	10.8	213	CL,SR
Feb	1.70	0.85	11.1	214	CL,SR
Mar	1.90	0.90	11.8	216	CL,SR
Apr	2.30	1.10	11.8	212	PL
May	2.90	1.65	11.2	214	PL
Jun	4.70	2.20	10.2	237	PL,SP
Jul	4.50	1.95	10.5	237	PL,SP
Aug	4.20	1.95	11.0	235	PL,SP
Sep	3.00	1.55	10.8	223	PL,SP
Oct	3.30	1.30	11.7	216	PL,CL
Nov	2.70	1.05	11.2	215	PL,CL,SR
Dec	1.40	0.80	11.4	212	PL,CL,SR

CL - collapsing; SR - surging; SP - spilling; PL - plunging.
*: average of the observed maximum in each month

Short and Hesp (1982) and Short (1984) have included beaches with breaker heights greater than 2.5 m in the high energy beach category while those with breaker heights below 1 m are classified as low energy beaches with moderate energy conditions falling between the two. Accordingly, the breaker climate observed here shows that moderate to high energy conditions prevail along this coast most of the time.

4.3 Surf Zone

Surf zone, by definition, is related to the breaker position. The breaker position shifts with respect to the changes in breaker height and beach-nearshore profile. Surf zone width on different days of a year are given in Fig.4.15. During November to March the width of the surf zone is practically zero when the breakers are surging or collapsing. Increase in breaker height since April causes an offshore migration of the breaker position resulting in an increase in the width of the surf zone. The breaker type by this time becomes plunging. With the onset of southwest monsoon, the breaker position shifts further offshore and the surf zone widens to around 100-150 m by June. Increase in breaker height and various surf zone morphodynamic features are responsible for this increase in surf zone width. This width continues to be large till August with some small variations depending on the severity of monsoonal activity. During this period the high breakers first plunge at the seaward edge of the surf zone and then reform in the surf zone to break on the beach face as plunging or collapsing breakers. The smaller breakers, on many occasions, spill across the surf zone. The width starts decreasing by September as the monsoon recedes. It is around 75 to 100 m by this time. This continues to decrease and by the second week of November, the width of surf zone becomes practically zero. By this time the breakers become collapsing or surging.

A sufficiently wide surf zone facilitates the development of various surf zone morphodynamic features including infra-gravity waves which play a crucial role in controlling different nearshore processes. Surf zone profiles also

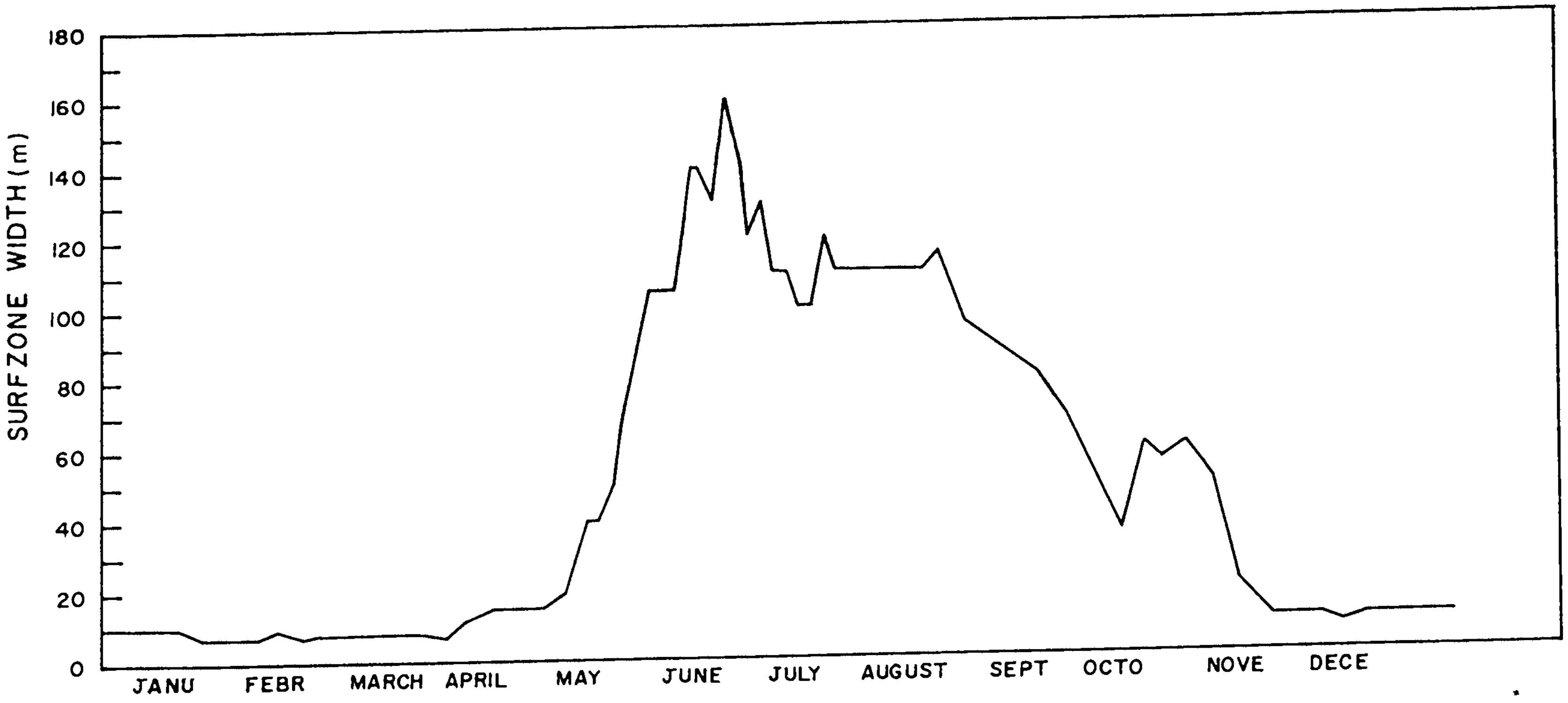

Fig.4.15 Surf zone width during one year.

undergo considerable transformations depending on the wave and breaker characteristics.

4.4 Nearshore Currents

Nearshore currents can significantly influence beach and surf zone morphodynamics. Waves and breakers provide the major part of the energy for these currents.Nearshore currents observed along this beach consist of longshore currents and cell circulation systems.

4.4.1 Longshore currents

This coast being oriented in a 315-135°N direction (NW-SE). waves (breakers) from 135-225°N will generate up-currents (towards northwest) and waves (breakers) from 225 to 315°N will cause down-currents (towards southeast). An year-long observation of longshore currents (Fig.4.16) shows that these longshore currents are usually upcoast and weak (mostly between 0 to 0.3 m/s) during January to March. The direction corresponds to the dominating breaker direction of 200 to 225°N during this time. Low breaker heights, characteristic to this season, is the cause of weak currents. Down coast currents generated by the infrequent locally generated sea waves from 240 to 270°N (due to persisting west to northwesterly winds) may occur during these months.

An increase in breaker height since April, results in stronger longshore currents. These are usually up the coast. Current speeds upto 0.92 m/s are observed in May. They change directions depending on the breaker directions.

The currents are down the coast during June and July. Velocities up to 1.4 m/s are observed. Currents in both the

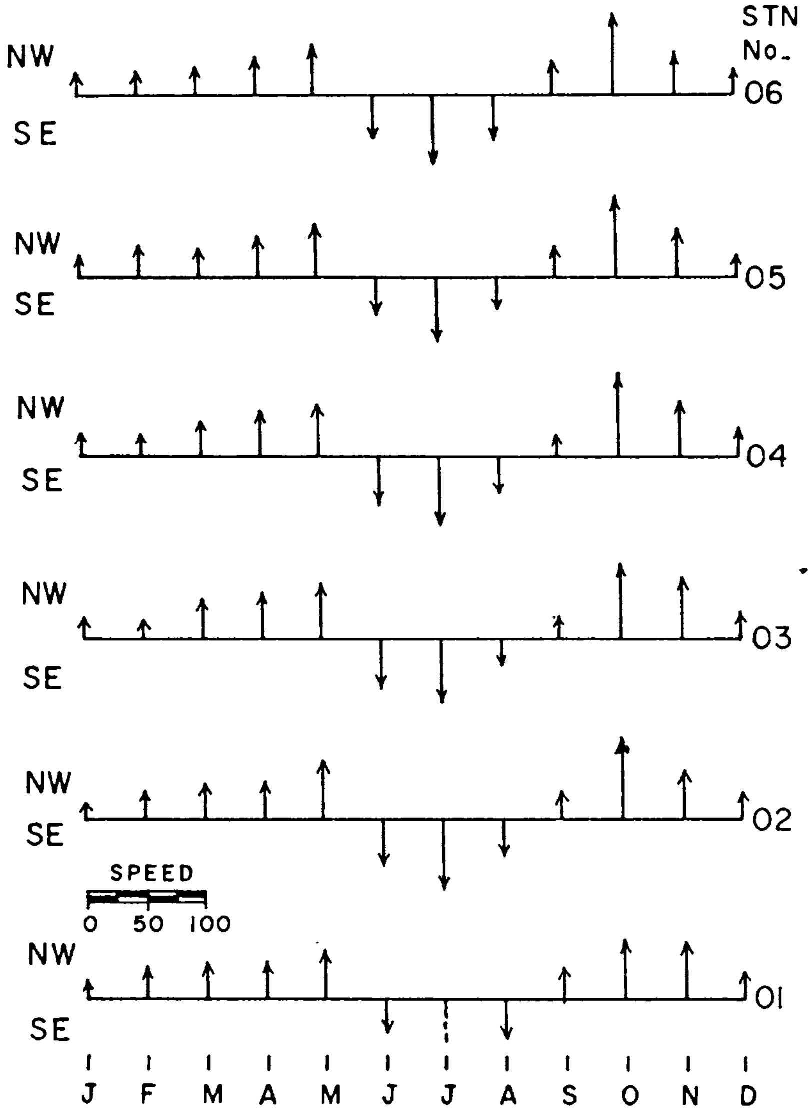

Fig.4.16 Longshore current velocity during one year.

directions are observed in August and September. There is a decrease in the velocity. The direction of currents become up the coast since October corresponding to the change in the breaker direction. The direction is very consistent. Current speeds are large (0.8 m/s) on many days in October. By December the speed becomes very low.

4.4.2 Cell circulation

The surf zone is fairly wide during June to September. Rip currents appear all along the coast within a few days of the onset of monsoon. These rip currents have lengths around 100 m and are at an interval of 40-50 m. Along with the feeding longshore currents they can form cell circulation systems. The necessary longshore head of water to drive the feeding longshore currents to produce rip currents is provided, probably, by the alongshore variations in breaker heights. The length of the rip current varies with changes in the surf zone width. The rip current length is around 50 to 75 m during September. Rip currents are not seen since October. No field measurements of the speed of rip currents or of the alongshore variations in breaker heights could be made. The observed nearshore currents during June to September are, probably, the result of a combination of longshore currents due to oblique wave approach and cell circulation due to the alongshore variations in breaker heights. It may be noted that the low values of longshore current speed during September are not associated with low breaker heights. The wide range of wave directions and various surf zone morphodynamic features like crescentic bars present during September cause the formation of cell circulation systems and oscillating current directions; hence the low values of mean longshore current speeds. Though the breaker heights during June to August are higher than those during

October, the longshore currents are sometimes even larger in October than June, to August. This is because of the fact that longshore currents are affected by cell circulation systems during June, July and August while no cell circulation system is present in October. Moreover, the direction and speed of the longshore current are more consistent during October.

Though up-currents dominate the nearshore current system for almost 3/4th of the year, its sediment carrying capacity may not be as large as the stronger down-currents and rip currents. During most of the time when up-currents occur, the breakers which mainly throw the breaker zone and surf zone sediments in suspension are comparatively small. Since the width of the surf zone is narrow during this period, the area over which the longshore currents act is also narrow. These adversely affect the sediment carrying capacity of up-currents.On the other hand the high breakers and wide surf zone observed during June-August increase the sediment carrying capacity of longshore currents and cell circulation systems. Hence sediment transport due to up-currents may not be as large as that due to down-currents, eventhough up-currents dominate the nearshore system almost 3/4 th of the year. The presence of cell circulation systems adversely affect the longshore transport due to down-currents. It may also be noted that the beach sediment here, being non-cohesive and medium-sized sand, have relatively large fall velocities and thus remain in suspension for only short duration of time. Under these circumstances onshore-offshore sediment transport may become more prominent than longshore transport.

Actual field measurements of the complete structure of onshore and offshore currents could not be made. The movement of beach sediment has been used as an indicator of onshore and offshore drift, as is discussed at a later stage.

4.5 Beach Sediment

Beach sediment is composed of medium-size sand. Sediment characteristics are given in Table 4.5 as monthly averages for 1980-82 period. The mean sediment size is between 0.25 and 0.40 mm with a standard deviation between 0.4 and 0.6. Median sediment size is between 0.28 and 0.38 mm. The sediment distribution is positively skewed. Berm and foreshore sediments do not show significant differences in textural characteristics. Sediment characteristics do not show any appreciable seasonal variations as well.

Table 4.5 Variation of sediment characteristics in a year.

	Berm sample				Foreshore sample			
Month	Mean size (mm)	Median size (mm)	S.D.	Skewness	Mean size (mm)	Median size (mm)	S.D.	Skewness
Jan	0.32	0.33	0.49	0.07	0.33	0.34	0.48	0.08
Feb	0.34	0.35	0.47	0.12	0.37	0.38	0.40	0.14
Mar	0.31	0.32	0.50	0.06	0.35	0.36	0.43	0.11
Apr	0.32	0.34	0.52	0.14	0.36	0.37	0.43	0.13
May	0.31	0.34	0.30	0.21	0.33	0.35	0.47	0.16
Jun	0.35	0.36	0.43	0.14	0.34	0.36	0.34	0.16
Jul	0.33	0.34	0.47	0.10	0.36	0.38	0.45	0.15
Aug	0.35	0.36	0.41	0.20	0.32	0.33	0.49	0.10
Sep	0.31	0.32	0.49	0.08	0.32	0.33	0.48	0.09
Oct	0.27	0.28	0.55	0.06	0.35	0.36	0.43	0.14
Nov	0.31	0.32	0.50	0.06	0.35	0.36	0.46	0.14
Dec	0.32	0.33	0.49	0.07	0.33	0.34	0.46	0.05

S.D. - standard deviation.

4.6 Summary

Waves during November to April are characterised by low wave height (< 1.5 m), long period (> 10 s) and low steepness (<0.3). These waves come from a direction between 170 and 230 °N, where 190 to 210°N dominate. During June to September the wave climate is dominated by high, short period (< 10 s) waves. Steepness increases upto 0.07. Waves from 230 to 270 °N dominate. During the latter half of this season, a gradual shift to longer periods is observed. A large number of waves from 190 to 230°N are also observed during this period. During May and October a wider range is noticed in all the wave characteristics. Calm spells are noticed during rough season due to the breaks in the severity of monsoon. The wave spectra is generally multi-peaked indicating the presence of different wave trains. The peak spectral density varies from 0.4 m^2s during low wave activity to 7.5 m^2s during rough season. The wave climate along this coast is characterised by moderate to high energy conditions. Waves are well grouped and significant correlation (up to five waves) between successive wave heights is evident. Average breaker height is usually greater than 1 m during most part of the year which is characteristic of high energy conditions. During November to March long period, low breakers dominate. Highest breakers are observed during June to September. Breaker periods are lowest during June-July. Dominating breaker direction is between 210 and 225 °N during September to May. During June to August 235 to 240°N dominate. Plunging breakers are the most common breaker type. The surf zone is fairly wide during June to September. The width is practically zero during December to March. Nearshore currents are a combination of longshore currents and cell circulation systems during June to September. During the other months currents usually flow up the coast.

Beach sediment is composed of medium-sized sand. Mean sediment size is between 0.25 and 0.40 mm. Sediment characteristics do not show any appreciable seasonal variations.

CHAPTER 5

BEACH AND SURF ZONE MORPHOLOGICAL FEATURES

Morphological features of the beach and surf zone are the direct manifestations of the land-sea-air interaction. The study of these features will reveal the processes in operation on a given beach. Various morphological features like berm, scarp, beach face, longshore bar, beach profiles and rhythmic features are discussed in this chapter.

5.1 Surf Scaling Parameter (ϵ):

Since surf scaling parameter, ϵ, is a very useful indicator in describing various beach and nearshore processes (Guza and Inman, 1975; Guza and Bowen, 1975; Wright et al., 1979; Wright and Short, 1983) an attempt is made to understand the temporal variations in this parameter. Wright et al. (1979) has suggested that surf scaling parameter may be calculated separately for beach face and inshore, whenever a wide surf zone is present. The presence of a longshore bar can cause breaking of waves and this can influence reflection and dissipation of wave energy. This will, most probably, depend on ϵ of the offshore side of the bar. Hence, in the present study ϵ of the offshore side of the bar has also been taken into account in addition to that of the beach face and the inshore for a barred profile. The values for one year for Valiathura are presented in Fig.5.1.

Surf scaling parameter for the beach face, ϵ_b, is usually low (< 2.5) during December to April. During May to November it is mostly between 2.5 and 20. A bar is normally present in the surf zone during June to September. Hence the surf scaling parameter for the inshore region (from MWL to

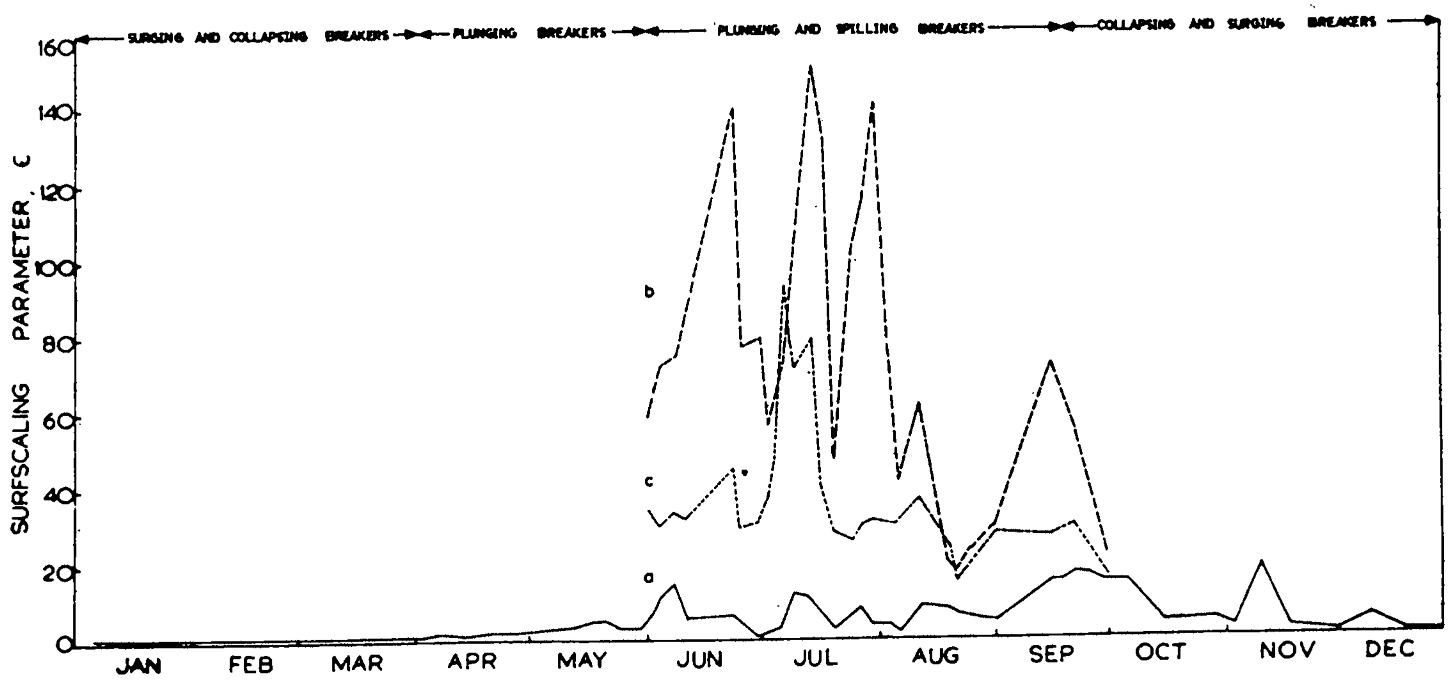

Fig.5.1 Surf scaling parameter for (a) beach face
(b) inshore (c) offshore side of the bar.

the bar), i.e. ϵ_s, and that for offshore side of the bar, i.e. ϵ_{bar}, are also presented. It is seen that ϵ_s is usually high ($>$ 33). ϵ_{bar} is between 10 and 100, with its values less than 33 most of the time.

As mentioned earlier beach and surf zone reflectivity and the type of breakers are indicated by ϵ. For a reflective beach, where most of the incident wave energy is reflected back to the sea, surf scaling parameter will be less than 2.5 and the breakers will be surging. Highly dissipative condition is represented by ϵ greater than 33 while $2.5 < \epsilon < 33$ represents partially reflective conditions. Spilling breakers are characteristic of the former while plunging breakers characterise the latter conditions.

Low values of ϵ_b (≤ 2.5) suggest that the beach face is highly reflective during December to April. It is partially reflective (i.e. partially dissipative) during May to November when ϵ_b is less than 33. Hence the breakers at the beach face will be dominated by surging or collapsing types during December to April. Plunging breakers dominate the remaining months. The occurrence of plunging breakers are more probable on the offshore side of the bar which has $2.5 < \epsilon_{bar} < 33$. An inshore with ϵ_s greater than 33 favours the occurrence of spilling breakers.

5.2 Berm

Berm width and height are very useful parameters to identify the nature of beach erosion/accretion processes (Hine, 1979; Baba et al., 1982). Figure 5.2 gives the distance of the seaward berm crest from the bench mark and its height with respect to MWL at the six stations for one year.

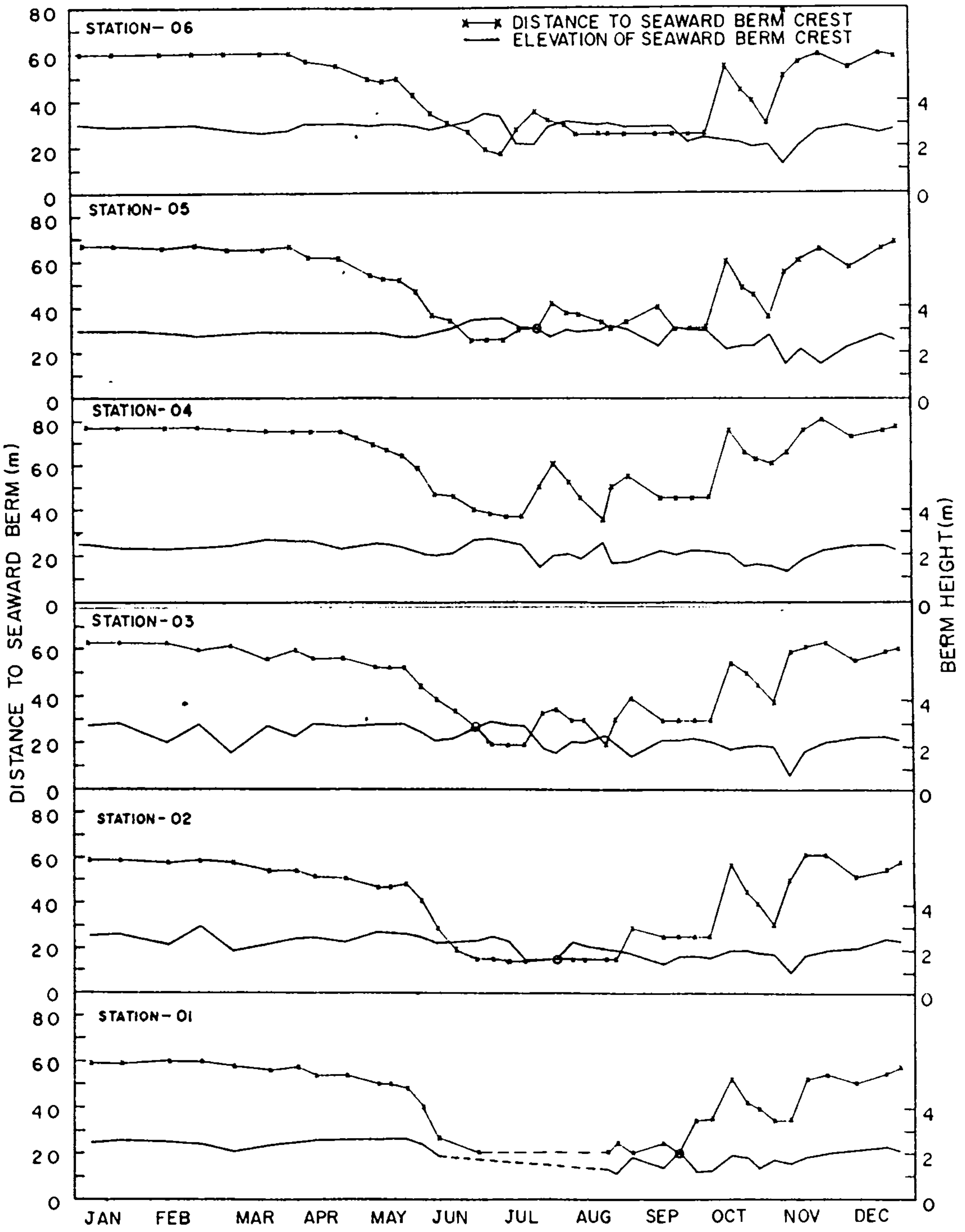

Fig.5.2 Distance of the seaward berm crest from the benchmark and height of berm crest from MWL.

In general, this beach has a wide, high berm during November to May (Fig.5.3). The berm is usually narrow during June to September. Berm characteristics are greatly dependent on the rough and fair season wave climate.

Berm width does not vary much since the second half of November till the end of March. Wave height and steepness are low ($H_s < 1$ m ; $H/L < 0.02$) during this period. Surging and collapsing breakers dominate the breaker climate. The surf zone is very narrow and the beach-surf zone system is highly reflective ($\epsilon < 2.5$). Most of the energy released from breakers is reflected from the beach-surf zone system causing least energy dissipation. Hence they do not affect the berm characteristics significantly. The breaker height increases inducing berm erosion and this causes a rapid decrease in the width and height of the berm. The initial spell of monsoon itself causes a loss of berm width of around 15 to 20 m within a week. The decrease in berm width is around 25 to 35 m within one month. The height of the seaward berm crest initially decreases and then increases (Fig.5.2) during berm erosion. This is due to the presence of multiple berms. Very low berm heights observed towards the latter half of the monsoon season are due to the newly forming berms.

A fall in the severity of wave action occurs when there is a break in the monsoon. The berm starts rebuilding during this break which is evidenced by an increase in the distance of the seaward berm crest from the bench mark (latter half of June and July in Fig.5.2). This is a low berm which is usually removed when the monsoon intensifies after the break. This rebuilding and removal of berm may occur one or more times during the monsoon depending on the number of sufficiently long monsoon breaks.

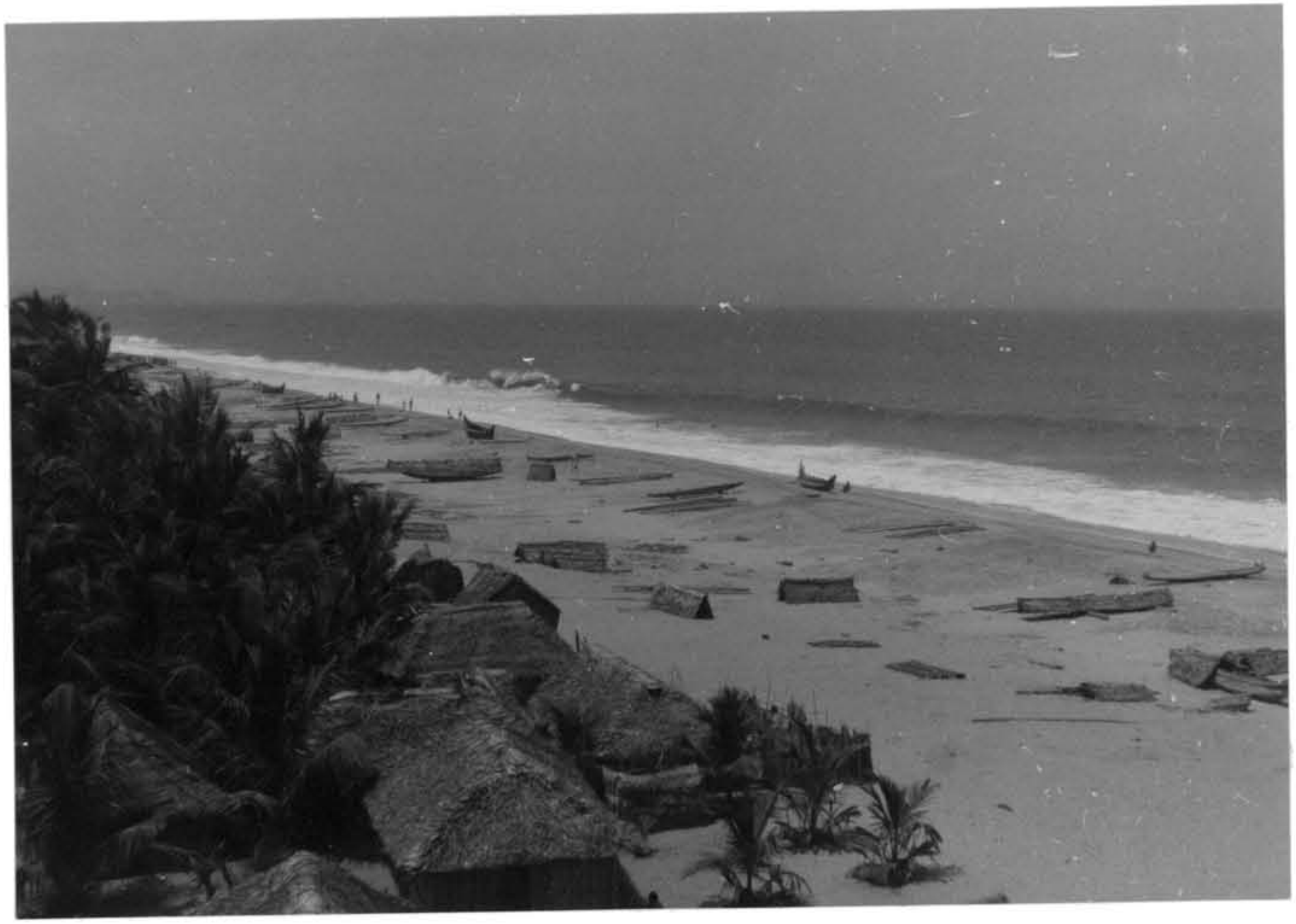

Fig. 5.3 Wide beach / berm.

A continuous increase in berm width is noticed since the end of August. Long period swells dominate the wave climate during this time of berm widening. The major widening of the berm is in jumps rather than gradual. These jumps can be seen in Fig.5.2 during July to October which are accompanied by low berm heights. In between the jumps, berm width decreases slightly as they get stabilised and the height increases. By October the width of the berm increases almost to the pre-monsoon level.

It is observed that the variations in berm width are more or less uniform at all the stations throughout the year except during monsoon breaks. An increase in berm width at station 03 and a decrease at station 02 occur simulataneously. This aspect is discussed in detail in forth-coming section (5.9).

The height of the newly forming berm is initially low. The berm then grows vertically. This vertical growth is gradual. The horizontal growth (increase in the width) of the seaward berm virtually ceases by December when the pre-monsoon level is almost achieved. The vertical growth of the berm still continues. By March, berm height reaches its maximum and is almost equal to the pre-monsoon height. This pattern of berm erosion and rebuilding is observed in all the six locations in the study area.

5.2.1 Berm erosion and reformation

One of the most obvious parameters associated with berm erosion and reformation is the wave steepness. Wave steepness at the study site varies between 0.02 and 0.07 during April to October (Fig.4.3). It gradually increases in May. The surf scaling parameter for the beach face (ε_b) also increases. Breakers become plunging. Hence more energy is dissipated on the beach face resulting in its gradual erosion. This increases the beach face slope. The slope becomes maximum in May, immediately before the monsoonal erosion. Steeper beach face is more conducive to eorsion (King, 1972). With the onset of monsoon wave steepness becomes greater than 0.04. ϵ_b also increases and is greater than 10, making the beach face further dissipative. Breakers as high as 6 m are observed and beach surf zone becomes a high energy, high dissipative area. Thus more energy is available in this zone and the berm gets quickly eroded (15-20 m within a week) and a longshore bar develops (Fig. 5.4 - profile no.3).

A fall in wave steepness below 0.04 (Fig.4.3) due to decreased wave activity (either due to a sufficiently long break in the monsoon or due to a receding monsoon) initiates an onshore movement of sediment from the longshore bar resulting in a flat, unbarred inshore profile (Fig.5.4 - profile nos.6,10,14). The beach continues to be partially reflective. A wide bar nearer to the shoreline then develops due to the continuing onshore transport of sediments together with the backwash from a partially reflective ($2.5 < \epsilon_b < 33$) beach face (Fig.5.5 - profile nos.7,11,15). A few days later, the wide bar gets divided into two and the inner bar migrates and welds onto the beach, followed by the outer bar (Fig.5.4 - profile nos. 8,12,18). A low berm develops as a result of the welding of the inner bar. These processes repeat, thus increasing the width of the newly formed berm. This process of berm development stops or reverses on intensification of wave activity.

The outer bar mentioned above develops as a breakpoint bar due to the plunging breakers on the partially dissipative ($2.5 < \epsilon_{bar} < 33$) offshore side of the bar. The development of inner and outer bars is prominent when the

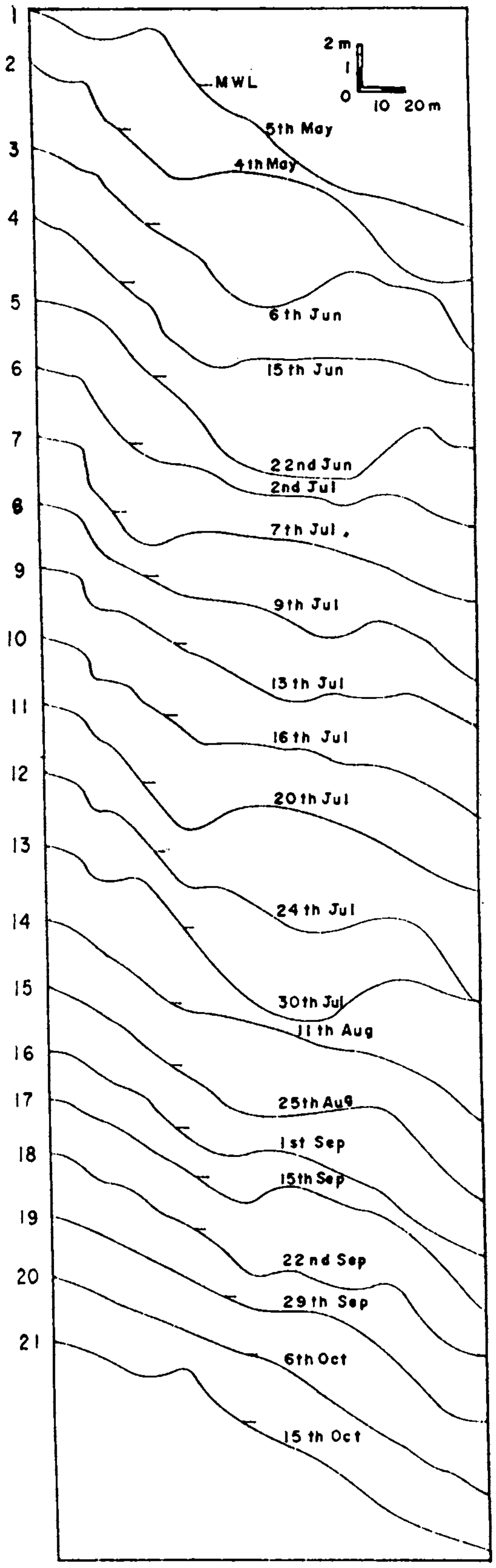

Fig.5.4 Beach profiles at station 04 during 1981.

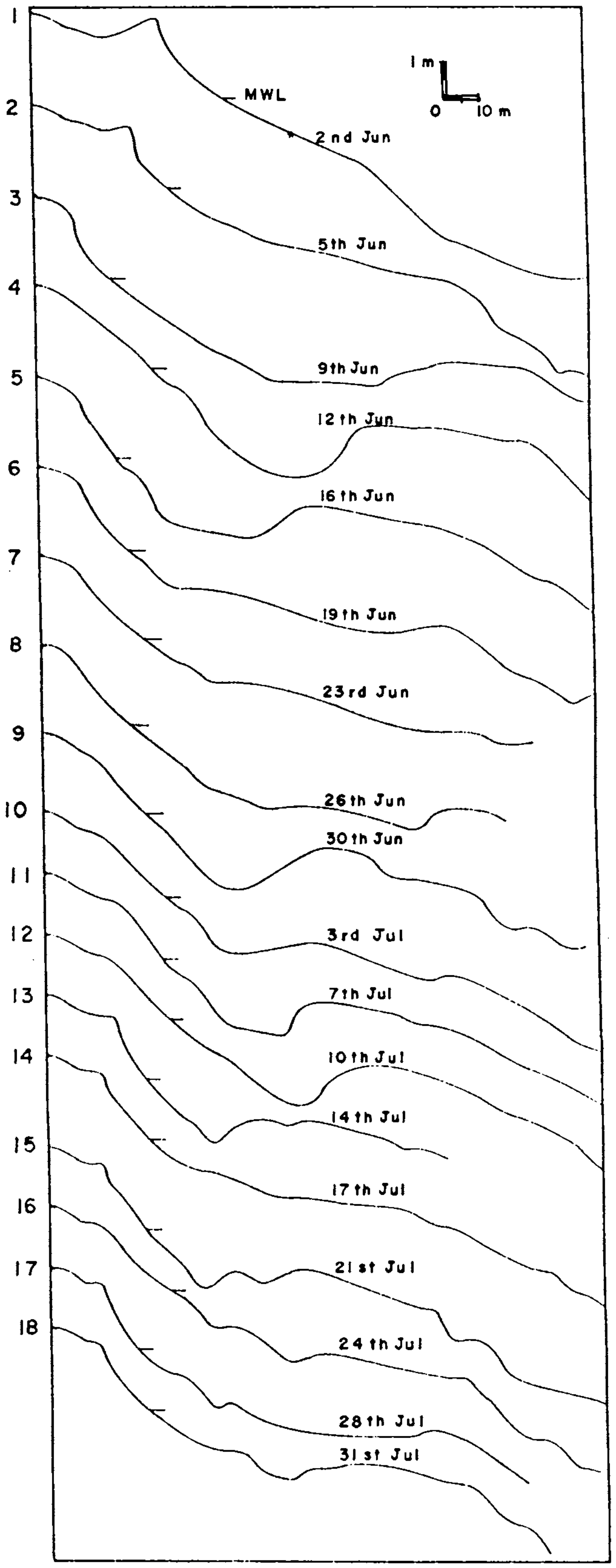

Fig.5.5 Beach profiles at station 04 during 1980.

surf zone is wide. Goldsmith et al. (1982) have also observed the formation of an additional inner bar at the shallow inshore when the bar tends to migrate onshore.

A similar sequence of berm development is observed in Fig.5.5 also which gives the sequence of processes during another year.

5.2.2 Vertical growth of the berm

The low berm, newly formed as a result of the initial migration and welding of the bar, grows vertically in addition to its horizontal growth. Vertical growth of a beach occurs when the profile slope is out of equilibrium with the existing sediment size and wave energy (King, 1972). Vertical growth continues till an equilibrium slope is attained. The slope of the flat profile (0.07-0.09) which forms immediately after the welding of the inner bar is out of equilibrium with the mean sediment size (0.35 mm) and wave energy (H_s = 1-2 m) of this beach. A decrease in wave height and steepness also necessitates an increase in beach slope (Bascom, 1951; Weigel, 1964) as seen here since September. Hence the berm has to grow vertically to attain an equilibrium slope.

Vertical growth of a berm is mainly due to the variations in water level which causes variations in the upper limit of swash (Hine, 1979). Variations in water level along this microtidal beach are due to the variations in the breaker height and type which leads to varying set-ups. This contributes to the variations in the upper limit of swash, helping the vertical growth of the berm. Short period monsoonal waves are followed by long period waves which are accretory. Sediment is deposited in the upper parts of the beach face when long period, moderate breakers dominate.

When there is an increase in wave height, swash of the breakers overtops the berm crest and increases the berm height by moving the sediment deposited in the upper parts of the beach face to the berm crest. Low wave steepness during the post monsoon period is helpful for accretion. As the berm grows vertically the beach face becomes more reflective causing collapsing and surging breakers. Relative amplitude of swash increases as the breakers tend to be collapsing and surging. Hence the swash can still overtop the berm crest and increase the berm height further eventhough there is a fall in wave height. This gradual vertical growth continues until the beach attains a slope which is in equilibrium with the existing grain size-wave energy relationship. As a result the beach face becomes highly reflective. This condition continues without causing any appreciable change in the beach and surf zone morphology during October-April.

The variations in the berm width and height during one year shows that the beach erosion-accretion processes along this part of the coast is cyclic and seasonal. The southwest monsoon waves cause intensive beach erosion during June to August. Erosion is not a continuous process. It is interrupted by monsoon breaks which initiate beach reformation. This reformed beach is removed when monsoon intensifies subsequently. Beach accretion after monsoonal erosion proceeds in steps. Formation of new berms increases the width of the beach abruptly. But the vertical growth of the beach is a gradual process as evidenced by the gradual increase in berm height.

5.2.3 Long term changes in berm width

To get a better idea of berm width variations during a longer period, the maximum berm width observed every month during 1980-84 is given in Fig.5.6. The maximum observed berm width at station 04 is between 80 and 90 m. The minimum is between 35 and 45 m. The maximum width is observed during November-December while the minimum is observed during July. The maximum width does not correspond to the fully developed berm since the berm height does not attain its maximum position by then. This maximum width decreases as the berm grows further vertically and stabilises at 70-80 m by January. This does not show any significant variation during these 5 years.

The distance to the shoreline from the bench mark at all the six stations for 1980-84 are also given in Fig.5.6. This also confirms that the beach is more or less stable here.

Yearly variations in wave characteristics, are not fully reflected in the amplitude of variations in berm width. There are some more factors like the presence of rhythmic features and the presence of longshore bars, in addition to the incident waves that regulate the amplitude of beach erosion. These aspects will be discussed later.

5.3 Scarp

Scarp is an erosional feature. This is observed on a few days during March to August. Figure 5.7 shows a deep scarp observed along this coast. Scarp heights vary between 0.3 to 2 m (Table 5.1). This Table gives only a few typical occurrences. The highest scarps are found during giant cusp erosion (also see section 5.9). Scarps which are not associated with erosion in the embayments of giant cusps are usually uniform and observed throughout the coast. Those scarps formed in the embayments are limited to the embayments themselves with its height decreasing towards the cusp horns

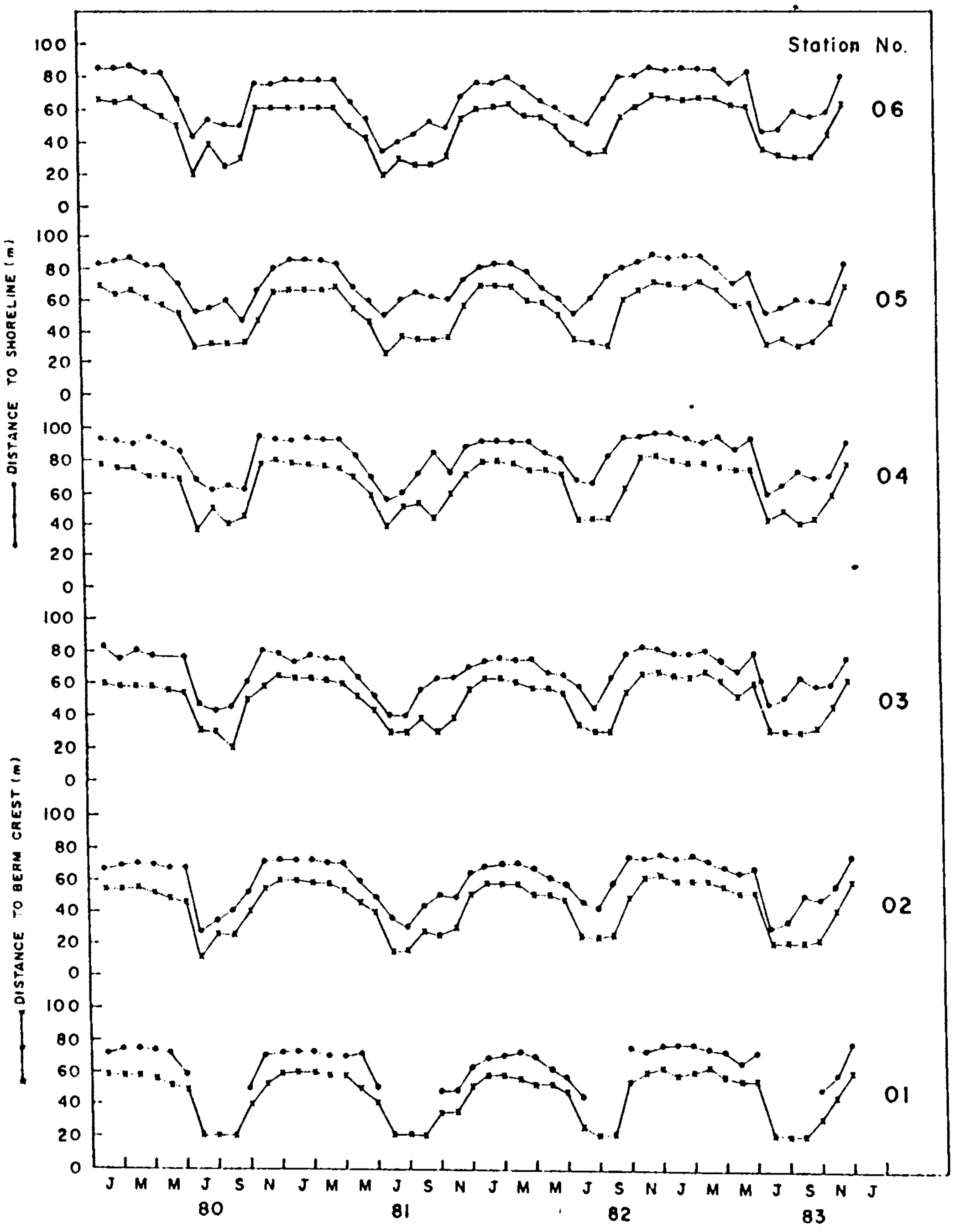

Fig.5.6 Distance of the seaward berm crest and shoreline from bench mark.

Fig. 5.7 Deep scarp.

Table 5.1 Scarp Characteristics

Date	Scarp height (m)	Status
12.05.80	0.50	all along the beach
26.05.80	0.90	-do-
19.06.80	1.40	at embayments
13.04.81	0.40	all along the beach
12.05.81	0.55	-do-
01.06.81	0.75	-do-
04.06.81	1.10	-do-
02.07.81	2.00	at embayments
03.12.81	0.30	all along the beach
22.03.82	0.25	-do-
03.04.82	0.40	-do-
04.06.82	0.75	-do-
24.06.82	1.10	at embayments
08.07.82	1.20	-do-

5.4 Beach Face Slope

The variation in beach face slope during one year is given in Fig.5.8. Slope is generally high during December to May and is usually greater than 0.15. The slope is maximum immediately before the monsoonal beach erosion. This is due to the gradual erosion of sediment from the beach face with increasing wave heights preceding the onset of monsoon. An increase in beach slope makes the beach more prone to erosion. With the onset of monsoonal waves, severe erosion results in the formation of scarps. Still the beach face does not attain its minimum, though erosion is at its peak. The minimum beach face slope(0.07) occurs immediately after the welding of the bar onto the beach face during beach reformation.Vertical growth of the berm, which developed with the welding of the bar, increases the slope further. A steep beach face slope ($>$0.15) is attained by November.

5.5 Beach Profiles

The type of profile along a particular beach is deter-

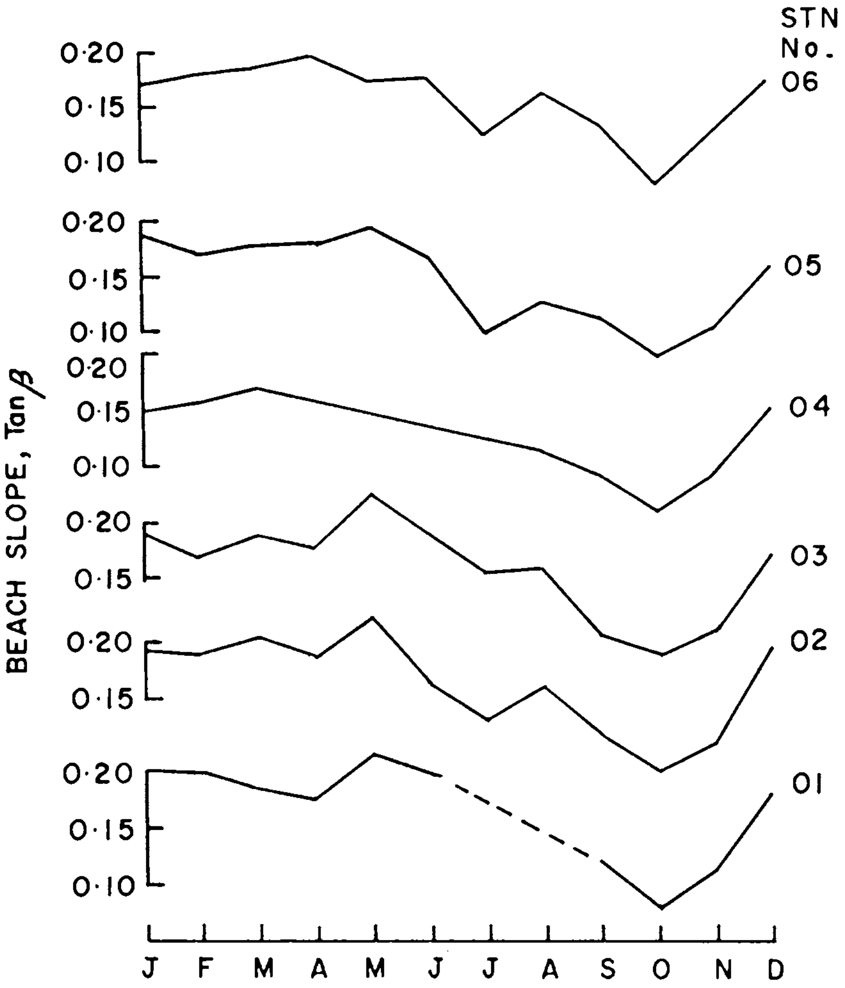

Fig.5.8 Variation in beach face slope.

mined mainly by the wave energy regime prevailing in that region. Since the different seasons in an year are having distinct wave characteristics, the type of the profile will also be different during different seasons.

In general, three distinct types of beach profiles are noticeable along this coast. Typical examples of these types at the six profiling stations in the study area are given in Fig.5.9. The profiles at station 04 cover more area extending beyond the surf zone for most part of the year. Profiles observed during December to May can be considered as Type I. This type has a wide beach with a well developed berm and a steep beach face. The berm is concave-shaped with a landward dipping slope on the seaward side. The corresponding wave climate is characterised by long period (mostly >10 s), low waves from 190 to 220°N. Short period (4-6 s), low sea waves (<0.5 m) from 240 to 270°N may also occur during this time.

Surf scaling parameters show that both reflective and partially reflective conditions exist with the Type I profiles. Highly reflective conditions ($\epsilon_b < 2.5$) are observed during most part of December to March while they are partially reflective during April and May. It means that surging, collapsing and plunging breakers are associated with Type I profiles. Wave energy dissipation in the surf zone is least for surging and collapsing breakers which occur with reflective conditions. Hence no major changes in beach morphology take place. Surf zone width is also minimum or even negligible. Plunging breakers due to partially reflective conditions during April and May can cause slight erosion of beach face and increase in its slope. Except this change in beach face slope, the beach and surf zone is free from major morphological changes. The surf zone becomes slightly wider during April and May. Rhythmic shoreline features like beach cusps are usually absent when the pro-

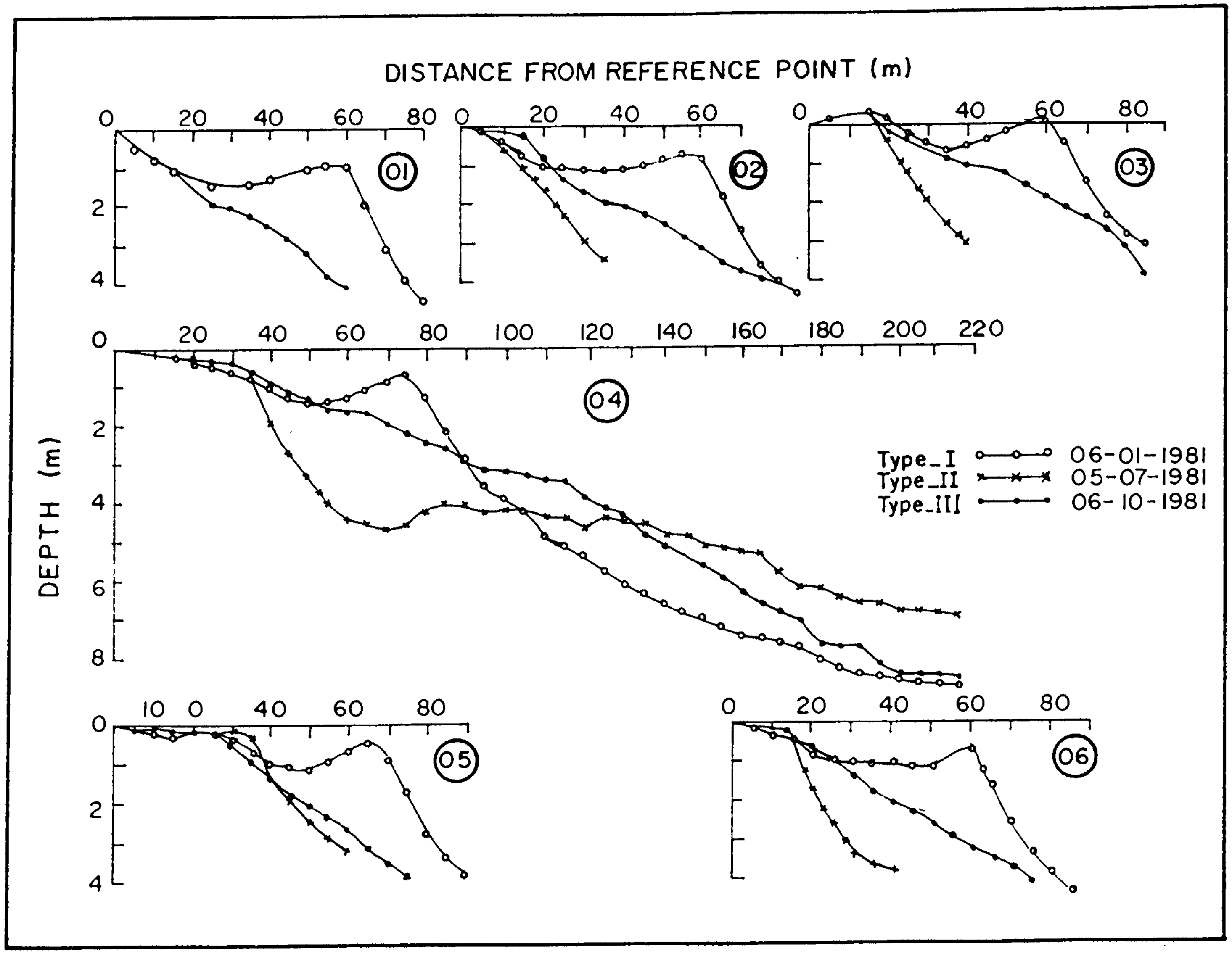

Fig.5.9 Typical examples of different beach types.

files are of Type I.

Type II profiles are observed during the southwest monsoon season. This is characterised by an eroded, narrow beach. Beach face is usually steep. Scarps may be present. Surf zone is wide (100 to 150m). A longshore bar is prominently present in the surf zone with a trough shoreward of the bar. Rip currents are observed all along the coast.

The beach face remains partially reflective with ϵ_b usually less than 2.5. The inshore is dissipative. The offshore side of the bar is partially reflective with ϵ_{bar} values between 2.5 and 33. Since nearshore wave breaking is depth limited, waves above a particular height alone breaks at the bar. Partially reflective conditions at the offshore side of the bar causes plunging of breakers at the bar. The broken waves reform in the trough and again plunge or collapse at the beach face. Waves which do not break at the bar dissipate most of the energy in the surf zone and form spilling breakers.

Uniform scarps may be observed during the initial stages of beach erosion and may co-exist with Type II profile (Fig.5.10). Beach rhythmic features may or may not occur with this type of beach profile. Short period, high waves (steep) characterise the wave climate associated with the Type II profile.

Type II profiles show different and distinct beach morphologies under decreasing and increasing wave energy conditions. Under rising wave energy conditions this profile has a prominent longshore bar and the shoreline is generally straight. Under falling wave conditions the longshore bar becomes crescentic and the shoreline may have giant cusps on it (This will be discussed later in this chapter).

Fig. 5.10 Uniform scarp.

Type III profiles occur when the bars weld onto the beach face during beach accretion. Beach face slope becomes the lowest and the surf scaling parameter increases accordingly. Surf zone becomes highly dissipative with very high ϵ_s ($\gg 33$). Most of the waves spill through the surf zone and break as spilling breakers dissipating a major part of the energy in the process. It may be noted that a decrease in wave activity from the monsoonal peak initiates beach accretion. A few high waves also occur during this period and they break at the offshore side of the bar as plunging breakers. The offshore side of the bar still continues to be partially reflective with ϵ_{bar} between 2.5 and 33. Rhythmic features like beach cusps may form on this beach. Type III profiles gradually grow vertically and horizontally to become Type I, thus completing a cycle.

5.5.1 Beach profile classification

The widely used categorisation of beach profiles as summer and winter profiles do not have universal applicability (Komar, 1976). The classification proposed by Komar (1976) and Greenwood and Davidson-Arnott (1979) as storm (barred) or swell (non-barred) profile too do not reflect fully the different stages in a beach undergoing seasonal and cyclic erosion-accretion. It has been found during the present study that the beach exhibits two-dimensionality only when the beach is in a fully accreted equilibrium form or when the profile is having a shore-parallel longshore bar at the time of the initial phase of monsoonal erosion under rising wave energy conditions. Under decreasing wave energy after the formation of a longshore bar, the beach completely loses its two-dimensionality. Both the shoreline and the surf zone show strong alongshore variation in the morphology as mentioned earlier. Hence a more meaningful classification could, perhaps, indicate the energy levels alongwith the prominent morphology. The profile types discussed earlier can be re-named explicitly as follows: (1) non-barred profile (Type I), (2) barred profile under rising wave energy (Type II), (3) barred profile under decreasing wave energy (Type II) and (4) welded profile (Type III).

Of these, the non-barred profile is associated with low to moderate wave energy conditions and the other three are associated with moderate to high energy conditions. The morphology corresponding to each profile is similar to those described for Types I, II and III. But the barred profile under decreasing conditions generally has a wide or a split bar.

A more general and simple classification of beach profiles along a monsoon-influenced coast, like the one presently studied, can follow the wave climate classification discussed in Chapter 4. Then the profile types will be as follows: (1) rough season (monsoon) profile and (2) fair season (non-monsoon) profile. The rough season profile includes the last three of the previously given classification. The fair season profile is the same as the first one.

The idea behind the usual profile classifications like summer and winter or barred and non-barred is that bars form during storm or high energy conditions and low energy conditions maintain non-barred profile. These extreme conditions are generally thought to be more important. But the present study highlights the importance of intermediate stages which can be incorporated into profile classifications only with reference to the energy level. This aspect is taken into account in the profile classification being proposed in this study.

5.6 Volume of Beach Sediment

Changes in beach profile configurations during different seasons cause corresponding changes in the volume of beach sediment. The volume of beach sediment at each one of the six locations in the study area are given in Fig.5.11. They correspond to the observed beach profiles during an year. Profiles upto MWL have been used in all locations except in station 04 to calculate the volume of sediment. In station 04 the profile covers the surf zone too in addition to the subaerial portion.

A significant fall in the volume of sediment (of the order of 50 m^3/unit width of the beach) above MWL occurs in June, coinciding with the onset of monsoon. The decrease is very sharp and the minimum value is obtained by the end of June itself. Low values of sediment volume continue through July and August without any significant further decrease. An increase in beach sediment volume as a result of gradual beach rebuilding is observed since September. The premonsoon volume of beach sediment in the profile is almost attained by December. More or less the same pattern is observed in all the stations. This again points to the cyclic nature of beach erosion-accretion process in this region. The net loss or gain of beach sediment during the erosion-accretion cycle is insignificant.

The change in the total volume of beach sediment at station 04 gives an indication as to what happens to the eroded sediment. Sediment in the inshore is also accounted in this total volume. It is interesting to note that the volume remains almost the same during March to September when its variations are only between 1090 and 1110 m^3/unit width of the beach. The erosion of beach above MWL during

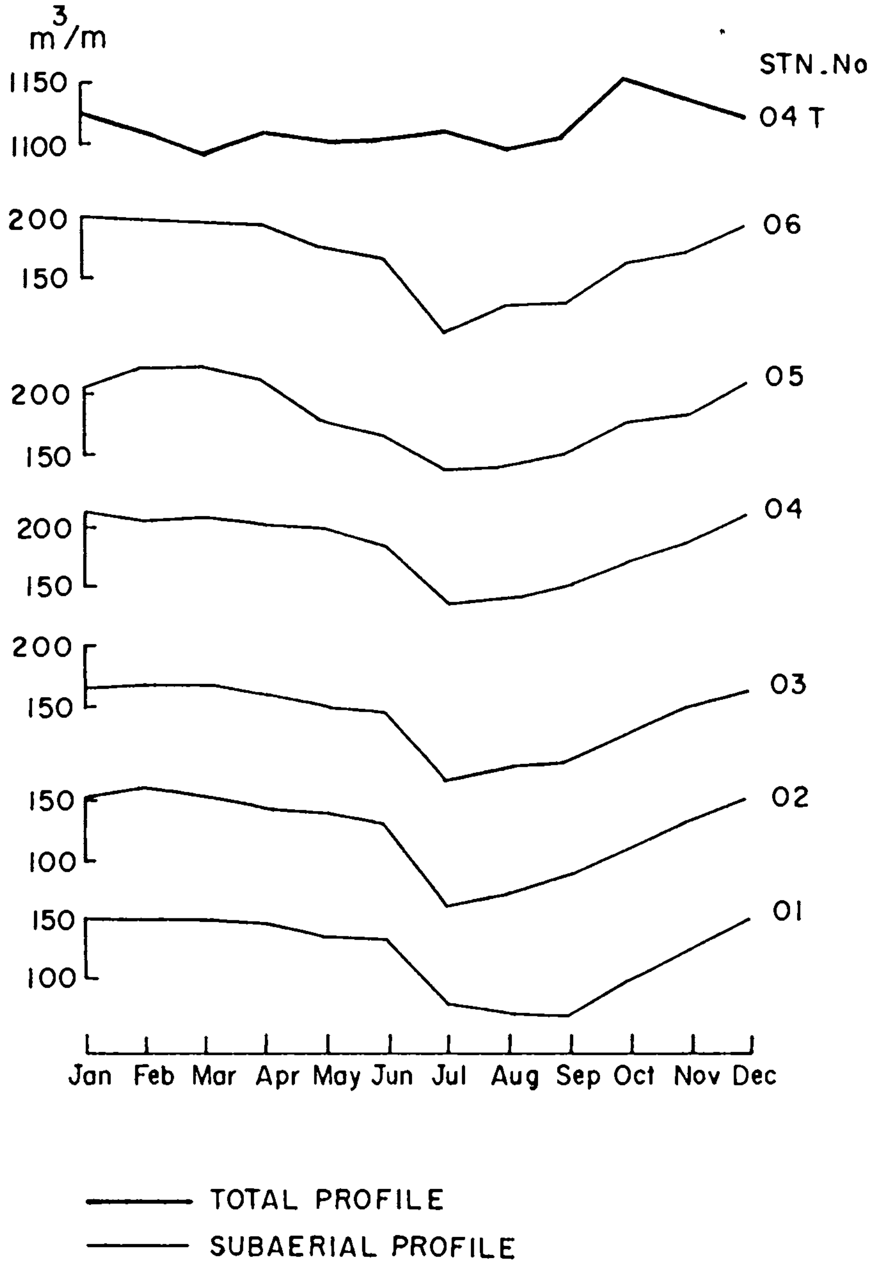

Fig.5.11 Volume of beach sediment at different profiling stations above MWL. 04T is the volume of the total profile.

monsoon is not reflected in the total volume of sediment. In the earlier sections it has been noted that the monsoonal erosion results in the formation of a longshore bar in the surf zone. These imply that the major part of sediment removed from the subaerial portion of the profile during monsoon is moved offshore and stored in the inshore profile itself. This is later brought onshore for beach reformation during the post - monsoon period. These suggest a dominance of onshore-offshore transport of beach sediment in the process of beach erosion-accretion cycle along this part of the coast. The sequence of profile changes discussed in the earlier sections also suggest such a domination.

5.7 Longshore Bars

Along this coast, longshore bars are usually found to exist during the monsoon season. These are associated with monsoonal waves and the resultant beach erosion. Bar characteristics are presented in the Table 5.2 in the form of the ratio between the depth of the trough (h_t) to the depth of the bar crest (h_c) from the mean water line. The ratio h_t/h_c is a measure of the bar relief. The value of h_t/h_c approaches one for a non-barred profile. Large values of h_t/h_c indicate better developed bars. The distance of the bar crest from the shoreline (x_c) is also given in the Table 5.2.

The ratio h_t/h_c is generally between 1.1 and 2.1. This is maximum immediately after the peak of a severe wave condition which produces a longshore bar (eg. 12th and 30th June, 1980; 8th and 23rd June, 1981 in Table 5.2). Usually the bar relief decreases with the splitting of the bar into inner and outer bars (to be discussed later in this chapter). The inner bar relief is less than the outer bar relief. The bar relief generally increases as the dis-

Table 5.2 Longshore bar characteristics

Date	h_t/h_c	x_c (m)
09.06.80	1.33	115
12.06.80	1.74	160
19.06.80	1.19	101
19.06.80	1.14	--
26.06.80	1.28	112
30.06.80	2.00	92
07.07.80	1.75	67
10.07.80	1.84	70
14.07.80	1.53	62
17.07.80	1.10	60
21.07.80	1.38	60
21.07.80	1.34	50
08.06.81	1.73	100
16.06.81	1.18	110
23.06.81	2.10	158
30.06.81	1.10	120
06.07.81	1.71	160
09.07.81	1.44	105
09.07.81	1.09	--
20.07.81	2.17	--
24.07.81	1.37	100
24.07.81	1.15	--
27.07.81	1.82	110
06.08.81	1.44	75
25.08.81	1.21	90

1 - outer bar; 2 - inner bar

tance from the shoreline to the bar crest increases. The maximum distance of the bar crest from the shoreline is observed to be around 160 m. Bar relief is low during the onshore migration of the bar.

Longshore bar forms when a 'non-barred profile' gets eroded and transforms into a 'barred profile under rising wave energy'. It has been shown that the former has a steep beach face and an inshore with a narrow surf zone. Erosion of the beach starts prior to the onset of monsoon. This decreases the inshore slope, but not that of the beach face. Surf zone width also increases and a beach terrace forms and widens seaward of shoreline. This process continues and the bar develops after a few days (7-10 days) after the onset of monsoon. It seems that the longshore bar develops only when the surf zone width exceeds a minimum value. Field observations on surf zone width just before bar formation indicates that these values are in the range 50 to 60 m. Prior to bar formation surf scaling parameter for the beach face (ϵ_b) is less than 10 and that of the inshore (ϵ_s) is much greater than 33. This shows that the beach face is reflective to partially reflective and the inshore highly dissipative just before bar development. The profiles (Fig.5.4 - profile nos.4,6,14 and Fig.5.5 - profile nos. 2,7,14) show almost flat, highly dissipative surf zone. Such flat profiles are common immediately before bar formation or before the occurrence of major changes in bar topography.

The breakers are usually plunging during the period of bar formation. High and steep spilling breakers also infrequently cause the formation of longshore bars as in June, 1983. An increase in breaker height (also wave steepness) pushes the longshore bar 15 m offshore within a period of 8 days (profile nos. 2 & 3 in Fig.5.4). The significant wave height increases to 4 m during this period. It may be noted that wave steepness shows a slight decrease in between (ie. on 12th June). But the bar continues its offshore migration. The bar is well-formed with a ·better bar-trough relief (Table 5.1) after the peak of the first phase of monsoon. The bar crest, by now, is around 120-130 m from the shoreline.

The bar crest is 120-130 m off the shoreline even at the time when the bar is first observed during the monsoon of 1980 (Fig.5.5 - profile no.3). Probably the time scale of observation is not suited to account a rapid offshore migration of the bar during June, 1980. A fall in breaker height and wave steepness change the bar topography considerably.

The sequence of onshore migration of the bar corresponding to a decrease in breaker height and wave steepness for the year 1981 is given in Fig.5.5. A fall in the crest-trough relief, widening of the bar and shrinking of the trough and the splitting of the bar into inner and outer bars are noticed in the process of onshore migration (Fig.5.5). A decrease in breaker height and steepness is observed since 23rd June. The bar crest-trough relief becomes low ($h_t/h_c = 1.1$) on 30th June by the filling up of the trough. The trough depth which was 4.4 m from MWL on 23rd has become 2.75 m on 30th. A wide bar nearer to the shoreline (almost covering the entire inshore) is observed on 6th July. The cross shore width of this bar is around 100 m. The trough becomes narrow with a width of nearly 10 m. The profile on 9th July shows that this wide bar splits into an outer and inner bar. The bar crest-trough relief is generally low for the split bars. Usually the outer bar is well-formed with a greater relief than the inner bar (Table 5.2). The accretion of the beach face has started almost simultaneously with the onshore migration of the bar, well before the welding of the bar onto the beach face (Figs.5.4 & 5.5)

A flattening of the inshore by the filling.up of the trough is observed on most of the occasions just before the onshore migration of the bar. Such flat inshore profiles are observed in profile nos. 6,10 & 14 (Fig.5.4). A wide bar forms nearer to the shoreline on this flatter inshore profile as part of the onshore migration of the bar.

A similar morphological sequence of bar formation and its migration with the resultant beach accretion is observed during 11th August to 8th October (Fig.5.4 - profile nos. 13-18).

A substantial decrease in beach face slope occurs immediately after the welding of the inner bar onto the beach face (Fig.5.4 - profile nos.9 & 19).

The initial welding of the inner bar causes the formtion of a low berm. This berm grows vertically and horizontally under favourable wave conditions. Onshore migration and welding of outer bar also take place in between. A more or less similar sequence of bar formation, onshore/offshore migration and welding onto the beach face are noticed during the year 1980 also (Fig.5.5).

The flattening of the inshore profile, discussed earlier in this section, is an interesting feature that occures during different stages of bar formation and migration. This has been observed to occur prior to longshore bar formation (profile no.2 in Fig.5.5) and also just before the onshore migration(profile no.10 & 14 in Fig.5.4 and 6 & 14 in Fig.5.5). Profile no.4 in Fig.5.4 shows a flattened inshore profile just before the offshore migration of the bar. This flattening of the inshore profile before onshore and offshore migration of the longshore bar is not yet documented by other researchers.

5.8 Breaker Modification Due to Bars

As waves cross nearshore sand bars, they break under certain conditions and subsequently reform in the trough to break nearer to the shoreline. During this process wave energy is dissipated at the bar so that the impact of incoming waves on shoreline processes is reduced. This breakwater effect (Davis, 1978) is important for a wide range of geomorphological processes.

Once the bar is formed, the breaker position and type are controlled, to a certain extent, by the bar. Depth at the crest of the bar from MWL is usually between 2 to 4 m. When the bar forms nearer to the shore as part of onshore migration, this depth decreases to 1 to 2 m. As this bar splits, the outer bar crest will be at a depth of 2 to 3 m and the inner bar at a depth of 1 to 2 m. According to linear wave theory the maximum nearshore breaker height is 0.78 d where 'd' is the local depth. Then only waves with heights less than 1.5 m will cross the outer bar crest without breaking. When the depth of the outer bar crest is 4 m, all the waves greater than 3.10 m break before crossing the bar crest. The surf scaling parameter ε_{bar} on the offshore side of the bar is found to be between 2.5 and 33 most of the time. This indicates that the offshore side of the bar is partially reflective and hence breakers at the outer bar are mostly plunging. The breaker waves usually reform in the trough and again plunge on the beach face which is reflective to partially reflective with ε_b less than 10. Waves which cross the bar without breaking also plunge at the beach face.

During the onshore migration the bar is wider and nearer to the shore usually with a narrow trough. Wave heights will also be less since a decreased wave activity is initiating onshore bar migration. Most of these waves spill across the wide bar and cross the narrow trough and again plunge at the beach face. Higher waves will be plunging at the offshore side of the bar. Broken waves travel as a bore across the wide bar and plunge at the beach face.

Thus, the presence of a bar causes the breaking of most of the high waves at a distance from the shoreline. Only smaller waves could cross the bar unbroken and plunge directly at the beach face. Carter and Balsillie (1983) has found that individual reformed waves rarely contain more than 20% of the original incident wave energy. A well developed bar which forms within 8-10 days after the start of monsoonal erosion prevents most of the wave energy from reaching the shoreline. Hence beach erosion after the initial phase of monsoonal erosion should be due to forces other than the direct impact of incident waves.

5.9 Crescentic Bars

Longshore spacing of the crescentic bar horns varies between 150 to 350 m. The trough is narrow at the horns. Both plunging and spilling breakers are observed. Spilling breakers are more common across the bar horns.

It has been shown that monsoonal berm erosion results in the formation of a longshore bar. A decrease in breaker height and wave steepness initiates an onshore migration of this bar. The bar migrates faster at some places. Crescentic bar horns form at these locations and the embayments form at the places where this onshore migration is slow.

Onshore bar migrations are observed on two occasions. One is during monsoon breaks and the other is during the post-monsoon recovery of the eroded berm. Longshore bar migration and the cresentic bar formation during monsoon breaks may be interrupted when monsoon revives. But these processes during the post-monsoon recovery usually continue without interruption and the bar welds onto the beach face. Crescentic bar formation during monsoon breaks is reflected along the shoreline in the form of giant cusps. Crescentic bars formed during the post-storm recovery does not show any such rhythmic shoreline features. But beach cusps are observed to form immediately after the welding of the post-monsoonal bar horns onto the beach face.

Thus the crescentic bars are always associated with the onshore migration of longshore bars during post-storm beach recovery. This aspect has not yet got proper consideration in the study of longshore crescentic bars. Another important aspect to be noted is that the time scale for the transition from linear to crescentic bars seems to be short, only of the order of days.

5.10 Giant Cusps

Table 5.3 gives the observed characteristics of giant cusps along the Valiathura coast. They form usually during the southwest monsoon months of June, July and August. Wave length of these giant cusp horns are between 150 to 400 m (Fig.5.12). Alongshore width of these giant cusp horns are in the range 70 to 100 m. Cusp embayments experience severe erosion producing scarps of 1 to 2 m (Fig.5.12). Height of the scarp is maximum at the middle of the embayments and decreases towards the cusp horns.

Fig. 5.12 Giant cusps and embayment erosion.

Table 5.3 Giant cusp characteristics.

Date	Average cusp wave length(m)	Max. embayment scarp height(m)	Width of the cusp horn(m)
19.06.80	175	1.4	75
26.06.81	230	1.9	90
02.07.81	255	2.0	100
24.06.82	180	1.1	70
08.07.82	175	1.2	70

Giant cusps develop as crescentic bar migrates onshore. Giant cusps co-exist with crescentic bars, with bar horns forming close to the shore. Corresponding to the break in the monsoon towards the end of June, giant cusps are observed to form along the foreshore (since 26th June, Fig.5.13). This break in the monsoon is exceptionally long almost extending to the entire month of July. The behaviour of giant cusps during this period is documented with the help of three-dimensional beach topography. Since the occurrence of giant cusps has not been taken into account in the selection of profile stations (as the occurrence of giant cusps has not been documented in the available literature on beach processes of this coast), the topography presented here do not give a total picture of such morphological features. Hence the inferences made are based on some additional measurements specifically made on the cusps.

Fig.5.13(a-h) give a three-dimensional picture of the beach upto the MWL. Figure 5.13a shows the pre-monsoon beach which has an almost straight shoreline. The topography of the beach immediately after the formation of a longshore bar (a well developed bar has developed by 8th June) is shown in Fig.5.13b. The shoreline continues to be straight in this topography also. A break in the monsoon initiated an onshore migration of the longshore bar towards the end of the 3rd week of June (Figs.5.4 & 5.5). In this process longshore bar becomes crescentic. Giant cusps develop on 26th June. Figure

5.13c shows the topography immediately after the formation of giant cusps. A cusp horn has developed between stations 04 and 03 and another south of station 02. An embayment is at station 05 and another just south of station 03. Based on special observations and measurements in the field a cusp horn between stations 05 and 06 and an embayment north of station 06 are located. Due to the relatively large spatial scale of the alongshore position of profiles these are not revealed in the topography. Slope of the beach face is steep at stations 03 and 05 while they are more gentle at stations 02 and 04. The embayments are affected by severe erosion resulting in the formation of scarps of around 1.5 to 2 m.

Break in the monsoon and the resultant calm conditions are continued. Fig.5.13d gives the beach topography after about one week which shows changes in the cusp and embayment positions. There is considerable longshore widening of the cusp horn. Scarp at station 03 has migrated towards station 04 and the scarp at station 05 has become a gently sloping cusp horn. There is a cusp horn between station 03 and 02. The width of the beach at station 02 has decreased and steepness increased. A widening of the beach is observed at station 06 also. Topography after another week depicts further variations in these features (Fig.5.13e). The place of erosion (embayment) is now at station 02 while the beach at station 04 has become gently-sloping and wide. A cusp horn has developed at station 06 while an embayment forms with a high scarp at station 05. An embayment is present just south of station 04 and a horn around station 03. Again these features are not clear due to the inadequacies in the alongshore positioning of stations. Fig.5.13f shows further changes in the topography. Beach accretion and widening of the beach is observed between stations 05 and 03. Embayments are observed near stations 02 and 06.

A revival of the monsoon towards the end of July almost smoothened these morphological states (Fig.5.13g). A wide beach without any significant shoreline irregularities after the post-monsoonal accretion is given in Fig.5.13h. Figure 5.14 gives the profiles along cusp horns and embayments of giant cusps. Cusp horn profile is gently sloping while the embayment profile is steep and has a deep scarp. The cusp horn at station 02 on 30th June has become an embayment on 13th July and the embayment at station 06 on 30th June has become a horn on 13th July. Such substantial changes in the morphology is due to the lonshore migration of giant cusp horns and embayments.

5.11 Beach Cusps

The beach under study is generally non-cuspated with a straight shoreline. Beach cusps appear during the post-monsoonal recovery of the beach, ie. during September-November (Fig.5.15). These cusps last only for two to three weeks, by which time the cusp troughs get filled up due to accretion or get destroyed due to an increased wave activity

Post-monsoonal recovery of the beach and the onshore migration of the longshore bar take place simultaneously as a result of a fall in wave height and wave steepness. But the welding of the bar onto the beach face is responsible for a substantial beach accretion. Longshore bar transform into crescentic bars in the process of its onshore migration, very much similar to the onshore bar migration during monsoon breaks. No rhythmic shoreline features like giant cusps could be observed during this process of onshore bar migration. It should be remembered that giant cusps were observed under similar circumstances during monsoon breaks. Beach cusps developed immediately after (or almost simulta-

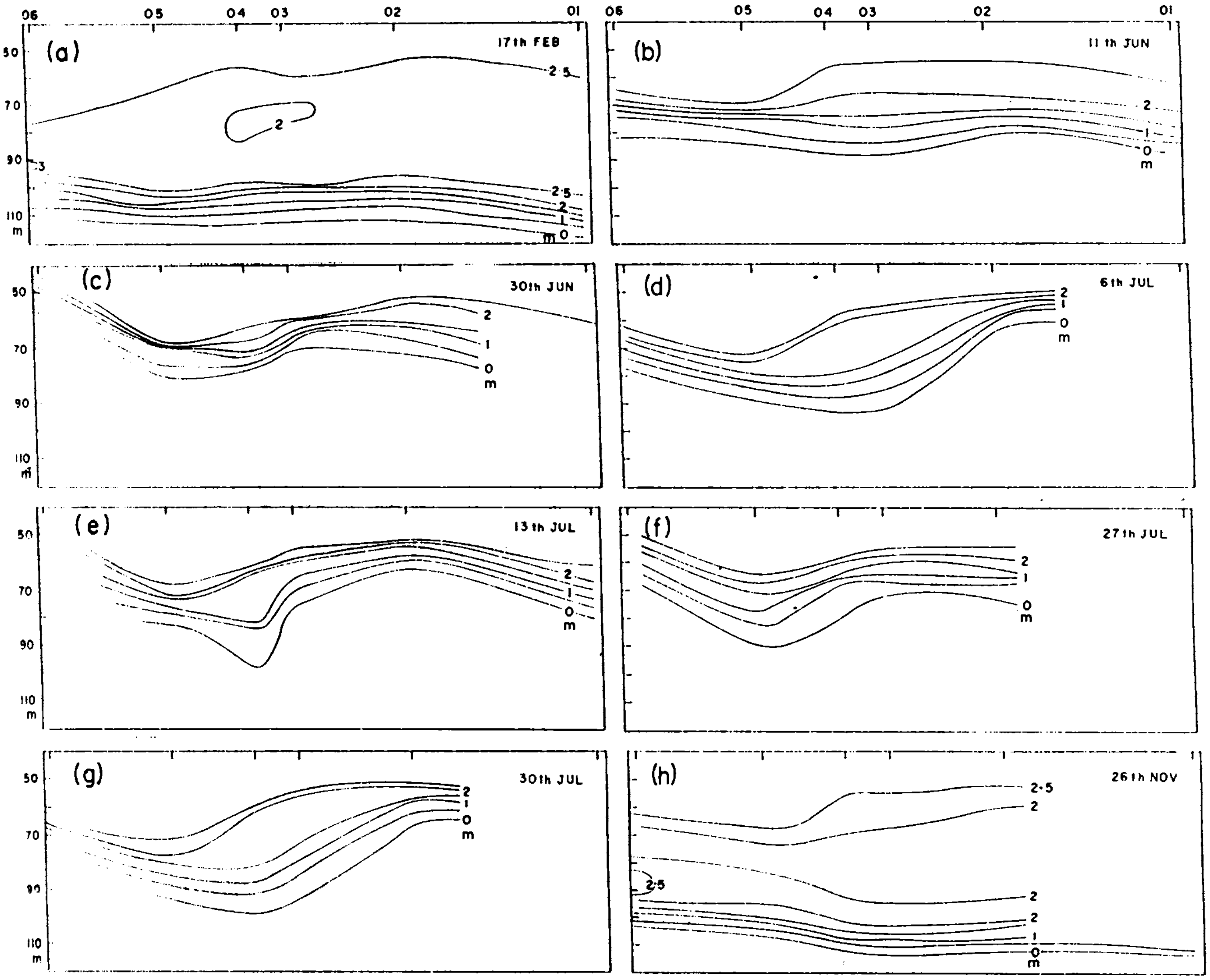

Fig.5.13 Variation in three-dimensional beach topography.

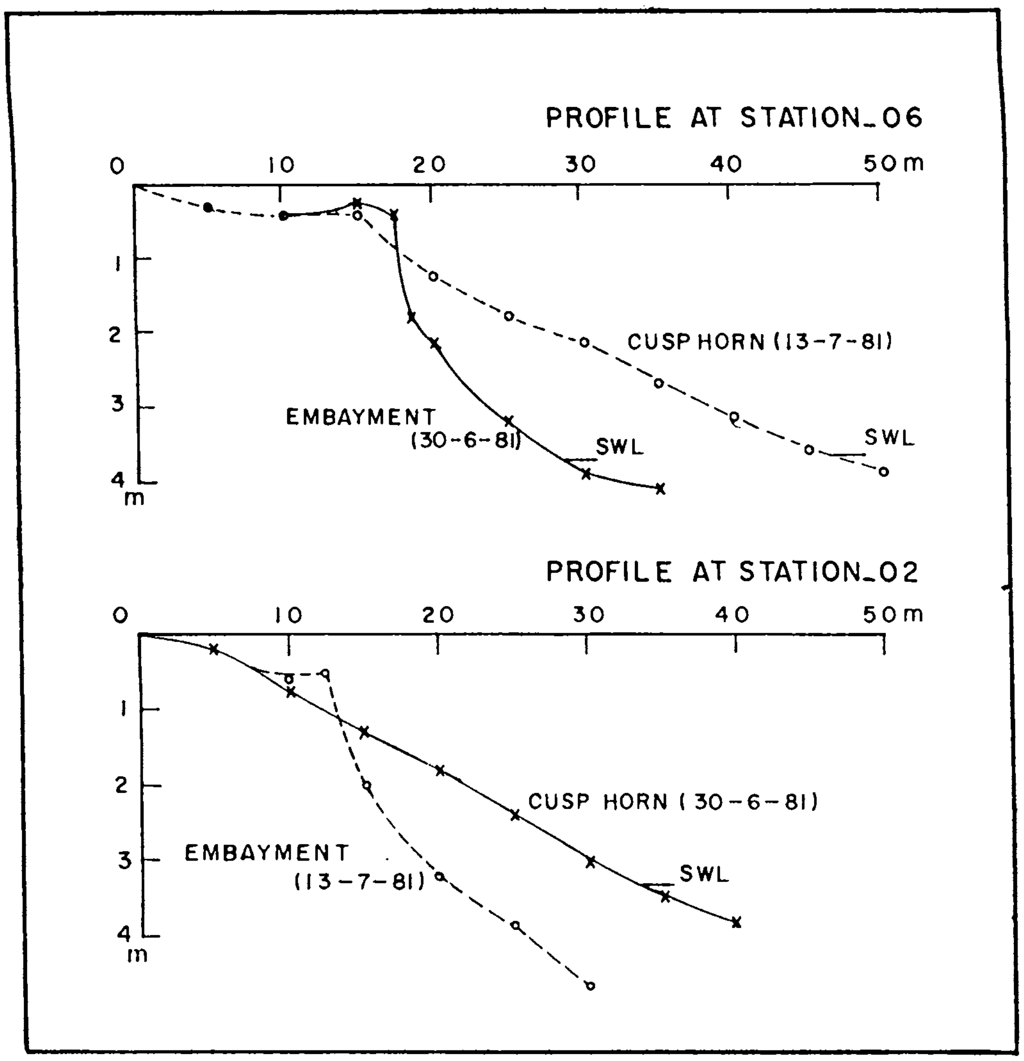

Fig.5.14 Profiles along a giant cusp horn and embayment.

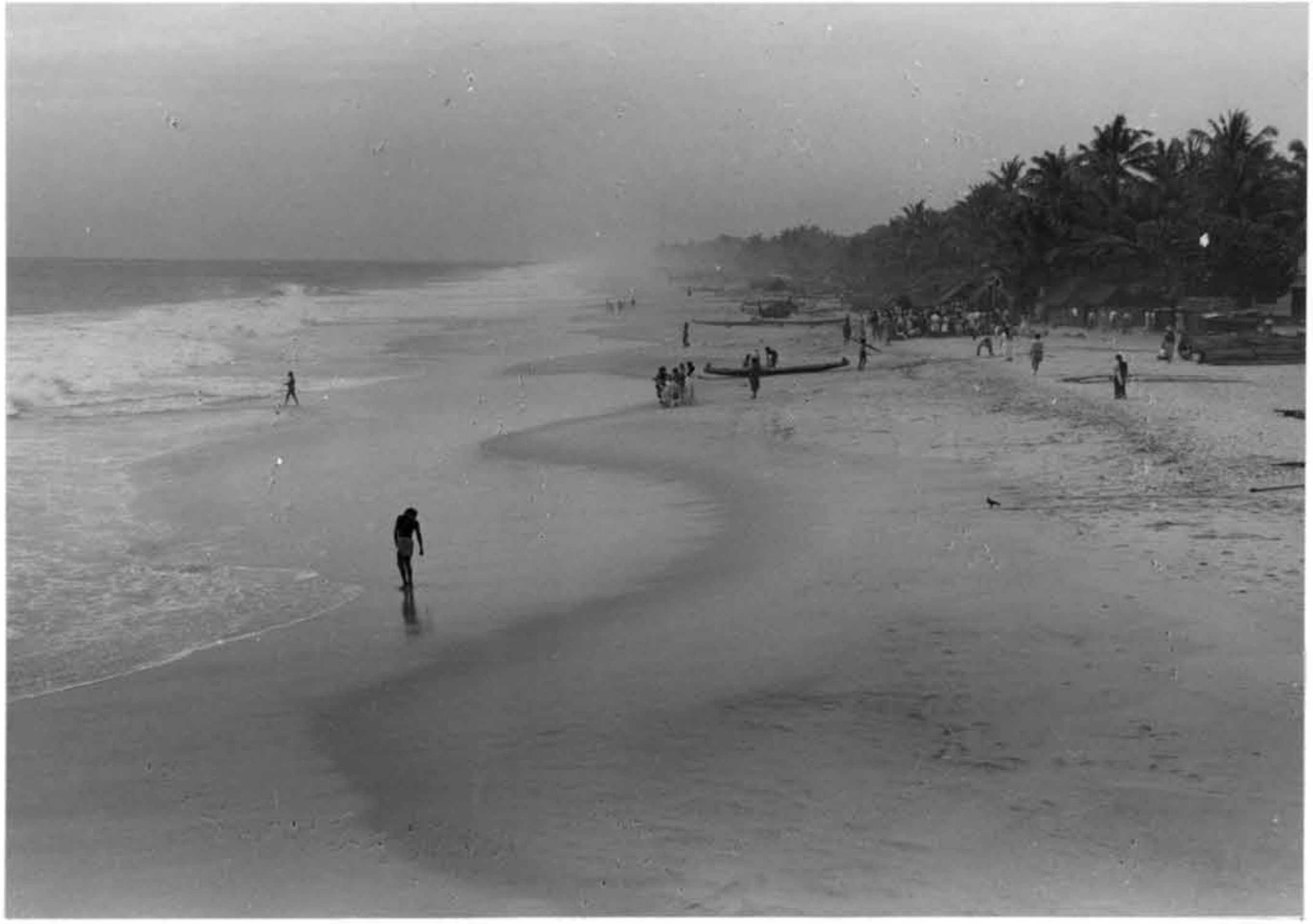

Fig. 5.15 Beach cusps.

neously with) the welding of the crescentic bar horns with the beach face.

The observed cusp characteristics are presented in Table 5.4. Longshore spacing of the cusps varies between 35 and 58 m. Cusp heights (horn-trough relief) are between 0.48 and 0.95 m. The axes of the cusps are either normal or oblique to the shoreline. Longshore currents were either oscillatory or northwesterly (up current). Surf scaling parameter, ϵ_b, for the beach face is always less than 10 during the process of onshore bar migration prior to cusp development. This indicates that the beach face is always reflective to partially reflective prior to cusp formation and the breakers are mostly plunging.

Table 5.4 Cusp characteristics

Year	Cusp wave length (m)	Cusp height (m)	Orientation of axes	Longshore current (m/s)
1980	36_l	0.54	normal	oscillatory
	38_h	0.95	oblique	0.25-0.50 NW
1981	40_l	0.55	normal	oscillatory
	58_h	0.60	oblique	0.30-0.72 NW
	33_h	0.48	oblique	0.20-0.35 NW
1982	38_l	0.56	normal	oscillatory
	43_h	0.62	oblique	0.37-0.45 NW
1983	35_l	0.48	normal	oscillatory
	42_h	0.70	oblique	0.23-0.38 NW
	40_h	0.68	normal	oscillatory
1984	36_l	0.49	oblique	0.18-0.41 NW
	43_h	0.68	normal	oscillatory

l - on a low berm; h - on a high berm.

Beach cusps usually form on two occasions during September-November period. Those formed during September are of low relief. September being the initial phase of beach reformation after monsoonal erosion, only a low berm is present. Cusps form on this low berm which may probably interrupt the longshore currents making them oscillatory; cell circulation dominate the longshore currents. Cusp axes normal to the shoreline are found during this time (Fig.5.16a). These cusp troughs get filled up within two to three weeks and a straight beach with a higher berm develops. The beach face becomes more reflective with lower values of ϵ_b. Beach cusps found during October-November form on this high berm. Strong north-westerly longshore currents (upto 0.72 m/s) are observed during this period. Higher relief and oblique axes are other characteristics of these cusps (Fig.5.16b). Cusp trough gradually gets filled up to form a straight, steep, non-cuspated beach by December.

The processes of cusp development indicates that the response of the beach to low energy conditions can be very significant and rapid. This aspect is particularly important in planning and executing beach nourishment programmes. Moreover, existing theoretical models on beach erosion-accretion have not yet taken into account of this feature properly. Formation of both giant cusps and beach cusps are related to onshore migration of longshore bars. Crescentic bars develop on both occasions. But giant cusps develop only during monsoon breaks and beach cusps during post-monsoonal recovery. Surf zone widths and the distance of the longshore bar from MWL on both occasions are different. These are large during monsoon breaks compared to post-monsoonal recovery period. It seems that the surf zone width and the distance of the bar crest from MWL should exceed a minimum width for the formation of giant cusps.

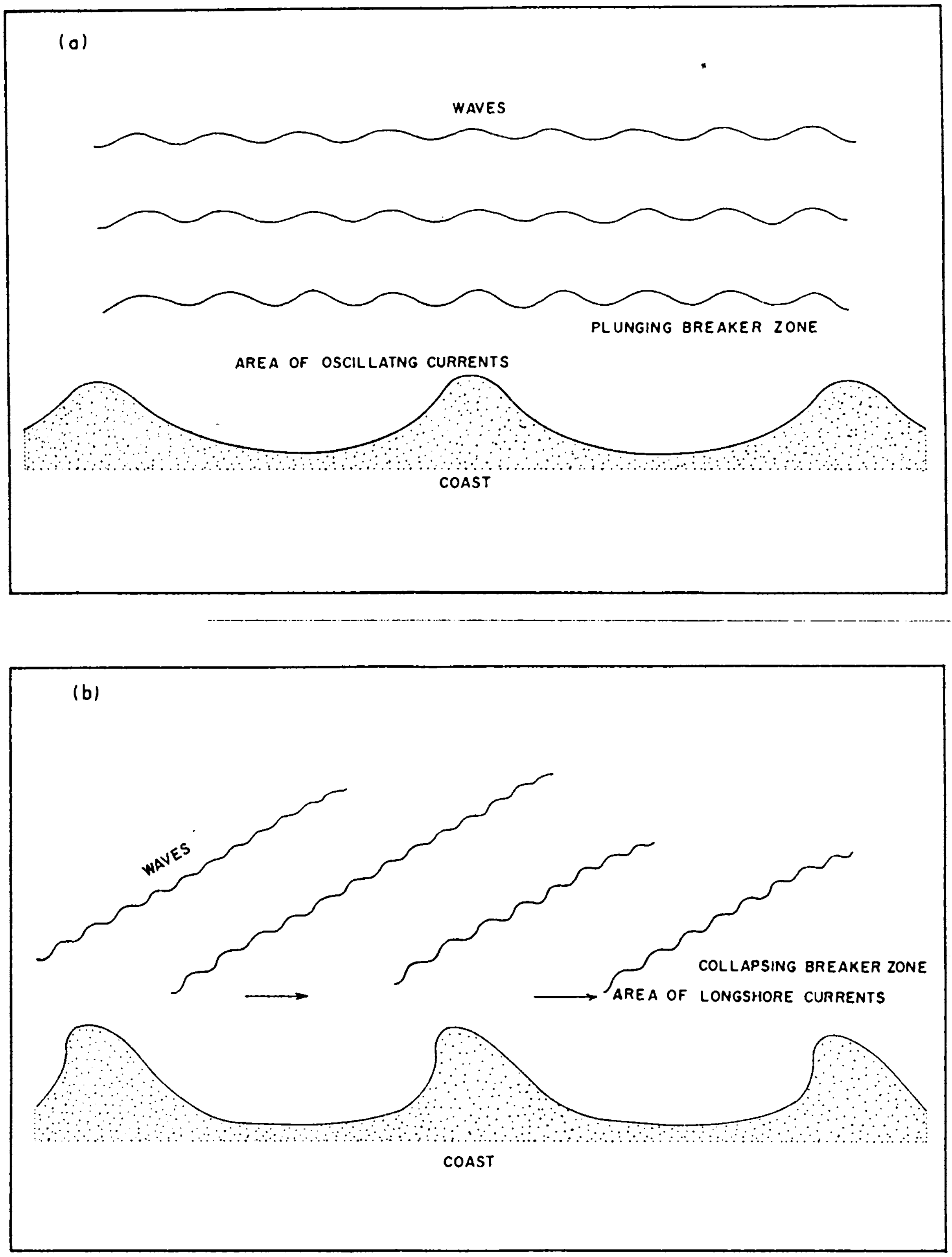

Fig.5.16 Schematic diagram of beach cusps (a) axes normal to the shoreline (b) axes oblique to the shoreline.

5.12 Summary

A surf-scaling parameter can be used to identify various beach and surf zone morphological states. Three distinct types of beach profiles are identified in this part of the coast. Each type is associated with characteristic beach and inshore reflectivity and breaker type. An indication of the energy levels along with the profile types will provide a hint on the associated three dimentional beach morphology. Berm erosion is a result of the high energy monsoonal wave climate. Berm erosion is interrupted by breaks in the severity of monsoon. Berm rebuilding occurs during the post-monsoon months. The major widening of the berm is in jumps rather than gradual. But the vertical growth of the berm is a gradual process. Berm erosion - accretion along this part of the coast is cyclic and seasonal. Scarp heights upto 2 m have been observed during monsoonal erosion. Beach face is reflective to partially reflective throughout the year. An effective dominance of onshore-offshore transport of beach sediment is observed in the process of beach erosion-accretion cycle.

Berm erosion results in the formation of a longshore bar which migrates offshore or onshore depending on the increase or decrease respectively of breaker heights. Bar relief(h_t/h_c) varies between 1.1 and 2.1. Bars act as submerged break waters which effectively reduce the direct impact of high energy waves on the shoreline. Onshore bar migration is by way of the formation of a wider bar nearer to the shoreline. Accretion of the berm starts well before the welding of the bar on to the beach face, but the welding causes substantial beach rebuilding. Rhythmic features like giant cusps and crescentic bars are associated with the onshore bar migration. Beach cusps form immediately after the welding of the bar onto the beach face. Severe beach erosion may occur in the embayments of giant cusps. The response of the beach and nearshore zone morphology to changes in wave climate is very rapid and significant irrespective of increasing or decreasing wave activity.

CHAPTER 6

MORPHODYNAMIC RESPONSE OF BEACH-SURF ZONE SYSTEM

The interaction of beach-surf zone morphological features with the nearshore environmental forces leads to various beach processes. The most prominent among these processes is the seasonal and cyclic erosion - accretion. This cycle is normally presented in its simplest form as 'storm/normal profiles'. But in practice beach cycle is more complex than the simple model normally used. The complexities involved in the cycle are of great significance, for accurate beach modelling. The present chapter discusses the complex processes along the microtidal and moderate-to-high energy beach under study.

6.1 Beach Erosion

It is evident from the earlier discussions that beach erosion can occur under both increasing and decreasing wave energy conditions. Similarly it is also observed that both reflective and dissipative beaches can get eroded.

A slight increase in wave energy is sufficient to initiate erosion on a non-barred (see section 5.6.1) profile. The surf zone corresponding to this profile is devoid of any three-dimensional morphologies and waves directly act on a highly reflective beach face with ϵ_b less than 2.5. Prior to the onset of southwest monsoon, there is a gradual increase in the incident wave energy. Nearshore wave height (H_s) and wave steepness become larger than 1 m and 0.02, but do not exceed 2 m and 0.04 respectively during this occasion.

The erosion under these conditions on a highly reflective beach is partially due to the lack of a subaqueous storage of sand (entire active sand is stored subaerially), which leads to beach instability under increasing wave conditions. It is also due to the fact that reflective conditions are conducive to the growth of resonant subharmonic edge waves under rising wave energy (Guza and Davis, 1974). Growth of subharmonic edge waves on reflective beaches to amplitudes greater than those of incident waves under rising long period swells on steep beaches causes accentuated run up (Short, 1979). This can cause beach face scarping (overtopping can also cause initial breaching of the berm). Erosion along this beach is initiated in this fashion. It is to be noted that this erosion occurs under moderate incident wave energy conditions. Since subharmonic edge waves are easily excited by long period and low-steepness swells (Guza and Davis, 1974), this form of erosion requires the least energy to get induced. Thus a highly reflective beach is most susceptible to erosion during rising wave energy though this beach represents a fully rebuilt condition.

The initial phase of erosion increases the beach face slope and sometimes produces a low scarp (< 0.5 m). The onset of monsoon produces a sudden burst of incident wave energy. Wave steepness increases to 0.04 to 0.07 and wave height is now 2 to 4 m. The peak energy of the spectra shows a shift to high frequency. Breakers are plunging and breaker heights as high as 6 m occur. These high and steep waves unleash tremendous energy directly onto the beach. The beach face is partially dissipative with $10 < \epsilon_b < 20$ allowing more energy to dissipate on the beach face. This causes severe beach cut and results in the formation of a barred profile under rising wave energy which is characterised by a longshore bar in the surf zone. Once formed, the longshore bar acts as an effective filter for wave heights. High energy waves no longer break on the beach face. They break at the partially dissipative seaward side of the bar.

Thus the available incident wave energy on the beach face decreases and the pace of beach erosion too decreases considerably even under high energy conditions. Thus the beach with a longshore bar is least sensitive to .erosion and appreciable wave energy is required to induce further beach erosion.

The presence of the bar results in a segmentation of the beach-surf zone showing significant cross-shore variation in the surf scaling parameter with the beach face and the offshore side of the bar becoming partially reflective while the surf zone becoming highly dissipative. On a highly dissipative surf zone infragravity oscillations are more prominent than run up and surf zone flows (Wright et al., 1979). These become destructive only under very high wave energy conditions. Also, the large surf scaling parameter of the inshore causes an increase in the eddy viscosity and this along with the presence of larger breaker heights cause pronounced wave set-up at the shore (Wright, 1980). Growth of set up and infragravity oscillations under high energy conditions can allow the bores of partially dissipated waves to penetrate to the backshore and cause backshore erosion (Short and Hesp, 1982). The most probable mode of erosion of a highly dissipative, longshore barred beach along this coast seems to be under the influence of surf zone infragravity oscillations rather than incident wave energy. This can occur only under very high incident wave energy conditions.

The mode of erosion described till now takes place under increasing wave energy conditions and is almost uniform throughout the coast. Beach erosion can also take place under decreasing wave energy conditions. But this is not uniform all along the beach and is restricted to certain specified locations. This erosion is associated with breaks in the southwest monsoon when the incident wave energy decreases from a peak and when it interacts with a longshore barred profile.

Immediately following the fall in wave energy, the longshore bar develops a crescentic morphology and giant cusps develop along the shoreline within two or three days. These changes in morphology do not depend on any absolute values of wave height or steepness. Simply a decrease in wave energy (fall in both height and steepness are observed) from the peak is sufficient. Severe erosion is experienced at the giant cusp embayments. Strong rip currents have been observed in these embayments. Embayment scouring is most probably due to scouring by rip currents. If the break in monsoon continues for a long period the cusp horns widen due to deposition under low energy conditions. This widening results in the alongshore shifting of rip currents. The site of embayment erosion too shifts alongshore and becomes narrow but with severe erosion. A marginal increase in wave energy enhances the erosion in the embayments without destroying the giant cusps. But a return to high energy conditions initially causes severe erosion but finally destroys the whole cuspated system.

Though localised, this type of erosion is more severe than the earlier described modes. The scarp in the embayments sometimes reaches a height of 2 m and cuts well into the backshore. This occurs under decreasing wave energy during a high energy situation, when no erosion is normally expected. Embayment erosion which can even damage coastal protective structures (Dolan, 1971) is of severe consequence along comparatively narrow and thickly populated beaches like the one studied here. Failure of beach nourishment programmes due to giant cusp formation and resulting embayment erosion have also been reported (Nummedal et al.,1984).

6.2 Beach Accretion

Accretion generally occurs under decreasing wave energy conditions. Along this coast it happens during breaks in the southwest monsoon and during post-southwest monsoonal season. Beach accretion during monsoon breaks is in the form of giant cusp horns. Cusp horns grow laterally as the monsoon breaks prolong. The exact mechanism behind this type of deposition is not clear. Accretion at the cusp horns takes place well before the welding of the bar onto the beach face. The nearshore wave steepness is usually less than 0.04. The breakers are a mixture of plunging and spilling types with significant cross-shore variation in ϵ. The wave heights are usually < 3 m. The spectra are wide and more energy is on the high frequency side. Accretion starts immediately following a decreasing trend from a peak wave energy, i.e. well before the conditions become moderate or low. Accretion continues under moderate energy conditions which follow.

Breaks in the southwest monsoon usually do not continue long enough to cause the welding onto the beach face of the crescentic bar horns and these giant cusp-crescentic bar systems are usually destroyed by high energy waves. Beach accretion during post-monsoon season is the result of onshore migration and welding onto the beach face of nearshore bars under moderate energy - low steepness waves. The welding onto the beach face results in the formation of a low berm. Beach cusps develop on this low berm. The berm grows vertically and cusp troughs get filled up gradually. These processes take place when wave steepness is between 0.03 and 0.02 and wave heights are mostly less than 2 m. The breakers transform from plunging to collapsing and surging as the berm grows vertically. The surf scaling parameter and surf zone width also decreases while the beach face slope increases.

It is clear that beach accretion occurs both under decreasing and moderate wave energy and steepness conditions. During the southwest monsoon breaks under decreasing wave conditions accretion starts at the crescentic features. The vertical growth of the beach and berm crest takes place under post-southwest monsoon moderate conditions. Hence beach rebuilding actually starts well before the post-southwest monsoon welding of the bars onto the beach face.

Giant cusps that form during monsoon breaks appear just after the development of crescentic bar as more or less a mirror image. But the small scale beach cusps formed during post monsoon accretion are not related to the surf zone crescentic morphology. They appear immediately after the welding of the bar onto the beach face and seems to be related to foreshore sediment deposition (to be discussed later).

Cuspated beaches observed are intermediate stages in the process of beach accretion and they get filled up as the beach acquired a fully accreted equilibrium state.

6.3 Longshore Bar Response to Changing Wave Conditions

It is seen that longshore bar develops as a result of monsoonal erosion and it migrates offshore with an increase in the height of the breakers which are of plunging type. The cross-shore distance of the bar crest from the shoreline is more or less, equal to the distance of this prominent breaker line. The offshore migration of the bar is accompanied by offshore shifting of the breaker position. These indicate that there is a close relationship between bar formation and the processes in the vicinity of breaker zone.

A breaker zone mechanism suggested by Miller (1976) is trough excavation which causes erosion of a depression by the enhanced stresses at the impact point of breaking waves. Model studies have also shown that the vortex of a plunging breaker extends to the bottom to initiate such a process. During the present observations, it is noted that the plunging breakers dominating during April-May do not cause the formation of longshore bars. It produces a subaqueous terrace. Monsoon waves too produce a subaqueous terrace initially. High breakers acting on this subaqueous terrace excavates a trough to form longshore bar.

It has been shown in the earlier sections that the bar started as linear and later became crescentic. Sufficient data is not available to exactly decide the time and processes involved in the transition. Field estimates point to a better developed crescentic form just after the peak wave energy coinciding with a recovery period. Some evidence for such a transition exists in literature also (Short, 1979).

6.4 Crescentic Bar Development

Bed-form modifications by strong rip currents has been suggested as the reason for the formation of crescentic bars (Short, 1979; Sonu, 1973). According to Holman and Bowen (1982) and Bowen and Inman (1971) drift velocities associated with standing edge waves are responsible for generation of crescentic bars.

Rip currents observed along the present study area before the development of crescentic bars are not space fixed. Hence the possibility of rip currents scouring bed form is less. But once the giant cusps are formed, rip currents get space fixed at the embayments and scouring of embayments is possible.

If standing edge waves are responsible for the formation of crescentic bars, then the observed wave lengths have to be compatible with those computed using edge wave theory (Chapter 3). Since direct measurements of crescentic bar spacings are difficult, an indirect way of using the giant cusp spacing as equivalent is adopted here. Giant cusps commonly co-exist with crescentic bars forming as a reflection of the bar morphology on the shoreline (Sonu, 1973; Komar, 1976). Studies by Sonu (1973), Wright and Short (1984) and Sallenger et al. (1985) justify this approach.

Bar crest distance from the shoreline as observed here are between 50 to 160 m (Table 5.2). The bar distance corresponding to giant cusp formations during monsoon breaks are between 120 and 160 m. The corresponding standing mode-1 edge wave periods computed using Eq. (3.8) are in the range 80 to 100 s. The beach slope used for this computation is the average slope of the beach face and the inshore. Crescentic bar wavelengths corresponding to these periods, computed using Eq. (3.3. 3.4 & 3.7), are between 190 and 300 m. The observed giant cusp spacings of 150 - 350 m are broadly comparable with the estimated crescentic bar spacings. It may also be noted that the beach face is partially reflective ($\epsilon_b < 20$) during this time (Fig.5.1). But for computing ϵ_b the amplitude measured just outside the breaker zone has been used. Note that an amplitude measured at the seaward margin of the swash zone is probably more relevant in computing ϵ_b. The effect of using an inner surf zone amplitude would be to further lower ϵ_b making the foreshore even more reflective. High beach reflectivity is very much conducive to the generation of edge waves. This indicates that the chances of crescentic bar development due to mode-1 standing edge waves are good.

Since the crescentic bars occurring towards the latter half of monsoon do not possess any rhythmic shoreline features, such conclusions are not possible for that season..

6.5 Beach Cusp Formation and Disappearance

Beach cusps are found to occur during beach rebuilding process. Hence an understanding of the morphodynamic processes behind their formation leads to a better understanding of the processes of beach and berm development.

The probable edge wave lengths are computed for subharmonic (edge wave period = twice the incident wave period) and synchronous (edge wave period = incident wave period) edge waves (see Chapter 3). These are compared with the corresponding cusp wave lengths and are given in Table 6.1. These are comparable and points to a relationship between cusp wavelengths and edge wavelengths. Most of the cusp spacings are comparable with the length of synchronous, mode-1 edge wave. It may be noted that those comparable with the length of subharmonic, mode-zero edge waves were observed for cusps formed on a higher berm with a steeper beach face during the final stages of beach reformation.

A partially reflective beach face is present when the longshore bar formed due to monsoonal erosion starts migrating onshore. The breakers are mostly plunging during this period. A low, subtle berm develops seaward of the monsoon berm. Many of the waves break at the longshore bar and then reform in the trough. These waves plunge onto the partially reflective beach face. These breakers are more or less normal to the shoreline. Wright et al. (1979) have observed

Table 6.1 Computed and observed cusp wavelengths (m).

Year	Observed	Computed	
		subharmonic n = 0	synchronous n = 1
1980	36_l	27	41
	38_h	29	44
1981	40_l	10	15
	58_h	42	63
	*33_h	31	47
1982	38_l	21	32
	43_h	26	39
1983	35_l	24	36
	* 42_h	40	60
	* 40_h	58	87
1984	36_l	20	30
	* 43_h	40	60

l - on a low berm; h - on a high berm;
* - comparable with subharmonic edge wave wavelength

that different types of edge waves can occur under these conditions. These edge waves can cause the formation of beach cusps on the low berm already formed. Nearshore currents are then dominated by cell circulation partly due to the influence of a cuspated shoreline.

Once the beach becomes cuspated the morphology may interfere with the continued edge wave excitation. Thus the edge wave amplitude may be reduced by the presence of well formed cusps (Guza and Bowen, 1981). This along with the continued accretion of the beach and filling up of the bays, cause the disappearance of cusps. The shoreline becomes straight and the berm becomes higher. The second set of beach cusps form on this beach with a higher berm and a more reflective beach face. The breakers are plunging, collapsing or surging. A reflective beach face with surging breakers is most conducive to edge wave formation. Thus, edge waves can form under the conditions existing at Valiathura towards the final stages of beach reformation and may initiate the development of beach cusps. During this period the supply of sediments to the beach face is maintained since the beach continues to be in an accretive phase. The waves break very near to the shoreline and they are from a south to southwest direction. The axes of the cusps orient themselves in a direction parallel to wave approach so as to provide least resistance to the incoming swash. Hence the cusp axes are inclined to the shoreline in a south-southwest direction. The longshore currents are not affected by these cusps since they are on a high berm. Currents continue to be northwesterly. Formation of beach cusps when oblique waves dominate goes against the observations of Johnson (1919), Timmermans (1935) and Longuet-Higgins and Parkin (1962) that beach cusp formation is most favourable when waves approach normal to the beach.

The beach remains reflective with collapsing or surging breakers after the disappearance of cusps. Though these conditions are most conducive to edge wave formation, no cusps are observed along the beach. It may be noted that there was a continued supply of sediment to the beach on both occasions of cusp development described earlier. Since the beach has acquired an equilibrium profile by December, excess supply of sediment to the beach ceases by then. Hence no cusps are formed even if edge waves are present along this beach during this period.

6.6 Conceptual Models of Beach Morphodynamic States

The interaction of morphologies and the driving forces leads to a more or less equilibrium condition. Perfect equilibrium conditions are not usually reached in the field due to the frequent changes in the forces. Notwithstanding the frequent variations in the beach and nearshore system, certain beach states can be distinguished at different stages of an erosion - accretion cycle. Each beach state is associated with certain characteristic morphodynamic process. Based on the observations made, a model comprising of six morphodynamic states in an erosion - accretion cycle is suggested.

The different beach states thus identified are:

Fully reflective accretional extreme (Beach state I)
Reflective eroding beach (Beach state II)
Fully eroded beach (Beach state III)
Crescentic barred beach with giant cusps (Beach state IV)
Highly dissipative beach with welded bar (Beach state V)
Cuspated beach (Beach state VI)

These beach states occur usually in the above sequence along this coast as wave climate changes from fair to rough and back to fair seasons. The evident characteristics of these beach states are described below and summarised in Table 6.2 and Fig.6.1.

6.6.1 Beach state I

This is a fully reflective accretional system with most of its active sediment stored in the subaerial part of the beach. It has a well developed berm with a high berm crest running parallel to the shoreline. The berm crest is

Beach state	Shoreline and surf zone morphology	Wave energy, surf scaling parameter, breaker type	Nearshore currents	
I (Fully reflective accretional)	'Non-barred profile' type, no alongshore variations in morphology, steep beach face.	Low-to-moderate energy, highly reflective beach face, $\epsilon_b < 2.5$, surging and collapsing breakers.	Weak longshore currents.	Hi wa ri un wa
II (Reflective eroding)	'Non-barred profile' type uniform small scarp and a subaqueous terrace. No alongshore variations in morphology. Steep beach face	Increasing from low-to-moderate energy. Reflective to partially reflective beach face, $\epsilon_b < 10$, plunging breakers.	Strong longshore currents	Er en de
III (Fully eroded)	'Barred profile under rising wave energy'type. Longshore bar in the surf zone. No alongshore variation in the morphology. Moderately steep beach face	High energy situation cross-shore variation in reflectivity. $\epsilon_b < 10$; $\epsilon_s \gg 33$; $2.5 < \epsilon_{bar} < 33$. Cross-shore variation in breaker type. Plunging and spilling breakers.	Cell circulation with rip currents (not space fixed).	Le wa tc
IV (Crescentic barred with giant cusps)	'Barred profile under decreasing wave energy' type. Crescentic bar in the surf zone, significant alongshore variations in morphology. Shoreline is giant cuspated. Alongshore variation in beach face slope.	Decreasing from high energy. Cross-shore variations in reflectivity $\epsilon_b < 33$; $\epsilon_s \gg 33$; $2.5 < \epsilon_{bar} < 33$ cross-shore variations in breaker type. Plunging and spilling breakers.	Cell circulation with strong rip currents at the embayments.	Er de
V (Highly dissipative with welded bar	'Welded profile'type. No alongshore variations in morphology. Very gently sloping beach face.	Moderate wave energy $10 < \epsilon_b < 20$; $\epsilon_s \gg 33$ Partially dissipative beach face. Highly dissipative inshore spilling and plunging breakers.	Cell circulation	Be pr wa VI rg
VI (Cuspated beach)	'Barred profile under decreasing wave energy' type. Beach cuspated with normal/oblique axes.	Moderate wave energy $\epsilon_b < 20$ Partially dissipative beach face plunging, surging and collapsing breakers.	Cell circulation/ longshore currents.	Be un in Be

teristics.

Nearshore currents	Erosion/accretion condition
Weak longshore currents.	Highly sensitive to increasing wave energy. Erosion under rising wave energy. No change under existing or decreasing wave energy
Strong longshore currents	Erosion under rising wave energy. Accretion under decreasing wave energy.
Cell circulation with rip currents (not space fixed).	Least sensitive to increasing wave energy. Highly sensitive to decreasing wave energy.
Cell circulation with strong rip currents at the embayments.	Erosion at embayments and deposition at cusp horns.
Cell circulation	Beach cusps form under prevailing or decreasing wave energy (Beach state VI). Increasing wave energy causes beach state III.
Cell circulation/ longshore currents.	Beach state I develops under decreasing. Increasing wave energy causes Beach state III.

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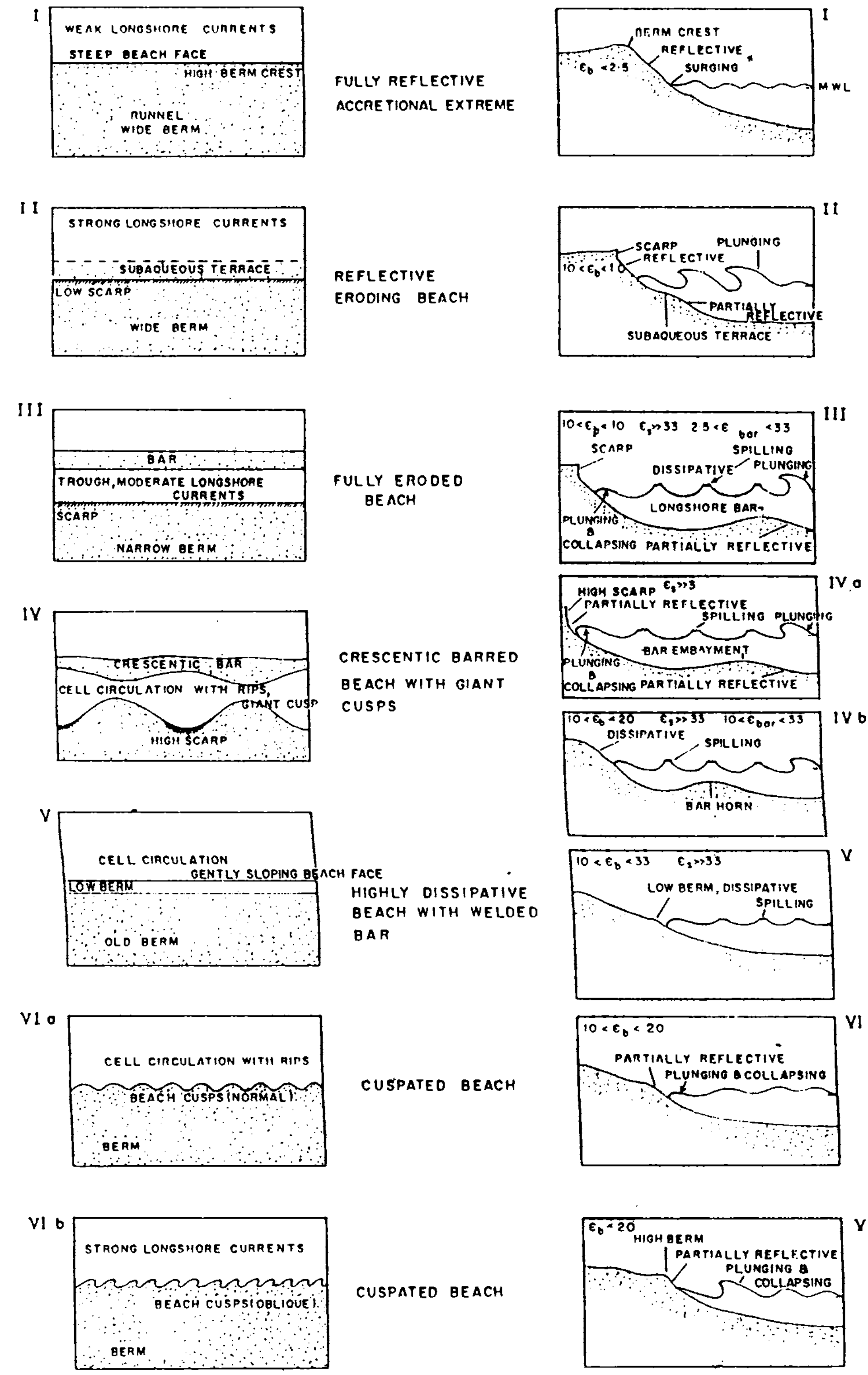

Fig.6.1 Conceptual model of beach morphodynamic states.

backed by a landward dipping slope. Breakers are exclusively surging or collapsing and the turbulence related to breaking processes is confined to the zone of run-up on the beach face. Low-to-moderate energy conditions and a steep beach face cause a highly reflective beach face ($\epsilon_b < 2.5$). This state is in dynamical equilibrium and no significant changes occur as long as the existing wave conditions continue or decrease. But it is highly sensitive to increasing incident wave energy and even a marginal increase in incident wave energy causes beach face scouring or scarp development. Components of cell circulation are absent in the nearshore current and only weak longshore currents are present.

The beach shows strong two-dimensionality with no significant alongshore variation in the morphology and it corresponds to the 'non-barred profile type.

6.6.2 Beach state II

This is a reflective eroding beach and results from the previous state due to a marginal increase in wave energy forming a moderate-to-high energy situation. A uniform small scarp (< 0.4 m) may be present, but the beach face will be steeper than that of Beach state I and reflective with $\epsilon_b < 10$. This is an unstable state and an increase or decrease in the incident wave energy can induce changes in the morphology. Further erosion is mainly due to the incident high energy waves. This state, too, shows strong two-dimensionality without any significant alongshore variation. The profile is closer to a 'non-barred profile' type. A subaqueous terrace seaward of the shoreline is present and most of the breakers plunge seaward of the terrace. Irregularly placed weak rip currents are present along with strong longshore currents.

6.6.3 Beach state III

It is a fully eroded beach. An almost straight shoreline and a well developed longshore bar are characteristic to this beach state. Continuous action of high energy waves for a few days results in the development of this beach state. The beach face is partially reflective with $\epsilon_b < 10$. The surf zone is highly dissipative with $\epsilon_s \gg 33$. The offshore side of the bar is partially reflective with $2.5 < \epsilon_{bar} < 33$. High waves plunge at the seaward side of the bar while smaller waves spill across the bar. Broken waves reform in the trough and collapse on the beach face. Hence most of the incident wave energy gets dissipated before reaching the shoreline. The direct impact of the incident waves on the shoreline is considerably reduced. The beach becomes least sensitive to increasing wave energy and further erosion takes place only under exceptionally high energy waves. But a fall in wave energy causes significant changes in the morphology. The beach continues to show strong two-dimensionality and the profile corresponds to a 'barred profile under rising wave energy' system. Cell circulation with rip currents dominate the nearshore currents. But these are not space fixed.

6.6.4 Beach state IV

This is a crescentic barred beach with giant cusps. This beach state develops from a fully eroded state under decreasing wave condition. Subaqueous crescentic bar and shoreline rhythmicity in the form of giant cusps are the pronounced features of this beach state. The crescentic bars become dissipative with $\epsilon_{bar} < 33$ for decreasing breaker heights. Most of these waves spill across the bar and collapse on the partially reflective ($2.5 < \epsilon_b < 20$) beach face. Beach loses its two dimensionality and significant alongshore variations in the morphology occur. Giant cusp embayments are affected by erosion while deposition takes place at the horns. Alongshore migration of giant cusps causes the shifting of the site of erosion and deposition. These changes take place under a decreasing wave energy situation. Rising wave energy initially increases embayment erosion and finally destroys rhythmic features and goes back to Beach state III. Nearshore currents associated with Beach state IV are dominated by cell circulation systems with strong rip currents at the cusp embayments.

6.6.5 Beach state V

This is a highly dissipative beach with a welded bar. Beach face is very gently sloping with $10 < \epsilon_b < 33$ and the inshore is dissipative with $\epsilon_s > 33$. Breakers are mostly spilling. This is an accretive state and a continuation or a decrease of the prevailing wave condition leads to the development of beach cusps. An increase in wave energy transforms this beach state into Beach state II or III. The profile corresponds to a welded bar profile' type which is by and large two-dimensional. Nearshore is characterised by weak, irregularly spaced cell circulation system.

6.6.6 Beach state VI

Continuation of Beach state V transforms the beach to the cuspated beach state. Axes of the cusps are either normal or oblique to the shoreline with an alongshore spacing of 40 to 60m. Beach face is reflective to partially reflective with $\epsilon_b < 20$. Breakers are plunging, surging or collapsing. The corresponding profile of this beach state is similar to barred profile under decreasing wave energy type and shows significant alongshore variations. Decrease or continuation of the prevailing wave conditions cause beach building and Beach state I results. But an occurrence of high energy condition can bring in Beach state II or III. Cell circulation with spatially inconsistent rip current dominate when cusps have oblique axes.

6.7 Summary

Beach erosion under rising wave energy is more or less uniform throughout the coast. Erosion under decreasing wave energy is confined to the embayments which may migrate alongshore. Beach accretion occurs under decreasing and moderate energy conditions. The transformation of longshore bars into crescentic forms and the development of beach cusps can be due to the presence of edge waves. Six beach states with characteristic morphodynamic features are identified in an erosion-accretion cycle. Various beach states react to the same wave conditions differently. It emphasises that the existing beach morphodynamic state is an important factor in determining the erosional or accretive nature of the beach.

CHAPTER 7

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

The different processes on the beach which are characterised by complex fluid motions and fluid-sediment interactions are not fully understood. These processes along a wave-dominated coast are investigated in the present work. This is essential in modelling the beach system.

The present study shows that wave climate along the southwest coast of India is characterised by moderate to high wave energy conditions. Significant changes in wave characteristics are found during different seasons and these are repeated every year almost in an identical fashion. Two distinct seasons - rough (May-October) and fair (November-April) - representing two separate wave energy regimes are identified. The rough season with a 50% H_s exceedance level at 1.75 m belongs to a high energy regime while the fair season having a 50% exceedance level at 0.95 m may be considered as a moderate energy regime. Wave spectra are generally multi-peaked indicating the presence of different wave trains. The peak spectral density varies from 0.4 m^2s during fair season to 7.5 m^2s during rough season. Waves are usually well grouped and significant correlation between successive wave heights is evident up to five waves.

Average breaker height is usually greater than 1 m. Highest breakers are observed during June to September. Periods are lowest during June-July. Dominating breaker directions are between 210°N and 225°N during September to May and between 230°N and 240°N during June to August. Plunging breakers are the most common breaker type.

The surf zone is fairly wide during June to September. The width is negligible during December to March. Nearshore currents are a combination of longshore currents and cell circulation systems during June to September. During 'the other months currents usually flow up the coast.

Beach sediment is composed of medium-sized sand. Mean sediment size is between 0.25 and 0.40 mm. Sediment characteristics do not show any appreciable seasonal variations.

Long-term changes in berm width and variations in the volume of beach sediments show that the process of berm erosion/accretion is seasonal and cyclic. It also suggests that the prominent mode of sediment transport causing erosion/accretion is onshore/offshore. A longshore bar forms as a result of monsoonal beach erosion. Bar causes cross-shore variation in the surf scaling parameters. The beach face and the offshore side of the bar are partially reflective and inshore is highly dissipative. Most of the incoming waves break at the bar. Smaller waves spill across the bar. Broken waves reform in the trough to collapse or plunge onto the beach face. The bar acts as an effective submerged breakwater which prevents the direct impact of high energy waves on the beach face. This bar migrates offshore or onshore depending on the wave conditions. Prior to the onshore/ offshore migration, the bar flattens to form an almost horizontal inshore profile. Bar reforms at a new location on the profile on this flat profile. Onshore migration of the bar due to decreasing wave energy initiates berm rebuilding. Major part of beach reformation takes place by way of the welding of the longshore bar onto the beach face. Initially a low berm forms seaward of the monsoon berm which then grows vertically. Horizontal growth (widening) of the berm is mainly episodic while vertical growth is gradual.

Uniform scarps are found all along the coast during erosion under rising wave energy. Scarps found at the embayments of giant cusps disappear towards the cusp horns. The embayment scarps are usually high (about 2 m)

Beach face is steep most of the time with slope between 0.1 and 0.2. Lowest beach face slope occurs when the onshore migrating longshore bar welds on to the beach face.

Response of beach and nearshore morphology to a decrease in wave energy from a high energy situation is very significant and rapid. Beach exhibits strong three-dimensionality with significant longshore variations under decreasing wave energy. Longshore bar transforms into crescentic bars. Shoreline becomes rhythmic with giant cusps. Beach builds at the cusp horns while embayments experience erosion. Embayment erosion can become very severe with scarps reaching a height of 2 m. Giant cusps occur during the break in the monsoon. Beach cusps, another type of shoreline rhythmic feature, form during the post-southwest monsoon beach recovery.

A Beach profile classification indicating the wave energy level can provide a better picture of the beach state and its alongshore morphological variations. The proposed beach profile classification is: (1) non-barred profile, (2) barred profile under rising wave energy, (3) barred profile under decreasing wave energy and (4) welded profile.

A non-barred profile is most susceptible to erosion under rising wave energy. Accentuated run-up due to the growth of subharmonic edge waves under rising long period swells causes the initial phase of erosion which occurs under moderate energy conditions. Under high energy steep wave conditions more energy is available on the partially reflective beach face and this causes severe beach cut and results in the formation of a barred profile. This profile is least sensitive to further increase in wave energy. A barred profile under decreasing wave conditions experiences embayment erosion. Beach cusps develop on a welded profile, the berm of which grows vertically to become a non-barred profile.

The comparability of the computed and observed giant cusp wavelengths suggests the possibility of the formation of giant cusps and crescentic bars due to mode - 1 standing edge waves. The formation of beach cusps is also found to be related to the presence of edge waves.

Six distinct beach states with characteristic morphodynamic features are identified in an erosion-accretion cycle. Various beach states react to the same wave conditions differently and hence erosion and accretion can occur under the same wave conditions.

The following conclusions and suggestions are made based on the present study.

(i) Valiathura is a wave dominated, moderate-to-high energy coast. The dominant role of onshore-offshore sediment transport in causing beach erosion-accretion means that the beach is in dynamic equilibrium as far as the longshore sediment transport is concerned. Hence no human interference should be allowed which disturbs this equilibrium. If at all any interference becomes necessary, steps should be taken by way of beach nourishment to compensate the deficit of sediment in any location.

(ii) The maximum extent of shoreline oscillation in the seasonal cycle is 40 to 50 m. Hence the best method for the protection of the coast should have been keeping a buffer beach of around 50-60 m width for the waves to act upon.

(iii) The 'submerged breakwater effect' of the longshore bar considerably reduces the direct impact of high energy waves on the beach face. Hence while designing any coastal protective structure with a frontal beach the effect of only a lower breaker height need be considered. This may bring down the optimum design wave height and consequently the cost of construction of coastal protective structures.

(iv) Enhanced impact due to wave groupiness on coastal and nearshore structures is an important factor to be taken care of in their design. Well grouped, long period swell waves may also cause unexpected flooding of the coastal regions even during the fair season.

(v) Embayment erosion can cause significant scouring at specific locations. This can adversely affect beach nourishment programmes and shore protective structures. Designs and models for this coast should take also into account the embayment erosion. Beach erosion-accretion depends also on the beach state. Even decreasing wave energy can cause erosion of some beach states under high energy conditions. The presently available models predict erosion due to increasing waves. Models require necessary modification to take into account erosion due to decreasing wave energy during high energy conditions.

(vi) The rapid and significant response of the beach to decreasing wave energy has important implications in surveying nearshore morphology. Improper spacing of profiles could seriously affect the result of field investigations. Alongshore length scales of morphology should be accommodated properly in any plan for monitoring morphologic changes. The apparent ease with which the longshore-barred beach becomes giant-cuspated with crescentic bars points to the rapid time scales of beach response to changing (even decreasing) wave climate. Hence the selection of time scales (frequency) of observations also becomes important.

Based on the present study the following related fields are recommended for future research.

(i) Edge waves in surf zone are studied in this work indirectly. Field investigations on edge waves and the nearshore set up due to them along this coast are needed for a detailed understanding of these waves and their impact.

(ii) Some inferences on the processes involved in the giant cusp and beach cusp formation are given in the present investigation. A closer study into these processes are needed to predict the embayment erosion.

(iii) The transition of the longshore bars into crescentic form due to onshore bar migration could be described only qualitatively in the present study. The time and processes involved in this transition needs detailed investigation.

(iv) The present study shows that the post-monsoon recovery phase of the beach is very rapid and significant. Accurate information on this aspect is very important in beach nourishment programmes and impact assessment of net erosion. Hence models successfully defining the recovery phase which includes berm formation are to be developed. Theoretical models on beach processes are to be developed based on the conceptual model presented in this study.

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APPENDIX I

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