CHAPTER 1

INTRODUCTION

1.1 GENERAL

Coastal zones all over the world have always been thickly populated and are centres of urbanization, industrial growth and intense agricultural activities. These coastal zones are characterised by a variety of complex environs like bays, beaches, estuaries, dunes and marshes, evolved through processes like depositional activities of major rivers, eustatic changes, tidal effects and neotectonic activity.

The coastal zones also have their own geomorphological, hydrogeological and hydrochemical characteristics. The world’s coastlines, dividing land from sea, are geological environments unique in their composition and the physical processes affecting them. Many of these coastlines have beaches composed of loose sediments such as gravel, sand or mud that are constantly acted upon by waves, currents and winds reshaping them continuously. However, despite the different wave climate, which exists around the world and the variations in coastline composition, the nature and behaviour of beaches are often very similar.

Humans have been building structures at the dynamically active intersection of land and the oceans throughout history. Ports and harbours have always served as bases for naval forces and as commercial egresses to upland
trade routes or major centres of civilization. More recently, coastal development has become more important as recreation and tourism are playing a vital role in economy. The shoreline development is causing an increasingly important conflict with the natural coastal processes (Dean and Dalrymple 2002). With the population pressure on the shoreline and the threat of sea level rise and coastal storms, the need for research into coastal processes is certain to increase (NRC 1999). Since coastlines are more often tend to change from its own course due to natural as well as man-induced problems, it is essential to study the coastal dynamics of the area of interest.

1.2 TERMINOLOGY OF COASTAL DYNAMICS
1.2.1 Equilibrium Beach Profile

It is a remarkable fact that beaches around the world are quite similar in composition and shape. The beach profile, which is a cross section of the beach taken perpendicular to the shoreline, is generally composed of four sections: the offshore, the nearshore, the beach and the coast, as shown in Figure 1.1. The sand making up this profile is shaped by waves coming from the offshore and breaking in the nearshore zone, where sand bar may exist. The foreshore or swash zone is the region of the profile that is alternatively wet and dry as the waves rush up this steep portion of the profile. The dry beach may have one or more berms, which are horizontal sections of the profile. Scarps which are near-vertical cuts, are caused by wave action during higher water levels perhaps associated with a storm. The landward portion of the beach may have sand dunes created by winds blowing sand off the beach into these features or a bluff or a cliff, particularly on elevated eroding shorelines (Dean and Dalrymple 2002).
Figure 1.1 Beach profile terminology (adapted from CERC 1984)
The beach profile is the variation of water depth with distance towards offshore from the shoreline. The equilibrium profile conceptually is the result of the balance of destructive versus constructive forces. In nature, the equilibrium profile is considered to be a dynamic concept, for the incident wave field and water level change continuously in nature; therefore, the profile responds continuously. But averaging these profiles over a long period, a mean equilibrium can be defined (Dean and Dalrymple 2002).

The onshore and offshore transport is closely related to the form of the coastal profile. Several investigations have revealed that a coastal profile possesses an average characteristic form, which is referred to as the theoretical equilibrium profile. The equilibrium profile has been defined as “a statistical average profile, which maintains its form apart from small fluctuations including seasonal fluctuations” (Mangor 2001). Changes in beach and nearshore profiles are the results of cross-shore and longshore sediment transport. If the longshore gradients in the longshore component can be considered small, it is possible, through the continuity equation, to infer the volumetric cross-shore transport from two successive profile surveys (CTR 1998).

Beach and nearshore profiles are the major sources of data for engineering studies of beach changes. Sometimes littoral transport can be estimated using these profiles. Usually, beach and nearshore profiles are measured at about the same time, but using different techniques. The nearshore profile is usually measured from a boat or amphibious craft, using an echosounder or from a sea sled, etc. (Kolessar and Reynolds 1966; Reimnitz and Ross 1971). Beach profiles are usually surveyed by standard levelling and taping techniques (CERC 1984).
1.2.2 Waves

Waves are the prime movers for the littoral processes at the shoreline. The dynamics and kinematics of water waves are important factors to be addressed in any coastal engineering study. Waves are generated, for the most part, by the action of the wind over water but also by moving objects such as passing boats and ships. These wave transports the energy imparted to them over vast distances, for dissipative effects, such as viscosity, play only a small role. The dynamics and kinematics of water waves are discussed by several authors (Wiegel 1964; Philips 1980; Mei 1989; Dean and Dalrymple 1991).

Waves undergo many important transformations as they reach shallow waters and when a depth of approximately 1.3 times their height or in other words wave height of 0.78 times their depth is reached they break. Strongest nearshore currents and highest waves cause seabed erosion leading to bottom topography changes and shoreline recessions of hundreds of metres (Dean 1976; Zilberstein and Safronov 1995).

1.2.3 Tides

Tides are the daily rise and fall of the ocean water surface, caused by the gravitational attractions of the moon and sun acting on water particles on the surface of the earth. A convenient model for examining the mechanisms of the tides is the equilibrium theory of tides proposed by Darwin (1898). Tides are important processes in controlling water elevations on the beach and thus the probability of waves reaching coastal structures. The highest predicted tides of the month are the spring tides. A storm surge can create high water levels lasting for several days. The winds create storm surges by blowing the ocean
water up against the coastline. For some sites, either with shallow offshore bathymetry, such as the Gulf of Mexico, or, where the coastline forms a funnel, such as offshore of Bangladesh, which lies on the delta of the River Ganges, the storms can cause immense flooding and the loss of many thousands of lives (Dean and Dalrymple 2002).

1.2.4 Long Shore Currents

The nearshore circulation system occurring at the beach often includes non-uniform longshore currents, rip currents and cross-shore flows (Dean and Dalrymple 2002). When waves break at an angle to the shoreline they generate long shore current, confined primarily to the surf zone. This current interacting with the wave surf, in turn produces a sand transport along the beach parallel to the shoreline. The sediments especially the material thrown into suspension at the breaker zone is easily transported by the longshore currents (Sundar 1999).

The long shore movement of sand on beaches manifests itself whenever this natural movement is prevented through the human interventions. In the nineteenth century it was believed that tidal currents and ocean currents that approach close to the shore are primarily responsible for littoral sand transport. Now it is known that the wave-induced long shore currents are the chief cause of the sediment movement; the ocean currents are effective only under exceptional circumstances. For example, near the mouth of a bay where tidal currents become strong, they may become significant in sediment transport on the beach. Strong winds may also generate long shore currents, that combined with wave action, produce a sediment transport (Komar 1976).
In establishing the long shore currents and sediment transport distributions in the surf zone, the theories of Longuet-Higgins (1972), Ackers and White (1973) and Willis (1978; 1979) are important. The major modes of generation of long shore currents are due to (a) oblique wave approach, (b) longshore variation in wave heights and (c) radiation stress. Komar (1975) has suggested a method to calculate the contribution of longshore variation of wave heights. Later on many researchers (Wang et al 1975; Van de Graff and Van Overeem 1979; Basco 1982; Komar 1983 a, b) consider the oblique wave approach as the major contributor in the generation of longshore currents.

1.2.5 Sediment Transport

The transport of material in the alongshore direction by waves and currents near the shore is known as littoral drift, sometimes the material so transported is also called by the same name (Sundar 1999). Alongshore (littoral) drift is one of the major modes of sediment transport on the beach. The longshore current is the driving force behind littoral drift (Baba et al 1988). Coastal sediment particles are transported by the influence of waves and nearshore currents in the onshore-offshore directions or parallel to the shoreline. There is only slight exchange of fluid between the offshore and the surf zone. There are two modes of sediment movement: suspended sediment movement and bed load movement.

The sediment moved along a coastline under the action of the waves and the longshore currents is transported in several modes: bedload transport, which is either in sheet flow or rolled along the bottom; suspended load, which is carried up within the fluid column and moved by currents; and swash load, which is moved on the beach face by the swash. Littoral transport can occur in
two alongshore directions, depending on the wave direction. Typically the longshore transport at a site will consist of positive drift for one or more seasons and negative drift for the remainder of the year (Dean and Dalrymple 2002).

The pattern of coastal sediment movement is different in offshore, inshore and foreshore regions (Horikawa 1978). It is generally agreed that a major part of littoral transport is caused by waves that approach the shore obliquely. As the waves break, they set the sediment on the bed into suspension. The suspended sediment will be entrained into the long shore current generated by the breaking waves, thus causing transport (Savage 1962).

Considering the action of waves on any beach in plan, the wave crest reaching the shore are seldom parallel to the shoreline or the under water contours. The effect of this oblique attack of the waves on the shore is to generate two components of the fluid velocity, of which one along the direction parallel to the shore is called as longshore currents responsible for the transport of sediment along the shore. This is referred to as “longshore sediment transport”. The second one is the component of the field velocity in the direction normal to the shore transport, the sediment in the direction perpendicular to the shore. This mode of sediment transport is referred to as “onshore-offshore sediment transport”. The longshore sediment transport is more dominant and mainly responsible for shoreline instabilities (Sundar 1999).

The net long shore movement of sediment at any beach is the sum of the transport under all the individual wave trains arriving at the shore from countless wave generation areas. For example, on a north-south trending beach, the sand may move northward for a time due to waves arriving from the south
and then later move to the south under waves coming from the north. The net transport of sediment under these two wave trains will be the difference between the north and south movements. This net transport is generally small, much smaller than the total transport up and down the beach and on some beaches may be essentially zero. This change in direction may be seasonal.

1.3 COASTAL EROSION AND ACCRETION

The real conflict of the beach is not between the sea and shore, for theirs is only a lover’s quarrel, but between man and nature (Komar 1976). On the beach, nature has achieved a dynamic equilibrium that is alien to man and his static sense of equilibrium. Once a line has been established, whether it is a shoreline or a property line, man unreasonably expects it to stay put (Soucie 1973).

If the beaches are considered as a natural resource, it is very important to consider their inherent variability. The changes to which beaches are subjected may be very long time, in the order of decades (e.g. shoreline retreat); seasonal, episodic or they may be as short as a single tidal cycle or even occur from wave to wave (Adeath 1995). In recent years the phenomenon of beach erosion has become important, as the coastline has become a focus of human activity.

In most instances the erosion begins with a loss of the beach itself, together with its recreational assets that are of economic importance to the coastal communities. The loss of the beach also eliminates the protection it offers to homes, hotels and other developments, recognizing that the sloping beach acts as a natural buffer between storm waves and coastal properties. Once
the beach reaches beyond the extent of the fronting beach, they can cut into dunes or erode the base of a sea cliff, undermining homes or other developments (Komar 1995).

Generally the coastlines are supposed to undergo severe changes during monsoon periods and these changes will disappear and the shorelines will regain their original position during non-monsoon periods. The long shore movement of sand on beaches manifests either as accretion or erosion whenever this natural movement is obstructed through the construction of man made structures like jetties, breakwaters, groynes, etc. Such structures act as barriers to the littoral drift, causing a build up of the beach on the updrift side and simultaneous erosion on the downdrift side. The erosion of coastal property has severe consequences and for this reason, a detailed study of the quantities of littoral drift and the processes that produce this movement is important (Komar 1976).

1.4 INFLUENCE OF MAN-MADE STRUCTURES ON COAST

Shoreline is one of the important dynamic coastal features where the land, air and sea meet each other. Due to the action of waves, the shorelines of many coasts change periodically. This is a very common phenomenon in the coastal areas. In any open coast, if interference of man-made structure is happened, such as construction of breakwaters, groynes, etc., in to the seaside, the structure will cause drastic changes on the shoreline, particularly along the east coast of India. The changes on the shoreline by way of accretion on the southern side (updrift side) and erosion on the northern side (downdrift side).
When jetties or breakwaters are constructed, they upset the natural equilibrium between the sources of beach sediment and the littoral drift pattern. In response, the shoreline changes its configuration to reach a new equilibrium. The construction of a groyne or breakwater has the following effects (Bakker 1968; Bakker et al. 1970):

- Prevention of the littoral sand drift in the area between the coastline and the head of the groyne
- Formation of a sheltered area at the leeside of the groyne caused by diffraction and
- Changing the wave height by reflection.

Komar et al (1976) examined the patterns of beach erosion and accretion due to jetty construction on the Oregon coast, which has a seasonally reversing littoral drift with an insignificant net drift. Komar's study proved that even in areas of zero or near zero net littoral sand drift, large changes in shoreline configuration can occur, giving areas of pronounced shoreline erosion as well as stretches of beach where accretion occurs. Due to the construction of structure, the updrift side experiences accretion while the down drift side, erosion; as the structure impounds sand moving in a shore parallel direction thus reducing the volume of sand reaching the downdrift side.

The evaluation and estimation of long shore current velocities, transport rates and the resulting shoreline dynamics is complicated due to the many uncertainties prevailing in the near shore zone. In order to control and mitigate the natural and man-made problems of beach erosion and accretion, protective coastal structures are constructed. However, these measures against
the forces of nature have sometimes proved not only to be futile but also expensive and destructive. There are several examples to show that the construction of coastal structures or the modifications on the beach prove problematic to the existing shorelines.

The breakwaters at Ceara, Brazil, Santa Monica and Santa Barbara, California also provide examples of the resulting deposition-erosion problems (Komar 1976). The positions of updrift and downdrift areas affected by construction would alternate depending on sediment flux direction, which is in turn controlled by the storm conditions. As a result the general trend of the coast development in this case is a beach erosion and the shoreline recession (Leont'yev 1997).

Similarly, the breakwater constructed in 1875 at Ceara, Brazil, provides another early example of the resulting deposition-erosion problems (Carey 1903; Johnson 1957). The prevailing drift in this section of the Brazilian coast is from east to west. Following construction of the breakwater, sand continued to accumulate on the updrift side, eventually moving around the seaward side of the breakwater and forming a bar on the downdrift side which joined with the shoreline.

Shoreline modifications are generally smaller if the jetty is located on a coast where there is a very small (nearly zero) net littoral sand transport. Due to the protective shadow zones adjacent to jetties, sand accumulates there and the shoreline advances. Further along the shoreline, away from the jetties, erosion occurs in order to supply the sand close to the jetties. This erosion is generally small – unless the segment of beach is short, as in the example at
1.5 INDIAN SCENARIO

The total length of coastline along the peninsular India stretches about 6100 km and the coastline of islands such as Andaman and Nicobar, Lakshadweep and Minicoy islands extend about 1500 km. India has an exclusive economic zone of 2.02 million km² (Appasamy and Lundqvist 1993). The main land consists nearly 2500 km long sandy beaches in Orissa, Andhra Pradesh, Tamil Nadu, Kerala, Karnataka and part of Goa coast; 670 km long rocky coasts with cliffs in Maharashtra, part of Gujarat, northern part of Rann of Kachchh, Kanniyakumari and Vishakhapatnam; 2100 km long mud flats in Gujarat and parts of Andhra Pradesh, West Bengal, Tamil Nadu and Maharashtra; and 600 km long marshy coast in parts of Gujarat and West Bengal (Jena 1997). Around 170 million people who live in the 100 km belt along the coastal area directly or indirectly depend on the coastal ecosystem (Appasamy and Lundqvist 1993).

The east coast (Bay of Bengal) of India is often characterized by gentle sloping profile of the shelf, the continental growth of land into the sea in the form of deltas, the presence of lagoons, barrier islands, mangroves, spits, tidal inlets, harbours, etc. Therefore, in a panoramic view, the entire coast looks much intended. The continental margin along the east coast of India has a distinct topographical and geological peculiarity (Jayaraju et al. 1995). The catchment area of the Bay of Bengal having different fluvial sources such as, the Himalayas, Peninsular India and Myanmar, have tended to change the
physical geography, i.e., changes in the course of rivers, rise and fall of sea level, uplifts of mountains, etc (Ramesh 1997).

The accumulation of sediment in small quantities in the form of bars and spits encourages harbour development and hence, a number of small and medium sized ports have developed along this coast (Jayaraju et al 1994). Subramanian (1993) estimated that the peninsular India’s largest rivers discharge approximately a sediment load of 106 tonnes per year on the coast, where exposure to wave and wind energy is relatively high. The rivers, Ganges and Brahmaputra also contribute an enormous sediment load to the region (UNEP 1996).

The predominating features of Indian meteorology is the semi-natural reversal of the wind systems, causing the southwest monsoon (June to September) and the northeast monsoon (October to January). These monsoon winds play a significant role in the morphology of the coast by bringing about erosional and depositional activities. February to May is the fair weather period. The peculiarity of the east coast of India is that it is straight, wary and protuberant and hence it experiences both the positive and negative effects of the monsoon by their windward and leeward nature. The detrital material brought by the rivers is washed northwards up the coast by the Southwest monsoon and down coast by the retreating monsoon. The recently formed littoral in excess quantity has led to the formation of spits and bars. As a result, not only the general configuration of the coast has undergone changes but also many ancient ports have become silted and gone into disuse (Jayaraju et al 1995).
1.6 DYNAMICS OF INDIAN COAST

The elevation of the Indian coastal zone, in general, is in the range of 2 to 30 m above MSL except in areas where cliffs abut the sea, with beach ridges and broad inter-terrace depressions. Periodic upheavals and subsidence in the geologic part have played a major role in shaping the present geomorphology of the coastal zone. Hence, the hydrogeology and surface water conditions of this zone have been greatly influenced by the landforms and structures resulting from neo-tectonic activity. The coastal zone, for most part, displays a fairly plain or gently undulating topography. Various landforms of fluvial, fluviomarine and marine origin are present all along the coastline (Raju 2000).

In India, while southwest and northeast monsoon have equal impact along the southern part of the east coast, only the southwest monsoon has the significant effect on the west coast. The west coast experiences high wave activity during southwest monsoon and calm sea conditions prevailing during the rest of the year. On the east coast, the wave activity is significant during both southwest and northeast monsoons. Extreme wave conditions are however, found to occur under severe tropical cyclones, which are frequent in the Bay of Bengal during northeast monsoon period (Chandramohan et al 1989). Based on the wave measurements carried out by the National Institute of Oceanography, Goa, at different places and at Cochin (Baba and Joseph 1988), the average wave characteristics at few places are presented in Table 1.1.
Table 1.1 Wave characteristics along Indian coast

<table>
<thead>
<tr>
<th>Location</th>
<th>Significant Wave Height (m)</th>
<th>Wave Direction with respect to North (in Degrees)</th>
<th>Location</th>
<th>Significant Wave Height (m)</th>
<th>Wave Direction with respect to North (in Degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SW Monsoon (Jun-Sep)</td>
<td>NE Monsoon (Oct-Jan)</td>
<td>FW Period (Feb-May)</td>
<td>SW Monsoon (Jun-Sep)</td>
<td>NE Monsoon (Oct-Jan)</td>
</tr>
<tr>
<td>Pipavav</td>
<td>0.2 - 1.2</td>
<td>0.1 - 0.8</td>
<td>0.1 - 1.5</td>
<td>N.A</td>
<td>N.A</td>
</tr>
<tr>
<td>Mumbai High</td>
<td>1.2 - 5.1</td>
<td>0.4 - 1.8</td>
<td>0.5 - 1.9</td>
<td>N.A</td>
<td>N.A</td>
</tr>
<tr>
<td>Goa</td>
<td>0.8 - 5.8</td>
<td>0.3 - 1.6</td>
<td>0.3 - 1.8</td>
<td>212-340</td>
<td>200-330</td>
</tr>
<tr>
<td>Cochin</td>
<td>0.9 - 1.8</td>
<td>0.2 - 1.0</td>
<td>0.3 - 0.8</td>
<td>N.A</td>
<td>N.A</td>
</tr>
<tr>
<td>Nagapattinam</td>
<td>0.5 - 1.0</td>
<td>1.0 - 1.5</td>
<td>0.5 - 1.0</td>
<td>90-120</td>
<td>30-120</td>
</tr>
<tr>
<td>Kakinada</td>
<td>1.0 - 2.7</td>
<td>0.5 - 2.2</td>
<td>0.3 - 1.7</td>
<td>N.A</td>
<td>N.A</td>
</tr>
<tr>
<td>Gopalpur</td>
<td>0.4 - 1.7</td>
<td>0.2 - 1.7</td>
<td>0.3 - 2.2</td>
<td>138-185</td>
<td>110-211</td>
</tr>
<tr>
<td>Chennai</td>
<td>0.5 - 1.5</td>
<td>0.8 - 2.0</td>
<td>N.A</td>
<td>100 - 160</td>
<td>60 - 90</td>
</tr>
</tbody>
</table>

(SW – southwest, NE – northeast, FW – fair weather, N.A. – Not Available)  
(Source: Jena 1997)

Semi diurnal tides are most commonly experienced in the Indian coastal region with tidal ranges varying from place to place. The peninsular part of the India is subjected to tides around 0.5m whereas Gulf of Kachchh, Gulf of Khambhat and Sundarbans experience large tidal variations exceeding 5m. Tidal variations at few locations along Indian coast as per predicted tides are given in Table 1.2. Currents near the river mouths are greatly influenced by tides, but the regions along the open coast within 2 km from the coastline are mostly dominated by wind and seasonal circulation pattern.
Table 1.2 Tidal variations along Indian coast

<table>
<thead>
<tr>
<th>Station</th>
<th>Spring Tidal Range (m)</th>
<th>Neap Tidal Range (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kandla</td>
<td>5.86</td>
<td>3.90</td>
</tr>
<tr>
<td>Mumbai</td>
<td>3.66</td>
<td>0.73</td>
</tr>
<tr>
<td>Goa</td>
<td>1.69</td>
<td>0.56</td>
</tr>
<tr>
<td>Mangalore</td>
<td>1.22</td>
<td>0.56</td>
</tr>
<tr>
<td>Cochin</td>
<td>0.63</td>
<td>0.23</td>
</tr>
<tr>
<td>Tuticorin</td>
<td>0.70</td>
<td>0.16</td>
</tr>
<tr>
<td>Chennai</td>
<td>1.01</td>
<td>0.41</td>
</tr>
<tr>
<td>Vishakhapatnam</td>
<td>1.43</td>
<td>0.54</td>
</tr>
<tr>
<td>Paradeep</td>
<td>1.87</td>
<td>0.70</td>
</tr>
<tr>
<td>Kolkata</td>
<td>4.21</td>
<td>2.10</td>
</tr>
</tbody>
</table>

(Source: Jena 1997)

It is observed that only 12 severe storms have crossed the Tamil Nadu coast out of 82 severe storms reported between the years 1582 and 1985 (Mani 2000). Out of these storms only four have crossed the Tamil Nadu coast between Cuddalore and Chennai. The funnel shape of the sides of the Bay of Bengal and the shoaling of its bottom cause high tides, seiches, and internal waves of varying period and heights (Narasimha Rao and Sundar 1982). The average annual excess of precipitation in the Bay of Bengal region is of the
order of 70 cm. The total annual river runoff in the Bay of Bengal has been estimated to be about 2,000 km$^3$ (Subramanian 1999).

On a regional scale, the entire coastal belt of Tamil Nadu along the east coast of India has been studied for shoreline oscillation which indicate erosion, accretion, stable and oscillating sites, the behaviour of which are analysed in the light of coastal regulation zone (Ramaiyan et al 1997). For the state of Kerala, given the scale of coastal processes, different alternate coastal protection strategies have been outlined by Baba et al (1993; 1997).

Along the east coast, erosion occurs in all the states but only moderately. In Tamil Nadu, about 80 km of the coastline is affected. In Orissa, about 30 to 40 km are affected. In the state of West Bengal, erosion occurs in 180 km along the coastline stretching from the confluence of Hooghly River in the west to the confluence of river Jadgan in the east. The rate of erosion is as high as 30 metres per year (Joshi 1995).