## Chapter 21 SEDIMENT MOVEMENT AT INDIAN PORTS

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#### INTRODUCTION

India has a large coastline being bounded on three sides by On the west side, the coastline faces the Arabian Sea. water. Similarly the coastline on the east side is bounded by the Bay The Indian ocean separates the Arabian Sea and the of Bengal. Bay of Bengal at the southern-most end of the coastline (Fig. 1) Since the last 15 years, there have been proposals from time to time to establish new harbours or improve existing harbours or save vast lengths of coastal strips from erosion by wave action. In evaluating the merits and de-merits of the sites, a study of the coastal sediment movement is important since what may be beneficial to a harbour may be harmful for preservation of a coastal strip. Defective planning may cause the loss of the entire shoreline and or the complete blocking of the harbour Improper use of protective structures such as seawalls. areas. breakwaters, groins, jetties etc. will not only be unscientific and uneconomical but accelerate the changes along the shoreline rather than stop them.

The frequent or long-term changes in shoreline, beach, offshore zone, inshore zone, under ground bars, spits, lagoons, tombolas and similar characteristics of the coastline have significant meanings regarding the sediment motion at the coastline. With respect to sediment available for motion, the shore may be a source, a drain, overnourished, undernourished, sufficiently nourished (Per Bruun, 1955), or a physiographic unit (Mason, 1950). With each type, coastal works will be different for shoreline improvement and for harbour maintenance. Erosio and accretion by natural processes extend upto offshore zones while with man-made structures, erosion will always start in the inshore and foreshore zones of the shallow water area. This distinguishing feature in the changes of a shoreline will be a good and reliable preliminary check to determine the type of erosion. Having classified a shoreline according to its sediment nourishment and as a source or a drain, the type of coastal



Fig. 1. Map of India with coastal areas considered.



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protection may be selected tentatively. The selected works may then be studied by model techniques. If the premilinary analysis was complete and accurate, the tentatively selected type of coastal work will be found to be most satisfactory thereby saving unnecessary waste of time and money from testing various types of works by model analysis. This method of analysis will be found to be extremely useful in many countries where investigations of the coastlines are far from adequate. Analysis of the changes at existing coastal structures along the coastline and the interpretations of the results as outlined above will be the most satisfactory method. The coastline of India may also be interpreted similarly in relation to erosion, accretion, and transportation of sediment from the data available from existing structures, harbours and coastal strips, and divided into arbitrary overnourished, sufficiently nourished and undernourished strips and classified as sources or drains as far as possible so that various suitable types of coastal protective structures may be suggested.

Indian coastline as a preliminary step may be divided into the West coast facing the Arabian Sea and the East coast facing the Bay of Bengal since the characteristic features of both the coastlines are entirely of different nature with respect to the wind forces, erosion, accretion, and littoral drift along them.

#### WIND SYSTEM

As described in an earlier article (Manohar, 1958), the whole year may, in general, divided into 4 seasons with respect to the wind system. They are:

- 1. N.E. monsoon season from December to March when the winds blow in a north-easterly direction.
- 2. S.W. monsoon season from June to September when the winds blow in a south-westerly direction.
- 3. Hot weather period in April and May just before the S.W. monsoons when N.E. winds are replaced by southerly winds.
- 4. Transition monsoon period in October and November when S.W. winds are replaced by northerly winds.

WIND SYSTEM ALONG WEST COAST

1. <u>N.E. monsoon season</u> - Figs 2a and 2b show the wind roses for the wind system on the west side. Though in the Arabian





Fig. 3c. Wind roses for Bay of Bengal - September to December.



Fig. 4. Gulf of Cutch - Kandla port.

Sea, the wind direction is between N.N.E. and N.E. with force of 2 to 4 on the Beaufort scale, winds are lighter near the coast with N.E. or E. direction. The wind force gradually rises from north to south and is a maximum in January with an average force of 2 to 4 rising to 7 on frequent occasions. They progressively decrease in February and March and become northerly and north westerly along the coast.

During the hot weather period, the wind blows in the same direction as in March with force of 2 to 3.

2. <u>S.W. monsoon season</u> - The S.W. monsoon which is stronger in force and longer in duration starts in the third week of May in the lower part of the coast and over the whole area by the second week of June. Generally the direction of the wind is between south west and west with a wind force of 5 to 8 in the sea and west or north west along the coast with a force of 5 to 5. Winds are fairly constant in June, July and August. Gales of force 8 to 10 are encountered in the centre of the Arabian Sea with similar gales of slightly lesser intensity along the coast. In September, the wind force decreases to between 3 to 4 rising upto 7 occasionally but the winds are of the same general character as in previous months.

During the transition monsoon period, winds are of land origin blowing with a force of 2 to 4 in N. and N.E. direction

#### WIND SYSTEM ON THE EAST COAST

Wind roses (fig. 3a to 3c) show the direction and inten sity of wind both in the sea and at the coastline. N.E. and S.W. monsoon winds over the Bay of Bengal and east coast of India vary in strength and direction at different parts of the coast. In the northern regions, the north-easterly and easterly winds of N.E. monsoons are fully established in the first week of December while they are in full swing in the southern part only in the third week of December. Similarly S.W. monsoons become regular in the southern part only at the end of April or beginning of May while in the north, they set in only in the middle of June.

1. <u>N.E. monsoon season</u> - In December and January, the average force of the wind is 4 while in the central region, a force of 6 is reached at times. On the Pamban coast (fig. 1) which is shielded by the island of Ceylon, the force is less and of the order of 2 to 3. On the Orissa coast, they are strongest in January while on the Coromandel coast, they are strongest in February, the direction being northerly to easterly. From the

beginning to the end of March, the winds gradually change beginning from the northern end to the southern end to a southerly to southerly-westerly direction.

In hot weather period, wind direction is variable with frequent occurrances of storms called "Nor'westers".

2. <u>S.W. monsoon season</u> - These continue consistantly from June to September with an average force of 5 though gale forces between 6 and 7 and storm forces between 8 and 9 are also experienced during this period. They are predominent over the central and western areas of the Bay of Bengal and their direction is south westerly.

In the post S.W. monsoon period in October, the direction of the wind is still south-westerly with an average force of 3 to 4 but there are many periods of calm weather, light winds and fair weather. In November, the N.E. winds start blowing with an average force of 2 to 4.

Therefore, on both coasts, the south and south-westerly winds are stronger and more durable and exist for almost 8 months a year generating an alongshore component from south to north. Similarly for the remaining 4 months the alongshore component travels from north to south because of north-easterly winds. Frequent storms of great intensity occur along both coastlines affecting the stability of the coastlines to a great extent.

#### WEST COAST

General topography - The west coast of India from latitude 23°N to the southern-most tip, namely, Cape Comorin has a coastline of about 2,000 miles. Along the coast up to latitude 21° N, and at 20 to 100 miles inland, a continuous chain of mountains rises upto an elevation of 8,000 feet. These mountains are known as the Western Ghats. The coastline is mostly sandy with the exception of a few rocky outcrops, a few marshy areas in the north and a few lagoons and a backwater in the south. Very few rivers discharge into the Arabian Sea. Even those which do so are small and since they start from the Western Ghats which is so near the coast, the sediment carried by them from land areas is comparatively little. Mistorical records show that the work of nature of millions of years had somewhat carved an equilibrium along this coast with only localised erosion and accretion at isolated coastal strips. As usual, because of the alongshore component, there was littoral drift getting its nourishment from rivers, lagoons and eroded areas. But unfortu-



nately man-made installations such as construction of harbours, blocking of rivers discharging into the sea and natural disturbances such as silting of inlets, river mouths etc., have upset the material-energy balance resulting in large scale localised erosion along the entire west coast. Though natural disturbances are rather very slow in their occurrances, the one along the Kerala coast, namely, the blocking of the passage of the backwaters to the sea near Alleppey long ago seems to have upset the sediment supply along this coast with consequent disastrous erosion to which reference will be made later. To evaluate the methods necessary for the preservation or restoration of a shoreline or the maintenance of a harbour along this coastline, the coastline has to be interpreted on the basis of the behaviour of the existing coastal works and coastal strips which are in order from north to south as follows: (1) Kandla port, (2) Mithapur intake channel, (3) Porbunder port, (4) Veraval port, (5) Kelva, (6) Versova, (7) Bombay harbour, (8) Karwar, (9) Bhaktal port, (10) Malpe port, (11) Mangalore port, (12) Cochin harbour, (13) Chellanam coastal strip, and (14) Asthamudi port.

#### GULF OF KUTCH COASTLINE

Kandla port and vicinity - Kandla port is the northern-most port along the west coast and lies in the Gulf of Kutch at latitude 23° N and longitude 70° E. The shoreline along the Gulf of Kutch is low and marshy (fig. 4) and is inundated with salt bed mud in many places, the biggest marshy area being the Little Rann into which many streams and creeks discharge as much as 1,800,000 cfs during S.W. monsoon season. The tidal range in this area being high and as much as 23', the coastline along the Gulf of Kutch should be viewed as a tidal one. The tides as usual bring a large amount of sediment from the sea bottom and coupled with this, the sediment brought by rivers and streams are left along the coast resulting in With waves reaching the shore being comparamarshy areas. tively small, sedimentation by tidal action causes large scale silting of the Gulf except where ebb tide follows certain channels of flow. Thus because of large ebb flow, there exists along the northern shore, a deep and wide creek called the Kandla creek at its eastern end (fig. 5). A depth of over 30' without dredging exists in this channel for about 6 miles in length ideally suited for anchorage and turning space for ships (C.W.P.R.S., 1952). This site is at present being developed into a port called the Kandla port. There are also many interconnected creeks which subsequently join the Kandla creek and the Little Gulf. The problem encountered in this region is the shifting of channels due to natural causes such



Fig. 7. Porbundar port.



Fig. 8. Veraval port.

as deficiency of outflow and therefore the flushing velocity due to a weak monsoon season or the deficiency of ebb over tide or tide over ebb. The shifting of tidal channels may be rather a slow process or a sudden process but it has to be checked if the harbour is to be kept effective. If these changes are hastened due to human interference such as reducing the ebb flow by structures upstream, then the remedy will, obviously, be to restore the original conditions so that the scouring velocities of the ebb and tide are the same as they used to be. Dredging the silted portion will be the other remedy.

SAURASHTRA - KUTCH COASTLINE

Mithapur intake channel - Beyond the Gulf of Kutch and 1. moving towards the south in the Saurashtra-Kutch region, an intake channel had been in existence since 1933 at Mithapur, 7 miles from Okha port (fig. 6a) (C.W.P.R.S., 1948). This intake channel was constructed to divert the sea water into two shallow water lakes existing inland from the shore. As soon as the intake channel was constructed, silting was noticed on both sides, the southern side accretion being far in excess of that on the northern side. The shoreline at the intake channel thus advanced every year and in order to prevent silting of the intake channel, it was extended towards the sea every year and walls were built on both sides normal to the There was also considerable decrease of depth in shoreline. the foreshore zones on both sides (fig. 6b).

2. Porbundar port - At Porbundar (fig. 7) which is situated a few miles south of Mithapur, at present an open roadstead exists and ships anchor about 12 miles away from the shore (C.W.P.R.S., 1956). The present plans are to develop it into an all-weather port by providing an approach channel 26' deep and by providing a sufficiently long breakwater enclosing a basin for safe anchorage. Currents and tides are small and have no effect on coastal changes. Along this coast, the S.W. monsoon from April to October with waves reaching the coast from westerly direction is the strongest. Wave heights usually range from 6' to 15' with periods of 5 to 10 seconds. In June, frequent storms with waves as high as 201 During the months from November to March, are not uncommon. waves are relatively low in height varying from 3' to 6' with periods from 3 to 5 seconds. Thus littoral drift during the S.W. monsoon season is far greater than during the N.E. monsoon season. The rate of accretion measured at nearby existing structures as at Mithapur indicates the yearly littoral drift to be of the order of 7,000 tons from south to north, and 3,100 tons from north to south. This quantity is rather

very little to cause any difficulty in the maintenance of a harbour located in this area. The bed under the sea is exte sively rocky at comparatively shallow depths.

3. <u>Veraval port</u> - Veraval port (fig. 8) which is situated at about 70 miles south of Porbunder is at present a small fishing port having no protection from waves (C.W.P.R.S., 195 Though a small breakwater was built in 1931 to prevent waves of the S.W. monscon entering the harbour from the south-west direction, it had been far too short to meet the requirements of an all-weather fishing port. In order to develop this port, an approach channel 150' wide and 18' deep has to be dredged and maintained and the existing breakwater extended further into the sea to give enough protection to the basin.

#### WEST COAST FROM SURAT TO MANGALORE

This coastline of about 670 miles has practically no river discharging into the sea except at the northern end and at Mangalore. Hence the littoral drift is very small except in the foreshore zones due to local erosion. Starting from the northern end, some information about the behaviour of the coastline and harbour works is available at (i) Kelva, 55 miles north of Bombay, (ii) Versova beach, a suburb north of Bombay, (iii) Bombay, (iv) Karwar, 350 miles south of Bomba (v) Bhaktal, 415 miles south of Bombay, (vi) Malpe, 465 mile: south of Bombay, and (vii) Mangalore 500 miles south of Bombay This coastline is exposed to a severe swell of S.W. monsoon and to a lesser extent to the waves induced by the northwesterly winds. Thus the littoral drift occurs from both directions, namely, from south to north and north to south, the former being greater in magnitude than the latter. Because of the absence of lagoons, tidal inlets, or big sediment carrying rivers and since the deep water areas are very near the coast, natural disturbances are few so that the coastline had been fairly stable except for localised changes. The localised changes have been mainly around river mouths due, chiefly, to the sediment load discharged into the sea travelling as littoral drift along the coast. Man-made structures, however, have disturbed the local equilibrium causing erosion and accretion.

1. <u>Kelva</u> - This is a fishing port (Joglekar, 1958) at the mouth of a creek 55 miles north of Bombay (fig. 1). The small amount of sediment brought by the creek resulted in the formation of low lying areas at its mouth. In the process of reclaiming the low lying marshy land, a salt water barrier and a bridge which constricted the waterway considerably were

constructed across the creek about 35 years ago resulting in the reduction of flushing velocities, tidal influx and sediment discharge into the sea. This, in turn, caused silting of the mouth of the creek, erosion of the downdrift side and the consequent change in the course of the creek to the sea (fig. 9). It may be noted that waves as high as 10° and tidal range as much as 14° occur in this area.

2. Versova - This is a suburban beach of Bombay situated north of the city (fig. 10). As at Kelva, waves as high as 10' with periods of 7 to 9 seconds reach the shore from S.S.W to W. direction during the S.W. monsoon period (Joglekar, 1958). With deep water zone very near the coast and the underwater slope as much as 1 in 40, high waves strike the Since 50 years, with Bombay city coast eroding the coastline. expanding to suburban areas, marshy areas at the Versova beach were being reclaimed by shutting off the creeks flowing into the sea and by filling those areas with sand removed from the Though littoral drift by itself is very small along beach. this coast, these reclamation processes caused depletion of the available littoral drift, and resulted in higher waves reaching the shore and eroding the coastline further. With tides as high as 14', there has been large scale erosion in this area.

3. <u>Bombay</u> - Bombay harbour (fig. 11) is one of best natural harbours in the world. Though waves as high as 10' with periods from 7 to 9 seconds reach the coast, the littoral drift as at Kelva and Versova is small. Coupled with this the tide is high at 20' so that the main entrance channel which is at present sufficiently deep to admit ships of drafts upto 30' has never been dredged upto the present time. However previous soundings indicate that silting occurs beyond that depth and that dredging will be necessary for maintaining any depth beyond.

4. <u>Karwar</u> - About 340 miles south of Bombay, there exists a bay called Karwar Bay with varying depths upto 25<sup>1</sup>. At the southern end of the bay, a rock outcrop named Karwar head extends into the sea giving protection to the bay from the S. W. monsoons. Protection from N.W. winds is partly afforded by a number of islands on the northern side. Rock is usually found at 32<sup>1</sup> to 58<sup>1</sup> below ground level. Clay and silt brought into the bay by river Kalinadi from the Western Ghats and by the tides from the sea are found above the rocky bottom. Littoral drift being very small and shoreline being very rocky, erosion and accretion of the shoreline area are negligible.







5. <u>Bhaktal</u> - About 70 miles south of Karwar, there exists a small port where a river discharges into the sea. The river in question is Bhaktal river and it carries a large amount of sediment causing the formation of a large sand bar at its This area is subjected to a direct attack from the mouth. S.W. and N.E. monsoons with no natural protection of any kind existing in that area. The bottom is rocky and the 5 fathom line lies 3,000' from the shore. As in other cases, littoral drift is very small being fed mostly by the river sediment. The difficulty in providing an all-weather port at this place will be the construction of the breakwaters upto deep water areas on both north and south sides and to dig an approach channel through the rocky bottom.

6. <u>Malpe</u> - 50 miles further south from Ehaktal, a small river discharges into the sea in a northerly direction. About a mile from the shore, there exists a row of rock outcrops running parallel to the coast and offering protection to it from the monsoon waves. Rocky bottom exists 33' below sea level. Littoral drift is very small and erosion and accretion around the area are also very small. Since sediment carried by the river is not considerable, river mouth silting is also not considerable.

Mangalore - This is, at present, an open roadstead with 7. vessels unloading about 2 miles away from the port (Manohar, 1958). Conditions are similar to those sites mentioned already except that they are of far greater magnitude. Two fairly large rivers, (fig. 12) Gurpur and Netravati having a maximum discharge of 60,000 cfs and 120,000 cfs respectively during the S.W. monsoon season and carrying a large quantity of coarse sediment flow into the sea through a tidal estuary at Mangalore. Part of the sediment settles in the estuary, another part forms a large sand bar at their common mouth in the sea and another part supplies material for the littoral drift. Two large sand spits separate the rivers from the sea so that the tidal estuary is protected from the waves. The depth over the sand usually varies from 7' to 9'. The sand bars and sand spits grow in size after the S.W. monsoons becau of large river deposits and shrink during fair weather season apparently due to littoral drift and loss in deep sea areas. The net littoral drift is about 200,000 tons per year from sou to north as estimated from erosion and accretion at a natural rock outcrop 3 miles south of the gut. However there is also considerable littoral drift from north to south during the With a large sediment load from the Netravati N.E. monsoons. river, the Netravati portion of the estuary is usually shallow er than the Gurpur portion. A tide of 5' coupled with maxi-

mum wave conditions during the monsoons results in large sediment deposits in the estuary. During the ebb period, this sediment partly finds its way into the approach channel, and the sea providing littoral drift for localised accretion and erosion. Experiments indicate that the tidal influx is strong enough only to maintain a depth of 20' in the approach channel with some dredging and with the provision of a 1,000' long breakwater on either side of the channel. Since there is littoral drift from both sides along the coastline, coastline changes are few and to a small extent.

#### COASTLINE FROM MANGALORE TO CAPE COMORIN

Coastline from Mangalore to Cape Comorin is in many ways different from the coastline discussed above. The foreshore zone is covered with mud and silt. Several mud banks with their characteristic behaviour of sudden appearance and sudden disappearance exist at several places. The continental shelf has a gradual slope upto 100 fathoms and then there is a steep fall. Between Cochin and Cape Comorin, there exist several lagoons and a large sheltered area of backwater of 125 square miles extending as far as 40 miles south of Cochin with only one small outlet, 1,500' in width, open to the sea at Cochin. Mud banks have considerable calming effect on waves so that even the roughest waves are damped as they travel over them resulting in the stoppage of the littoral drift movement. The littoral drift as in other cases travels from south to north during the S.W. monsoon season and from north to south, during the N.E. monsoon season. Three mud banks have been known to appear between Mangalore and Cochin and two between Cochin and Cape Comorin. Because of their peculiar property of appearing at different places, these natural phenomena do not allow material-energy balance to exist so that erosion is considerable along this coastline. The following examples in order from north to south show the behaviour of the coastline under different situations.

1. <u>Cochin harbour and adjoining areas</u> - This harbour is located about 100 miles from the southern-most tip of India (Manohar, 1958). It is situated in the sheltered area of the backwater just behind the 1,500' wide outlet of the backwater to the sea (fig. 13). The southern end of the Western Ghats drains through many small rivers into this backwater bringing down silt and sand from its slopes. It is possible that the long peninsula between the backwater and the sea was formed as a result of the opposing forces of the waves and the discharging power of the rivers into the sea. At present, with only one opening of the backwater to the sea, namely, at Cochin,

most of the silt from the Ghats settles in the backwater itself though part of it finds its way out through the opening forming a bar at the entrance, causing siltation of the approach channel and supplying littoral drift material along the coast. Before the development of the harbour, an outer bar in the form of a horse-shoe with a depth of only 9' above, used to be formed just outside the entrance moving farther towards the sea during the monsoons and towards the peninsula during the fair However, two natural channels of depths 40' weather season. existed inside the backwater near the opening mainly due to the flushing power of the large quantity of water discharging into the sea during the ebb period. One may visualise the enormous quantity of water drained from the backwater from the fact that the backwater level is usually 3' to 4' higher than the sea level during the monsoon season. At present, with the approac channel maintained to a depth of 38', much of the littoral drift is arrested from forward movement at this point. As far as the harbour is concerned, maintenance by dredging for about 4 months a year is sufficient to keep a safe minimum depth of 32' at all times in the harbour.

As far as the neighbouring coastline was concerned, with the stoppage of the littoral drift movement by the deepening of the approach channel and with the net littoral drift occurring from south to north, there was considerable erosion on the northern side and accretion in the immediate neighbourhood in the south. There was also silting of the bottom on the south side and deepening of the bottom on the north side. The fact that there was littoral drift from north to south, was made use of to regain the lost coastline by providing a stonefaced bund in the lower part of the spit and a series of discontinuous stone groynes running nearly parallel to the shore and overlapping each other in an eschelon fashion for a distance of 2 miles (fig. 14). By making these groynes discontinuous, there had been less erosion at the outer toe and even silting was induced behind them. The result was that the shoreline was considerably restored to its original position.

It may be mentioned that S.W. monsoons are very strong along this coast with waves as high as 6' with a period of 10 seconds reaching the coast during a considerable part of this season. Frequently severe storms with waves as high as 13' also occur during this season. The net littoral drift is northwards at a comparatively small quantity of 42,000 tons per year, so that the littoral drift problem is not as great as the problem of silt brought into the backwaters from the Western Ghats.

2. Coastline, south of Cochin - Though there is considerable accretion on the south side of the approach channel of Cochin harbour causing the growth of the sandspit, a 20 mile strip of a shoreline southwards beyond 2 miles from the sand spit, and popularly called the Chellanam coastline (fig. 15) had been undergoing considerable erosion (C.W.P.R.S., 1955) threatening a break in the peninsula between the backwater area and the sea - an occurrence which would be a calamity endangering the entire disappearance of the peninsula separating the backwaters from the sea. Within the last 60 years, a coastal strip 20 miles in length and 1,300' in width had been completely lost to the sea as a result of the erosion. Seawalls were constructed along this stretch but most of them were destroyed after they experienced a few storms of the S.W. monsoons with waves as high as 13' striking the walls during the During the fair weather season - November to March, storms. with waves reaching the coast from west to north west, the southerly drift partly restored the eroded area but the net result however, was a loss by erosion of the coast. Since seawalls alone could not prevent erosion as experienced in this case, a mile length of seawall combined with groynes was constructed in the worst eroded section. These structures have since then, prevented erosion but because of very little littoral drift, only a few groins at the southern end were filled up. The erosion of the coastline has, however, been reduced and the groynes are slowly getting filled up. Measures are under way to protect the entire 20 mile strip with similar structures.

Beaches along the coast of Kerala are narrow with fairly steep (1:12) underwater slopes. During the S.W. monsoon season (June to September), the wave direction is between 10° and 40° south of west while during the fair weather period (October to May), it is usually in the north direction. Prior to the construction of protective structures, coastal strips as wide as 30' used to be eroded by storm waves within 48 hours. The net erosion per year used to be as much as 15' to 20' of the coastline.

3. <u>Ashtamudi fishing port</u> - Near Quilon, north of Trivandrum, there exists a lake called Ashtamudi Lake (C.W.P.R.S., 1956) with an outlet to the Arabian Sea (fig. 16). There are proposals, at present, to develop this lake into an all-weather fishing lake. At the entrance to the lake, there exists a bar with water to a depth of 3'. Waves break over the bar and during the monsoon season, these breakers assume large proportions making it difficult for any craft to pass through.

A number of shoals exist at the outlet between a channel in the south and one in the north. The northern channel has depth of 7' to 9' at all times while the southern one is shall and gets silted due to sand movement. Unlike in other parts of the west coast, this movement is not, most probably, due to the S.W. monsoon waves since these waves reach the coast almost at right angles with no alongshore component in existance. These S.W. monscon waves, however, which are sometimes, as his as 10' probably bring sediment towards the shore from the sea bottom. The sediment thus brought by the waves along with th sediment discharged from the lake by the S.W. monsoons and by tides of 3' to 4' is moved alongshore from north to south by coastal currents of speeds upto 2 knots and from the south to north by less stronger currents. Obviously since there are r major rivers to supply the sediment for this drift, most of it is derived from the sea, by erosion of the coastline and from the lake.

Very near this lake and towards the south, there exists a rocky outcrop called Tangasseri Point projecting into the sea. Between the lake and this point, the coastline is rocky and the bottom is covered with sand (1 mm), mud and silt (0.25 mm The foreshore zone is flat and the waves break at a distance from the shoreline. Sediment analysis indicates that most of the coarse sediment between this Point and the lake must have been derived from coastal erosion and brought to this zone by diffraction of waves at this Point. The beach south of this Point is very steep causing waves to break at the shore and mo of the sediment in motion to disappear into deep sea areas. As such there seems to be very little sediment in motion beyon this point. On the other hand, the foreshore zone north of the lake is shallow containing silt (0.25 mm) and mud. - Sedi ment analysis shows these to have their origin in the Lake and in the small streams discharging into the sea.

A feature of this coastline upto Cape Comorin is that there are many lagoons separated from the sea by small strips of land. In general, the outlets point towards the south ind cating sand drift in this region to be from north to south pro bably due to coastal currents.

#### WEST COAST-HARBOUR PRESERVATION

From the point of view of littoral drift, this coast is ideally suited for location of a harbour. With very few rive discharging into the sea, littoral drift is localised with onl local accretion and erosion. However with the rainfall heavy along the coast, rivers bring down a large quantity of sedimen





Fig. 15. Kerala coast near Chellanam.



Fig. 16. Ashtamudi port.

which manifests itself in the form of sand bars, sand spits, shoals and littoral drift. In addition, with the severe and consistant S.W. monsoons for 4 months, heavy swells reach the coast making it difficult to do any effective dredging to keep the approach channel and the harbour basin from silting. In general, the foreshore zone is steep and thus the difficulty of extending the breakwaters to the sea as protective structures to the basin is a factor to be reckoned with. Considering the coastline from Kandla to Cape Comorin the following may be concluded.

(a) <u>Coastline bordering Gulf of Kutch - With wave action and</u> littoral drift small and tides high, the problem along this coastline is mainly a tidal one. With a large number of small streams discharging into the Gulf and with the coastlin consisting of low lying areas, there exist many flow channels to the Gulf which shift due to natural causes such as deficiency of outflow as a result of a weak monsoon, or deficiency of ebb over tide or tide over ebb. The shifting of tidal channels may be rather a slow process but it has to be checke if the harbour basin is to be kept effective. The only remedy will be to have regular depth soundings of the flow channels and prevent change of course of the channels by restoring the original ebb and tide discharges so as to have the same scouring velocities and resort to dredging if necessary.

(b) Saurashtra-Kutch Coastline - Beyond the Gulf of Kutch an towards the south on the west coast in the Saurashtra-Kutch region, the coastline between marks A and B in fig. 1 may be called a physiographic unit, that is, a coastal strip in which the energy and the material available within the area and therefore erosion and accretion in the area are not dependent upon the adjacent areas. This area can, therefore, be treate as a separate unit by itself. From the behaviour of the coastline and harbour areas, the following may be interpreted Since the littoral drift is small of the order of 7,000 tons per year from south to north and 3,100 tons per year from north to south, maintenance of the harbour from this point of view will be easy. A little dredging during fair weather season will be sufficient. However, breakwaters have to be extended sufficiently into the sea for the littoral drift to be directed to deeper portions and to protect the harbour from the severe swells of S.W. monsoons. Diffraction of waves and the resulting deposition of sediment in the lee of the breakwaters and ranging in the harbour have to be carefully analyse in these regions. With very little littoral drift, the danger of erosion and accretion of the adjoining coastline is

slight except during storms. Seawalls to withstand the wave action and groins to trap the available sediment will be sufficient.

However for small intake channels such as at Mithapur, construction of long breakwaters will, not only, be expensive but is not warranted by the situation. In such cases, the high range of tide may be used beneficially and the original conditions especially the tidal velocities and discharges as they existed before the construction of coastal works should be restored. The coastline is bound to get shallow behind the breakwaters but if the tidal velocities especially those of the ebb are strong enough to flush the sediment deposits, no further remedial measures may be necessary.

An ideal example of accretion caused by man-made structures can be found at Mithapur. With coastal works, erosion and accretion will always start first in the inshore and foreshore zones, that is, in comparatively shallow water causing a gradual decrease in depths in the shallow water zones on the accretion side and gradual flattening of the beach profile. This is typically evident in fig. 6b.

(c) West coast from Surat to Mangalore - This coastline is directly in the zone of severe S.W. monsoon swell and to a lesser extent to the waves induced by the north-westerly winds. Thus the alongshore components occur from both south to north and north to south, though the former is stronger than the latter. The deep water areas are very near the coast and much of the material brought by the rivers go into those areas. Littoral drifts are localised and vary from 3,000 tons per year to a maximum of 200,000 tons per year at places where the sediment load carried by the rivers is great such as at Mangalore.

Harbours along this coastline can mostly be located at river mouths only because of the difficulty of construction of long breakwaters into deep sea areas near the coasts and because of the severe monsoon swells reaching the coast. However, river harbours of the type which can be constructed along this coast have the following disadvantages. Rivers bring a large amount of sediment which deposits partly at river mouths because of the tidal influx opposing the heavy swells at those places. Also the ebb tide takes part of it to the approach channel. Thus the harbour basin and the approach channel get silted and sand bars, sand spits and sandy shoals are formed. Usually along this coastline, the flushing power of the ebb is large enough only to maintain a maximum depth of 20' during the

monsoon season. Dredging of the approach channel will also difficult during the monsoon seasons due to high swells. Therefore for the maintenance of a harbour, river sediment should be arrested or disposed off before reaching the harbou basin. The proper remedy will be to build sand traps just above the harbour basin and to dispose off the trapped sedime to the sea by dredging during fair weather season. If the sediment is placed along the shoreline at proper places, the sediment thus placed will act as artificial nourishment for 1 Because of high waves reaching the coast, sea toral drift. walls and groins should be constructed at critical places of erosion to prevent erosion and restore the eroded strips resp tively.

Along this coast, Bombay is, however, an exception becau it is situated in a bay having a large tidal influx maintaini a depth of 30' in the approach channel without dredging and thus making it an ideal natural harbour.

(d) Coastline from Mangalore to Cape Comorin - Along this coastal strip, there exist many distinct features not found elsewhere and as described before. These are in the form of many lagoons, mud banks, and a large backwater separated from the sea by a peninsula. The direction and quantity of litto ral drift are almost the same as in the coastal strip above (northwards) except for the coastline below (southwards) from Ashtamudi Lake to Cape Comorin where the waves reach the coas almost at right angles leaving no alongshore component. HOW ever in this southern-most area, coastal currents are of sufficient magnitude for alongshore movement of the sediment. Except at Cochin where the flushing power of the ebb is great due to the large quantity of water discharged into the sea through the harbour entrance, it will not be possible to main tain a depth of more than 20' in the approach channel at any other place for reasons mentioned earlier. If however this depth is to be maintained, dredging for a few months of year : the fair weather season will be sufficient if a sand trap is built above the harbour basin to trap the sediment brought during the monsoon season.

#### COASTLINE PRESERVATION OF THE WEST COAST

Because of very little erosion along the coastline and that too localised to a great extent at places where the material-energy balance is disturbed by the construction of coastal works, the shoreline and foreshore zone considered as a whole seem to be in equilibrium. With very few rivers discharging into the sea and with no serious erosion or accretion

the littoral drift seems to be just sufficient to keep the shoreline in equilibrium moving in both directions, namely, from south to north and vice versa restoring the eroded parts However, erosion of considerable of the previous season. extent occurs during storms in isolated places and restoration of this area by littoral drift of the fair weather season is never complete because of insufficient littoral drift. Thus the erosion extends inwards gradually every year. In such cases, a seawall situated sufficiently inside the shore to prevent erosion and groins to trap the sediment in motion will be If littoral drift is insufficient to cause any required. accumulation of sediment at the groins, artificial nourishment in the form of the dredged sediment from the river mouths or harbour or accretion areas may be necessary if economically feasible and if this does not affect the nearby harbour areas to a harmful extent.

#### EAST COAST

General topography - The east coast of India which extends from Cape Comorin in the south to the mouth of Ganges in the north has a coastline of about 1,750 miles. The west coast of Gulf of Mannar shielded by the island of Ceylon extends from Cape Comorin to Pamban. From Pamban to about latitude 16° N, the coast is called the Coromandel coast. The remaining coastline is divided into Circars coast upto latitude  $19^{\circ}$  23' N and the Orissa coast upto the River Hoogly. Numerous hills lie along the coast and unlike on the west coast, they are not continuous. For a considerable length, these hills are far inland from the coast and a broad strip of low lying land lies between them and the Bay of Bengal. Southwards of Madras, the width of the coastline is about 80 miles and in the north, it narrows to 30 miles. Most of the sediment carrying big rivers of the south and central India, such as Mahanadi, Godavari, Cauveri, and Kistna have their origin in the Western Ghats and flow into the Bay of Bengal in the east between the hills. North of Godavari river (lat. 16° 30' N), the Eastern Ghats are conti-muous and very near the sea. The coastline above Circars coast essentially consists of the wide deltas of Mahanadi and Hoogly rivers.

From the point of view of littoral drift, this coastline is at large variance from the west coast. Rivers discharge a large amount of sediment into the sea and this travels back and forth along the coast. As on the west coast, the littoral drift is from south to north during the S.W. monsoons and north to south during the N.E. monsoons. It has been estimated from existing installations that the net drift from south to north is of the order of 1 million tons per year. This large littoral



drift has resulted in flat foreshores for long distances on either side of the river outlets. Under natural conditions before the development of harbours and other coastal structures, there seem to have existed equilibrium conditions with this large quantity of sediment moving in comparatively shallow depths along the coastline balancing erosion and accretion. But with the construction of coastal works arresting the large littoral drift, there had been large scale accretion on the updrift side and large scale erosion on the downdrift side. The difficulty of restoring such a tremendous material-energy inbalance has been the bane of the east coast. The following descriptions of a few existing installations, the difficulties experienced and the methods used to overcome those difficulties will give a correct picture of the problem.

Madras - This is an artificial harbour situated in southern 1. India along the east coast (fig. 17). This shoreline harbour is formed by the projection of two artificial breakwaters from the shoreline (Manohar, 1958). An extension of the southern breakwater northwards and called the sheltering arm protects the entrance on the northern side. A masonry arm of about 720 feet at the south-eastern corner of the southern breakwater prevents rabid silting of the foreshore zone on the south side with the sediment being deflected into deeper areas. Two rivers, one north of Madras, namely, Pennar and one south of Madras, namely, Cauvery contribute to most of the sediment to the coastline. Waves of the S.W. monsoons reach the shore at an angle of 30° and with the large scale northerly littoral drift the foreshore zone was advancing rapidly on the southern side till the construction of the sand screen. Because of silting, the original entrance on the east side was shifted to the present one on the northside. At present, with the foreshore zone flat on this side, the surf breaks at about 1,000' from the shore with waves as high as 14'. With the shallow coastal shelf very narrow and ocean depths comparatively close inshore, the danger of littoral drift silting the harbour entrance is no longer a problem with the provision of the sand screen (masonry arm) which serves two purposes, namely, deflection of a large amount of sand drift into deeper areas and allowing the removal of sediment by dredging from behind the screen. On the northern side where there had been considerable erosion, provision of stone revetments along the coastline and the sediment brought by the southerly drift during the N.E. monsoons have prevented further erosion. The trouble with this harbour, at present, is not from littoral drift but from 'ranging' which is sometimes, as high as 2'9".

2. <u>Vizagpatam</u> - This harbour is situated farther north of

Madras and unlike that harbour, the neighbouring coastline is bounded by hills in some places and rock outcrops in other places (fig. 18). It is a natural harbour at the mouth of a small river which flows into a bight and then into the Bay of Bengal (Ash & Rattenbury, 1935). The entrance channel is short and is situated between the high bluffs of Dolphin's nose in the south and Vizagpatam town with its small hills in the north. At times, the rainfall is intense so that the large quantity of silt brought by the river is deposited in the harbour basin. This slit, however, can easily be dredged and disposed off into the sea. As at Madras the worst troubl is from littoral drift estimated to be a million tons per year moving towards the north and about 20,000 to 300,000 tons per year moving towards the south. To keep the 300' wide approac channel in operation at all times and to a depth of 33', a detached breakwater in the form of two sunken ships and approximately 1,000 feet in length sunk in shallow water of 18' to 25' depths has been very effective in preventing sand from reaching the channel. The breakwater acts as a sand trap depositing sand in its lee from which it is dredged and disposed off to the northern side.

3. <u>Paradip port</u> - Halfway between Vizagpatam and Calcutta, on of the major rivers in India, namely, the Mahanadi river discharges into the Bay of Bengal. About 2 miles up the river, a port called Paradip port (fig. 19) is being developed to cater to traffic for areas between Vizagpatam and Calcutta.

River Mahanadi divides itself into a large number of tributaries just before reaching the sea. During the S.W. monsoon season when the discharge from the river is as much as 500,000 cfs, a large amount of silt and sand of the order of 28 million tons per year is discharged into the sea. Much of the sediment deposits at the mouth of the river or travels alongshore as littoral drift material with the result that a large triangular delta of 4,500 square miles is in existance During the fair weather season (October to Ma: at its mouth. river discharge being very small and flood tide being comparatively large, some of the silt finds its way back into the river. At the southern entrance, however, a depth of 40' has always been maintained and it is at this place that a port is being developed (C.W.P.R.S., 1956). Between this basin and the sea, a sand bar is formed at a minimum depth of 11' below water moving towards the river during the fair weather season and shifting back to the sea during the S.W. monsoon season. Because of the large quantity of silt brought by the river, a long and narrow sand spit, 6 miles in length, always exists parallel to the coast. When it assumes a large size, a break

occurs for the river to flow into the sea and then it shifts its position from north to south and vice versa. This growth and movement of the sand spit with the consequent change of course of the river mouth is a recurring phenomenon, for, this area acts as a source for distribution of sediment to other As in the case of Madras and Vizagpatam, the southareas. westerly winds with littoral drift from south to north exists for 8 months a year with the strongest drift occurring during the S.W. monsoon from June to September. Similarly there exists a drift from north to south during the other four months. S.W. monsoon waves are, sometimes, as high as 10' and with this intense wave action and large quantity of sediment available from the river, there is a net littoral drift of 1.5 million tons per year travelling from south to north. This drift along with the tides (maximum of 7') has been responsible for the various changes that occur in this area from time to time.

Calcutta - Calcutta port situated 120 miles up the river 4. Hoogly from the sea (Bay of Bengal) is a typical river channel harbour (fig. 20). With the harbour far inland from the sea and with a large tidal influx, there are channels of sufficient depths at the river mouth which are not affected by the littoral drift. However, the large amount of sediment brought by the river from the upland reaches through its many tributaries, chiefly Rupnarain and Damodar moves back and forth in the river as a result of the large variation in the tides. The tidal range is as much as 17" near Calcutta and the effects of tides are felt upto Swarupganj, 84 miles north of Calcutta. Soundings indicate that the Hoogly estuary is deteriorating rapidly especially in the reaches above the Diamond harbour. Depths below Diamond harbour usually maintain themselves at 14' but depths above deteriorate to as low as 6' without dredging. It may be noted that but for the fact that only coarse sediment settles to the bottom, the river would have silted up long ago. It is also interesting to note that most of the sediment brought by the river settles in the river reaches themselves resulting in very little sediment discharge into the sea. Consequently about 70 to 80 million cubic yards of sand are dredged every year from the various bars to keep the navigational channels in operation. These bars are the worst from February to middle of May during the equinoxial perigree spring tides when there exists very little freshet discharge and a large influx discharge of the order of 50 to 60 million cfs creating many channels of flow through the bars. From middle of May to middle of July, these bars are prevented from further deterioration by the gradual increase in the freshet discharge. From middle of July to end of October, that is, during the S.W. monsoon season, the flood tide is held back by the large

freshet discharge which reaches a maximum of 210,000 cfs in the Hoogly and the bars improve so that in some places, depth are as much as 24'. However these freshet discharges create more flow channels and these being not the same as those form during the fair weather season and not being the same every year, result in the formation of a large number of bars, shoa! and twisting channels in the river necessitating enormous continuous dredging to keep open the navigational channels. Ba and shoals deteriorate later during the post freshet period from November to January when the freshet discharge decreases and the flood tides predominate. In addition, Hoogly experiences variation in mean tide level from season to season resul ting in change in velocity for the same range of tide and thu: affecting the bar formation. Hoogly estuary shows another peculiarity in that there are rotary currents caused by the change in the direction of the flood and ebb tides in some places due to the peculiar regime of the estuary. Yet anothe peculiarity in the Hoogly river is the occurrence of the "hydraulic bore" with waves of 8' to 10' heights travelling very fast up the river and destroying the banks and neighbouring property in their path. All these affect the bar and channel formations and the depths in the river and therefore the harbour area, with the littoral drift along the coast havin very little to do with them.

#### EAST COAST-HARBOUR PRESERVATION

With the large amount of littoral drift of the order of 1 million tons travelling along the coast, construction of harbour works will result in rapid silting of the foreshore zones, approach channels and harbour basins as experienced at In addition, the difficulty of dredging such a large Madras. quantity of sediment under severe wave action of the S.W. monsoon season will also be a problem to be dealt with. If the harbour is an artificial one as at Madras with breakwaters extending from the shoreline to the sea, arrangements similar to those made at Madras for the disposal of the sediment deposit and for prevention of erosion may be made. A better arrangement would, probably, be to dispose off the accreted material to the erosion side, that is, the north side, to replenish the coastline. If the harbour is a natural one as at Vizagpatam, a similar arrangement in the form of a detached breakwater acting as a sand trap and disposal of the accreted material dredged from behind the same trap to the erosion side may be the best one if the foreshore depths are shallow. If the harbour is situated in a river delta as at Paradip it will be difficult to predict the type, position and nature of the coastal works because of the shifting nature of the flow

channels and sand bars and because of large littoral drift. In any case, for any harbour along this coastline, it will be difficult to state exactly the type of coastal works necessary unless rigorous model studies are conducted though the measures taken at Madras and Vizagpatam may be used as guides.

#### COASTAL PRESERVATION

From the point of view of coastal preservation under natural conditions, the methods to be adopted on the east coast are fairly straight forward because of the heavy littoral drift. A series of groynes spaced properly and with sloping top surface to allow the excess littoral drift to pass over them and seawall built sufficiently inside the beach to prevent the heavy waves from damaging the coastline will be more than The groyne space, will get rapidly filled ressufficient. toring or extending the coastline. This coastline may be termed an overnourished coastline and the river mouths which are numerous, act as sources with sediment brought by the rivers acting as the littoral drift material. If, however, coastal works such as breakwaters, approach channels and other similar harbour works are built, consequences will be disastrous. The large material energy inbalance will be so large that large scale accretion on the updrift side (south side) and large scale erosion on the downdrift side (north side) will The best way to restore equilibrium along the shoreresult. line will be by artificial nourishment from updrift to the downdrift side of the excess material available on the former side, if economically feasible.

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