Siltation and Coastal Erosion at Shoreline Harbours

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Abstract

One of the major maintenance problems encountered by the shoreline harbours along east coast of India is siltation of approach channels due to huge longshore sediment movement by wave action along the coast. Wave induced longshore sediment transport rates along east coast of India at selected major shoreline harbours Chennai, Visakhapatnam and Paradip have been estimated using an energy flux method. The direction of littoral drift is generally from south to north during the period March to October when southwest monsoon blows over Bay of Bengal and reverses its direction from north to south during the period November to February during northeast monsoon season. The rates of sediment transport however vary from one shoreline harbour to another depending upon the wave climate and other near shore features. While the littoral drift rates are high during south west monsoon season from March to October at Visakhapatnam and Paradip harbours, the Chennai harbour on the other hand experiences high rates of littoral drifts during north east monsoon months particularly from November to January due to storm waves along the coast. The estimated sediment transport rates have been compared with the available dredging quantities to know their accuracies. The problems of siltation and coastal erosion have become severe over the years due to deepening of the harbour channels as a part of expansion and modernization of ports. Hence, a detailed study on siltation problems faced by the shoreline harbours will definitely useful not only for dredging management plan for existing ports but also for planning new port locations along the coast. The historical problems of the shoreline harbours due to construction of harbour installations at selected important ports along east coast of India have been discussed briefly.
1. Introduction

The harbours along east coast of India viz., Tuticorin, Chennai, Ennore, Krishnapatnam, Gangavaram, Visakhapatnam and Paradip come under shoreline harbours except the Kolkata and Haldia harbours which are river channel harbours. Whereas the harbours along west coast of India are classified as channel harbours in tidal estuaries. Location of harbours along Indian coastline can be seen in Fig. 1. Depending upon the classification of the harbours, the problems of siltation and maintenance of the channels are quite different. In the case of shoreline harbours the shoaling effects are generally in the immediate vicinity of the harbour where manmade structures are erected. The sedimentation problem of harbours in tidal estuaries varies from one tidal inlet to another and shoaling can occur right from the entrance of the estuary, although the harbour might be at a remote site up the estuary. In this paper the siltation problems encountered by the shoreline harbours are discussed.

Fig 1: Location showing important harbours along Indian coastline

The objective of this research is to estimate the sediment transport rates using suitable empirical relations and correlate the same with maintenance dredging records so as to arrive a meaningful solution for the siltation problem faced by shoreline harbours. The effectiveness of the erosion control measures has been discussed. The appropriate and beneficial disposal of dredged material is a major problem for port authorities in India. The issue of current dredged material disposal practices is critically examined based on a scientific understanding of the related processes.

2. Siltation problem at shoreline harbours

One of the major problems encountered by the shoreline harbours along east coast of India is siltation in the form of littoral drift. In fact, the littoral drift is one of the largest on the world coastlines. For effective monitoring of the port approach channel and harbour basin, the rates of siltation due to littoral drift should be known.
The monthly values of wave induced sediment transport quantities evaluated using wave energy flux method (SPM: CERC, 1977) at shoreline harbours of Chennai, Visakhapatnam and Paradip are depicted in Fig 2. The sediment movement along the north is taken as positive and shown upward in the figure whereas the southerly sediment movement is taken as negative and shown down ward in the same figure. The direction of sediment movement is from south to north during the period March to October when south west winds prevail over Bay of Bengal and the wave directions are predominantly from south and southeast along east coast of India where Chennai, Visakhapatnam and Paradip harbours are located. During north east monsoon period from November to February when wave directions are between northeast and east, the direction of sediment movement get reverses along east coast of India, that is, north to south.

![Sediment Transport Rate](image)

**Fig. 2: Sediment Transport Rates at Chennai, Visakhapatnam and Paradip harbours**

The littoral drift quantities are large from May to August for all the three port locations viz., Chennai, Visakhapatnam and Paradip, due to heavy breakers along east coast associated with southwest monsoon. The northerly littoral drift from March to October is by far the most dominant at the shoreline harbours located along this coast. The rates of northerly sediment movement (littoral drift) are generally high at Paradip harbour when compared to Chennai and Visakhapatnam harbours. However, the rates of southerly littoral drift are high at Chennai harbour when compared to Visakhapatnam and Paradip harbours. As the Chennai harbour lacks natural protection and is exposed to strong swell from east during cyclone period from October to December causes large quantity of sediment movement towards south. The history of the Chennai harbour had also shown that the original entrance of the harbour from east was closed in 1911 and moved to north to protect the harbour from violent storms and associated siltation during north east monsoon (Johnson, 1957). The particular orientation of coast at Chennai and bottom topography perhaps amplifies the wave energy in the near shore zone particularly during cyclone period when long waves are generated. This is also one of the reasons that the Ennore port planners and engineers have provided long north and east breakwater of length 3080 m to protect the harbour from strong swell during north east monsoon season when the coast is exposed to frequent cyclones. The Ennore port which is located just 24 km north of Chennai port has similar site conditions as that of Chennai.
The total estimated northerly littoral drift is 1.51, 0.84, 1.92 million cubic meters per year while the southerly drift is 1.05, 0.29, and 0.24 million cubic meters per year respectively at Chennai, Visakhapatnam and Paradip harbours in that order. The gross littoral drift quantities estimated are 2.56 million cubic meters per year at Chennai harbour, 1.13 million cubic meters per year at Visakhapatnam harbour and 2.16 million cubic meters per year at Paradip harbour. The net northerly littoral drift progressively increases from south to north along the east coast of India, i.e., 0.46 million cubic meters per year at Chennai harbour, 0.55 million cubic meters per year at Visakhapatnam harbour and 1.68 million cubic meters per year at Paradip harbour.

It is clear from the foregoing discussion that a substantial quantity of sand constantly moves along east coast in the littoral zone, because of waves and currents. Any natural or manmade construction such as jetty or breakwater across the surf zone would act as a barrier, and sand would be deposited on the up drift side of such a barrier. Consequently, the down coast shoreline must change its configuration in reaching a new state of equilibrium. As shown in fig 2, the northerly littoral drift (from March to October) is by far the most dominant along east coast. Some of this northerly drift is deposited behind the southern breakwaters at the shoreline harbours; some of the drifts gets deposit in the sand traps designed adjoining the southern breakwaters and some of the drift finds its way into the dredged channel necessitating careful maintenance of the channel while the remainder of the material may get by-passed to the northern side of the harbours. This huge longshore sediment transport creates a problem of shoaling at shoreline harbours along the coast.

To assess the accuracies of the estimated sediment transport rates, the best way is to compare the estimated quantities with the actual quantities of maintenance dredging at the harbour and sediment deposited at up drift side of the harbour structures. For this purpose the annual maintenance dredging quantities have been considered for comparison. The recent annual maintenance dredging quantities provided in the table (1) are variable from year to year for any given port location. The average dredging quantities (Table 1) for three harbours viz., Chennai, Visakhapatnam and Paradip are of the order of 0.77 million cubic meters per year, 0.79 million cubic meters per year and 2.74 million cubic meters per year respectively. The annual dredging quantities are closely comparable with the estimated net northerly littoral drift rates. The annual maintenance dredging quantities do not represent the period in which the dredging works were carried out to compare with the monthly estimated values. For better comparison, the monthly dredging quantities over the years as available at Paradip port have been used (Fig. 3).
From the fig. 3, it is clear that the trend of actual quantities of sediment transport based on dredging at approach channel, sand trap and harbour area is closely comparable to the predicted/estimated values at Paradip port. However, for many months the actual values are marginally higher when compared to the estimated quantities. The reasons for high dredging quantities can be attributed to the fact that the method of assessment at Paradip port was based on counting of number of hoper loads. In the hoper, the dredged material was a mixture of sand and water but not the consolidated material. Hence, the dredging quantities are exaggerated. The dredging works were carried out during south west monsoon season from April to October when northerly littoral drift is predominant along the coast. In the month of August, the dredging quantity was highest when the littoral drift was at its peak. During north east monsoon season (November to March) when the predicted littoral drift rates are low, there is no necessity to carryout dredging works and hence not carried out. Hence, it can generally be concluded that the predicted quantities of sediment transport are closely correlated with actual dredging quantities and can be useful for planning the dredging works.

Several studies on sediment transport include cross shore (onshore – offshore) sediment transport coupled with longshore sediment transport have been carried out earlier along east coast of India at shoreline harbours viz., Visakhapatnam port (Reddy et al, 1984 and 1985, Chandramohan et al, 1981 and 1984), Gangavaram port (Chandramohan et al 1985, Prasad et al 2010), Paradip port (Sarma and Sunder, 1988), Ennore port (Ranga Rao et al 2009). These studies have been comprehensively included all aspects of sediment transport in different time scales including normal and storm periods as the east coast of India is prone to cyclones and the sediment transport is related to seasonal changes in wave characteristics (south west and north east monsoon seasons). Most of these studies have revealed that the longshore sediment transport play a vital role in maintenance of the navigation channels whereas cross shore sediment transport coupled with longshore sediment movement is important in natural conditions where no interference by manmade structures. Hence, it can generally be concluded that each harbour is somewhat unique in terms of possible causes of harbour siltation.

3. Maintenance Dredging

The maintenance dredging is one of the serious problems encountered by the ports in India. The maintenance of harbour entrances is an expensive item in maritime administration. It would be helpful if some suggestion could be made for planning the future harbours or on improving the design of the existing harbours based on past lessons learned. The predictions on sediment transport rates and its relation to the dredging activities on possible lines of research would definitely throw light on maintenance of the harbour channels to some extent. The quantities of the dredging for various important ports in India are furnished in table 1.

From the table 1 it is clear that the dredging is an annual maintenance problem encountered by various ports in India. The dredging quantities vary from port to port depending upon its location and draft required to be maintained. On an average about 50 million cubic meters per year of dredging quantity is involved for all the major ports for maintenance of channels. Hence, huge amounts are incurred by the port trusts for dredging and disposal of dredged material. Therefore, planning of maintenance dredging is an important activity of the Port Trust.

4. Disposal of Dredged Spoil

The maintenance dredging material at shoreline harbours is partly utilized for direct nourishment of the down drift shoreline and partly dumped offshore at a short distance by hopper dredger on the assumption that the material would be moved onshore by wave action. Hence, the dumping grounds at shoreline harbours along east coast of India are normally located offshore north of the approach channel so that the dredged material would not move towards the channel during persistent south west monsoon season. The direct nourishment of the shoreline is normally done through pumping of the dredged sand by floating pipelines or by dispersal of sand along the coast by rainbow technique as shown in Fig 4. The selection of dumping grounds is a location specific and depends upon the near shore circulation phenomena and hydrodynamic characteristics of the sea.
The maintenance dredging quantities used for direct nourishment of down drift coastline and hoppered offshore at Visakhapatnam and Paradip ports from the available records have been examined to study the effectiveness of operations. On an average about 0.2 to 0.3 million cubic meters of sand used to pump on the down drift shoreline at Visakhapatnam port whereas about 0.5 to 0.6 million cubic meters of sand pumping takes place along eroded coastline of Paradip port. The balance quantity from maintenance dredging is used to dump at the earmarked offshore disposal grounds. From the estimates of littoral drift it is known that the net drift blocked by the southern breakwaters of Visakhapatnam and Paradip port are 0.55 and 1.68 million cubic meters per year respectively. It means that that the quantities pumped for nourishment of eroded beaches are not adequate to protect. As a result the down drift coastline experiences severe erosion as observed recently along Visakhapatnam coast (Fig 5).
As the material from the maintenance dredging could not be utilized for down drift shore nourishment severe erosion has been noticed along the downdrift coastline of Paradip port. Further there is a possibility to cause wave convergence along the shoal at dumping grounds offshore which further aggravates the erosion along the northern shoreline. Because of this, the 5 m contour and 3 m contour were shifted towards the shore (Fig. 6) from 1964 to 84 to 87 indicating large scale erosion all along the coast.

The erosion might have further aggravated during subsequent years since the material from maintenance dredging was hoppered offshore and not utilized for direct shore nourishment with an assumption that the material would move onshore. The detailed analysis of near shore profiles off Paradip port by Sarma and Sundar (1988) has revealed that the entire near shore area off Paradip even beyond 14 m depth is an active zone for sediment movement. Further these studies have proved that the method of dumping material offshore, on the assumption that the material would be moved onshore by wave action does not prove successful to safeguard the shoreline. Similar observations of wave convergence at dumping grounds due to formation of shoal which lead to erosion of shoreline was also observed at Visakhapatnam port by Sarma (1986).
5. Conclusions

Along east coast of India vast quantities of sand move in the near shore zone due to the action of waves and currents and cause siltation problem at shoreline harbours. The direction of littoral drift is from south to north during the period March to October when south west monsoon waves prevail over the Bay of Bengal and reverses its direction from north to south during north east monsoon season. Computations based on energy flux method give a northerly littoral drift of about 1.51, 0.84 and 1.92 million cubic meters per year and southerly littoral drift of about 1.05, 0.29 and 0.24 million cubic meters per year resulting in net sand movement of about 0.46, 0.55 and 1.68 million cubic meters per year towards north at shoreline harbours Chennai, Visakhapatnam and Pardip respectively.

The estimated littoral drift quantities were closely correlated with the recent maintenance dredging quantities of the ports under study with some minor deviations. The recent maintenance dredging quantities of the ports under study have shown that on an average about 0.76, 0.79 and 2.74 million cubic meters per year of sand was dredged out from the harbour channels of Chennai, Visakhapatnam and Paradip respectively. The actual dredging quantities are less when compared to the estimated gross littoral drift quantities for Chennai and Visakhapatnam harbours and more for Paradip harbour. It means that some of the gross littoral drift at Chennai and Visakhapatnam harbours is intercepted by the southern breakwaters, fallen into sand traps and bypassed the approach channels.

Since the northerly littoral drift is by far the most dominant along east coast of India which is intercepted either by the southern breakwaters or by the dredged channels at shoreline harbours, the down drift shorelines are nearly starved of sand supply, resulting in severe erosion. The direct pumping of sand to nourish the down drift shoreline at Visakhapatnam appears to be satisfactory. The disposal of dredged material by hoper in offshore dumping grounds with an assumption to move material towards sand starved coastlines have proved futile at Visakhapatnam and Paradip coasts. Further the offshore dumping grounds have become wave convergence zones and aggravated the erosion phenomena. Construction of seawall to protect the eroded shoreline at Paradip port has worsened the situation. The movement of bottom contours of -3 m and -5m towards the eroded Paradip coastline has revealed that the toe of the seawall may get collapse and hence the situation is alarming.

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References