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A Numerical Model Study for Development of a Harbour Layout in a Creek with Wide Tidal Flat

A NUMERICAL MODEL STUDY FOR DEVELOPMENT OF A HARBOUR LAYOUT IN A CREEK WITH WIDE TIDAL FLAT

L.R.Ranganath[1], B.Krishna[2] and C.N.Kanetkar[3]

Abstract: *Computer models now provide an efficient and economic tool for the analysis of coastal engineering problems. In particular, they are increasingly being used in conjunction with field studies to evolve the layouts of ports and harbours which has large demand due to the increasing economic activity all over the world. The ESSAR group of Industries proposes to develop 1200MW power project near Salaya, in Jamnagar District of Gujarat State in India, with marine facilities like jetty for handling bulk cargo and containers. The Salaya creek with wide tidal flat is part of the Gulf of Kutchch along the coastline of Gujarat. The proposal envisages construction of about 900m long jetty with an approach channel and a turning circle to cater to the vessels up to 150,000 DWT for bulk cargo and container cargo with desired draft of more than 17m. In this regard mathematical model studies were conducted at Central Water & Power Research Station (CWPRS),Pune to suggest suitable layout of the channel and turning circle for the proposed jetty. The hydrodynamics and sediment transport in the Salaya creek were estimated by means of field data and with the use of a two-dimensional hydrodynamic model coupled to a morphodynamic model. Tidal pumping was recognized as the main driving mechanism of sediments inside the creek. Studies were carried out for both existing natural condition and with the proposed developments. A suitable layout including approach bund was evolved based on the study. This paper highlights the details and importance of the study.*

Keywords: *Waves; Tides; Flow field; Sediment transport; Approach channel.*

INTRODUCTION

The quantification and monitoring of sediment dynamics in creeks has received plenty of attention in recent years due to both economic and environmental interests. Numerical models have been widely applied for predicting the morphodynamic evolution of these areas. However, the degree of uncertainty of these models is often very high due to the lack of measurements necessary for a complete model calibration and validation. The ESSAR group of Industries propose to develop 1200MW power project near Salaya, Jamnagar District, Gujarat with marine facilities like jetty for handling bulk cargo and containers, seawater intake and outfall systems. The Salaya creek is part of the Gulf of Kutchch along the coastline of Gujarat. It has wide tidal flats on both sides and deep pockets along the creek (Figure.1). The proposed project envisages construction of about 900m long jetty with an approach channel and a turning circle to cater to the vessels up to 150,000 DWT for bulk cargo and container cargo with desired draft more than

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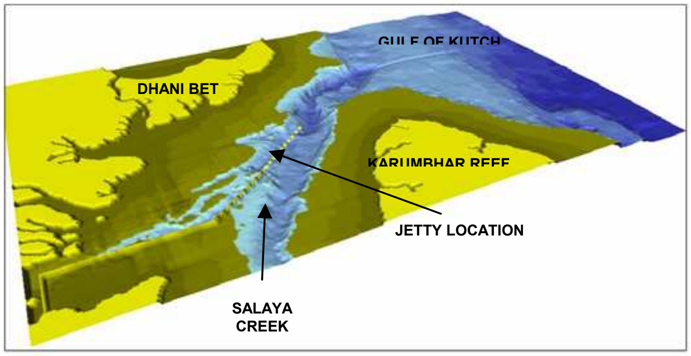

Fig. 1. 3D view of the computational model

17m. the proposal also includes construction of 10 m wide solid approach bund of about 7.2 km and an additional 1 km trestle up to the jetty. In this regard model studies were conducted at CWPRS to suggest a suitable layout of the channel and turning circle for the proposed jetty. Accordingly studies were carried out in two stages. Initially hydrodynamic studies were conducted to check the flow conditions and subsequently sediment transport and disposal studies were conducted to identify the probable zone of siltation and suitable dumping ground for the capital dredge material. Tidal pumping was recognized as the main driving mechanism of sediments inside the creek.

DATA ANALYSIS

The data required for the model studies are bathymetry, tidal conditions, wave conditions, wind, currents and sediment data. Field data collection regarding hydrographic survey, tide and current measurements, collection and analysis of water samples and bed sediment samples for silt concentration and sediment characteristics were conducted by M/S Sea Geo Surveys Pvt Ltd (2007) and monitored by CWPRS. Recent hydrographic survey chart was supplied by ESSAR. Brief description of the data used for the model studies is as follows:

Bathymetry

The Hydrographic charts provide bathymetric information at the project site. The bathymetry under the existing conditions digitized from the Admiralty Chart was used for the present study and the recent hydrographic survey chart supplied by ESSAR was superimposed on the digitized bathymetry to get the updated bathymetry. The model limits considered for studies is shown in Figure. 2. The green patch show that there is shallow and wide stretch of tidal flats and sufficient depths are available for navigation in the natural channel. As the tidal range is 6m,

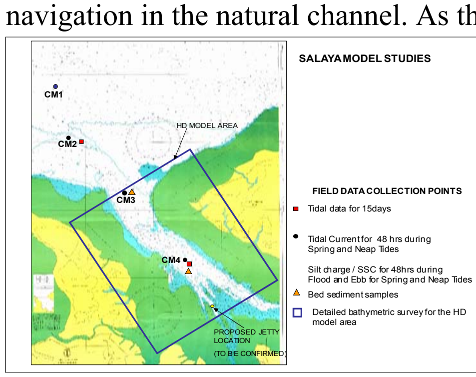

Fig. 2. Field data collection points with bathymetry

large area is subjected to flooding and drying. The hydrographic chart shows that at the sea entrance the Salaya region has a width of about 5km which includes flooding and drying area but the natural channel width is about 2km consisting of depths upto 20m which is conducive for channel alignment. The contours towards south are parallel and converging indicating narrow tidal flats. This depth information was used for setting up the computational model.

Tides

The tidal observations for the period of 15 days during May-June 2007 at Chudeshwar salt Jetty and from a moored boat near CM3 (Current Meter 3) at water depth of 6.2m reveal that the tide in the Salaya harbour region is of semi diurnal in nature with two high and two low waters in each cycle of a day. The tide data shows that the tidal range is of the order of 6.00 m during spring tide and 3.2m during neap tide (Figure. 3). The generated water levels considered as boundary condition for model simulation matched with the observed tide.

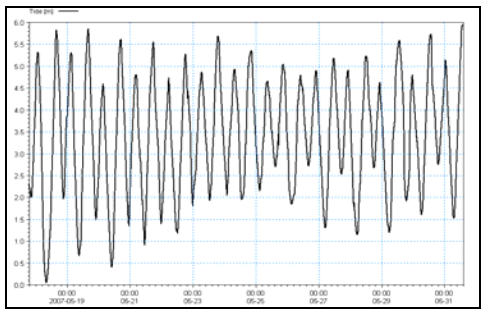

Fig. 3. Observed Tide

Tidal Currents

The current data collected in the Salaya harbour at four locations are given in Table 1. The data for 8 days period was analyzed and found that the current meter recordings are at 4 stations (Table – 1) but only currents at CM2 and CM3 locations seems to be reasonable. The currents are of the order of 0.6m/s during spring and 0.3m/s during neap. Flood and ebb currents are well defined and match with tidal phase recorded. The recording at CM1 and CM4 does not seem to be reasonable hence current observations at CM2 and CM3 were considered for calibrating the model.

Table 1. Current meter observation locations at Salaya Harbour

LOCATION	Latitude/Longitude	Easting/Northing	Depth
CM1	22° 29' 42"N 69° 30' 53"E	552936.847E 2487504.527N	13.4m
CM2	22° 28' 08"N 69° 31' 31"E	554032.592E 2484618.167N	9.9m
CM3	22° 26' 18"N 69° 33' 15"E	557016.800E 2481246.799N	11.7m
CM4	22° 24' 35"N 69° 34' 53"E	559829.951E 2478090.549N	14.0m

Water sample and Sediment Data

Water samples were collected at two locations (CM3) Lat. 22° 26' 18"N; Long. 69° 33' 15"E and (CM4) Lat. 22° 24' 35"N; Long. 69° 34' 53"E for 12 hours duration during day time for two days each. The samples were collected at three levels i.e. top depth, mid depth and bottom depth at one hour interval at both the locations to obtain silt concentration profile over depth at various phases of tide. The water samples were tested for salinity, silt concentration and grain size distribution of suspended load. Suspended Sediment Concentration analysis reported shows that the water is totally clear and no silt charge in Salaya waters. A typical water sample analysis table is given in Table 2.

Table 2: A typical result of water sample analysis

Sample ID	pH	Salinity	Silt Concentration	Particle Size Distribution (%)					
				Clay	Silt	Sand			Gravel
						Fine	Medium	Coarse	
M1/8	7.6	41.36	0.003	0.00	0.003	0.004	0.001	0.00	Nil
M1/9	7.6	41.56	Nil	0.00	0.00	0.00	0.00	0.00	Nil
M1/10	7.6	41.06	0.003	0.00	0.003	0.002	0.00	0.00	Nil
M1/11	7.8	41.76	Nil	0.00	0.00	0.00	0.00	0.00	Nil
M1/12	7.6	41.06	0.002	0.00	0.002	0.001	0.00	0.00	Nil

It was reported that bed sediment samples of 1kg each were collected at 3 locations (2 inside and 1 outside Salaya Harbour) using grab samplers. The samples have been tested for grain size distribution. It is reported that the bed is hard clay and silt is also less than 1%. Table. 3 shows the analysis of soil sample data.

Table 3: A typical result of Soil sample analysis at CM2 location

Sample Locations	Grain Size Distribution of suspended load (%)					
	Clay	Silt	Sand			Gravel
			Fine	Medium	Coarse	
CM2	98.99	0.22	0.49	0.30	0.00	0.00

Wind Data

It is reported that the wind has nominal effects on the tidal currents at Salaya. The analysis of the predicted data has shown that the average wind speed is of the order of 7km/hr for a return period of 100years from all the directions. In the sedimentation model studies the average wind speed of 7Km/hr is considered in the SE direction during March to September and NW from October to February.

TIDAL HYDRODYNAMIC STUDIES

For any major developments in coastal areas it is necessary to know dynamics of the water body in terms of velocity and water level fluctuations beforehand. The appropriate governing equations for studying water movement in coastal areas are the two dimensional shallow water equations. These are obtained by vertically integrating the Three-dimensional Navier Stokes equations of motion adopting simplified assumptions (DHI, 2005). These studies were conducted initially with existing condition and subsequently with the proposed channel layouts using MIKE 21 (HD) to investigate the current pattern in the channel due to the proposed development. Using the information about the bathymetry, the hydraulic parameters like observed tides and currents, the prevailing velocity field in the region was simulated. The proposed developments like bund and channels were incorporated in the computational model. The model limits considered for the mathematical model studies are shown in the Figure. 2. The model was calibrated for tidal levels and currents under the existing condition. The same model setup was used for predicting the flow conditions after the proposed development. The studies were carried out to reveal changes in the hydrodynamic condition and formation of tidal circulations if any after the proposed development. The orientation of the jetty, approach channel was verified based on the flow conditions. The results of the hydrodynamic studies are the basic input for the sediment transport studies and navigational studies.

Computational Model

The computational model considered for tidal flow simulation covered an area of 13500 m by 20000 m. The model limit extends up to 42 m depth contour in the offshore direction. The model area covers the entire proposed channel. The complete model area has been discretised into computational mesh of 50 m grid. The bathymetric conditions considered for the flow simulations under existing conditions, the points where simultaneous field observations are available (CM1 to CM4) and the results monitored at the corresponding locations is shown in Figure. 2.

Simulation of Flow Field in Existing Condition & Calibration of the Model

Initially the flow simulations in the existing condition were carried out to calibrate the model. The computational model has four open boundaries where flow conditions are required to be defined. Initially the flow simulations were carried out by providing spring tide observed during May-June. The tidal observations for the period of 15 days from a moored boat near CM3 at water depth of 6.2m reveal that the tidal range is of the order of 6.00 m during spring tide and 3.2m during neap tide (Figure. 3). The tidal boundaries were provided along the western and eastern boundaries with appropriate phase lag. As the flow is almost parallel to the contours along the northern boundary, no cross flow boundary was considered. The simulations were carried out for couple of weeks to simulate continuous variations in the flow conditions with changing tidal levels. The changes in flow fields were recorded every 30 minutes. The time history of velocities and water levels at different locations (CM2 to CM3) were monitored. The computed values of water level and currents at specified locations were compared with the field observed data. The studies were repeated by changing model parameters until the computed values matched well with the field observed data. Figure. 4. Shows the comparison of time history of computed and observed velocities at locations CM2 to CM3, the tidal levels match well with the observed data. The peak flood and ebb currents that are of the order of 0.8 m/s are matching well with the observed values. Thus the model was calibrated for levels and currents. Once the model was calibrated the same model set up was considered for predicting the flow conditions after the proposed development. Typical velocity vector plots during different phases of the tide under existing condition over the entire model region was analyzed and it could be seen that the flow during peak flood follows the natural channel and moves towards the proposed harbour and during peak ebb the flow is reversed and the currents are comparatively weak. Figure. 5. shows the close view of the typical flow condition. The length of the vector gives the magnitude of velocity to the scale and arrowhead shows the direction of flow.

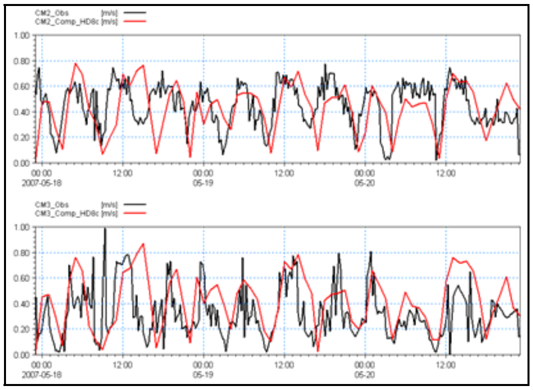

Fig. 4. Observed & computed currents

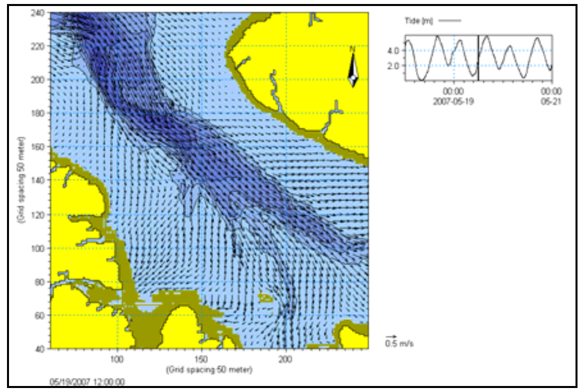

Fig. 5. Flow during peak flooding

Simulation of Flow Field with the proposed development

A notional alignment of the jetty with other features was finalized in consultation with ESSAR at CWPRS and the same was considered as proposed development. The proposed channel follows the existing natural channel with negligible change in the alignment having 200m channel width and 18m depth and this is incorporated in the model and is shown in Figure. 6. Flow during peak ebb is shown in Figure. 7.

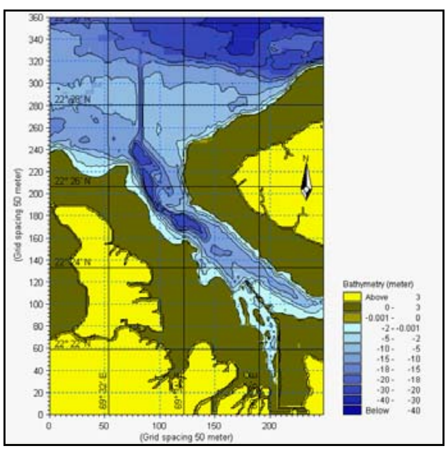

Fig. 6. Computational model

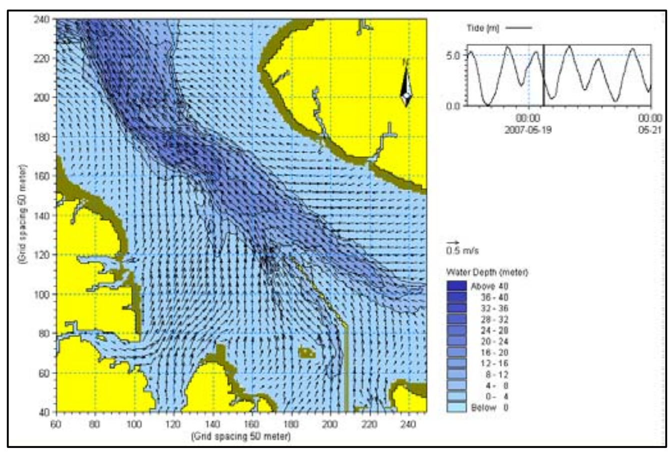

Fig. 7. Flow during peak ebb

The study indicates that the flow during peak flood follows the natural channel and moves towards the proposed harbour and during peak ebb the flow is reversed and the currents are comparatively weak, during low water almost half of the Salaya channel gets exposed as it is a wide tidal flat. At spring high tide, flow vectors are initially controlled by creek geometry and the topography of the marsh surface, but near high tide, when water depth over the marsh exceeds 1 m, flow vectors are controlled more by the general circulation in the Salaya creek and by the effects of winds and waves. It is noticed that the velocities are of the order of 0.5 m/s near the proposed jetty and the flow direction is parallel to the proposed approach channel and the cross flow is not significant.

SEDIMENT TRANSPORT STUDIES

Studies of sedimentation on sandy tidal-flats have long acknowledged that tidal flows and waves are the most influential hydrodynamic forcing factors operating on surficial sediments. Tidal flows influence the long-term evolution of tidal-flats because of the asymmetry of tidal regimes (flood and ebb). Tidal current activity is mainly confined to channels. Outside the channels, mainly on the upper tidal-flats, tidal current velocities decrease and sediment entrainment is frequently ascribed to wave action. The sediment transport studies were carried out using sediment transport model of MIKE-21. The results of the hydrodynamic simulations were considered as basic input along with sediment concentration data for simulating the sediment transport. The studies include simulation of sediment movement for different tidal conditions. In the present study data pertaining to silt concentration and sediment characteristics were available from field studies and the same was used for model studies and typical zone of siltation and zone of erosion were predicted. Using the flow fields obtained from the hydrodynamic model, the rate of sediment transport, depth of deposition was calculated and thereby areas of potential siltation were identified. The studies were also carried out for identifying the dumping ground for dredge spoil. The particle tracking method was adopted to simulate the movement of the dredge spoil after dumping.

Model Simulation of Siltation/Erosion

In order to simulate zone of siltation/erosion over the complete Salaya creek, the sediment transport model studies were carried out using the flow conditions simulated by hydrodynamic model. The hydrodynamic model and sediment model was operated for a period of one month covering both spring and neap tide conditions during monsoon period to study the sedimentation pattern. The field observed data do not indicate any suspended load concentration. The silt concentration in the region is reported to be very less and water is clear. From the studies conducted by Malvarez .et al (2001) it is inferred that at lower-than-optimum water levels, wave energy is less influential on sediment texture since (1) part of the tidal-flat is still exposed and (2) the fetch over which the waves are generated is reduced. At higher-than-optimum water levels, wave energy may be sufficient to transport sediment, but the wave penetration in the column of water is not sufficient to permit wave energy dissipation at the sediment surface. Tidal currents are dominant at low tidal elevations so outside channels wave-induced currents exert most influence on the tidal-flats and specifically on wide tidal flat such as Salaya creek. The sedimentation during different phases of the tide was observed. It could be seen that the zone of deposition is mainly in the tidal flats and zone adjacent to the deep pockets in the creek. The maximum siltation varies from 10cm to 20cm over a period of one month during monsoon season. The creek is almost stable and no significant sediment movement was observed.

Sedimentation studies with proposed development

The sediment transport studies were repeated considering the proposed development of bund and dredging of channel for both spring and neap tidal conditions. The sedimentation zone is found to be more or less same as in existing condition. It could be seen that the zone of deposition is mainly concentrated in the turning circle and adjacent to channel and deep pockets. Due to dredging the siltation near the proposed jetty has distributed over the area as could be seen from the Figure. 8. It is observed that depth of sediment deposition in the turning circle varies from 10cm to 20cm over a period of one month during monsoon season. It could be seen that the depth of deposition is about 0.2m in the region adjacent to the solid approach bund. Further marginal deposition of about 10 cm.is also observed in the outer channel where capital dredging was required. Thus it could be seen that there would be no significant change in the sedimentation pattern in the creek due to the proposed construction of bund and dredging of the channel.

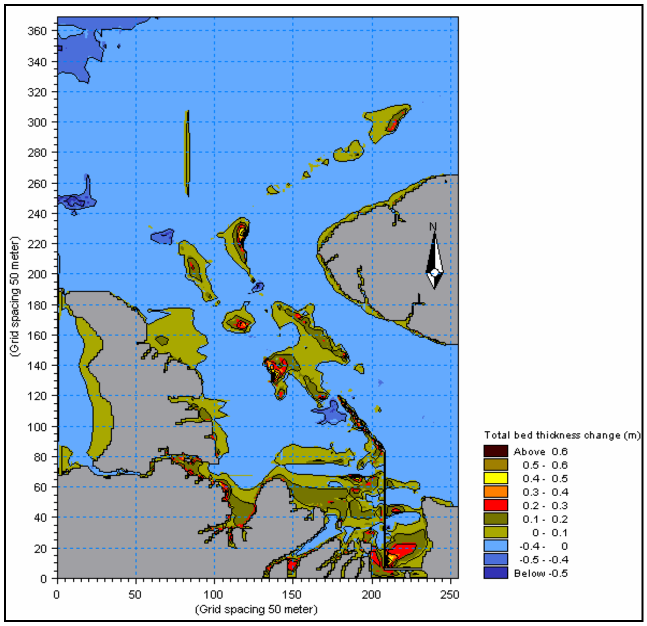

Fig. 8. Siltation pattern with channel & bund

Estimation of Capital Dredging and Maintenance Dredging

The capital dredging requirement for the proposed approach channel of 9.5 km length with the designed dimensions and dredged to –18m depth was estimated by considering the differential chart of existing bathy and proposed channel. It is seen that the desired depths are available in most of the stretches along the channel. The zone of actual dredging requirement is mainly in the outer channel and could be seen from the Figure. 9. Accordingly the quantity of capital dredging works out to be only about 7.5 Mm^3. In general the maintenance dredging in the highly silt prone area works out to be 15 to 20% of capital dredging. In the present case the Salaya creek waters is reported to be silt free. Further it is seen that the deep channel is maintained naturally over years. Even the requirement of capital dredging is also found to be minimum. From the sediment transport studies the depth of deposition along the outer channel and turning circle varies from 0.1 to 0.2m only during monsoon months. Considering the depth of deposition in the different regions it is found that the sedimentation in the outer channel and turning circle would be 0.2 to 0.3 Mm^3.

DREDGE DISPOSAL STUDIES

In order to identify the dredge disposal location the sediment movement studies were carried out by the method of particle tracking. Different sediment source points were selected and simulations were carried out for several days during flood and ebb conditions. The fate of these sediment particles disposed at various locations with time was tracked. The probable direction of movement of sediments discharged at different locations is simulated. These studies indicate likely movement of sediments when disposed at different locations in the gulf. Keeping these results in view the sediment transport studies were carried out by considering the dumping of the sediment at the rate of 400 kg/m^3 dredged material. The actual zone of sediment movement is observed.

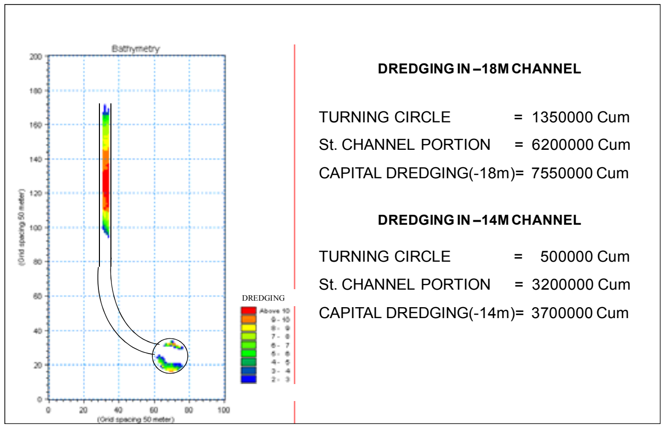

Figure. 9. Capital dredging and zone of siltation

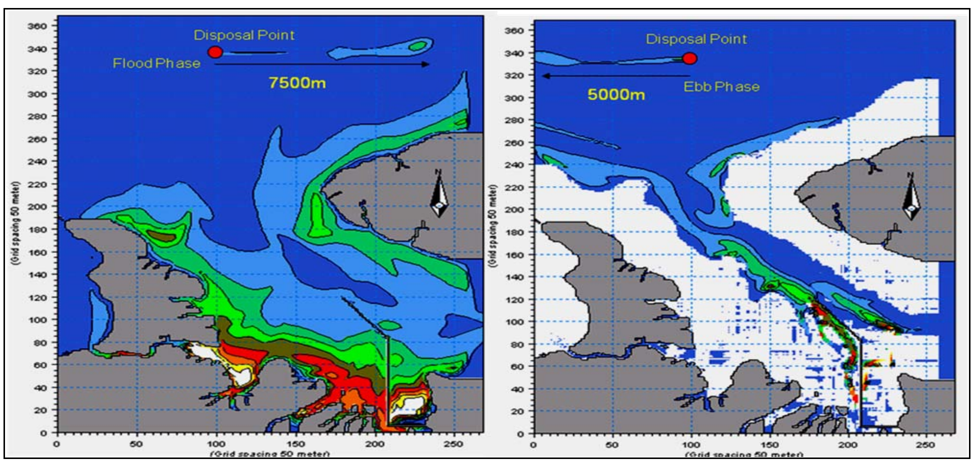

Fig. 10.Sediment dispersion during flood and ebb

Figure. 10. shows the fate of suspended sediments after 24 hours of simulation. Based on these results it is preferable to dispose the dredge material beyond 18 or 20 m contour in the gulf of Kachchh to avoid reentry of the sediments in to the channel or near jetty location. Thus dumping of the sediments may be considered at locations A (Lat. 22° 30’ 14”N; Long. 69° 31’ 50”E) during ebb and B (Lat. 22° 29’ 40”N; Long. 69° 34’ 50”E) during flood condition. In either case the sediments are expected to move in the flow direction for some period and settle depending on the sediment characteristics.

CONCLUSIONS

The model studies were conducted to investigate the feasibility of the channel alignment evolved during the mutual discussions with ESSAR. From the detailed studies carried out following conclusions may be drawn. The tidal currents follow channel alignment in the near shore region.

However, at the Salaya entrance beyond 8 m contour the currents cross the channel generally during high water. There would be no significant changes in the flow conditions after the proposed dredging of the channel except that the flow gets streamlined along the channel. The proposed alignment of the channel was found to be suitable with minor realignments considering the tidal flow conditions prevailing at the project site. The orientation of the proposed jetty is in line with the flow direction and there would be no cross currents near the jetty as well as in the turning circle.

The sediment transport study indicates that the depth of deposition along the outer channel and turning circle varies from 0.1 to 0.2m only during monsoon months. Considering the depth of deposition in the different regions it is found that the sedimentation in the outer channel and turning circle would be of the order of 0.2 to 0.3 Mm^3 per annum. It may be noted that the sedimentation is highly dynamic process and the sediment transport simulations are more of a qualitative than quantitative. The maintenance dredging quantities estimated are only indicative and may differ depending on the changing environmental site conditions as the studies were carried out only for given site conditions.

Sediment disposal studies indicates that it is preferable to dispose the dredge material beyond 18 or 20 m contour in the gulf of Kachchh to avoid reentry of the sediments in to the channel or near jetty location. Thus dumping of the sediments may be considered at locations A (Long 69,31,50 , Lat 22,30,14) during ebb and B (Long 69,34,50 , Lat 22,29,40) during flood condition. In either case the sediments are expected to move in the flow direction for some period and settle depending on the sediment characteristics.

From the studies carried out, it can be inferred that there would be no significant changes in the existing flow conditions due to proposed developments at Salaya, as the orientation of the proposed jetty and the approach bund are in line with the flow direction Further the sedimentation pattern in the region reveals that the depositions are mainly in the tidal flats adjacent to channel and marginal accretion along the outer creek banks. Thus the dredging in the Salaya creek and disposal of sediments in the gulf and construction of approach bund will not have any significant change along the coast of Salaya creek.

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