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Management Of Shoreline Morphological Changes Consequent To Breakwater Construction

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The coastal stretch from Veli to Varkala along Thiruvananthapuram coast, which was in dynamic equilibrium, has two identifiable sediment cells separated by the Muthalapozhi inlet with harbour breakwaters on either side of the inlet. Construction of breakwaters to develop a fishing harbour at Muthalapozhi has caused erosion immediately north of the inlet and beach build up south of the inlet. In addition, the harbour mouth gets blocked due to deposition of sand, virtually making the harbour unusable. In the present study, the processes of shoreline morphological changes along the high energy coast are analyzed using numerical models to propose management options to tackle morphological modifications. Shoreline changes, nearshore processes and beach characteristics along this sector are studied through extensive field observations. The data is used to calibrate and validate sediment transport and shoreline change models for this coast. Sediment transport and shoreline changes are simulated using different modules of LITPACK model. The LITDRIFT module is used to calculate annual sediment transport. The LITLINE module is used for shoreline evolution during fair season and the behaviour of coast during monsoon is simulated using the module LITPROF. The calibration of the model is done with field observations. It is found that beach sediments get deposited on southern side of the breakwater and bypassed sediment gets deposited at the inlet mouth. The model after validation is used to simulate the processes with different designs and a groin field of smaller transitional lengths comparable with the surf zone width. The groins having lengths 40, 30 and 20 m at 120, 220 and 300 m south of breakwater, has been found best suited to control the chocking of harbour mouth due to sediment deposition during beach building period.

(Keywords: Wave, Profile, Shoreline Changes, Breakwater, Modeling)

Introduction

Muthalapozhi is a tidal inlet between Veli and Varkala along the Thiruvananthapuram coast (Fig. 1). It is considered to be a dynamically stable coast except for the morphological changes associated with inlet oscillations. Tidal inlet has been developed into a fishing harbour for which two breakwaters on either side were constructed. Harbour is expected to provide access to the sea for fishing crafts throughout the year. Fishing harbour work was initiated in the year 2002. Model studies for the design estimated a net southerly annual sediment transport and accordingly the breakwaters were proposed with a length of 480 m (280 m towards west and further 200 m towards south) to the north arm and 170 m to the south arm[1,2]. In the course of construction, it was observed that the mouth gets chocked with sediment deposit and spit formation making the harbour unusable[2]. Based on expert advice to rectify the problem, the breakwater design was

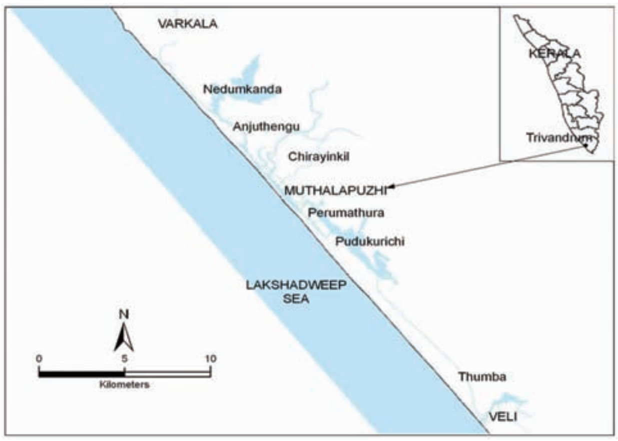

Fig. 1–Location of study region (Veli to Varkala) along Thiruvananthapuram coast.

modified and the extension of north arm towards south, once it reaches 280 m, was limited to 90 m and the south arm by a length of 120 m. Still the harbour remained unusable due to spit formation at the mouth during fair season and breaking waves at the mouth during rough season. Sediment transport pattern is reviewed and remodelled in this study to understand the siltation process leading to chocking of the harbour mouth and suggest appropriate remedial measures.

Materials and Methods

Coastal processes such as shoreline changes, nearshore waves, longshore currents and sediment characteristics are studied to understand various morphological changes including coastal erosion along Muthalapozhi coast. Data collected provides the input for numerical model studies. Fine grid bathymetry was generated up to a depth of 20 m from bathymetric survey carried out during premonsoon in 2008. Nearshore wave and current data were collected during premonsoon, monsoon and postmonsoon by deploying wave-tide gauges and current meters.

Beach profile data were collected regularly from different stations for one year to understand the profile modifications and beach sediment movements. Shoreline has also been regularly monitored through Differential Global Positioning System (DGPS) mapping. Sediments were collected from the beach and nearshore and were analysed for grain size distribution.

The LITPACK, a professional engineering software package for the modelling of non-cohesive sediment transport in waves and currents, shoreline evolution and profile development along quasi-uniform beaches, has been used for modelling shoreline changes. With its exceptional flexibility, speed and user- friendly environment, the LITPACK provides an effective design environment for engineering, management and planning application in the coastal zone. The LITLINE, LITDRIFT and LITPROF are different modules of LITPACK for computing shoreline, longshore transport and profile variation respectively. Since the nature and mode of shoreline change and sediment transport are different for monsoon and non-monsoon, numerical modelling is done separately for the 2 seasons[3&4]. Longshore sediment transport rate is calculated using LITDRIFT. The non-monsoon shoreline variation is modelled using LITLINE for which the sediment drift obtained from LITDRIFT forms the input. Monsoon shoreline variation is dominated by onshore-offshore mode of sediment transport triggered by storm like events for which LITLINE is not an effective model to replicate the system. LITPROF, the cross-shore profile variation model of LITPACK, is used for the simulation of profile change during monsoon. Shoreline along south side of the breakwater was simulated and calibrated with the observed DGPS shoreline data of this area during one year. After the validation of the model the production run is done for different designs proposed and the best suited management plan is suggested for controlling the chocking of the harbour.

Results and Discussions

Coastal processes at Muthalapozhi

Beach process along the Muthalapozhi sector has been highly modified by the harbour breakwaters dividing the coastal stretch into 2 distinct sediment cells. Shoreline changes are expected with the change in wave conditions of rough (monsoon) and fair (non-monsoon) weathers occurring along this coast. Beach gets eroded with the onset of monsoon when high steep waves approach the coast. Monsoon can be considered as storm event of one to two week duration with breaks in between as evidenced by the lows and highs in the wave heights (Fig. 2). During this season, the significant wave height (H_s) falls in the range of 0.37- 2.1 m during the recording period. Wave height was below 1.0 m during May, which started to increase towards the onset of monsoon. The increasing H_s indicates active monsoon while the decreasing H_s indicates breaks in monsoon.

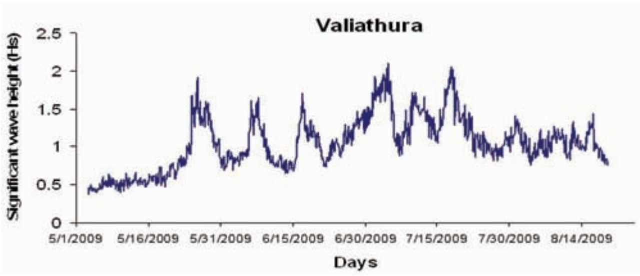

Fig. 2–Variations in H_s indicating breaks in monsoon wave climate during rough season (SW monsoon) at Valiathura, Thiruvananthapuram

Major part of monsoon erosion occurs with the onset of monsoon, which happens as a storm event, and this causes formation of a storm profile which gets modified with the breaks and reformation of succeeding monsoon events. Beach building starts after the monsoon, and it takes place as a slow process compared to erosion events. It is initiated when long period swell waves approach the coast during the fair weather period after the monsoon. Beach profiles for different stations are depicted in Figs. 3 & 4. It can be seen in the Figures that the beach gradually reforms to its pre-monsoon position during beach building period after monsoon erosion. In addition to this,

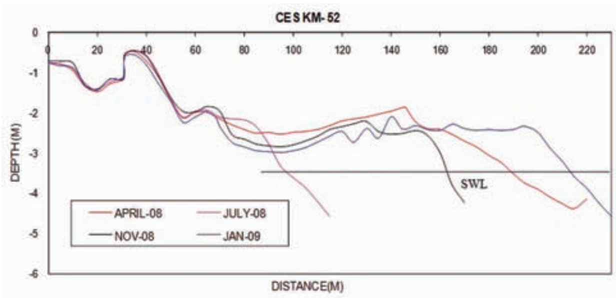

Fig. 3–Beach profiles close to Muthalapozhi breakwater

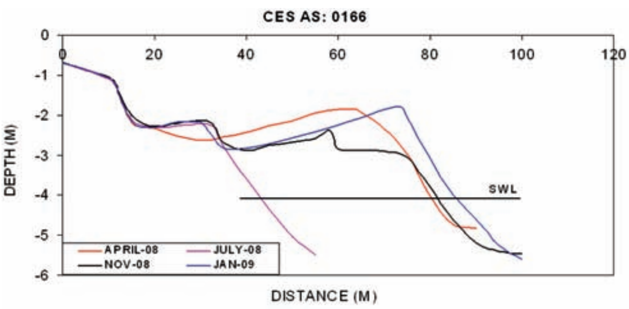

Fig. 4–Beach profiles at St Andrews (10 km south of breakwater)

shoreline morphology gets modified on both sides of the inlet since the construction of breakwaters. Close to the south breakwater, beach width has increased by about 70 m on its south during 2003-2008. Beach build up continues up to about 1.5 km towards south of the breakwater (Fig. 5). The beach building impact of the breakwater is not felt further south. Beach remains stable further towards south.

During March 2003 when the breakwaters were under construction, the sediment bypassed the then tip of the south breakwater and the shoreline got extended into the harbour (Fig. 5). Continuous sediment deposit has extended the shoreline up to the seaward tip of the south breakwater and got deposited inside harbour as seen through shoreline progradation during 2008-2009 (Fig. 6).

The bypassed sediments got deposited in the inlet causing the formation of a spit at the mouth (Fig. 7). It has already been reported in many studies that the longshore current and the resultant sediment transport is towards north during beach building period in Trivandrum coast[5&6].

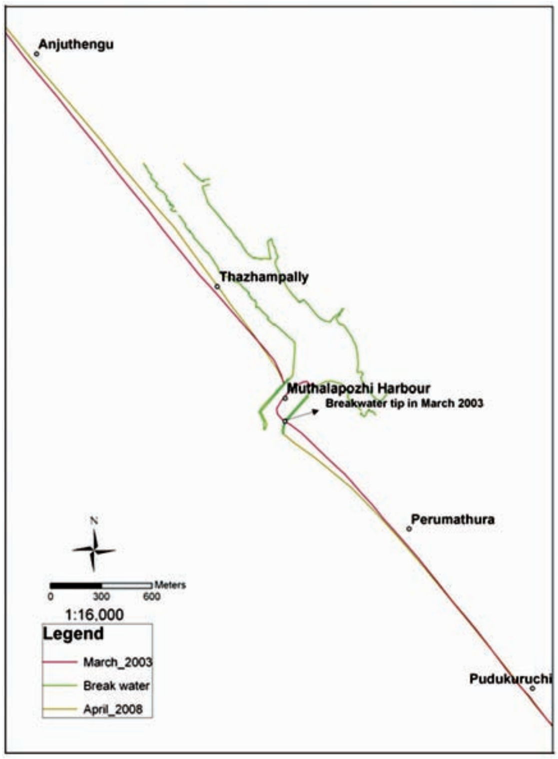

Fig. 5–Shoreline change due to breakwater construction

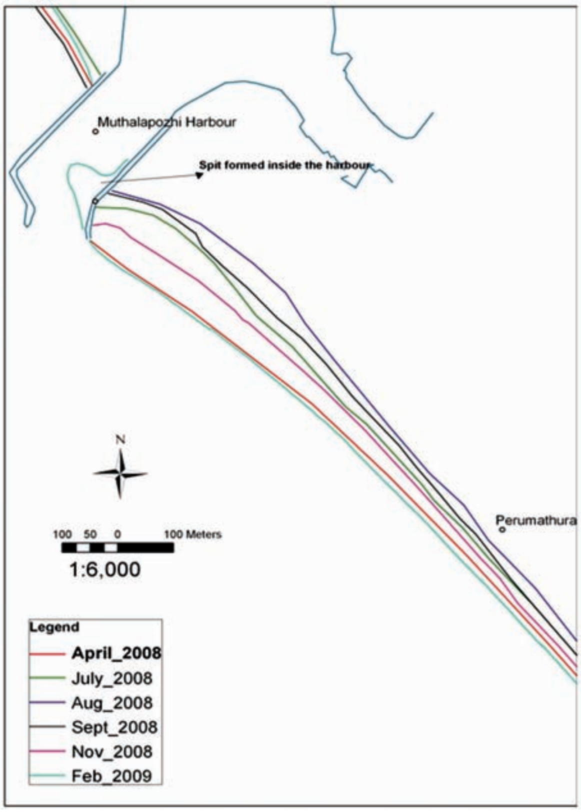

Fig. 6–Shoreline variation immediately south of Muthalapozhi breakwater

Fig. 7–Muthalapozhi harbour mouth during March 2011

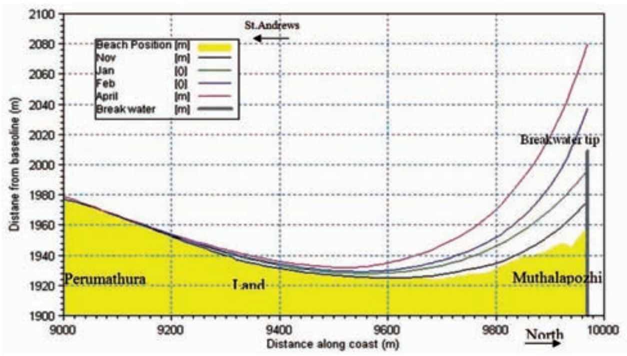

Fig. 8–Shoreline evolution close to breakwater during fair season (Nov-April)

Prior to the construction of the harbour breakwaters, the tidal inlet was seasonal which remained open for about 2 months during the monsoon and was partially or fully closed during the remaining period. This facilitated smooth exchange of sediments to either side of the inlet and the beaches remained stable except close to the inlet. With the construction of harbour breakwaters, the sediment transport got impeded, especially during the beach building period when the surf zone is very narrow compared to the breakwater length. It is observed that surf zone is very wide and the nearshore currents are dominated by cell circulation consisting of rip currents and feeder longshore currents during the monsoon period except during the month of June as also has been reported by Thomas and Baba[7]. Wide surf zone, the width of which is comparable or more than that of the offshore length of the breakwater, helps to reduce the impact of the breakwater on longshore sediment transport.

Numerical modeling

The LITDRIFT module simulates the cross-shore distribution of wave height, setup and longshore current for an arbitrary coastal profile. It provides a detailed deterministic description of the cross-shore distribution of the longshore sediment transport for an arbitrary bathymetry for both regular and irregular sea states. Longshore and cross-shore momentum balance equation is solved to give the cross-shore distribution of longshore current and setup. Wave decay due to breaking is modeled, by a model of Battjes and Janssen[8]. LITDRIFT calculates the net/gross littoral transport over a specific design period.

Shoreline

Based upon the results from LITDRIFT, the LITLINE simulates the coastal response to gradients in the longshore sediment transport capacity resulting from natural features and a wide variety of coastal structures. LITLINE calculates the shoreline by solving a continuity equation for the sediment in the littoral zone. Influence of structures, sources and sinks is included. With jetties and breakwaters, the influence of diffraction on the wave climate is also included.

Cross-shore profile development

LITPROF describes cross-shore profile changes by solving the bottom sediment continuity equation, based on the calculated sediment transport rates. LITPROF, being a time-domain model, includes the effects of changing morphology on the wave climate and transport regime. This enables a simulation of profile development for a time-varying incident wave field.

Model inputs

Bathymetry

The main input to the model is the initial coastline, given as a distance from a baseline and the cross-shore profiles, which are extracted from field surveys. DGPS tracking is used to represent the shoreline position. Cross shore profile represents the cross shore variation of depth contours. A grid spacing of 10 m is considered for an accurate representation of the shoreline. Profile data collected from different stations during monsoon, post and pre monsoon periods and bathymetry have been used for generating cross-shore profiles. Initial coastline grid number starts from extreme south (St. Andrews) up to southern arm of

Table 1–Input wave data used for non-monsoon period

Month	Duration(% of year)	Average H_{rms}(m)	Mean Wave Direction(^{0}N)	Tz(s)
January	8.33	0.738	200	10.60
February	8.33	0.856	200	10.00
March	8.33	0.809	200	9.90
April	8.33	0.918	199	10.30
September	8.33	2.02	214	8.40
October	8.33	1.81	200	10.4
November	8.33	1.27	202	9.10
December	8.33	1.106	200	11.10

Muthalapozhi breakwater. Coastline is determined by drawing the baseline at an angle of 227^0 N. For simulating good field conditions, 3 cross-shore profiles representing south, middle and north sectors, are used. From southern end to up to 4 km one profile is used. The profile near breakwater is less steep compared to southern side profiles. Cross-shore profile values are given at 5 m interval.

Wave data

Accurate assessment of the actual wave conditions and their occurrences is extremely important for the computation of the littoral drift at the shoreline. Wave climate is defined by the measured wave parameters (Table 1) like wave heights, wave periods and wave directions along with the respective probability of occurrence of wave incidents. Recorded 5 year data for the period 1980-84[9&10] has been used to arrive at the average monthly wave data to be used for modelling purpose.

Wave data used for non monsoon has been derived from the nearshore wave data recorded at 5.5 m water depth at Valiathura, Thiruvananthapuram, a nearby coastal station in the year 2007 (Table 2).

Sediment characteristics

Sediment consists of fine to medium sand with mean grain size varying from 0.11 to 0.39 mm. This includes sediment from nearshore and beach. Sediment parameters pertaining to sediment characteristics used in the model are fall velocity, bed roughness, specific gravity and geometrical spreading.

Model results

Littoral transport is calculated using LITDRIFT module (Table 3). It is seen that net sediment transport during May to August is towards south where the net southerly transport in May is not significant. Cell circulation and rhythmic morphology observed after the initial onset of monsoon[7] have not been considered in the computations. Sediment transport during the entire beach building period extending from September to April, is towards north with maximum values in September and October. Transport during January to April is not that significant. Sediment accumulation south of breakwater and siltation in the harbour occur during the beach building period for which the major contributor is the northerly sediment transport.

Shoreline evolution has been modelled using LITLINE module. The result obtained after running

Table 2–Wave data used for monsoon period

Period	Average H_s(m)	Mean Wave Direction(^{0}N)	Tz(s)
21.05.07-26.05.07	1.34	205	9.0
27.05.07-12.06.07	1.75	220	8.5
13.06.07-25.06.07	2.76	235	7.8
26.06.07-28.07.07	2.17	245	7.5
29.07.07-18.08.07	1.62	254	8.9

Table 3–Computed Littoral transport using LITDRIFT

Month	Sediment transport (m^3/month)	Accumulated or Net transport (m^3)
January	12723.6	12723.6
February	15957.4	28681.0
March	14213.9	42895.0
April	18778.7	61673.7
May	-21231.3	40442.4
June	-67631.8	-27189.4
July	-32275.8	-59465.2
August	-3644.4	-63109.6
September	31705.5	-31404.1
October	49333.4	17929.3
November	26272.0	44201.3
December	27569.4	71770.7

Table 4–Different options for managing chocking of the harbour

Options	Remarks
Case 1	2 groins having length 50 and 30 m at 250 and 500 m south of breakwater respectively
Case 2	3 transitional groins having length 50, 40 and 30 m at150, 250 and 350 m south of breakwater respectively
Case 3	3 transitional groins having length 40, 30 and 20 m at 120, 220 and 300 m south of breakwater respectively

the model for non- monsoon months (Nov-April) is given below. Major changes are observed close to breakwater.

Model result indicates significant bypassing of littoral transport since January. Field observations also show that shoreline reaches upto the tip of breakwater and further progression of shoreline results in sand bypassing into the harbour mouth resulting in its choking (Figs. 5&7). The spit formed inside the harbour have been dredged 3 times by Harbour Engineering department during 2009-10 and it is estimated that the volume of sediment dredged is about 1 lakh m^3 during beach building season (Nov-Apr). The computed littoral transport during this period is about 1.2 lakh m^3 (Table 3).

Management of sediment transport in the harbour mouth

The excess transport of sediment towards the harbour mouth during beach building period needs to be controlled for maintaining the mouth open. Transitional groins are generally recommended for reducing the erosion on the down drift side by allowing smooth passage of littoral drift to the unprotected area so as to eliminate any sudden change in the coastline. For all the cases the spacing between groins has been decided following the criterion given in Shore Protection Manual (1984) according to which spacing between groins shall be 2 to 3 times the groin length from the berm crest to the seaward end [11,12]. If the length of the proposed groins is comparable with the surf zone width during monsoon period, the sediment redistribution during monsoon erosion period will not be affected significantly. Sediment redistribution could reduce cumulative progradation of beach close to the groins. Three different options of groins which could ensure reduction of sediment transport towards the breakwater have been looked into (Table 4). Groins are proposed at about 500 m south of breakwater from where significant progradation of shoreline is observed towards north. Model is run for each of the above options to assess the performance (Figure. 9-11). Shoreline progradation gets initiated from 700 m south of the breakwater in all the options. There is good beach build up at 500 m south of the breakwater itself. In all the 3 cases, the shoreline progradation close to breakwater and the possibility of bypass are considerably reduced. In options 2 and 3, the shoreline

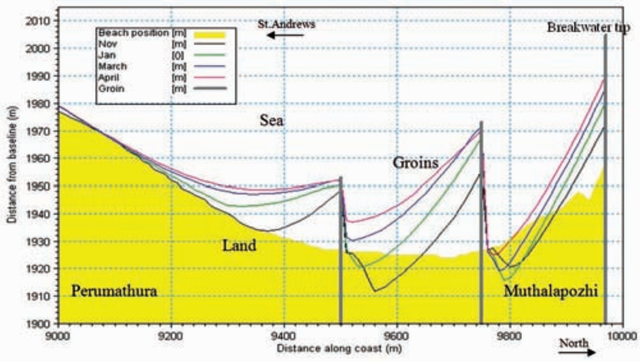

Fig. 9–Shoreline evolution during fair season (Proposed intervention-Case 1)

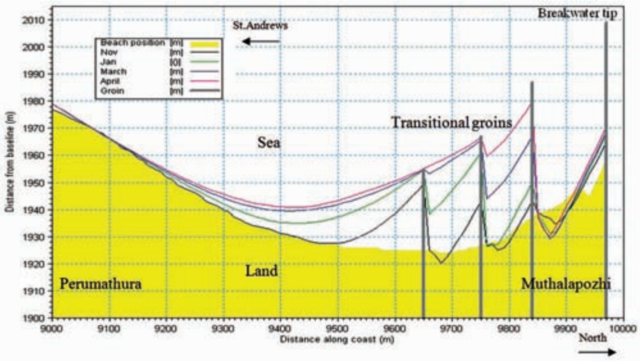

Fig. 10–Shoreline evolution during fair season (Proposed intervention-Case 2)

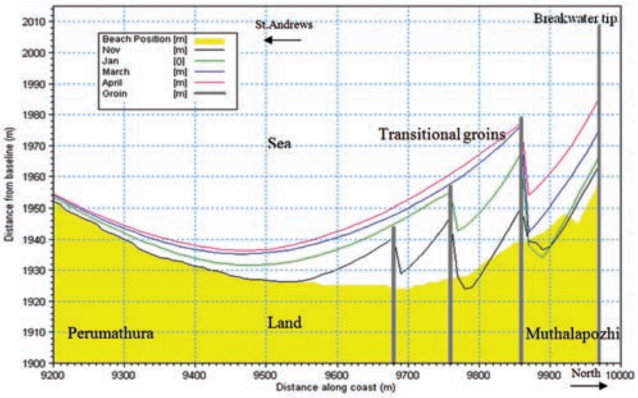

Fig. 11–Shoreline evolution during fair season (Proposed intervention-Case 3)

progradation close to breakwater in November-April is such that the remaining length of the breakwater is less than the surf zone width during the respective months. This provides limited scope for sediments to bypass the breakwater. The Case 3 has shorter groins compared to Case 2.

Of the above three options, Case-3 has less down drift erosion and the sediment transported towards north is redistributed within the groin fields and the progradation of shoreline close to the breakwater is limited. Moreover, option 3 with shorter groins less expensive.

Above simulated model is only for the beach building season. Monsoon shoreline variation is dominated by onshore-offshore mode of sediment transport and hence the simulation of the monsoon shoreline change is done with LITPROF, a cross-shore evolution module in LITPACK. This approach is tested at Panathura in Thiruvananthapuram where reasonable results for monsoon beach behaviour have been obtained[3]. Model computation with LITPROF for monsoon season is attempted for Muthalapozhi to understand the impact of the proposed groins on monsoon sediment transport.

Shoreline evolution during monsoon period

The monsoon wave climate is divided into 5 distinct events of waves (Table 2), which accounts for the breaks in the monsoon. Cross shore profile of the study area in May, immediately prior to monsoon onset, is used as input profile for LITPROF and the simulated output from the model is tuned using wave breaking and scale parameters. Validation of the output is done by comparing the observed and computed monsoon profile for Valaithura, a nearby location with similar wave and sediment characteristics. There is good correlation between predicted and observed monsoon profiles (Fig. 12). The level zero in the cross-shore profile indicates still water level.

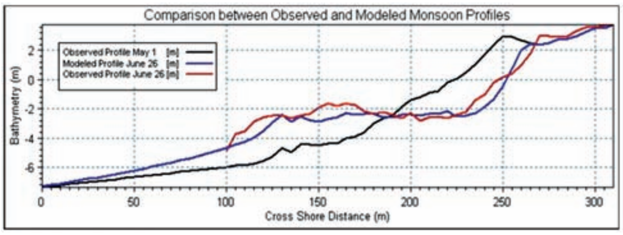

Fig. 12–Simulated monsoon profile from observed non monsoon profile

Beach profiles in the study area also show similar changes. Major beach morphological modification during monsoon is in the form of storm profiles. With the onset of monsoon the shoreline gets eroded mainly as storm profile with a longshore bar. Cross-shore transport is dominant with a southerly longshore component. Average retreat of shoreline observed south of breakwater is about 30-40 m. The sediments return to the beach during the following beach building period.

The cross shore movement extends to about 150 to 200 m offshore from the shoreline much more than the proposed groin lengths. Groin length is also less than the monsoon surf zone width of 100 to 150 m. Hence the normal sediment transport pattern during the monsoon season consisting of cross-shore, southerly longshore and cell circulation will not get significantly modified. This facilitates redistribution of the sediment that got accumulated within the groin fields in the cross shore and in the southerly direction limiting the cumulative deposition of sediment south of breakwater.

Conclusion

Beach morphology on either side of the harbour is significantly modified due to breakwater construction. Major contributor to siltation of the harbour mouth is the northerly sediment transport during the beach building period. Sediment transport towards north in the Perumathura sector (south sediment cell) during the beach building period gets bypassed the south breakwater and chocks the harbour mouth. Model studies have shown that the sediment transport towards north in the Perumathura sector (south sediment cell) during the beach building period could be controlled and redistributed towards south by making three transitional groins having length 40, 30 and 20 m at 120, 220 and 300 m south of breakwater respectively. These shorter groins would not interfere with cross shore (storm profile), southerly longshore and cell circulation driven sediment transport processes during monsoon season and the normal beach processes will be maintained in the Perumathura sector. Monsoon redistribution of beach sediments will limit the cumulative progradation of shoreline south of the breakwater.

The possibility of sediment bypass from north to the harbour mouth would be negligible considering the dominance of northerly sediment transport during the beach building period. Coast north of the breakwater has the characteristics of the distinct sediment cell for which the coastal processes and sediment transport need to be studied and modeled separately for understanding the sediment transport and shoreline changes.

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