Harbour Silting and Change in Wave Parameters due to Breakwater Construction

Geethu Sugathan, Anitha Joseph
Dept. of Civil Engineering
TKM College of Engineering
Kollam ,India.
e-mail: sugathangeethu@gmail.com
anithareebu@yahoo.co.uk

Abstract—**Problems of erosion, reduction in shorelines, disappearance of beaches, and environmental impacts have led to the recession of many economies around the world. To resolve, engineers have devised manmade structures like breakwaters and piers to address a variety of coastal problems such as shelter, fishing, docking and coast line recession. While these problems are resolved, new ones emerge when breakwaters and jetties are constructed in the areas. Clearly, breakwater engineering and related civil engineering fields are still at their rudimentary level, despite the fact that these structures have been in use since age old.**

The bathymetry of the study area is modeled using the commercial software MIKE21. The hydrodynamic parameters are analyzed using LITPACK modules. Four engines were used for simulation, namely, LITDRIFT – littoral drift, LITSTP – littoral sediment transport, LITLINE – long-shore coastline evolution, LITPROF – littoral cross-shore profile variation. The analysis is performed for three seasons - pre-monsoon, monsoon and post-monsoon.

In this study, the effects of breakwater construction on wave parameter (height), sediment accumulation, sediment transport, littoral drift, water flux, long-shore and cross-shore profile variation are studied and estimated.

Keywords—Littoral Sediment Transort; Sediment Accumulation; Littoral Drift; Long-shore; Cross-shore; Breakwater

I. INTRODUCTION

Large stretches of the coast are subjected to repeated erosion during the monsoon period yearly in Kerala. Many coastal zones worldwide have been eroded by waves, and hazards may thus happen. Some protection measures or protective structures are needed in these areas to either mitigate hazards from happening. Breakwaters are usually built parallel to the shore or at an angle to reduce serious wave action from its destructive impact on the shoreline. Apart from these, coastal areas are subjected to geological problems such as natural processes including coastal erosion, deposition, sedimentation, tsunami, tidal waves etc. Littoral sediment transport is the main reason for coastal erosion [2].

The Indian coastline measures about 7517km, about 5423km along the mainland and 2094km along the Andaman and Nicobar, and Lakshadweep Islands**.** Along the coastline of India nearly 585 km, Kerala has one major port at Cochin and 17 non major ports [13]. Currently, Kerala government is in the process of modernizing ports at Vizhinjam, Azhikkal, Beypore and Alappuzha and they are planned to setup a green field modern deep water multipurpose sea port at Vizhinjam in Thiruvananthapuram District of Kerala.

The study area, proposed port at Vizhinjam (Lat 8° 22’ N, Long 76° 57’ E) is located in India in the state of Kerala, at 16 km south of the State Capital, Thiruvananthapuram which falls in close proximity to the international East-West shipping route [13]. The natural water depth available at proposed Vizhinjam port is more than any competing Indian port and more or equal than competing international ports. It will be able to capture the increasing trend of larger container vessels which none of the existing Indian ports can service. Vizhinjam port will further enhance India’s ability to handle gateway and trans-shipment cargo while establishing a strong supply chain network in Kerala. The Government of Kerala is supposed to develop the port associated infrastructural facilities like the breakwater, quay wall, dredging, reclamation, utilities (drinking water, power supply to the terminal, etc.) and infrastructure connectivity (rail and road). The study area of this project concentrates on the effects of the construction of proposed breakwater structure in Sediment Accumulation, Sediment Transport and shoreline changes [1].

II. MODELLING OF BATHYMETRY AND BREAKWATER

MIKE21, developed by the Danish Hydraulic Institute (DHI), is a professional engineering software package containing a comprehensive modelling system for 2D surface flows, which simulates flows, waves, sediments and ecology in rivers, lakes, estuaries, bays, coastal areas and seas.

To study the effect of break water construction in wave field and harbor silting, a detailed site study is conducted to collect the data like meteorological and oceanographic data.

With the help of sounding map bathymetry [13] (seabed contour) of the study area is modeled using MIKE21 [14] and is shown in figure 1.

Define work area – UTM 43
Geographic position of origin –
  Map projection Coordinates in Meters:
  Easting:- 718000m
  Northing:- 923500m
Size (Spatial extent) –
  Width:- 4500 m
  Height:- 4000m

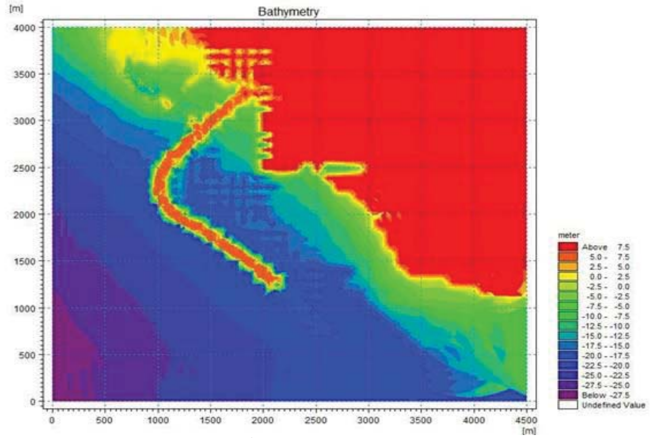

Fig. 1. Bathymetry of study area with proposed breakwater

The sediment accumulation, sediment transport and shoreline change study due to the proposed breakwater is done with the help of LITPACK module of MIKE21. With the help of master plan shown in figure 2, we have to define the Baseline and the Initial Shoreline to the interface [13]. Baseline is an imaginary line considered in LITPACK which is drawn parallel to the shoreline as shown in figure 2 [13].

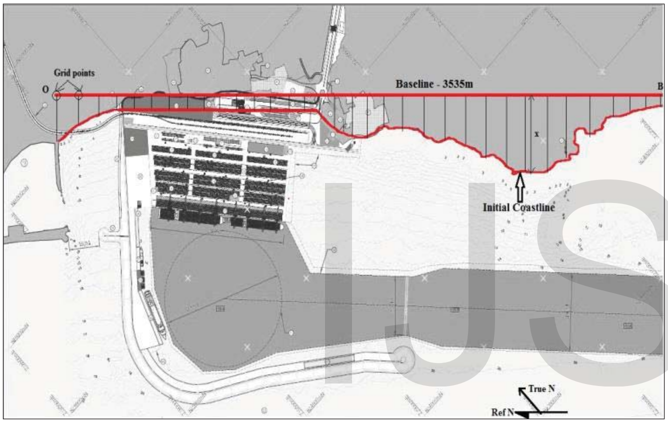

Fig. 2. Master plan with baseline, initial coastline and grid points

Baseline (OB) Details:

Baseline Origin (O):

X (Latitude) = 722000

Y (Longitude) = 924000

Baseline Grid:

Length = 3535 m

DX = 50 m

No. Of grid points = 71

Baseline Orientation relative to north:

Orientation = 233 degree

From the above details the baseline OB is divided into 71 grid points. And the distance between each grid point is set to be 50m. We can also see the initial coastline in the above figure. With the help of baseline we can model the initial coastline in LITPACK. Let ‘x’ be the distance from baseline to the initial coastline in meters as shown in figure. From the figure we can interpolate 71 numbers of ‘x’ values to model initial coastline. These values are the input for creating initial coastal alignment file. Then insert the points of breakwater structure for the simulation purpose in this LITPACK model. The study area with breakwater, which is modeled in LITPACK is shown in figure 3.

III. SIMULATION

The model created in LITPACK is simulated using four engines of LITPACK, viz: LITDIFT, LITLINE, LITSTP, LITPROF, for three different seasons. In this LITDIFT engine will give the littoral drift, there is no effect of current and wave is considered in this simulation. In this four different categories of simulation can be done. They are Long-shore Current, Long-shore Sediment Drift, Annual Sediment Drift and Transfer Wave Climate.

The second case of simulation is done by the engine LITLINE; this will give the shore-line changes during the time step. For simulating this case wave parameters like wave height, time duration, and wave directions used are shown in table 1.

TABLE. 1. OFFSHORE BOUNDARY CONDITIONS [7]

Season	**Mean Wave height**	**Mean Wave Direction**	**Mean Wave Periods**
Pre monsoon	0.8m	200	11s
Monsoon	2.5m	255	9.75s
Post monsoon	1.25m	200	10.75s

The third case is simulated using the LITSTP engine. This will give the littoral sediment transport.

The fourth case of simulation is done by the engine LITPROF; in this we can see the littoral profile variation that means the cross shore profile variation.

IV. RESULTS AND DISCUSSIONS

A. Litdrift

Long-shore Current:

For the simulation under this criterion, the end results will be current velocity, wave height, wave direction and Flux discharge. The end results for all the three seasons Monsoon, Pre Monsoon and Post Monsoon is presented in Table 2. The maximum and minimum value for each is calculated.

TABLE. 2. SUMMARY OF RESULTS OBTAINED FROM LONG-SHORE CURRENT SIMULATIONS

Season	**Wave Height (m)**	**Wave Direction (degree)**	**Flux (m^3/s)**	**Total Flux (m^3/s) * 10^7**
Monsoon	2.72	255	60525	0.3085
Pre Monsoon	1.06	233	60525	0.3085
Post Monsoon	1.50	233	60525	0.3085

The graphical representation wave height is shown in figure 3.

Annual Sediment Transport:

The end results of this simulation are given below in table 3 from the results it is clear that there is no seasonal variation for this simulation. The negative sign in values indicated the opposite direction.

TABLE 3 SUMMARY OF RESULTS OBTAINED FROM ANNUAL SEDIMENT TRANSPORT SIMULATIONS

Output	Maximum Value
Net Drift ($m^3/y/m$)	8439.74
Gross Drift ($m^3/y/m$)	8439.74
Drift +ve ($m^3/y/m$)	8439.74
Drift –ve ($m^3/y/m$)	$-5.045*10^{-24}$
Accumulated Net Sediment (m^3/y)	3878205.75
Accumulated Gross Sediment (m^3/y)	3878205.75
Calculated Net transport (m^3/y)	$0.3878 * 10^7$
Gross Transport (m^3/y)	$0.3878 * 10^7$

Long-shore Sediment Drift:
For the simulation under this criterion, the end results will be, Flux discharge, Suspended sediment load (Q_{sx}), Bed sediment load (Q_{bx}), Total Sediment load ($Q_{sx} + Q_{bx}$) and Accumulated Sediment Transport and is tabulated in table 4. Most of the sediment is transported in the form of suspended load and sediment transport rate is high in Monsoon season.

TABLE 4 SUMMARY OF RESULTS OBTAINED FROM LONG-SHORE SEDIMENT DRIFT SIMULATIONS

Output	Monsoon	Pre Monsoon	Post Monsoon
Flux (m^3/s)	62261.08	62261.08	62261.08
Q_{sx} ($m^3/s/m$)	40.27	0.74	0.86
Q_{bx} ($m^3/s/m$)	0.000387	0.000344	0.00358
$Q_{sx} + Q_{bx}$ ($m^3/s/m$)	40.269	0.74	0.86
Accum $Q_{sx}+Q_{bx}$ (m^3/s)	13151.77	73.78	86.78
Total Water Flux (m^3/s)	$0.3197*10^3$	$0.3197*10^3$	$0.3197*10^3$
Total Transport Rate (m^3/s)	$0.1315*10^5$	$0.7379*10^2$	$.8678*10^2$

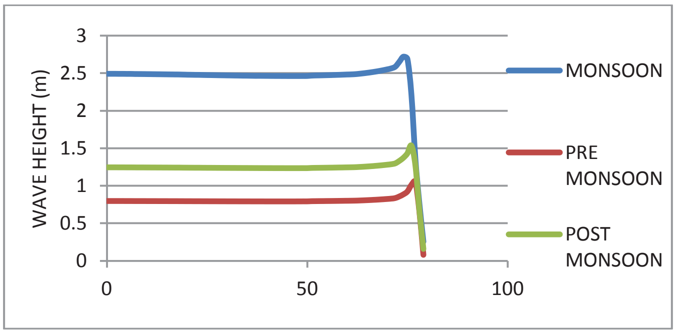

Fig. 3. Long-shore Current – Wave Height in m

B. Litline

In this engine, the simulation is done for three seasons and the graphical representation of coastline changes for the same are plotted as shown in figure 4, 5and 6. Coastline evolution in one year also simulated and is shown in figure 7. The proposed port breakwater alignment is expected to see accretion due to the presence of the proposed bund structure, action of wave, wind and water. The eroded portions may contain rock formations, in such case the erosion will not occur as shown in figures. The proposed port is also expected to reduce sedimentation inside the existing fishing harbour.

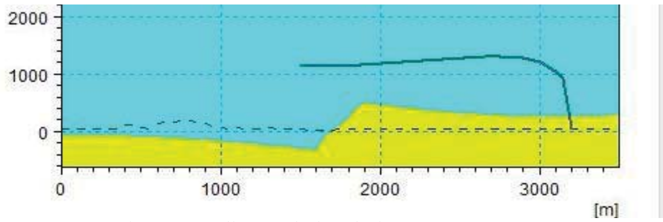

Fig. 4. Coastline evolution during Monsoon

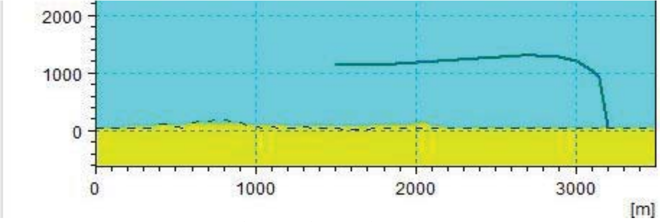

Fig. 5. *Coastline evolution during Pre Monsoon*

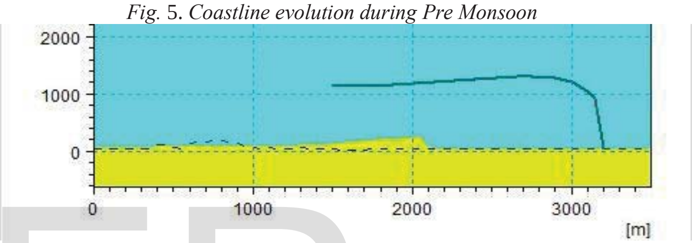

Fig. 6. Coastline evolution during Post Monsoon

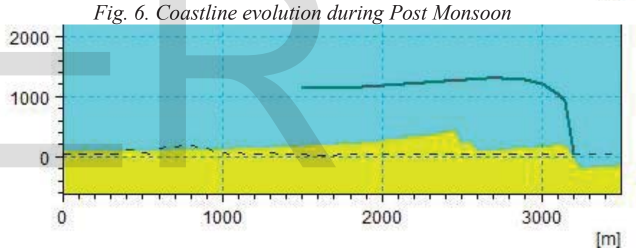

Fig. 7. Coastline evolution with all wave parameter

C. Litstp

The end results of this simulation are given below in table 5.

TABLE. 5. SUMMARY OF RESULTS OBTAINED FROM LITSTP

Item name	Minimum	Maximum
Gross drift [$m^3/y/m$]	$5.0457E^{-24}$	$2.1866E^{+09}$
Drift +ve [$m^3/y/m$]	0	$2.1866E^{+09}$
Drift -ve [$m^3/y/m$]	20.05	$-5.045E^{-24}$
Accum Net [m^3/y]	$2.522E^{-21}$	$4.5722E^{+12}$
Net and gross transport (m^3/year)	$0.4572E^{+13}$	

D. Litprof

The cross shore profile variations for all three seasons are simulated, from that only monsoon season shows significant variation in profile. Profile evolution in monsoon season is shown in figure 8. Sediment accumulation in the shipping trench area takes place, so maintenance dredging activities at the port are expected to takes place in proper interval to maintain minimum keel distance.

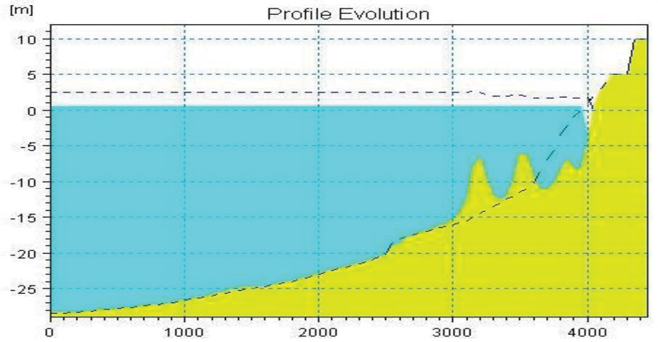

Fig. 8. LITPROF – Monsoon Season

V. CONCLUSIONS

Based on the numerical model studies conducted using the software MIKE21 and the LITPACK module, the principal conclusions arrived are:

- Introduction of shore-connected breakwater reduced the wave height in its basin and the harbour mouth to a significant amount makes the harbour safer for berthing of ships.
- In the near-shore region long-shore sediment transport dominant than cross-shore sediment transport.
- The near-shore current velocity is in the range of 1.0-2.7m/s in all the cases investigated.
- Reduction in wave height achieved by the introduction of breakwater can be expected to stabilize the beach and harbour basin, which prevent the temporary seasonal beach erosion.
- From the results it is clear that there is no seasonal variation in Flux.
- The introduction of shore-connected breakwater shows significant long-shore and cross-shore sediment transport and accumulation inside the harbour basin. So proper dredging inside the basin is frequently required to gain the minimum keel distance.
- The quantified values of harbour silting and the discussions regarding the results are tabulated and graphically presented.

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