Rejuvenation of Fishing Harbour Heavily Affected by Impact of High Waves and Sedimentation Using Numerical Methods

R. K. Chaudhari, S. K. Kori, and Prabhat Chandra

Abstract Design of fishing harbour is always site specific with required consideration of prevailing waves, tide and current conditions. In most of the cases when development is exposed to sea, the wave is the single parameter which affects the design considerations. Generally, the action of the waves is the principal cause of wave disturbance and movement of the sediment inside the harbour. The fishing harbour layout should be optimized enough to get the desired wave tranquillity inside the harbour with minimum siltation criteria. In the present paper, the case study of a already existing fishing harbour Marvanthe has been discussed which at present is facing high impact of waves and siltation inside the harbour basin and the studies undertaken may helped to over-come this problem. The location at Marvanthe is fully exposed to the incident waves from the Arabian sea with maximum significant waves of upto 4.0 m height. Numerical Model MIKE 21-SW, BW and LITPACK were used to evolve the optimum layout for the fishing harbour. Two alternative layouts; one having entrance in north direction and other layout having mouth opening in south direction, were assessed through numerical modelling. It is found that both layouts are providing enough tranquillity inside the harbour. However, the littoral drift studies shows that the net littoral drift is towards south so the mouth opening towards north may require periodically dredging at entrance. Hence, the layout having south side opening was recommended for the proposed Marvanthe fishing harbour. The details of the studies have been described in this paper.

Keywords Wave tranquillity · Numerical model · Shoaling · Refraction · Fishing harbour

1 Introduction

To cater the growing needs of the fishery industry, the development of fishing harbour with efficient and safe berthing facility is required. The coastal states where the fishing

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P. V. Timbadiya et al. (eds.), *Coastal, Harbour and Ocean Engineering*, Lecture Notes in Civil Engineering 321, https://doi.org/10.1007/978-981-19-9913-0_6

is the major food industry, need to develop fishing harbours at their coast to overcome needs of fishermen. But it is seen that due to lack of proper planning with consideration of the prevailing environmental conditions at the site, the implementation of fishing harbour carried in such condition leads to many problems. In the present case, a fishing harbour was constructed at Marvanthe in coastal region of Karnataka (Fig. 1). Maravanthe harbour consists of two breakwaters; north breakwater of 240 m length and south breakwater of 546 m length with mouth opening as 450 m constructed way back in the year 2014–15 (Figs. 2 and 3). The location at Maravanthe is fully exposed to the incident waves from the Arabian sea with maximum waves of upto 4.0 m height. The wave tranquillity conditions in the harbour with the present layout are not adequate for operation of the fishing vessels due to the exposure to the high waves particularly during the SW monsoon season. Also, inside the port basin, the beach erosion and accretion are taking place due to the attack of monsoon waves through the wide opening. To rejuvenate the fishing harbour, the mathematical modelling technique has been used, considering the prevailing environmental condition the modification in the layout of fishing harbour has been suggested to get required tranquillity with minimum siltation in the harbour. As per natural phenomena, waves attack coastal structure and infiltrate harbour entrance, generating disturbance inside the harbour areas. Hence, it is necessary to know beforehand the magnitude and direction of predominant propagating waves to design the optimal layout of harbours. MIKE 21-SW wave model was used to transfer offshore wave data of wave heights and wave propagation directions to the project site at (−) 8 m depth. Further, Boussinesq wave model (MIKE 21-BW) was used for prediction of the wave fields due to combined refraction and diffraction of directional random waves inside the harbour. These models were used to examine wave tranquillity in the proposed harbour and simultaneously the length and alignment of breakwater were optimized to get the desired wave tranquilly in the harbour. In this present case, the harbour opening is very large so the main target was to optimize the harbour breakwater length as well as suggest the proper alignment/layout so that the safe navigation of fishing boats at entrance should be feasible as well as wave disturbances inside the harbour should be minimum throughout the year. The alongshore sediment transport quantity and direction were also assessed through the numerical model LITPCK. In the present paper, the details of the mathematical model studies used to evolve suitable modification in the existing fishing harbour at Marvanthe, Karnataka, have been described.

2 Site Conditions

Marvanthe fishing harbour is situated at 50 km north of Udupi at the latitude of 13.7° N and the longitude of 74.6° E as shown in Fig. 1. The coastline consists of long, narrow sandy beaches and is oriented in NNW-SSE direction. The nearshore bathymetry is steep with straight and parallel depth contours. The tidal range at Marvanthe is about 1.2 m. Beaches at the site are having fine sand. The average

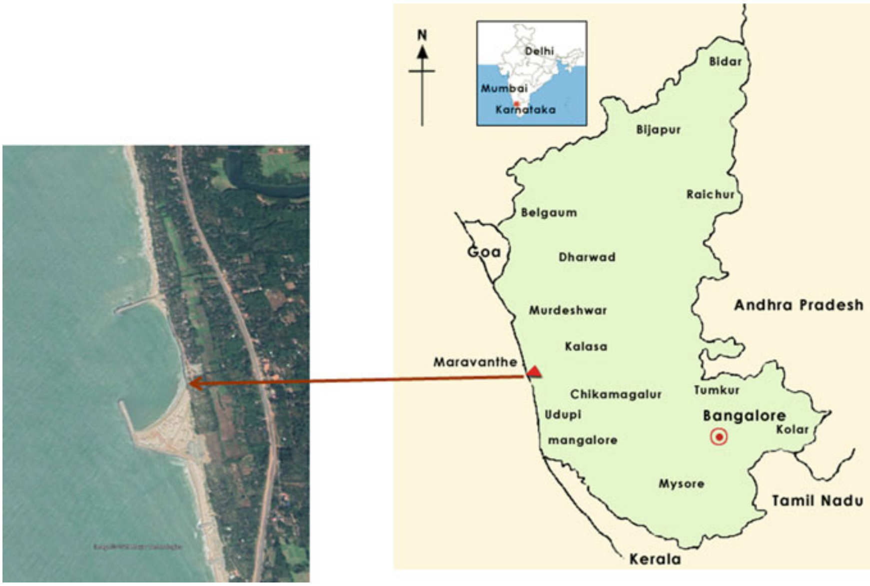

Fig. 1 Location map of Maravanthe site

value of D_{50} (mm) from various sand samples is about 0.25 mm and the same has been used for the model runs. Wave is a very important parameter which influences the littoral drifts that causes the erosion of coastlines. In absence of the measured wave data, the offshore wave data of 14 years from year 2001 to 2014 off Marvanthe fishing harbour as observed by India Meteorological (IMD) from ships plying in deep waters were analysed. This wave data information was considered at the offshore end of the model limits. The frequency distribution of wave heights for entire year for the above offshore wave data is presented in form of wave rose diagram shown in Fig. 4. It could be seen that the predominant wave directions in deep water are from 225° to 360° N with maximum wave heights of 4.5 m. These deep water wave data were transformed using the mathematical model MIKE 21-SW to get the nearshore wave climate near the Marvanthe.

3 Numerical Modelling Techniques

For rejuvenation of fishing harbour some modification in harbour layout carried out with use of mathematical models like MIKE 21-SW, MIKE 21-BW. These studies were mainly carried out in three following stages

1. Transformation of wave height and wave direction from deep water to (−) 8 m depth using spectral wave model MIKE 21-SW model.

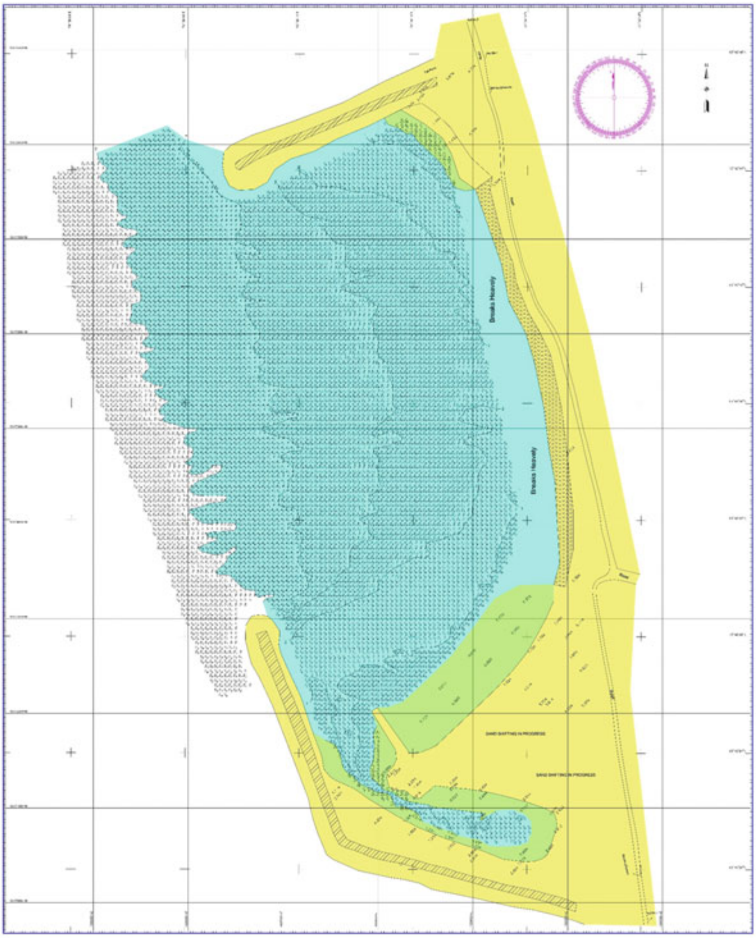

Fig. 2 Existing layout of the Marvanthe fishing harbour

2. Simulation of wave propagation in the harbour to obtain wave height distribution in the existing harbour as well as modified layouts using MIKE. 21-BW model.
3. Estimation of littoral drift movement.

3.1 Transformation of Wave Height and Wave Direction from Deep Water to (−) 8 m Depth

As waves propagate towards shore, a combination of shoaling, refraction, reflection, diffraction and breaking effects modify the waveform and the wave characteristics will be very different from those in deep water. To get the wave conditions from

Fig. 3 Marvanthe site photograph

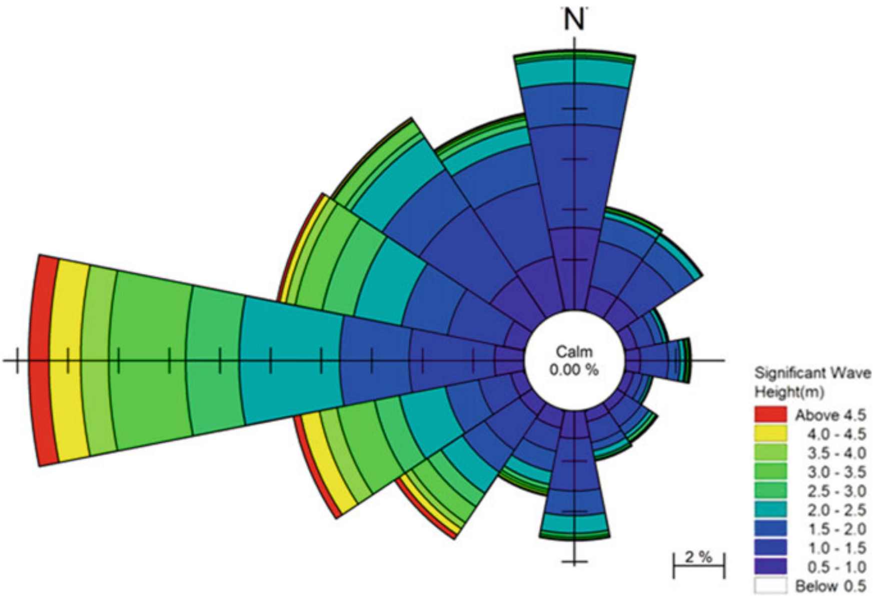

Fig. 4 Offshore wave rose diagram for entire year

offshore to nearshore at (−) 8 m depth, the numerical model MIKE21-SW was used. This is a state-of-the-art third generation spectral wind wave model based on unstructured mesh. The model simulates the growth, decay and transformation of wind generated waves and swells in offshore and coastal areas. It takes into account refraction and shoaling of waves, which are important in the transformation of waves from offshore to inshore. It also includes physical phenomena of wave growth by action of wind, dissipation due to white-capping, dissipation due to bottom friction and dissipation due to depth induced wave breaking. In the absence of measured wave data of at least one year near the proposed site of development, the nearshore wave climate at Maravanthe was obtained by transforming the ship observed deep water wave data using MIKE21-SW model. Model area considered for MIKE 21-SW model is shown in Fig. 5. Bathymetry in the model region of about 60 km × 88 km area was discretized using unstructured mesh. The model was run to obtain nearshore wave climate at the inshore point in (−) 8 m depth contour. The wave directions and ratio of wave heights at (−) 8 m depth to deep water wave height, with different directions of wave incidence at the offshore boundary are obtained. After applying the ratio of deep water wave height and direction as shown in rose diagram (Fig. 4), the frequency distribution of waves in (−) 8 m depth were obtained shown in Table 1 and corresponding rose diagram (Fig. 6).

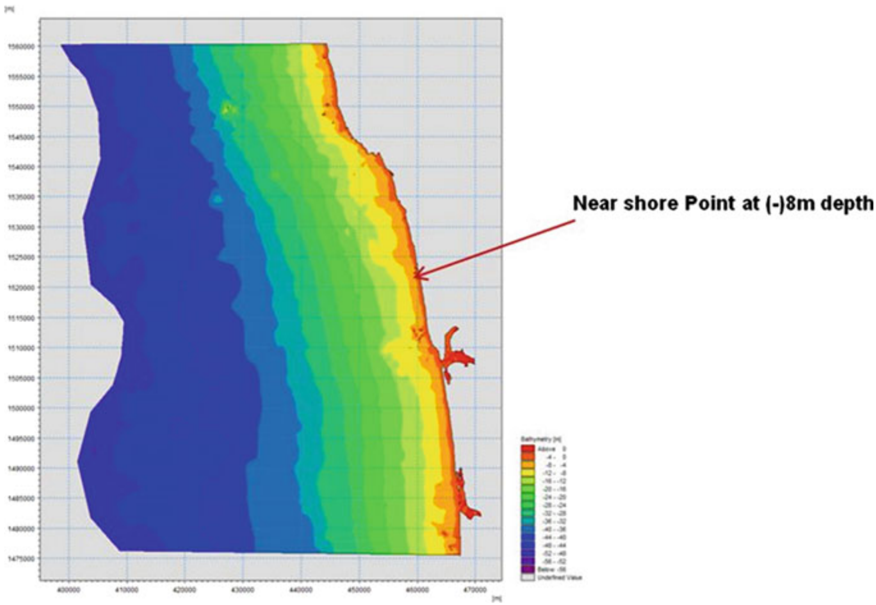

Fig. 5 Bathymetry for wave transformation from offshore to nearshore

Table 1 Input wave conditions for MIKE21-BW model

Wave direction (° N)	Peak wave period Tp (s)	Significant wave height (m)
225	10	2.5
247.5	10	3.5
270	10	3.5
292.5	10	2.5

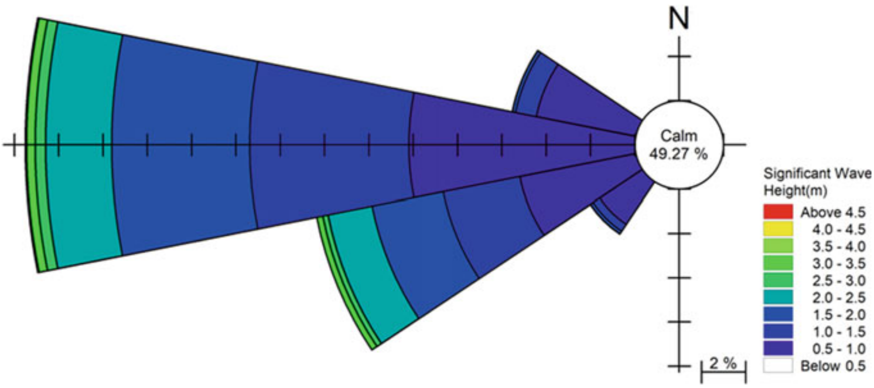

Fig. 6 Rose diagram at (−) 8 m depth (Year)

Based on the studies of wave transformation, following input significant wave conditions at (−) 8 m depth were considered for simulation of wave propagation in the proposed harbour using MIKE 21-BW model.

3.2 *Model Simulation of Waves Inside the Harbour Basin for Different Layouts*

The permissible wave disturbance at the berthing place depends on the ship size, mooring and berthing system. A permissible limit of 0.3 m for wave heights in the harbour is considered for of fishing harbour keeping in view the size of fishing boats. The modified layout was evolved considering the orientation of the entrance, littoral drift distribution and the wave tranquillity inside the harbour throughout the year. Due consideration was also given to ensure the safe navigation conditions of fishing vessels through the harbour entrance and an overlap was provided between two breakwaters to avoid broadside wave attack at the entrance. The numerical model MIKE21-BW was used for studying the wave disturbances in the harbour. This model is based on time dependant Boussinesq equations of conservation of mass and momentum obtained by integrating the three-dimensional flow equations without neglecting vertical acceleration. They operate in the time domain, so that irregular waves can be simulated. These equations include nonlinearity as well as frequency dispersion. The frequency dispersion is included in the flow equations by taking into account the effect of vertical acceleration or the curvature of stream lines on pressure distribution. The model simulates the processes of shoaling, refraction, diffraction from breakwater tips and bed friction. It also takes into account partial reflections from the boundaries, piers and breakwaters (DHI-2005) [1].

Wave propagation inside the harbour was simulated using MIKE21-BW model for input wave conditions as shown in Table 1. Simulations were carried out for the tidal level at +1.5 m corresponding to MHWS. The wave propagation studies to assess the wave condition inside the harbour basin carried out for different layouts, viz. Existing layout, Alternative-1 and Alternative-2 layout, are detailed as below:

3.3 Existing Layout

The studies were conducted to examine wave propagation for the existing harbour layout at Maravanthe. This layout consisted of two breakwaters; 240 m long northern breakwater and 546 m long southern breakwater with 450 m wide harbour entrance as shown in Fig. 7. Total length of breakwater in existing condition is 786 m.

The MIKE 21-BW simulations were carried out for all the four predominant directions mentioned in Table 1. The simulations plots of most critical and having maximum occurrence percentage has been shown in Fig. 8a, b.

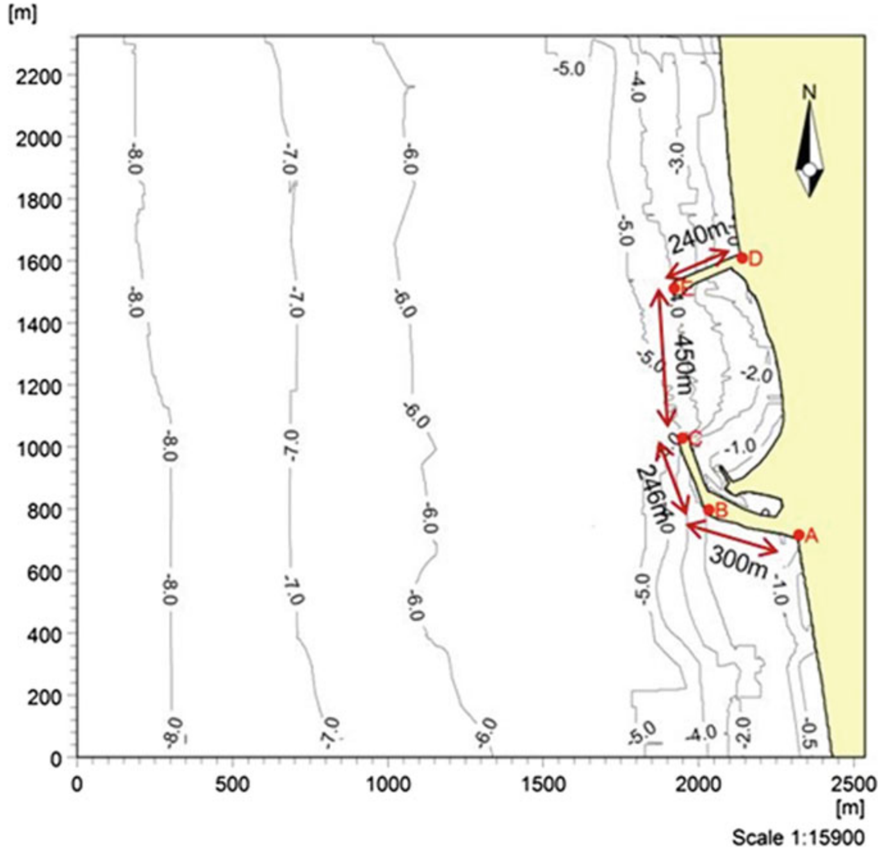

Fig. 7 Bathymetry and layout of existing harbour

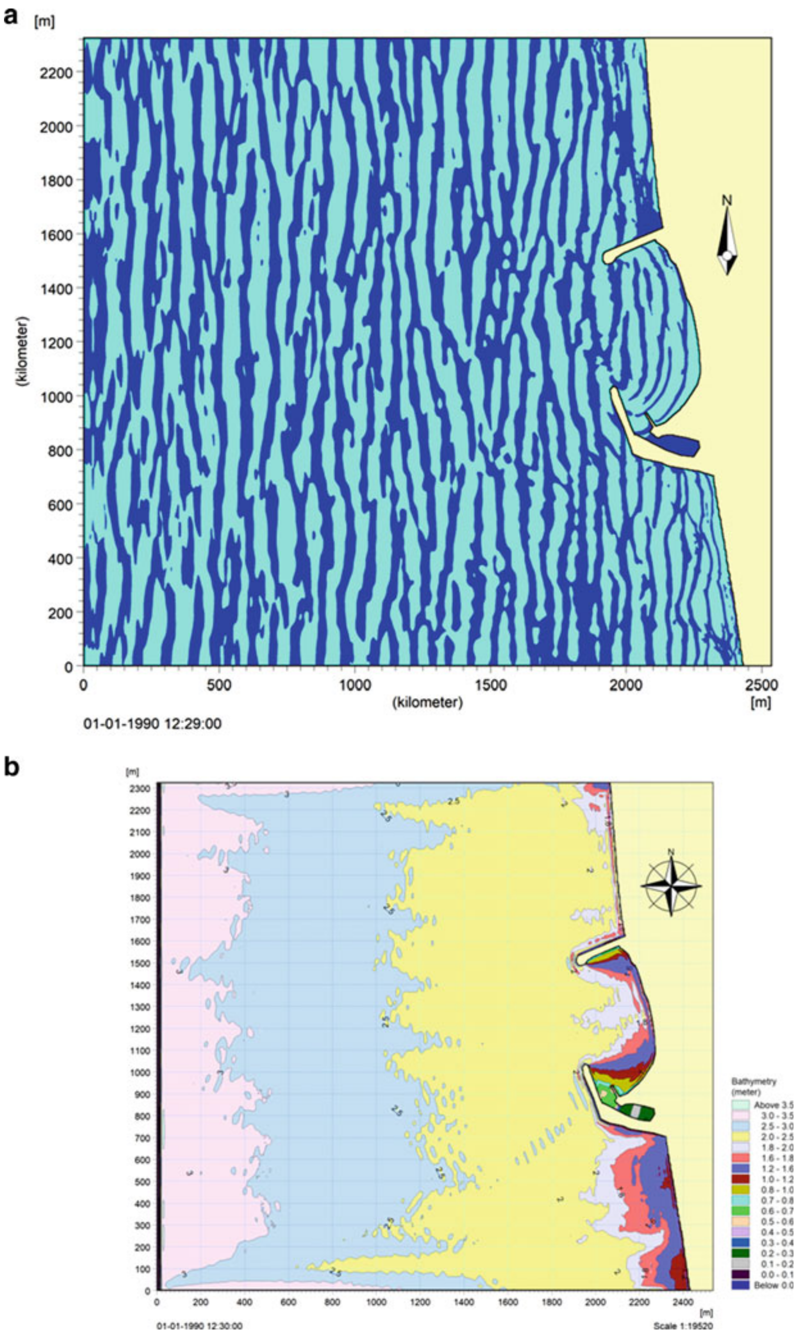

Fig. 8 **a** Wave propagation plot for waves incident from WEST (2700 N) direction. **b** Wave height distribution plot for waves incident from WEST (270° N) direction (Incident Wave Height: 3.5 m)

It is clearly seen from the wave distribution plots that the maximum significant wave heights of range of 1.8–2.0 m are seen inside the harbour basin which are much more than the permissible wave height of 0.30 m, also the fishing harbour entrance was exposed to the wave heights of order of 2.0 to 2.5 m. These wave conditions are not suitable for the safe operation of fishing harbour. A modified layout was evolved as alternative-1 details of model simulation given in next Para.

3.4 Alternative-I Layout

In order to provide required tranquillity inside the harbour and at the entrance of the fishing harbour a layout was suggested by CICEF the same has been taken as alternative–I. The studies were conducted to examine wave propagation in the proposed alternative–I harbour layout at Maravanthe. This layout consisted of two breakwaters; northern breakwater of 560 m more length than the existing Layout (total length of north breakwater is 800 m) while the southern breakwater having 65 m more length the existing layout (total length of south breakwater is 611 m) the harbour entrance is 105 m wide as shown in Fig. 9. Total length of the breakwater for this layout would be 1411 m. the entrance of the proposed harbour is situated in the south direction.

The MIKE 21-BW simulations were carried out for all the four predominant directions mentioned in Table 1. The simulations plots of most critical and having maximum occurrence percentage have been shown in Fig. 10a, b.

It was observed from above wave distribution plot from west and the plots from other predominant incident directions that the desired wave tranquillity in the harbour area would be achieved for all incident wave directions. Significant wave height is in range of 0.30 m for all four predominant directions inside the harbour basin would be obtained, suitable for berthing operations. It is also seen that the wave heights near the harbour entrance are higher in range of 1.2 m. During the SW monsoon season, there could be manoeuvring and navigation problems near the entrance facing south direction due to the presence of broad crested waves. Keeping in view such navigational difficulties, an alternative layout (alternative-II) was evolved at CWPRS having almost same breakwater length as the layout proposed by CICEF with harbour entrance on the north side.

3.5 Alternative-II Layout

An alternative layout was evolved at CWPRS with harbour opening on the north. This layout consisted of two breakwaters; northern breakwater consisted of 60 m more length than the existing layout (total length of north breakwater is 300 m) with breakwater tip at (−) 4.5 m while the southern breakwater having 550 m more length the existing layout (total length of south breakwater is 1105 m) with breakwater tip

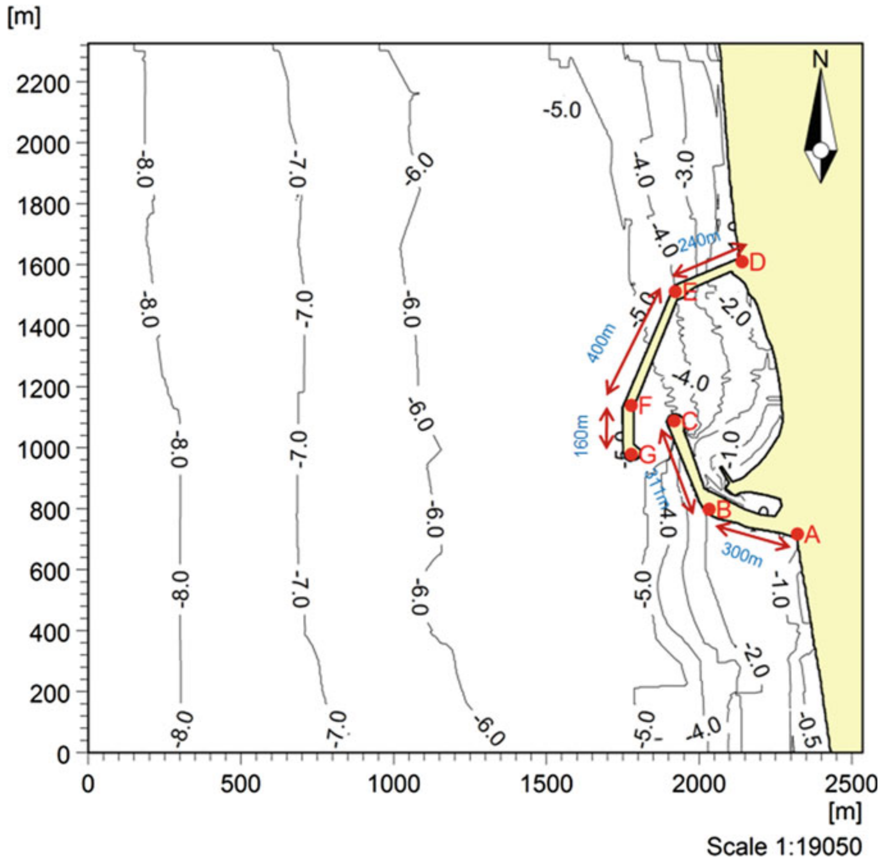

Fig. 9 Bathymetry and layout of modified harbour Alternative-I

at (−) 5.2 m and the harbour entrance is 110 m wide as shown in Fig. 11. Total length of breakwaters for this modified layout would be 1405 m.

The MIKE 21-BW simulations were carried out for all the four predominant directions mentioned in Table 1. The simulations plots of most critical and having maximum occurrence percentage has been shown in Fig. 12a, b.

It is seen from above simulation plot from west and with other prevailing incident directions that wave disturbances for the alternative layout-II will remain within the permissible limit of 0.30 m almost for all the predominant directions of incident waves. Only during the monsoon seasons, the waves would be more than the permissible limit for few days.

Consideration of the net littoral drift direction at the proposed site is essential in order to decide the suitable layout. In this regard, littoral drift studies were carried with the help of numerical model LITPACK.

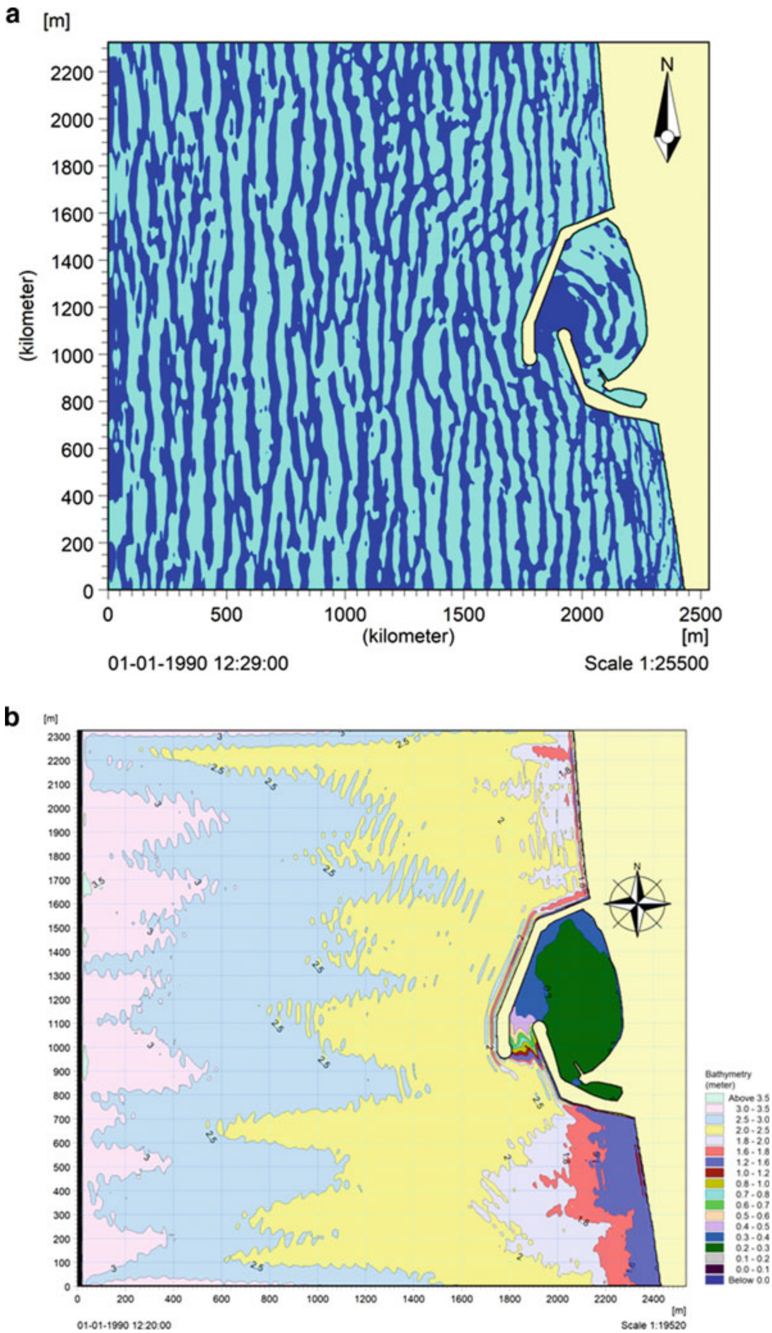

Fig. 10 **a** Wave propagation plot for waves incident from WEST (2700 N) direction, **b** Wave height distribution plot for waves incident from WEST (270° N) direction (Incident Wave Height: 3.5 m)

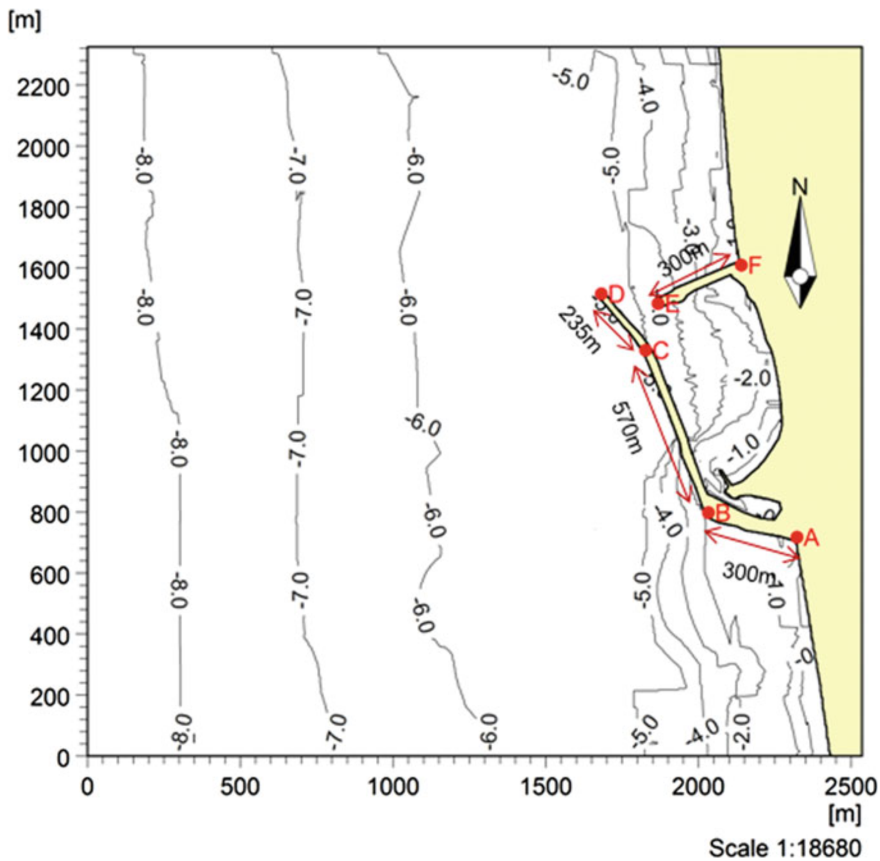

Fig. 11 Bathymetry and layout of modified harbour Alternative-II

3.6 Estimation of Littoral Drift Movement

The present studies were carried out using wave data mentioned above for years 2000 to 2014 in which wave heights ranged between 0.5 m and 4.5 m and wave directions between third quadrants. LITPACK model was used to estimate annual littoral drift rates and its distribution on the profile. Normal to the shoreline, i.e. 260° N, Fig. 13a shows the location of two cross shore profiles, one of northern side (Profile P1) (Fig. 13b) and other on the southern side (Profile P2) (Fig. 13c) of harbour, same were used for drift computation.

The both profiles cover a distance of 2.9 km extending up to about −10 m depth contour (with respect to chart datum) Fig.13b, c. The profiles were discretized with grid size of 5 m. Grain size distribution, fall velocity and roughness coefficients over the profile were required for computation of littoral drift. At the site, grain size is observed to be of the order of 0.25 mm. The Longshore sediment transport rates for

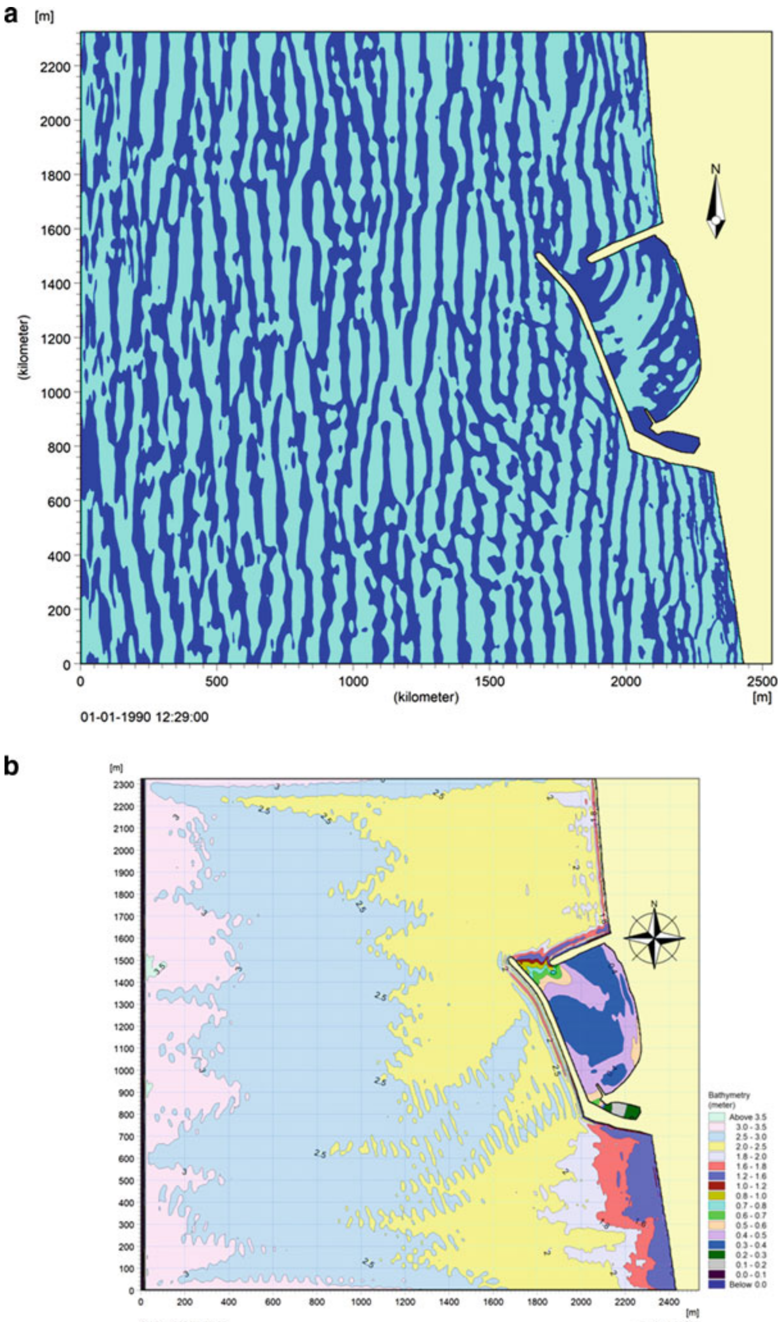

Fig. 12 **a** Wave propagation plot for waves incident from WEST (2700 N) direction, **b** Wave height distribution plot for waves incident from WEST (270° N) direction (Incident Wave Height: 3.5 m)

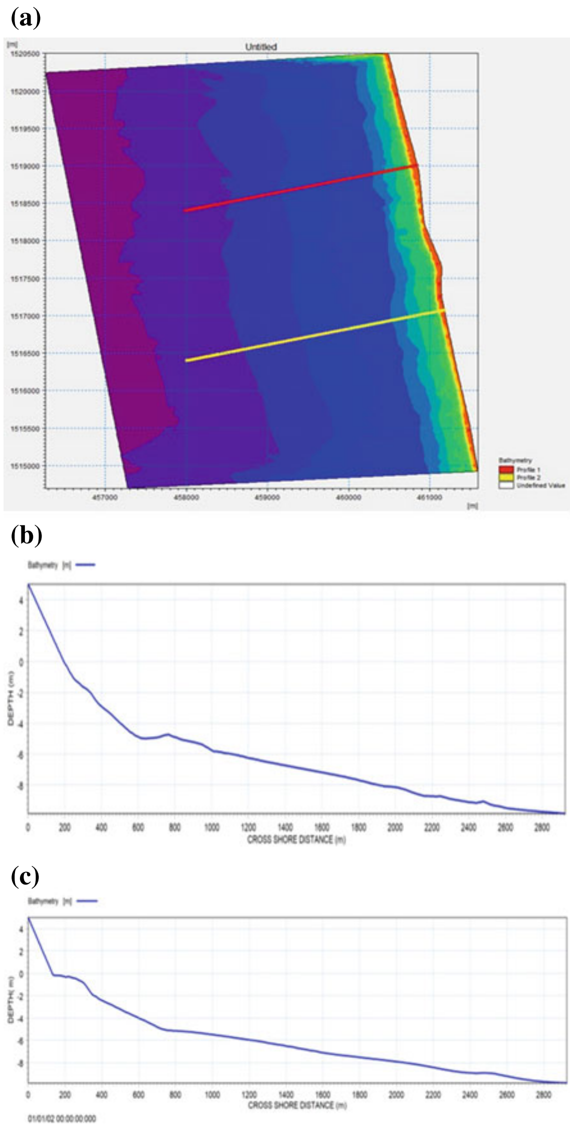

Fig. 13 **a** Location of cross shore profiles, **b** Cross shore profile P1, **c** Cross shore profile P2

the Maravanthe Coast were estimated by Sanil Kumar [2]. The annual net sediment transport estimated by Sanil Kumar was 0.025×10^6 m^3 in the northerly direction and the annual gross sediment transport was 0.029×10^6 m^3. In PhD thesis by Vijaya Kumar G T [3] annual net sediment transport at Maravanthe is estimated to be 0.35 $\times 10^6$ m^3 towards southward the annual gross sediment transport was 1.12×10^6 m^3. By discussions with local people during field visit to Maravanthe, drift towards south was recognized. Seasonal changes in shoreline were observed from the past

Google earth images. Annual net sediment transport of 0.35×10^6 m^3 towards south was considered for the model calibration.

The model was calibrated using bed roughness to get the annual net transport of the order of 0.34×10^6 m^3/year. The model was run for annual nearshore wave climate described above. Annual northward and southward drift distribution across the cross shore two profile is shown in Fig. 14a, b and also in Table 2. The northward drift is plotted positive as while southward drift is plotted as negative.

Net transport in a year is of the order of 0.34 million cum and is towards south and gross transport is of the order of 1.48 million cum.

As net littoral movement at the site was towards south, it means the harbour mouth towards the north side may get some sedimentation problem at mouth and may require periodically dredging at entrance. Considering above the fishing harbour layout (alternative–I) having south side mouth will be more suitable for fishing harbour.

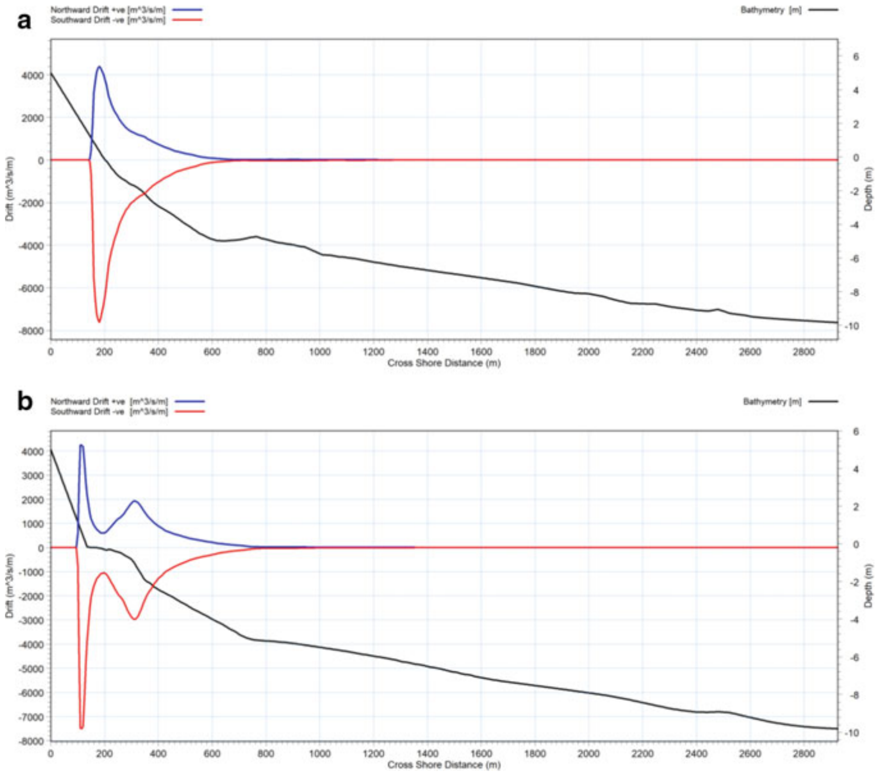

Fig. 14 **a** Cross shore distribution of northward and southward littoral drift during entire year for profile P1, **b** Cross shore distribution of northward and southward littoral drift during entire year for profile P2

Table 2 Littoral transport rate (m^3)

Location	Northward	Southward	Net *	Gross
Profile 1	583,600	928,400	−344,800	1,512,000
Profile 2	559,700	890,300	−330,600	1,450,000

Note * '−ve' Southward '+ve' Northward for the Net Drift

4 Conclusions

The main conclusions derived from above studies as follows:

- Wave propagation studies carried out for transformation of deep water wave conditions to (−) 8 m depth showed that the predominant directions of wave approach at the site of development are from 225° N, 247.5° N, 270° N and 292.5° N
- From the wave tranquillity studies carried out with alternative-I and alternative-II, it was found that both layouts were providing sufficient tranquillity inside the harbour basin but alternative-I having marginally better wave conditions than layout-II.
- LITDRIFT studies indicate that at the proposed site, sediment transport in a year is of the order of 0.34 million cum and is towards south and gross transport is of the order of 1.48 million cum.
- Considering these studies, the alternative-I layout was more suitable for the proposed rejuvenation of the Marvanthe fishing harbour.
- From above studies, it was found that numerical models may be used for rejuvenation of highly wave affected silted fishing harbour in very efficient and cost effective manner.

Acknowledgements Authors are grateful to Shri A.K. Agrawal, Director, Central Water and Power Research Station for his continuous encouragement and motivation during the course of studies and for granting permission to publish this paper.

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