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Study on the Wave Diffraction Patterns in the Kakinada Bay

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Abstract
Kakinada is one of the major upcoming ports of India and holds great importance for shipping activities. This region is said to be low-lying area and highly susceptible to erosion. To protect the port from action of waves, tides and strong currents, breakwater was constructed at the entrance of the channel. Current study makes an attempt to understand how wave energy gets reduced and wave diffraction occurs due to presence of the breakwater. Numerical solution of the mild slope equation and diffraction pattern are studied using MIKE 21 PMS model. Intense wave activity is higher during south west monsoon season than north east monsoon season. Significant wave heights have reduced considerably to 0–0.15 m because of the breakwater during both the seasons and no waves are entering inside the bay. Waves have bent at the breakwater due to diffraction along with the formation of concentric ripples with the decreased wave heights.

Keywords: *Breakwater, diffraction, mild slope equation*

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INTRODUCTION

Port development and shipping activities are major industries in coastal regions all around the world. They provide huge platform for international transport of consignments, large generation of employment and international business. Coastal areas are intermediate between land and sea; therefore, highly subjected to action of waves, tides and currents, erosion and often natural calamities like tsunamis, cyclones, etc. Thus, safety and maintenance of the ports against impact and intensity of these forcing is highly required and to overcome this artificial breakwaters are constructed. Sorensen [1] defined breakwater as a structure that protects the area in its lee from wave attack. Breakwaters are the artificial offshore structures which protect the harbour, anchorage area and ports from water waves. They reduce the intensity of wave action in inshore waters and prevent coastal erosion. Allery [2] explained that detached offshore breakwaters are introduced as self-contained coastal cells where the shore gets re-oriented towards the predominant waves for reducing loss of sand and mitigating long-term erosion.

This study aims to understand the diffraction patterns at the breakwater. Carr and Stelzriede [3] stated that diffraction is an important factor in the determination of the distribution of wave energy within a harbour and analysis of wave energy (wave height) distribution in the lee side of the breakwater. They explained significance of diffraction with harbour design that amount of energy entering the harbour and distribution of wave energy are conditioned by this phenomenon as shown in Figure 1. Sorensen [1] stated that analysis of wave refraction and diffraction helps to check if the required protection will be achieved by the presence of structures like breakwaters.

Diffraction occurs when the height of a wave is greater at one point along a wave crest than at an adjacent point. This causes a flow of energy along the crest in the direction of decreasing height and a consequent adjustment of wave height along the crest as the wave propagates forward as explained by Sorensen [1]. Sharmila *et al*. [4] stated that wave, wind and current change the coastline configuration determined by their interaction with the land and its run off.

Mild slope equation explains the phenomenon how wave energy is dissipated and the wave intensity gets reduced. Mild slope equation is of two types- elliptical mild slope and parabolic mild slope equation. Elliptical mild slope equation considers all four processes refraction, diffraction, shoaling, and reflection of waves, but the parabolic mild slope equation doesn't consider wave reflection parameter as stated by Dezvareh *et al.* [5] Mazzer *et al*. [6] stated that wave diffraction and refraction at inner continental shelf are influenced by bottom irregularities of rocks present as small coastal islands and rocky platforms. Wave reduces its height and energy upon reaching shallow water through wave attenuation due to the friction effect of the increasing viscosity by the soft fluid mud as stated by Daniel [7], Jiang and Mehta [8], Lee and Mehta [9], Inoue [10] explained Philips theory that waves change linearly with time in early stages of growth of waves. He further explained Mile's theory that after this stage, wave energy grows at an exponential rate due to shear flow instability in the air-water coupled system.

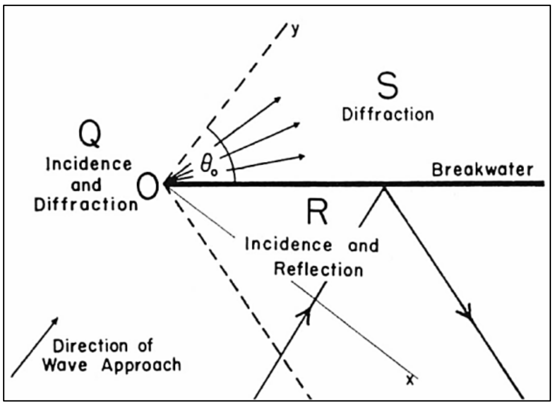


Fig. 1: *Phenomenon at Breakwater (after Carr and Stelzriede[5].*

Breakwater at Kakinada is of finite length and when waves approach a barrier of finite length and wave diffraction occurs at both ends, a wave crest pattern develops. Assuming waves to be linear waves, wave crests combine along lines to form the higher amplitudes which can be estimated by combining the two separate patterns as explained by Sorensen [1].

METHODOLOGY

The Parabolic mild slope equation (PMS) is one of the modules of MIKE 21. It is linear refraction-diffraction model based on a parabolic approximation to the elliptical mild slope equation. Mild slope equation describes combined effects of diffraction and refraction for water waves propagating over depth and due to lateral boundaries like breakwater, coastlines. It models propagation and transformation of water waves, as they travel through waters of varying depth and interact with lateral boundaries. As a result, it describes variation in wave amplitude or wave height. Amplitude of a periodic variable is a measure of its change over a single period. PMS takes into account the effects of refraction and shoaling due to varying depth, diffraction along perpendicular to the predominant wave direction and energy dissipation due to bottom function and wave breaking. It accounts the effect of frequency and directional spreading using linear superposition. Ranasinghe *et al*. [11] stated that PMS model is forced by specifying the wave characteristics (monochromatic or irregular) along the offshore boundary, while the output consists of matrices of wave parameters (wave height, wave period, mean wave direction), radiation stresses and surface elevations over the computational domain. Berkhoff [12] first developed numerical model for analysis of wave propagation where refraction and diffraction are important using mild slope equation.

Gunaratna *et al*. [13] stated that MIKE 21 NSW (Nearshore spectral wave) and PMS (Parabolic Mild Slope) wave models are used for near-shore wave propagation modelling for establishing variation of wave parameter for design of breakwater structures based on an irregular and directional description of wave field. Both models consider shoaling, refraction, and energy dissipation due to wave breaking and bottom friction, but PMS module has added feature to study diffraction patterns caused due to presence of coastal structures like breakwaters, etc. Sloth *et al*. [14] also mentioned capability of MIKE 21 PMS to reproduce shoaling, refraction, energy dissipation phenomena due to wave breaking and bed friction, forward scattering and partial diffraction of directional irregular waves and added further that MIKE 21 PMS simulates linear waves.

Broker *et al.* [15] stated that MIKE 21 PMS is based on the parabolic approximation to the mild-slope equation (Kirby) [16] and accounts for the effects of shoaling, refraction, diffraction, wave breaking, directional spreading, forward scattering, and bed friction. Allery [2] applied MIKE 21 PMS wave model to simulate the near-shore wave field and the radiation stresses because it includes representation of the 2D wave processes such as shoaling, refraction, wave breaking and diffraction. He also stated that breakwaters provide sheltered areas and results in localized changes in wave conditions in the vicinity of the breakwaters, with reductions in wave activity in the lee of the structures. This leads to modification of longshore currents and mitigate long term erosion. Zhang [17] stated that when waves propagate onto the outer margin of an intertidal flat and rapidly decreasing water depth, wave orbital currents increase and disturb the surface sediments and increase the suspended concentration. Sajeev [18] mentioned that the presence of barriers would cause the wave to diffract leeside.

Study Area

Kakinada Bay is located in East Godavari district of Andhra Pradesh on the east coast of India at latitude 16°58.37′N and longitude of 82°17.06′E as shown in Figure 3. This region is a low-lying area, majorly susceptible to natural disasters like flood, storm surges, cyclones, Tsunamis. Being a huge Paddy producing zone and also part of Special Economic Zone and a proposed Petroleum, Chemical and Petrochemical Investment Region, it holds great importance. Kakinada has semi-arid climate receiving high annual rainfall due to south west monsoon and post monsoon rainfall due to cyclonic activity in Bay of Bengal. It has average rainfall of 1040 mm year and is highly productive and economical low-lying area. Figure 2 shows the location of the Coringa mangrove region along with the Kakinada Bay and Hope Island also called as Kakinada Spit.

The area being highly susceptible to action of waves, currents, cyclones, and Tsunamis needs to be protected. For this a breakwater of 1 kilometer length was constructed as shown in Figure 3, which protects the port and city from action of waves. This breakwater is located between port and head of sandbar.

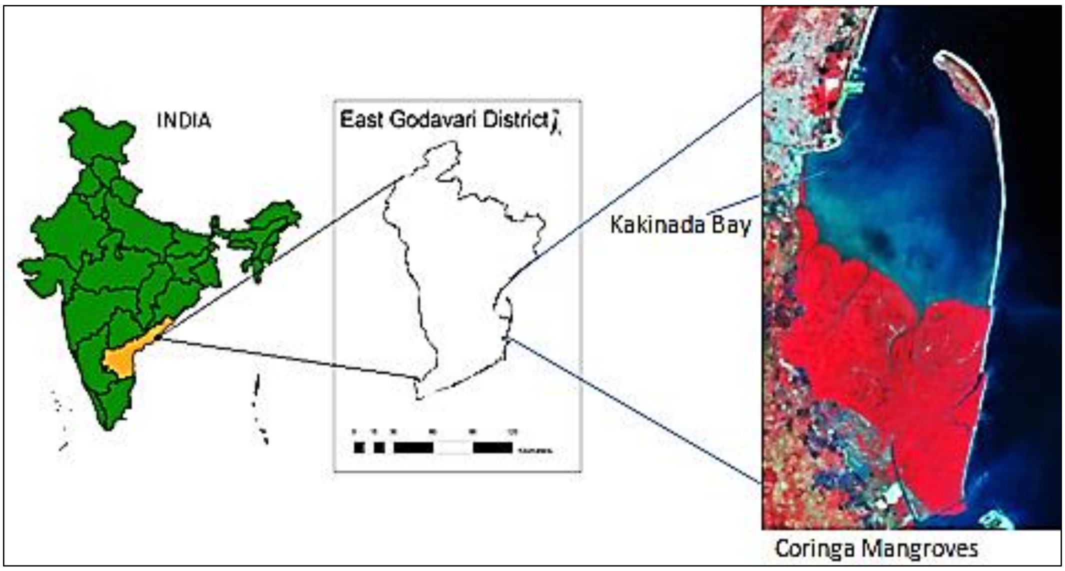


Fig. 2: *Study Area Kakinada Bay.*

***Fig. 3:** Breakwater in Kakinada Bay (Source Google Earth).*

Wave diffraction was studied for two seasons- north-east monsoon for month of January and south-west monsoon for month of September. Both seasons have different wave conditions.

Model Setup

To study wave diffraction at the breakwater in Kakinada Bay, PMS model was set-up. Grid spacing of $\Delta x = \Delta y = 20$ m were selected for modelling the wave module. Soliman *et al*. [19] stated that more resolution increases the accuracy of model results. In order to simulate wave conditions, the bathymetric grid requires an open boundary to the west, so for this original 400 m grid bathymetry was rotated by 180° with respect to North and given as input to the model as shown in Figure 4. Aboobacker *et al.* [20] mentioned that wave parameters like significant wave height, wave period and mean wave direction values are different for different weather conditions in Bay of Bengal as per wave data analyzed for several years.

Inputs for boundary condition were selected as Param Random as mentioned in Table 1.

Rao *et al*. [21] mentioned that the Bay of Bengal experiences seasonally reversing monsoon winds, in months of June-September, summer monsoon period, south-westerly winds, while north-easterly winds during the winter monsoon (December–February).

***Table 1:** Input Data for PMS.*

Season	Month	Significant Wave Height Hs (m)	Wave Period Tz (s)	Mean Wave Direction (degree)
North-East	January	0.5	4	105
South-West	September	1	5	150

Source: Sivakholundu et al. Wave Atlas of the Indian coast [22, 23].

Surface elevation was given as 0.5 m. Minimax model was chosen with aperture 20. Bottom dissipation selected as Nikuradse roughness with constant 0.002 and wave breaking was included in the model. PMS model gives wave and radiation stresses as output. Wave radiation stresses describe average flow over one wave period, and the stresses are connected to a certain water depth. Penchev *et al.* [24] mentioned the values of the parameters controlling the dissipation of wave energy due to breaking in the model as follows: $\alpha 1$ is a factor controlling the maximum wave steepness allowed before breaking = 1.0. α^2 is a factor controlling the maximum H/d allowed before breaking = 1.0. γ is a factor controlling the rate of dissipation = 0.75.

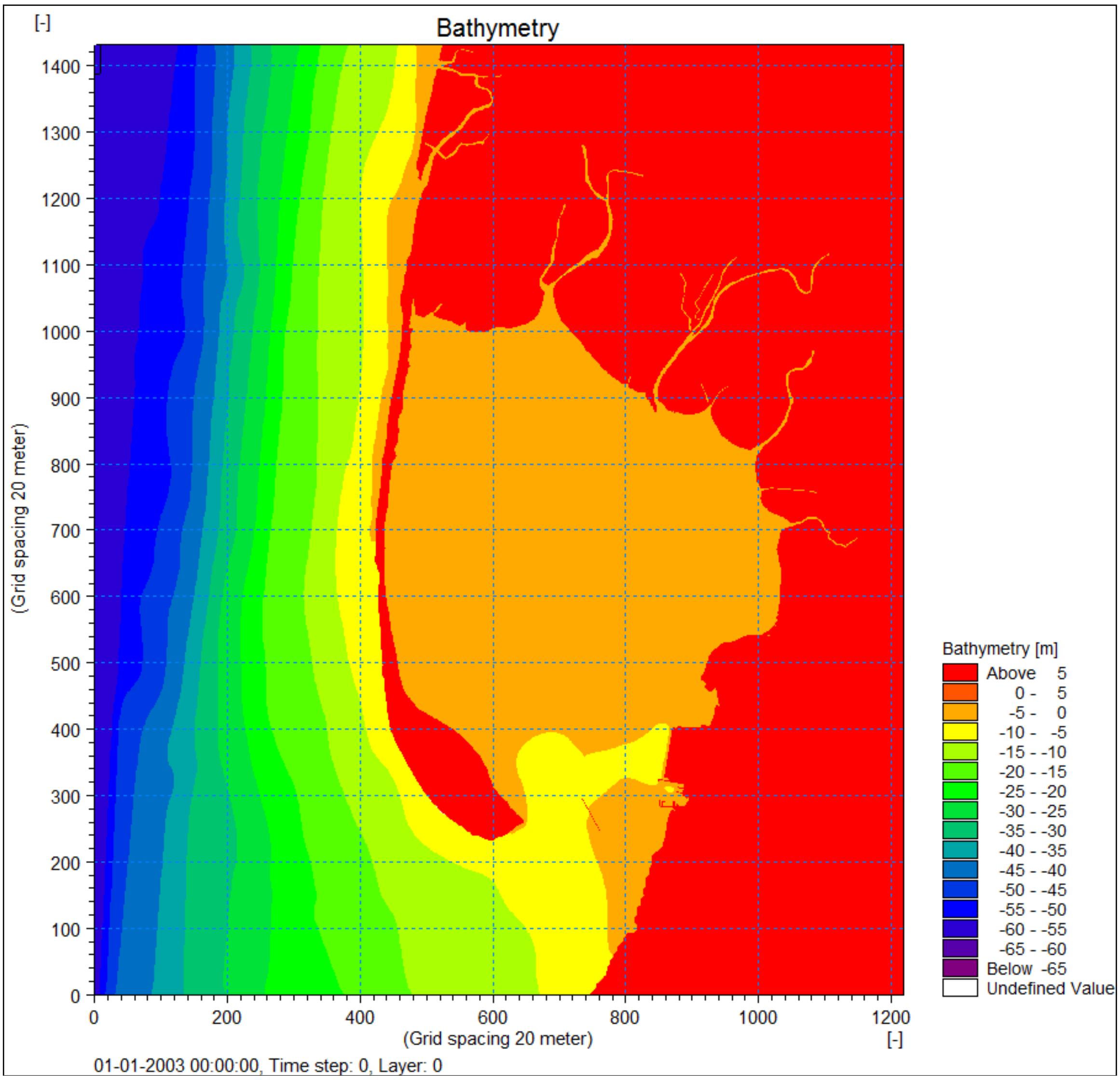
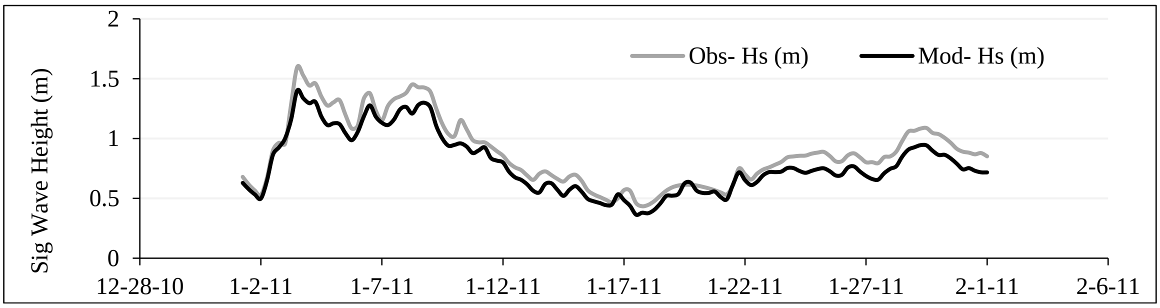
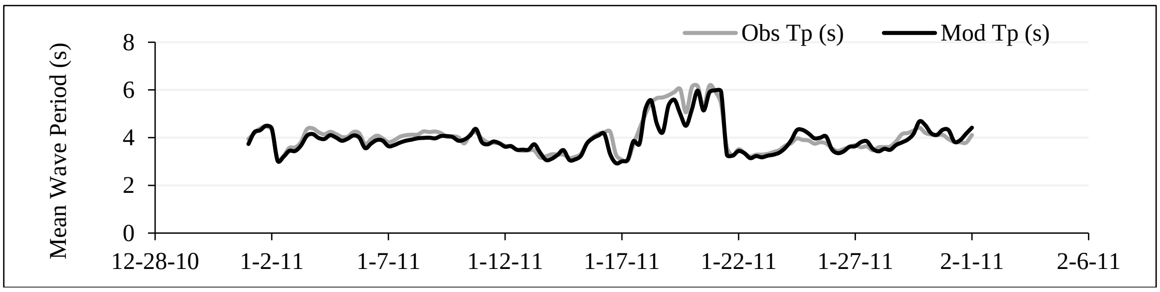


Fig. 4: *Bathymetry Rotated.*





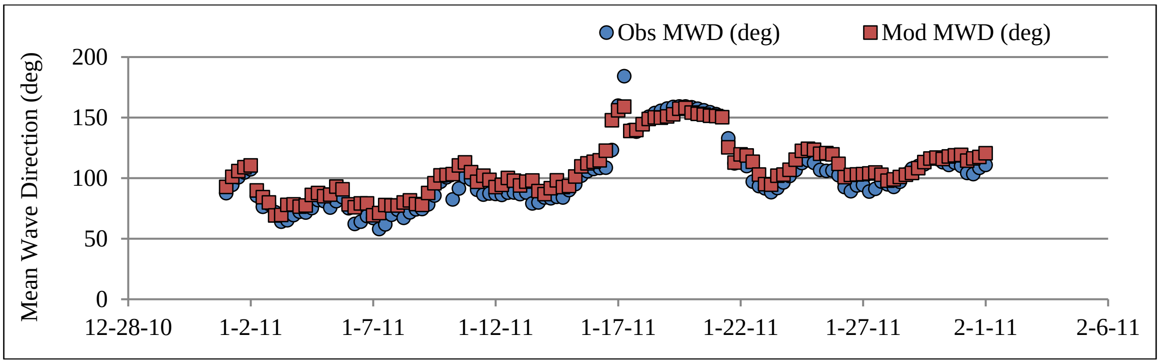


Fig. 5: *Wave Parameter Comparison of Observed and Model data off Kakinada Coast.*

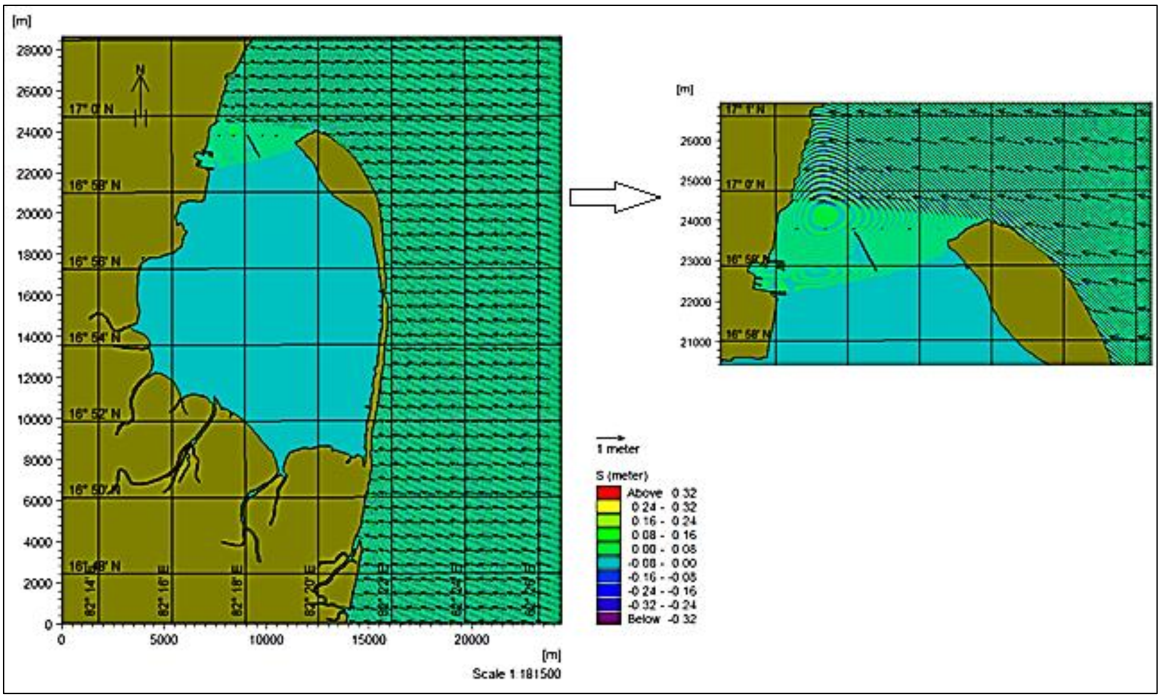


Fig. 6: *Diffraction pattern for January 2011.*

RESULTS AND DISCUSSION

Wave model was validated by comparing wave height, wave period and mean wave direction with observed wave data off Kakinada coast using modelled wave data simulated with NIOT wave atlas for period of January 2011 as shown in Figure 5 below:

Wave model was calibrated by comparing observed wave data off Kakinada coast with simulated waves obtained with NIOT Wave Atlas. The simulation results obtained are in good agreement and the model was further used to study diffraction in the bay.

Once PMS model was run, its radiation stresses, wave height, surface elevation for both the seasons were analyzed. Diffraction pattern and wave height for both seasons are explained. Waves have bent around the corners of the breakwater.

Diffraction patterns for January 2011 as shown in Figure 6, surface elevation is in between 0 to 0.08 m outside the bay near breakwater. But after hitting breakwater wave intensity have reduced and no waves are present in the bay. The portion of the wave that has passed at the end of breakwater has a lateral transfer of wave energy along the wave crest into the lee side of the breakwater. The diffracted wave crests around the breakwater have formed concentric circular arcs with exponentially decreasing wave height along the crests.

Diffraction patterns for September 2011 as shown in Figure 7, surface elevation is between 0 and 0.15 m near the breakwater while negative inside the bay. This shows how wave height is reduced by the action of breakwater. The wave crests have combined along lines like the dashed line to form the higher amplitudes.

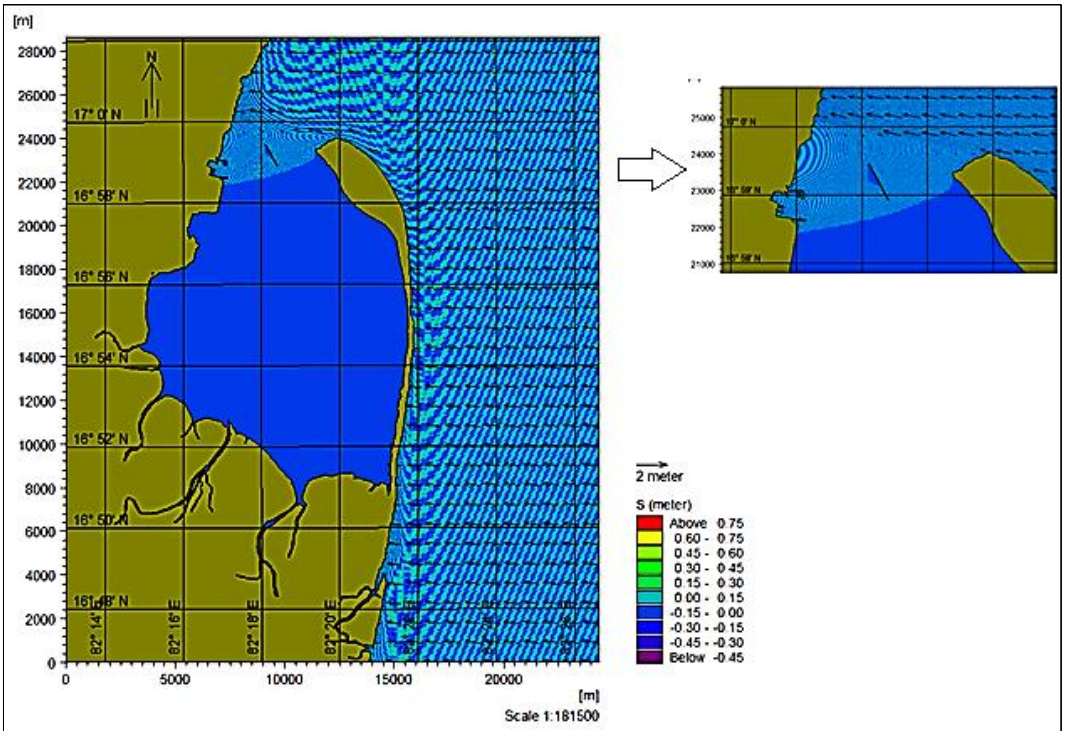


Fig. 7: *Diffraction Pattern for September 2011.*

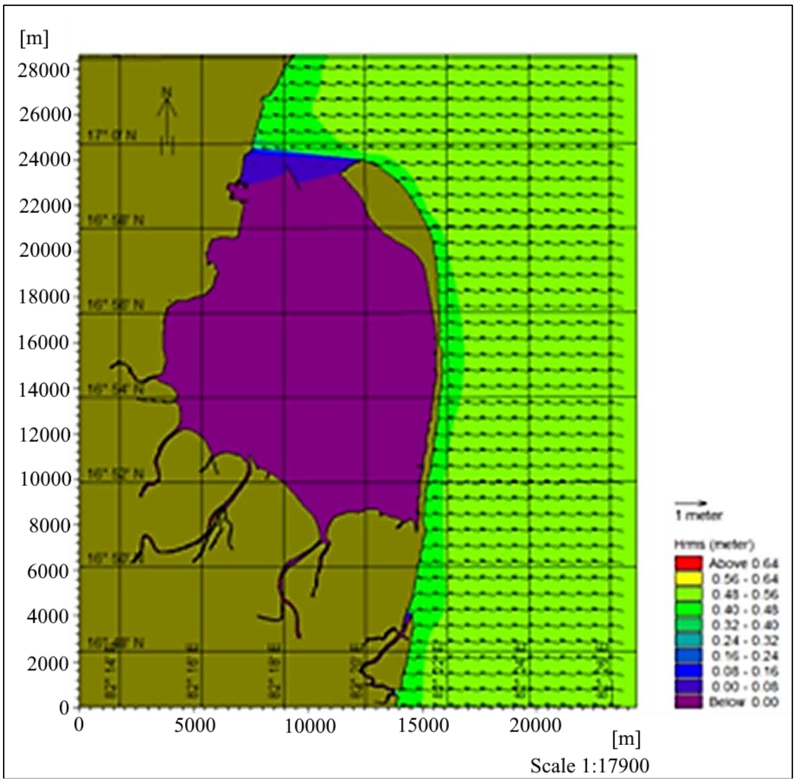


Fig. 8: *Significant Wave Height for January 2011.*

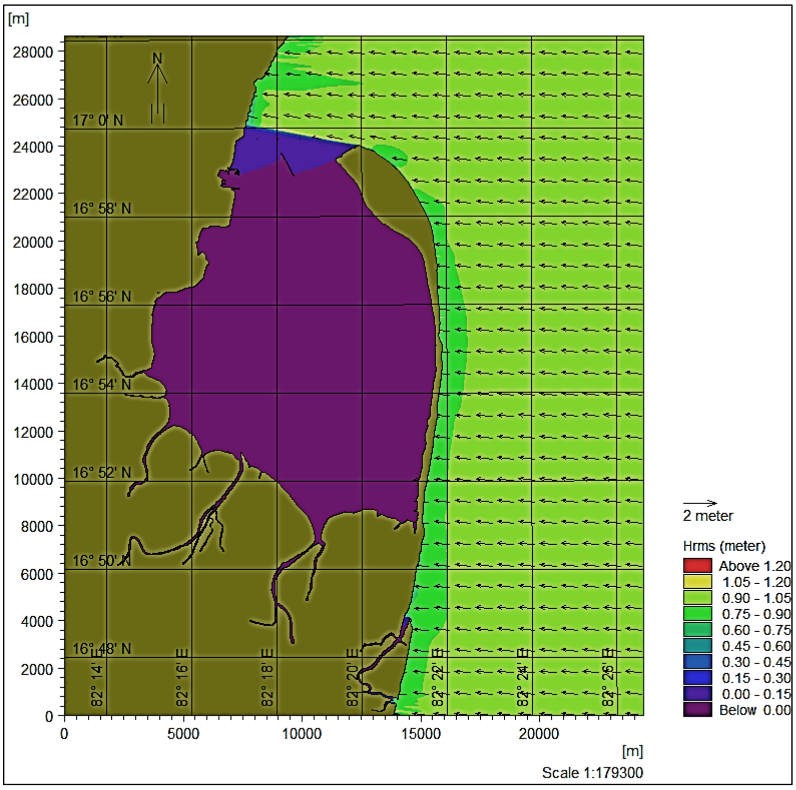


Fig. 9: *Significant Wave Height for September 2011.*

Figures 8 and 9 show the significant wave height for months of January and September 2011 respectively. In January, wave height outside the bay is between 0.40–0.56 m. Near breakwater it has reduced to 0.0 to 0.16 m. It is very clear and evident that there is no wave entering into the bay. In September, wave height is varying from 0.75 to 1.05 m. At the breakwater, wave height has reduced to 0.0 to 0.15 m and zero waves inside the bay. Breakwater has totally reduced the intensity of waves. Wave height is less than the incident wave height at the end of the breakwater. As wave spectrum is coming from the same direction, it has undergone a greater percentage of decrease in wave height at lower periods. Since difference in the depth of water is not much, therefore wave crest pattern and wave height have not been affected by refraction also explained by Sorensen (2006). These results show that presence of breakwater has reasonably reduced the wave intensity and there is no wave action inside the bay.

CONCLUSION

Diffraction is important phenomenon to determine the distribution of wave energy in harbour area. It is concluded that wave height and energy is reduced after striking breakwater due to wave attenuation. Breakwater in Kakinada prevents action of wave and protects the port from longshore current and long-term erosion. It has provided sheltered area and changed wave conditions in its vicinity. Diffraction patterns show that the wave scattering has occurred and waves have bent at the corners of the breakwater. This phenomenon has led to zero wave function and no wave energy inside the bay. Wave crest has truncated when it passed at the end of the breakwater extending out into the water. Wave energy has distributed uniformly at the lee side of the breakwater. Thus, breakwaters can be rightly called as wave-traps as they protect ports, harbours from action of waves and prevent coastal erosion. The model results showed that wave conditions are expected same throughout the year at the breakwater and inside the bay. Wave amplitude has along wave crests have considerably reduced as they approach breakwater. These waves breaking and attenuation due to breakwater ensure safety of port and safe navigation and shipping activities into and out of the harbour.

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