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Research Article

Assessment of Wave Tranquility by Boussinesq Model for Port Development

Komal. P. Sarnaik†*, B. M. Patil† and M. D. Kudale‡

†Department of Civil Engineering, Bharati Vidyapeeth University College of Engineering Pune, India
‡Central Water & Power Research Station, Khadakwasla, Pune, India

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Abstract

Over the last 40 years, Boussinesq-Type Models (BTMs) became well known and are favoured by the coastal engineering community. This is because of their ability to represent all main physical phenomena, mathematical well posedness and computational ease. A spectral wave model, MIKE 21 SW and a BTM, MIKE21 BW were used in the present study for simulation of wave propagation in offshore region and in the harbour region respectively. Analysis of about 12 years deep water wave data was carried out which became input to the MIKE21 SW model. The model results with existing breakwater were compared with the observed wave heights indicating satisfactory comparison and confirming the successful verification of the model. Finally, wave disturbances in the harbour were assessed for different extensions of an existing breakwater and suitable extension is suggested for the desired wave tranquility in the harbour.

Keywords:*Wave propagation, Boussinesq-Type wave model, Spectral wave model, Numerical modelling, Wave tranquillity, Harbour.*

Introduction

India is blessed with very long coastline of about 7516.6 kilometers, forming one of the biggest peninsulas in the world. It is serviced by 13 major ports, 40 intermediate ports, 150 minor ports and 200 fishing harbors. The existing ports are being extended and new ports are also being planned (Narasimhan*et al*, 2002).

The primary purpose of port or harbor is to facilitate on/off loading of the vessels at the berths by providing required wave tranquility and sufficient water depths. The desired degree of wave tranquility inside the harbor is the important parameter in the design of port/ harbor.

Every coastal or ocean engineering study such as harbor planning requires the information of wave conditions in the region of interest. Usually, wave characteristics are collected offshore and it is necessary to generate wave data at the project site from the offshore data.

Physical modeling and numerical modeling are very much useful tools to simulate wave conditions at the project site. Numerical modeling is efficient, cost effective and it can consider large area and different design conditions with ease. Over the last 40 years, Boussinesq-Type Models (BTMs) became well known and are favoured by the coastal engineering community. This is because of their ability to represent all main physical phenomena, mathematical well posedness and computational ease. Such computational techniques are essential tools for any design activity in which water waves play a significant role. One of such examples is design of harbours (Brocchini M*et al*, 2013).

A spectral wave model, MIKE 21 SW and a BTM, MIKE21 BW are used in the present study for simulation of wave propagation in offshoreregion and in the harbour region respectively (DHI, Denmark, 2014). MIKE 21 SW is a state-of-the-art third generation spectral wind wave model based on unstructured mesh. While, MIKE21-BW model is one of the most advanced comprehensive wave models, available today, which simulates the wave penetration in the harbor region. This study is carried out in three parts, namely, analysis of wave conditions near the typical project site, derivation of the wave conditions near the harbour and simulation of the wave conditions in the harbour. Finally, wave disturbances in the harbour were assessed for different extensions of an existingbreakwater and suitableextension is suggested for the desired wave tranquility in the harbour.

*Corresponding author **Komal. P. Sarnaik** is a Research Scholar; **B. M. Patil** is working as Professor, and **M. D. Kudale** as Scientist E

Table 1 % occurrence of resulting waves off Jaigad for SW monsoon period

Wave HT(m)	0.5-1.	1-1.5	1.5-2.	2.-2.5	2.5-3.	3.-3.5	3.5-4.	4-4.5	>4.5	Total
Direction								Calm		0.00%
160	0	0	0.04	0	0	0	0	0	0	0.04
170	0	0	0	0	0.04	0	0	0	0	0.04
180	0.02	0.16	0.02	0	0	0	0	0	0	0.19
190	0.07	1.59	2.96	1.02	0.42	0.18	0	0	0	6.23
200	0.19	1.98	5.03	3.68	2.1	0.6	0.18	0	0	13.75
210	0.33	1.37	2.63	1.98	1.14	0.56	0.16	0	0	8.16
220	0.16	0.86	1.7	0.98	0.84	0.4	0.18	0.09	0	5.2
230	0.09	0.77	0.96	1.38	0.53	0.14	0.14	0.16	0.07	4.24
240	0.07	0.67	2.29	3.75	3.27	1.82	1.49	0.84	0.35	14.55
250	0.12	0.44	2.21	4.43	5.01	4.96	3.76	1.89	1.75	24.57
260	0.11	0.19	1.56	2.26	3.41	2.19	1.86	0.88	0.86	13.31
270	0.04	0.11	0.7	1.86	1.98	1.23	0.67	0.28	0.35	7.2
280	0	0.05	0.42	0.67	0.33	0.14	0.07	0.04	0.02	1.73
290	0	0.05	0.12	0.21	0.02	0.09	0.02	0	0	0.51
300	0.04	0.07	0	0.02	0	0.02	0	0	0	0.14
310	0	0	0.02	0	0	0	0	0	0	0.02
320	0	0.04	0.04	0.02	0	0	0	0	0	0.09
330	0	0	0.02	0.02	0	0	0	0	0	0.04
340	0	0	0.02	0	0	0	0	0	0	0.02
TOTAL	1.23	8.33	20.71	22.26	19.09	12.31	8.51	4.17	3.4	100

Study area

An all Weather Green Field Port has been developed at Jaigad located on the west coast of India in Ratnagiri district of Maharashtra and is about 50 km north of Ratnagiri. The port is situated at latitude 17^0 18' N and longitude 73^0 12' E, (Fig. 1).

Fig.1 Location map of Port

In Phase I, the Port has been developed into two bulk berths, an approach channel of base width 200 m and turning circle of diameter 300 m dredged to -14.3 m with respect to chart datum as shown in (Fig.2). The port has a 510 m long breakwater projecting from the Jaigad Head to give protection from extreme weather conditions in South West monsoon. The site is mostly affected by the Westerly and North Westerly waves duringSouth West monsoon. During South West monsoon severe motions of moored ships were observed at the berths which affected loading, unloading operations at the berth badly. In this regard mathematical model studies were proposed to improve wave tranquility in the harbour to provide adequate tranquil conditions for port operations during South West monsoon.

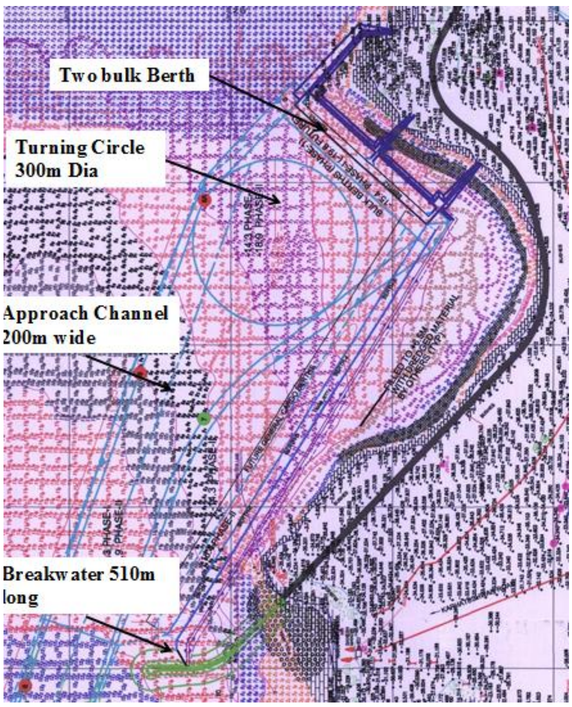


Fig. 2 Layout of Port

Deep Water Wave Data Analysis

The deep water wave data was available and was extracted at location EP (17^0 30' N and 72^0 04' E) in 90 m depth. This offshore wave data are of the period from October 1999 to June 2012 and are composed of Sea waves, Swell waves and Resulting waves (i.e. combined sea and swell). Frequency distribution analysis of the data (sea, swell, resultant wave data of yearly as well as of SW monsoon) was carried out extensively using Microsoft Excel. Typically, the frequency distribution of wave heights for different directions during SW monsoon is given in Table 1 for Resulting waves. The corresponding wave rose diagram is presented in Fig. 3.

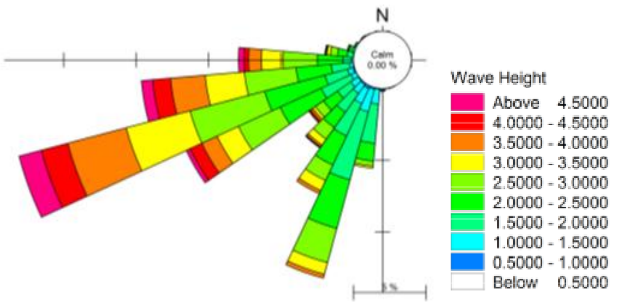


Fig. 3 Offshore wave rose diagram for SW monsoon

Modelling Techniques

A spectral wave model, MIKE 21 SW and a BTM, MIKE21 BW were used in the present study for simulation of wave propagation in offshore region and in the harbour region respectively.

The computation of wave transformation from deep to shallow coastal waters was carried out using MIKE21-SW model. It 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.

Mathematical model MIKE 21-BW was used for simulating the wave disturbance in the harbour area. It is one of the most advanced comprehensive wave models available. The model is a nonlinear wave model based on time dependant Boussinesq equations of conservation of mass and momentum obtained by integrating the three-dimensional flow equations without neglecting vertical acceleration. These equations include nonlinearity as well as frequency dispersion. They operate in the time domain, so that irregular waves can be simulated. 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. It simulates in time domain the propagation of irregular, directional waves into the harbor taking into account all important effects like moving boundaries, shoaling, depth refraction, diffraction, bottom friction, partial and full reflection, and transmission through porous boundaries and structures such as piers and breakwaters. Provision of application of sponge layers is available in the model when full absorption of wave energy is required. The model also includes internal generation of waves.

A major application area of MIKE 21 BW is determination and assessment of wave dynamics in ports and harbours and in coastal areas. The disturbance inside harbour basins is one of the most important factors when engineers are to select construction sites and determine the optimum harbour layout in relation to predefined criteria for acceptable wave disturbance, ship movements, mooring arrangements and handling downtime.

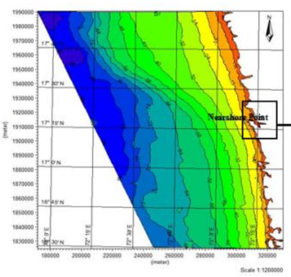
Model Simulations

Model simulations are carried out in the two parts as described below:

- Nearshore wave modeling using MIKE21 SW model using deep water wave data as input for Determining nearshore wave heights in normal conditions
- Modelling of wave penetration in the harbour using MIKE21 BW model using the nearshore wave conditions derived by the MIKE21 SW model as input.

Nearshore wave modeling using MIKE21 SW model

The nearshore wave climate at the port was obtained by transforming the deepwater wave data using MIKE21-SW model.



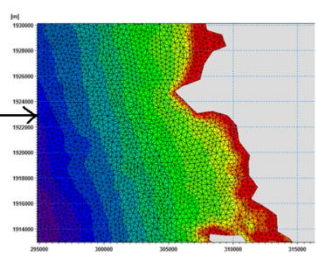


Fig4 Bathymetry for for MIKE21 SW model **Fig5**Triangular mesh MIKE21 SW model

Model area of about 160 km X 100 km is considered for the wave transformation and bathymetry and the model region are shown in Fig. 4. The model region is descretized by unstructured mesh as shown in Fig. 5. The model was run to obtain nearshore wave climate at the inshore location in 15 m depth contour (Fig.4).

Table 2 Transformation table from deep water to 15m depth

Sr.No.	OffshoreDirection (Deg. N)	InshoreDirection (Deg. N)	Ratio ((Hi /Ho)
1	180	213	0.59
2	190	216	0.64
3	200	220	0.69
4	210	225	0.73
5	220	230	0.76
6	230	236	0.79
7	240	243	0.80
8	250	250	0.80
9	260	257	0.79
10	270	264	0.77
11	280	271	0.75
12	290	278	0.71
13	300	285	0.68
14	310	290	0.64
15	320	295	0.59

Hi = Wave height at Refraction Point
Ho = Offshore wave height

Table 3 % occurrence of resultant waves in 15m depth at Jaigad for SW monsoon

Wave HT(m)	0.5-1.	1-1.5	1.5-2.	2.-2.5	2.5-3.	3.-3.5	3.5-4.	4-4.5	Total
Direction								Calm	0.12%
220	4.59	13.24	7.86	2.31	0.33	0	0	0	28.33
230	0.53	1.77	1.61	0.82	0.37	0.11	0	0	5.2
240	0.53	3.43	6.02	4.18	2.35	1.54	0.67	0.07	18.79
250	0.26	1.19	5.74	6.11	5.53	3.24	1.89	0.6	24.57
260	0.21	1.91	4.69	6.57	4.03	1.75	1	0.35	20.5
270	0.02	0.46	0.75	0.37	0.09	0.04	0.02	0	1.73
280	0.12	0.21	0.18	0.12	0.02	0	0	0	0.65
290	0	0.02	0	0	0	0	0	0	0.02
300	0.05	0.04	0	0	0	0	0	0	0.09
TOTAL	6.3	22.26	26.86	20.49	12.71	6.67	3.57	1.02	100

The location of inshore point at 15 m depth is considered at the boundary of the MIKE21-BW model region to derive the boundary conditions for the BW model.

The transformation table obtained by the model for wave propagation from deep water toshallow water for the port site is shown in Table 2. The table consists of offshore wave direction, inshore wave direction and the corresponding ratio of wave heights in 15 m depth with different directions of wave incidence at the offshore boundary.

This transformation function (Table 2) was applied to the deep water wave data (Table 1) to obtain the frequency distribution of waves at the inshore location (Refraction Point) in 15m depth for SW monsoon, which is presented in Table 3.The corresponding wave rose diagram is presented in Fig. 6.

Based on a frequency distribution analysis, a wave period of 9 sec was adopted for these studies. From the analysis of wave data and the results of transformation of deep water wave data to 15 m depth, (Tables 3), following design (input) wave conditions at 15 m depth were considered for simulation of wave propagation in the existing harbour and in the proposed harbour and modified layout using MIKE 21-BW model given in Table 4 as follows.

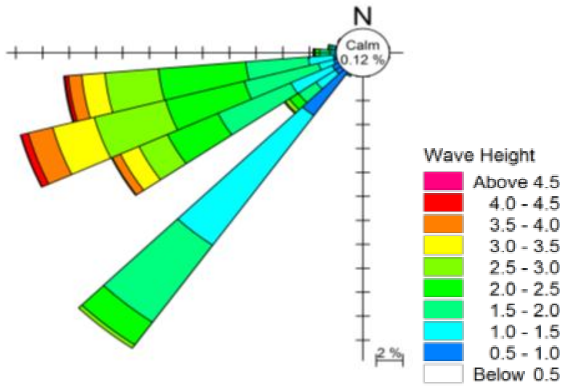


Fig. 6 Nearshore wave rose diagram for SW monsoon

Table 4 Input wave conditions for mike21-bw model

Wave direction (deg. N)	Wave height(m)/ Period(sec)	
	Existing Condition	Modified Condition
260⁰N	3.0/9	3.0/9
270⁰N	3.5/9	3.5/9
280⁰N	3.5/9	3.5/9
290⁰N	3.0/9	3.0/9
300⁰N	1.5/9	1.5/9

Wave Propagation in the harbour with Existing harbour Layout

The existing breakwater of 510 m length and the bathymetry is shown in Fig.7. Wave propagation inside the harbour is simulated for all the incident wave conditions listed in Table 4.

The model results corresponding to the incident wave direction 290^{0}N and wave height 2.5 m. are plotted in Fig. 8 which shows wave height distribution in the harbour. From this figure it can be seen thatwaveheights at the berth are in the range 1.0-1.2 m which exceeds permissible wave height 0.8 m. These wave heights obtained by the model were compared with the observed wave heights. The comparison was found to be satisfactory thus confirming the successful verification of the model.

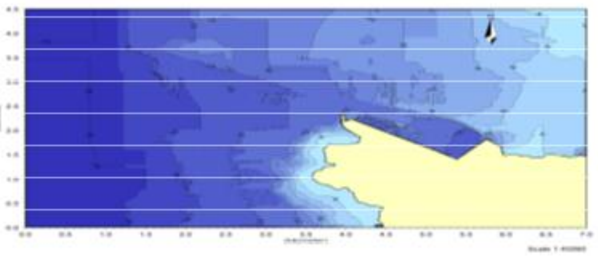


Fig 7 Bathymetry for MIKE 21 BW model with existing layout

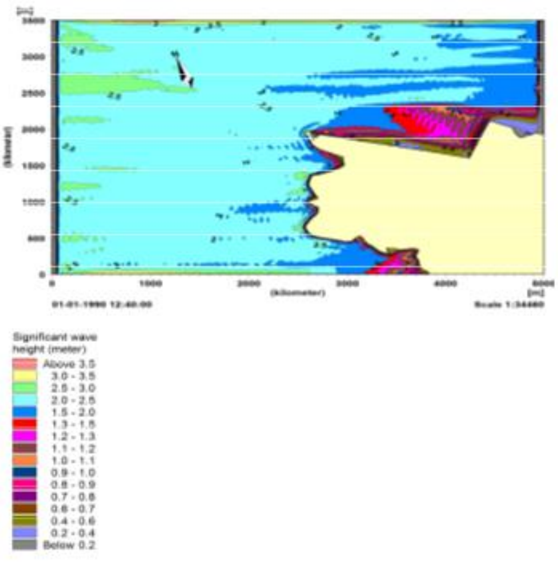


Fig 8 Wave height distribution in the harbour for existing layout

Wave Propagation in the harbour with the breakwater extension

The layout plan and bathymetry plot of the harbour with the proposed breakwater extension of 300 m length and modified channel alignment are shown in Fig. 9. Wave propagation inside the harbour is simulated for all the design wave conditions listed in Table 4 and for the breakwater extensions of 100 m, 200 m and 300 m. The model results corresponding to the incident wave direction 290^{0}N and wave height 2.5 m and extension of 300 m are plotted in Fig. 10 which shows wave height distribution in the harbour. It can be seen from Fig. 10, that wave heights at the berth are within the permissiblelimit. The corresponding surface elevation plot is shown in Fig. 11.

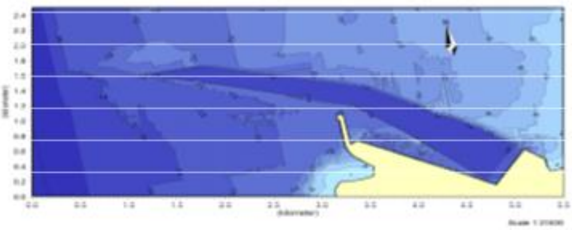


Fig 9 Bathymetry for MIKE 21 BW model with Breakwater extension

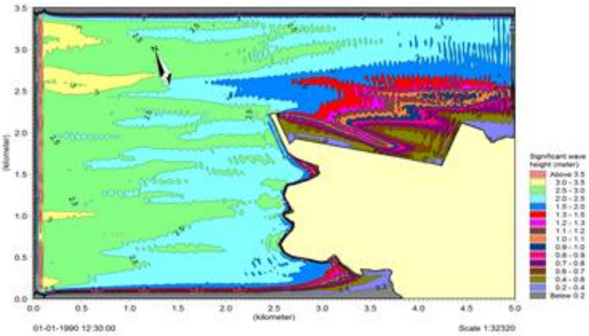


Fig 10 Wave height distribution in the harbour For breakwater extension

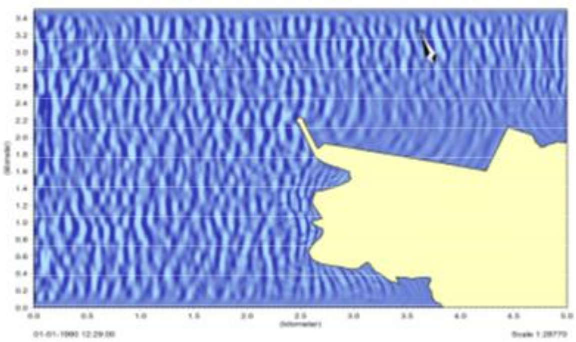


Fig 11 Surface elevations in the harbour

Conclusions

A spectral wave model, MIKE 21 SW and a BTM, MIKE21 BW were used in the present study for simulation of wave propagation in offshore region and in the harbour region respectively. The main conclusions of the study are as follows.

1. The wave transformation studies with MIKE21–SW model indicated that the predominant directions at 15 m depth are from 220^{0}N to 300^{0}N. The port gets

natural protection from Jaigad headland and the existing breakwater, for wave's incident from 220⁰N, to 260⁰N directions. Though the wave heights from directions 280⁰N to 300⁰N are less in magnitude, the berths are seen to be directly exposed to waves at beam causing problems in loading and unloading operations at the berth.

2. MIKE21 BW model simulations were carried out for the existing conditions with the 510 m breakwater length and the wave heights obtained by the model were compared with the observed wave heights. The comparison was found to be satisfactory thus confirming the successful verification of the model.

3. Wave tranquility studies with MIKE21- BW model indicated that wave heights are more than the permissible wave height of 0.8 m for the existing breakwater as well as for breakwater extension of 100m and 200m.Wave heights in the Berth area would be more than the permissible limit of 0.8 m during SW monsoon season for about 15 to 20 days for the existing layout and about 5 to 7 days for breakwater extension of 100 m.

4. Tranquility near the berths was found to be improved further with extension of the existing breakwater by 300 m. However, the waves are seen to be approaching the berth at beam and also with severe wind at beam. Therefore ship motion studies of moored ship are necessary to ensure safe operations at the berths during SW monsoon.

5. The existing breakwater extended by about 300 would be required for the desired wave tranquility in the SW monsoon.

6. The MIKE21 SW and MIKE21 BW models are found to be very useful for such studies.

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