Harbor Tranquility Study Using MIKE 21 BW

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Abstract

In order to facilitate ship berthing, obtaining an acceptable level of wave disturbance within harbor basin and its marine facilities is of significance and should be addressed in layout design of the breakwaters. The pattern of wave propagation into harbor basin is mainly governed by diffraction and in specific cases by refraction. The sheltering provided by breakwaters against incoming waves, wave transmission and reflection caused by the porous breakwater body are the main items being considered. In this paper, the specifications of the layout proposed and the wave climate at the entrance of the Port are introduced. BW Module (Boussinesq Wave Module) of MIKE21 Software which is used to simulate the pattern of wave propagation into the basin is briefly introduced and the setup conditions used in the simulations are described next. The wave disturbance modeling is carried out for a range of wave directions and periods and sample results of the penetrated wave patterns are presented. The accepted calmness criteria is reviewed and discussed and the probability of exceeding these criteria along the Port berths are calculated.

Keywords: wave diffraction; harbor Tranquility; MIKE21

1. INTRODUCTION

In order to facilitate ship berthing, and in general a safe harbor for ships, obtaining an acceptable level of wave disturbance within harbor basin and its marine facilities is of significance and should be addressed in layout design of the breakwaters. At the first, the breakwater layout is dictated by navigation requirements. After that the proposed layout drawn from this stage must be checked for the accepted level of wave disturbance. If suitable berthing conditions are not provided, the layout should be modified and tested till adequate sheltering is provided all along port berths and main position in harbor basin.

In this study, the specifications of the layout and the wave climate at the entrance of the Port are introduced. BW Module (Boussinesq Wave Module) of Mike 21 Software which is used to simulate the pattern of wave propagation into the basin is briefly introduced and the setup conditions used in the simulations are described next. The wave disturbance modeling is carried out for a range of wave directions and periods and sample results of the penetrated wave patterns are presented. The accepted calmness criteria is reviewed and discussed and the probability of exceeding these criteria along the Port berths are calculated and presented in the final part of this section. The proposed layout for Port breakwaters is presented as

Figure 1. The position of General Cargo Vessel Berth (GCV) and Tug Boat Berths (TUG) are shown in this Figure.

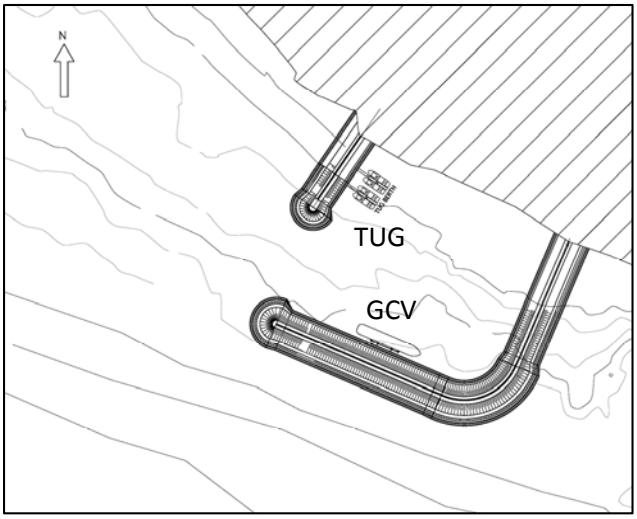

Figure 1: Proposed harbor layout

2. CALMNESS CRITERIA IN BERTHING POSITIONS

According to OCDI-2002, the threshold wave heights for cargo handling in front of berths should be estimated based on the type, size, and cargo handling characteristics of vessels. For this purpose, the values listed in Table 1 are suggested. In according to this Table, the allowable significant wave height (Hs, allowable) for the vessels smaller than 500 GT is about 0.3 meter. This range for very large ships (vessels larger than 50,000 GT) is about 0.7 to 1.0 meter. Medium and large size vessels (that is seems the range of vessels in this harbor are in this category) are in between. Thus in according to capacity of vessels that will berth in the studied port, its allowable maximum wave height is considered 0.5 meter.

Ship type	GRT (tons)	Threshold Significant Wave Height –H_s (m)
Small Ships	<500	0.3
Large and Average Ships	>500 and <50000	0.5
Very Large Ships	>50000	0.7 ~ 1.0

Table1. Calmness criteria in comparison of ship weight [OCDI-2002]

3. WAVE CHARACTERISTICS NEAR HARBOR ENTRANCE

As discussed before, BMO data were selected and analyzed to obtain near shore wave condition in the vicinity of the port. These data are calibrated with measurements data. The wave roses obtained from these data sets at -20 m to C.D. shown in Figures 2. As shown in this Figure, the shape of the coastal area and configuration of the Port breakwaters allow the waves coming from angles between 225 and 247.5 degrees to enter the basin. In fact considering the location and the geometry of the proposed layout, southwest (SW) and west southwest (WSW) waves seem to be more serious for the Port.

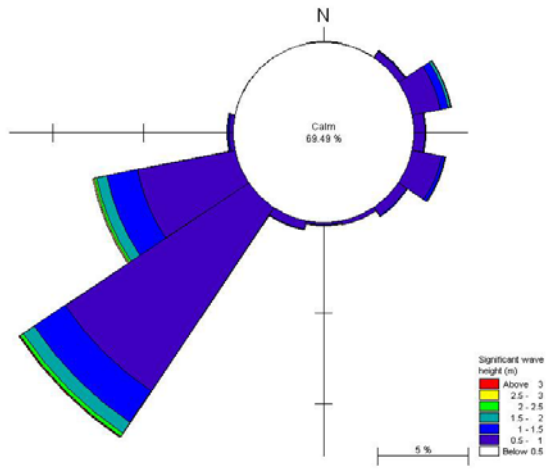

Figure 2: Annual wave rose in studied region at depth 30m based on BMO dataset

Based on BMO data, the peak period of the incoming waves to the site, are variable and between 2 and 12 seconds. It is common that one wave period is used for simulation of wave disturbance coefficients into the port; but in these studies, we try to categorize wave events in some periods to get the results more suitable than one period. Figure 3 shows the T_P versus Hs in the near shore zone. According to these figure, Tp=5s and 9s are considered for representative of wave periods (Tp) less and greater than 6s, respectively.

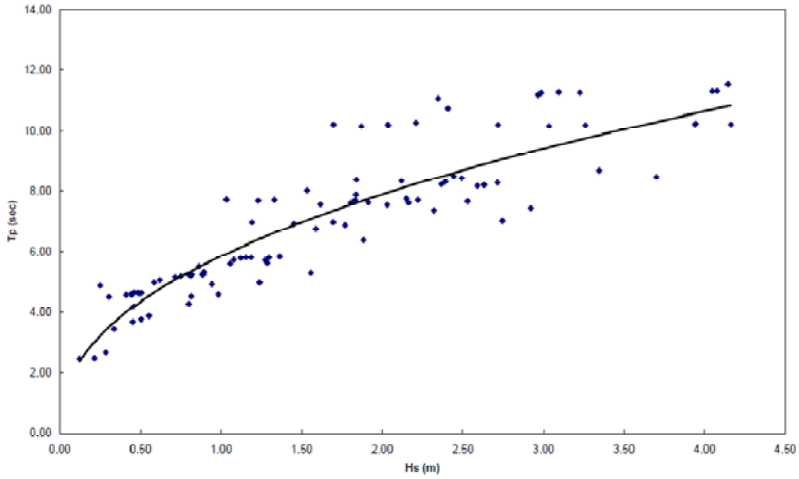

Figure 3: T_P versus Hs in the nearshore zone

4. BRIEF INTRODUCTION TO NUMERICAL MODEL

BW Module of Mike 21 Numerical Model applied for harbor tranquility simulations has unique features which enables it to incorporate the impacts of various hydrodynamic features such as wave diffraction, wave refraction, shoaling, bed resistance (Bottom friction), partial reflection and transmission, frequency spreading, and directional spreading. In this module, time dependant depth averaged Boussinesq Equations are solved. The governing equations are given as follows:

Continuity equation:

$$n\frac{\partial s}{\partial t}+\frac{\partial p}{\partial x}+\frac{\partial q}{\partial y}=0$$

Momentum equation in X direction:

$$n\frac{\partial p}{\partial t}+\frac{\partial}{\partial x}\left(\frac{p^2}{h}\right)+\frac{\partial}{\partial y}\left(\frac{pq}{h}\right)-\frac{\partial R_{xx}}{\partial x}+\frac{\partial R_{xy}}{\partial x}+F_x$$

$$n^2\,gh\frac{\partial s}{\partial x}+n^2p\left(\alpha+\beta\sqrt{\frac{p^2}{h^2}+\frac{q^2}{h^2}}\right)+\frac{gp\sqrt{p^2+q^2}}{h^2C^2}+n\psi_1=0$$

Momentum equation in the Y direction:

$$n\frac{\partial p}{\partial t}+\frac{\partial}{\partial y}\left(\frac{p^2}{h}\right)+\frac{\partial}{\partial x}\left(\frac{pq}{h}\right)+\frac{\partial R_{yy}}{\partial y}+\frac{\partial R_{xy}}{\partial y}+F_x$$

$$n^2\,gh\frac{\partial s}{\partial y}+n^2p\left(\alpha+\beta\sqrt{\frac{p^2}{h^2}+\frac{q^2}{h^2}}\right)+\frac{gq\sqrt{p^2+q^2}}{h^2C^2}+n\psi_2=0$$

The parameters used in this relationship include:
s: water surface level above the base level (m)
p: flux density in the X-direction (m3/s/m)
q: flux density in the Y- direction (m3/s/m)
h: total water depth (m)
H: average water depth (m)
n: porosity number
α: resistance coefficient for laminar flow in porous media
β: resistance coefficient in turbulent flow in porous media

The original Boussinesq Equations can only be used for the analysis of waves in shallow waters where the ratio of water depth to wave length (h/L_0) is less than 0.22. In dealing with irregular waves penetrating into a harbor, it is quite possible that small waves do not meet this criterion. To overcome this problem extended Boussinesq Equations, modified for deeper waters are applied so that the limiting criterion is increased. The enhanced Boussinesq equations include the so-called deep water terms allowing to extend the model into deeper water/smaller wave period, say, h_{max}/L_0= 0.5-0.85 (H_{max} is maximum depth of domain and L_0 is wave length related to minimum period at deep water). In this module, the partial

differential equations are solved by an Alternating Direction Implicit (ADI) algorithm on a staggered grid system.

5. SETTING UP THE MODEL

The stability and precision conditions for numerical solution of the governing equations dictates that:

1- Maximum grid spacing in horizontal directions of X, Y (ΔX& ΔY) is limited by the minimum wave length observed in the wave train. The grid spacing should be chosen so that the minimum wave length is resolved by the model.

2- Maximum time step it should be chosen based on the criterion that the maximum value of Courant number remains less than 1. Courant number is defined as:

$$C_r = \frac{c\Delta t}{\Delta x}$$

The parameters used in this relationship include:
c: wave velocity
Δt: Time step for the solution of the equation
ΔX & ΔY: the distance of calculation grid spacing in the X and Y directions

3- It is necessary to consider a minimum distance of four wave lengths between wave generation internal boundaries and harbor entrance.

Based on the above requirements a 5×5 meters grid spacing and a 0.1 second time step is which yield a maximum Courant number of 0.4 is applied. In many cases, what happens in part of the area between the outer face of a breakwater and an adjacent model boundary may have no influence on the main area of interest. These areas can be changed to artificial land without affecting the accuracy of the results in the harbor. This can result in significant savings in computation time. This absorbing boundary allows wave energy to pass out of the model area without unrealistic reflections at the open boundaries. In the model an absorbing boundary consists of a number of sponge layers typically backed up by a closed boundary is applied. Incoming boundary of model is an internal wave energy generation line that is placed in front of sponge layer. The wave generation Toolbox of Mike 21 is applied flux and surface slope variations to the model. Figures 5 show the layout of the model (Bathymetry).

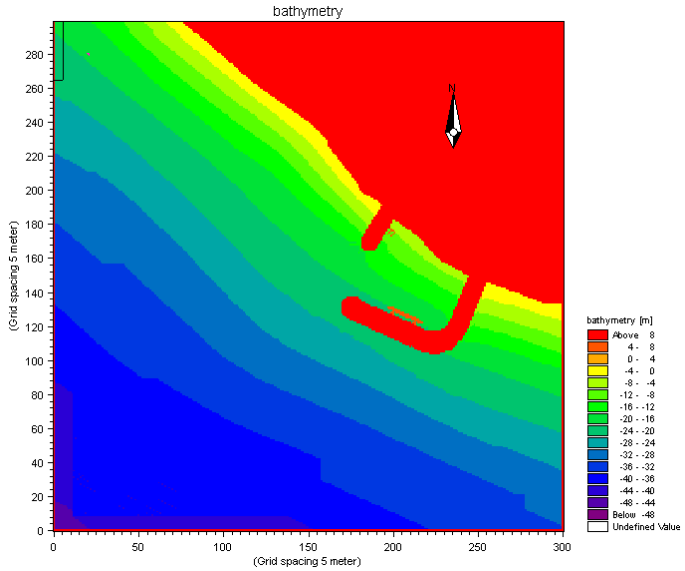

Figure 4: Layout of the model (bathymetry)

Meanwhile, Reflection and transmission coefficients of the structures in the simulation domain are introduced to the model by a porosity file containing relevant data for various segments of breakwater.

Waves with unit significant wave height (Hs=1 meter), two peak periods (Tp= 5 and 9 seconds) and two angles (225 and 247.5 degrees) are applied at internal boundaries of the model. A time series of water surface elevation must be defined at these internal boundaries. Three main spectrums are available which are applying Pierson-Moskowitz, JONSWAP, and TMA. Pierson-Moskowitz is only applicable to fully developed seas and TMA is suitable for shallow waters where wave breaking is dominant. Thus JONSWAP spectrum (that is so applicable in the region like this) was applied for the generation of the time series of surface elevations. This time series, was obtained for each pair of (Hs,Tp) by using random phases. In order to extend the results to wave heights other than 1 meter, it is assumed that diffraction coefficients obtained from these simulations remains the same for other wave heights. So by multiplying the height of the entering wave at the model boundary by the calculated diffraction coefficients the wave height at all the grid point is obtained.

The execution time of the model is controlled by the time required for obtaining stable values of diffraction coefficients all over the computational domain and the required time to reach incident waves to the farthest end point of the domain is the minimum simulation time. This time is determined about 30 min.

6. RESULTS

As was noted in the preceding sections, diffraction coefficients are the major outputs of BW Model which is the result of applying unit wave heights at the boundary. To facilitate the mooring or loading of GCV, the wave height at the berth shall not exceeded from 0.5 meter. In according to above mentioned discussion, the allowable wave height for tug boat berth is 0.3 m.

To determine the wave agitation duration at harbor quays, in the first step the significant wave height profile is computed along the two berth lines illustrated in

Figure 5. This is done by multiplying the diffraction coefficients obtained from the simulations of 1 meter wave height from different directions by the actual wave heights coming from the same directions. In the next step the frequency of occurrences of the wave roses are associated to the relevant calculated wave heights along the above lines. This procedure is carried out for BMO wave climates. Figures 6 and 7 illustrate the level of occurrence for 50, 30 cm wave height along each of the lines 1 and 2.

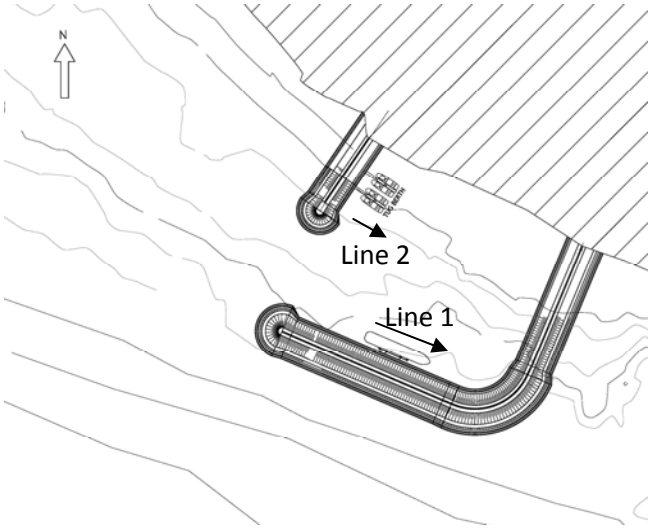

Figure 5: Quays numbering for determination of harbor calm

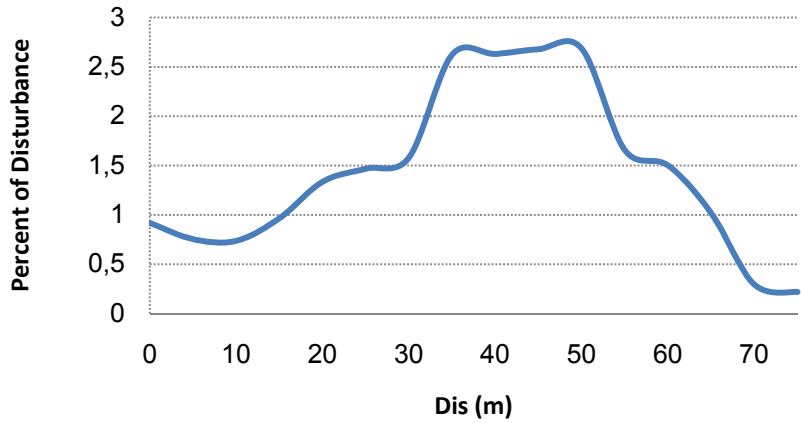

Figure 6: Percentage of critical condition (Hs<0.5 m) along the line 1

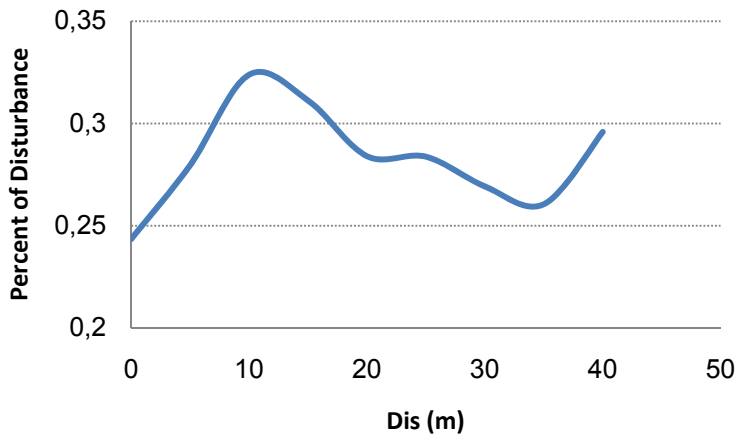

Figure 7: Percentage of critical condition (Hs<0.3 m) along the line 2

7. CONCLUSIONS

As can be deduced from Figures 6 and 7 the maximum duration of wave agitation almost line 1 which is more exposed, is less than 2.5% based on BMO data set (Hs<0.5 m). Also, the maximum percent of disturbance along the tug boat berth is 0.33% based on BMO data set (Hs<0.3m).Thus, we can say port breakwaters are providing relatively protection for the basin and berths. For more calmness on harbor (near line1), we have to change the layout of the breakwaters.

8. REFRENCES

1-Mike 21 HD and BW User Guide and Scientific manuals.
2-Bredmose, H., Schäffer, H.A., Madsen, P.A.: "Boussinesq evolution equations: numerical efficiency, breaking and amplitude dispersion"; Coastal Engineering 51 (2004), 1117-1142.