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Wave penetration modelling inside a Marina

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Abstract: Wave penetration analysis is usually carried out in order to ensure that the coastal structure at harbour or marina like breakwater creates enough shelter for the berthing of ships from waves and currents. Generally, wave penetration inside a marina takes place through the entrance. The type of coastal protection (usually breakwater) also influences the wave agitation inside the marina. This research aimed to investigate the wave penetration inside the marina, a practical case study of developing a marina along the coast of Netherlands was selected in this research. A marina needs to be constructed along the coast of Netherlands which has a significant amount of aesthetic value, safe, and contributes to the economic sector of the country. It should be noted that the design of a marina is not part of this paper. In this research, the wave penetration analysis has been done mainly by using Xbeach software in together with MATLAB and Delft 3D. The model results showed that the wave penetration inside the marina is not significant for considered layout and designedwave conditions. The observed wave heights are in the order of 0.1 m, which according to the criterion should be less than 0.6 m. Therefore, it can be concluded that the breakwaters are accomplishing the objective to decrease the effect of wave action and currents inside the marina.

Keywords: *Marina, Wave Height, Wave Penetration, Xbeach*

1. Introduction:

In general, wave penetration analysis is carried out in order to ensure that the coastal structure at harbour or marina like breakwater creates enough shelter for the berthing of ships from waves and currents. Wave penetration inside a marina generally takes place through the entrance. The type of coastal protection(usually breakwater) also influences the wave agitation inside the marina. For instance, low-crested breakwater which allows some overtopping can contribute such wave agitation inside the area of the breakwater. These locally generated waves will generally be smaller and have short periods. Some of these waves can be very steep that will not affect large sea-going vessels, however, it can cause some effects on smaller vessels like yachts and similar crafts. Therefore, to ensure safe berthing of ships inside the marina, wave penetration should be limited that means within the allowable range.

In general terms, the difficulty of limiting wave penetration in a harbour or marina is increasing along with the increasing wave period. In other words, swell with a period in the order 12 s or higher is harder to handle than waves with 8 s or smaller period. In order to overcome the situation, the only solution is to minimize the resonance in the water area of the design marina. This means that in limit state condition the ship must be able to remain at berth safely, and as for marinas, it means along the year.

In general, the safety criterions are defined below [1, 2]:

1. Significant wave height for safe mooring:Hs< 0.6 m
2. Significant wave height for safe living & boarding: Hs< 0.3 m
3. Current velocity for safe maneuvering: v < 0.5 m/s

In this research, a case study of designing a marina along the coast of Netherlands was chosen. A marina needs to be constructed along the coast of Netherlands which has a significant amount of aesthetic value, safe, and contributes to the economic sector of the country. All factors should be considered during the design process including location, expected traffic, design boat, wave conditions, etc. It should be noted that the design of a marina is not part of this paper.This research aimed to investigate the wave penetration inside the marina using Xbeach software in together with MATLAB and Delft 3D.

2. Case Study:

To investigate the wave penetration inside the marina, a practical case study of developing a marina along the coast of Netherlands was selected in this research. The study area of present research is Bergen town, situated along the Netherland coastline, see Figure 1. The red boundaries in Figure 1, shows the area under investigation. Furthermore, the red stars show the wave stations situated nearby the allocated area from which the wave data could be obtained. It is to note that some areas along the coastline are facing severe erosion which is combated with regular nourishments. Other areas do not meet the Dutch safety standards and required improvement. Based on morphological (erosion/accretion) and economical (hinterland) aspects, the present location was selected to construct marina [3].

***Figure 1**: Study area together with wave stations*

The layout of the marina considered in this research is presented in Figure 2. Regarding to the guidelines provided in Layout and Design Guidelines for Marina Berthing Facilities [1], for this study area layout of marina has been designed, see details in [3].

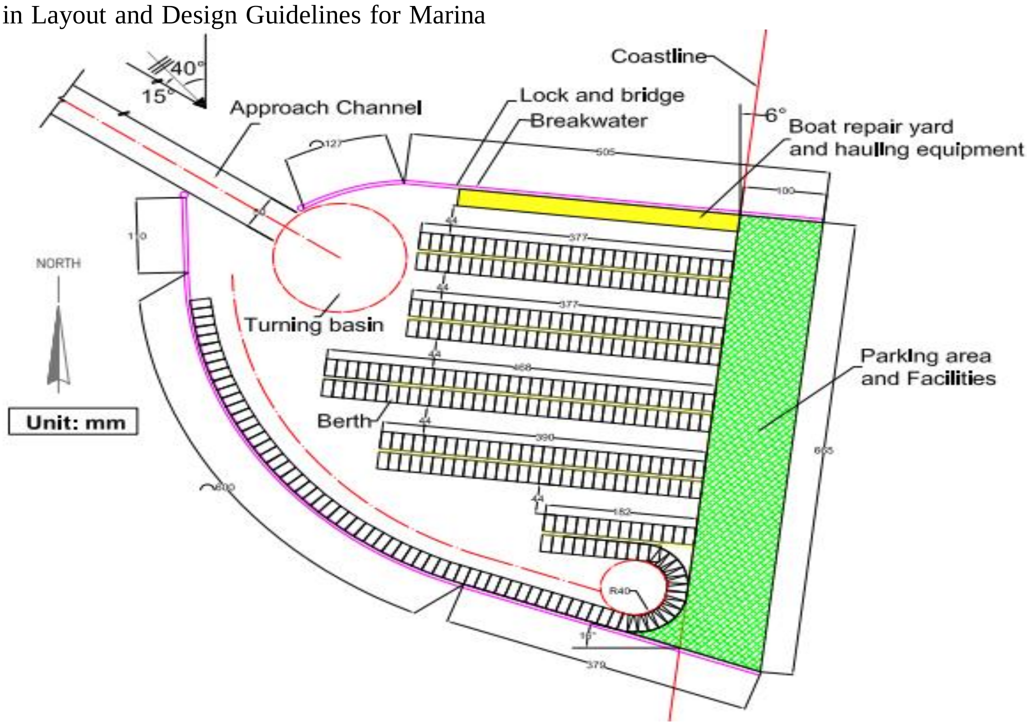


***Figure 2**. Layout of designed marina[Source: [3]]*

3. Methodology:

In this research, the wave penetration analysis has been donemainly by using Xbeach software in together with MATLAB and Delft 3D.During the numerical modelling process the various steps were taken to achieve the research goal. Firstly, wave climate input parameters such as significant wave height, wave direction and peak frequency wereanalyzed and adapted to give input in Xbeach model. Afterwards, the bathymetry of the area of interest was collected by downloading from open earth. Then, using Delft 3D, a grid was created for the study area. The computational grid cell size was 5 m each side (m and n). It should be noted that even though smaller grid cell size take more computational time, but provide a more accurate result. Once the location of the Marina was fixed, a polygon was created in QUICKIN (Delft 3D) which was drawn according to the breakwaters/marina design. To place the breakwaters more precisely into the QUICKIN, a Google Earth tool was used where a "kml file" was exported and used to create the depth file. The named files were used to set up a X-beach model. Input data (Params) were adapted to meet the demands of the model along with the JONSWAP text file. The time step was selected 600 seconds for each run. However, this time was assumed to represent a sea state. To decrease the computational time for running the model, this time step was chosen. Finally, model was run to obtain the results. Quickplot from Delft 3D was used to analyze the model results.

4. Data Analysis:

4.1 Wave Climate:

The area of new Marina is located on the north of Holland, which means that it is affected by the sea wave from all open sea direction. Wave data for this area is freely available on live.waterbase.nl[4] and tidal data on http://www.tide-forecast.com/ [5]. These data wascollected and generated to provide reliable information as a source for further analysis.

The daily wave climate data consists of wave height, wave period and wave direction. Ijmuiden station was used as an observation point since this station is located relatively close to the project (around 45 km from the shoreline). The data is considered to be reliable enough to predict the wave condition at surf zone area for the project. The gathered data was sorted only for summer period, as we use the summer period for each year (April to September) assuming that the marina will be occupied mostly in this period; and for the rest of year it will not be operational.

Figure 3 shows the percentage of occurrence of significant wave height and wave direction classes. And Figure 4 presents the frequency of wave direction observed in this study area. From these figures, it is clear that mainly two dominant wave directions are present; southwest (210-240 degrees) and northwest (330-360 degrees).

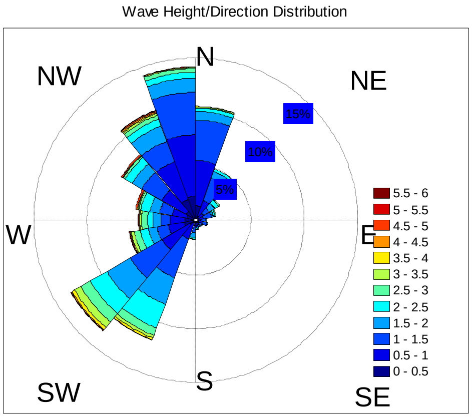


***Figure 3**: Distribution of wave height / direction*

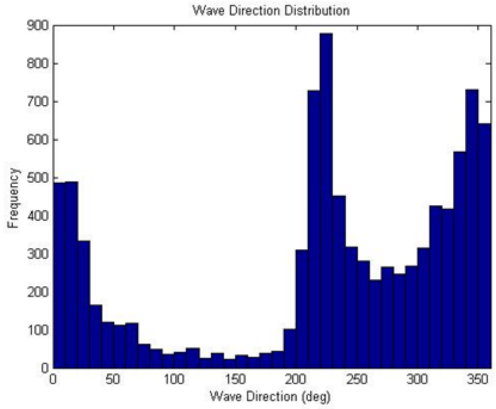


***Figure 4**: Frequency of wave direction*

In Figure 5, the frequency of wave period distribution is presented. It can be observed from this figure that in this area wave period mainly varies from 3 to 6 s. Further the probability of exceedance of wave height is shown in Figure 6.

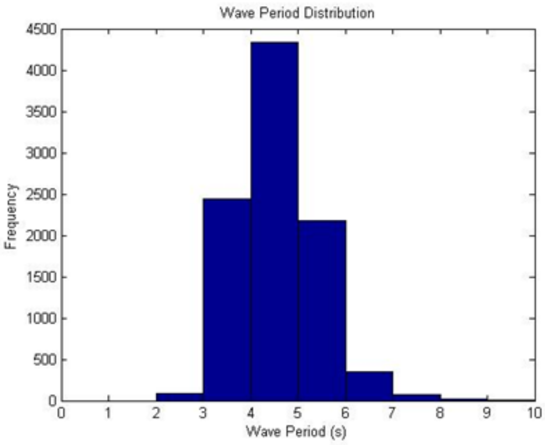


***Figure 5**: Frequency of wave period distribution*

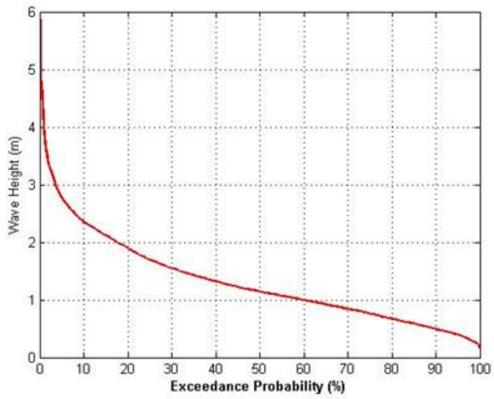


***Figure 6**: Probability of exceedance for wave height*

From the historical data above, it can be seen that the wave height that is most likely to happen around the marina area is in range of 0.5-1.5 m, with two dominant wave directions are present; southwest (210-240 degrees) and northwest (330-360 degrees). The wave period at the location is generally in range below 6 s, so it can be assumed that along summer there will be neither swell nor seiches.

4.2 Input Data:

Wave penetration model in MATLAB uses some inputs to predict the condition encountered by the design marina. As for input condition, we can consider wave direction and wave height as the most important parameters. Representative wave height can be calculated by using simplify CERC formula (see Equation 1) for a narrow wave angles [6]:

$$H_{s,rep} = \left(\frac{\sum_i [p_i H_{s,i}^{2.5}]}{\sum_i [p_i]}\right)^{1/2.5} \qquad [1]$$

Firstly, the design wave height has been selected from Figure 6with a probability of exceedance of 5%. The design wave height is observed 2.7 m for this study area. Furthermore, Figure 6 shows the predominant wave directions in summer time. From Figure 7, the dominant wave directions can be observed between 270 and 360 degrees. The wave height does not exceed 2.5 m in these wave directions. However, Hs is selected as 2.7 m, for conservative reason.

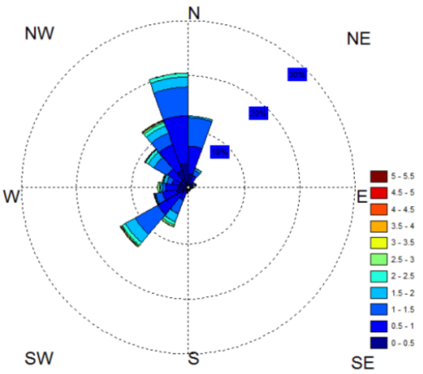


Figure 7: *Wind rose for summer 2013*

Furthermore 3 main scenarios are considered for the respective wave directions. (See Table 1). The first scenario represents wave action perpendicular to the coastline (280 degrees). The second alternative considers a wave direction occurring in summer time (350 degrees). The last scenario considers the wave action occurring in winter time (220 degrees).

Table 1*: Percentage of dominant wave direction*

Range	Mean Direction	Frequency	Total
360-330	345	1371-834	2205
300-260	280	1674-1094	2768
200-240	220	1605-411	2016

5. Results and Discussions:

To verify the influence of the wave action into the marina, 3 observation points has been added as the locations of importance. These locations are inside the marina, at the entrance, and off shore. These points will show the wave elevation along these points. See Figure 8.

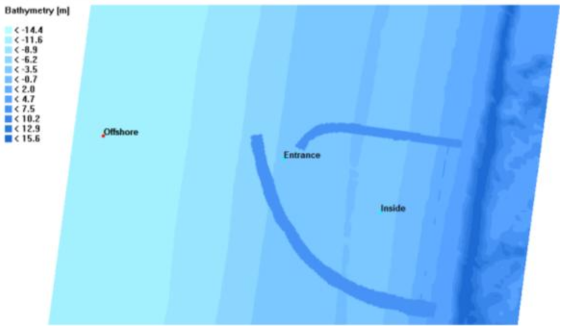


Figure 8: *Visualisation area with the 3 point of importance*

Figure 9, Figure 10 and Figure 11 represent 3D figures obtained from the Xbeachmodel. The figures show the diffraction pattern inside the marina. It can be observed from these figures that the water level obtained inside the marina is less than the water level outside of the marina.

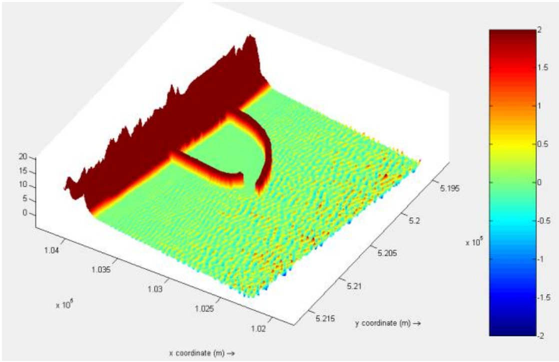


Figure9: *Wave direction of 280 degrees, perpendicular direction to the coast*

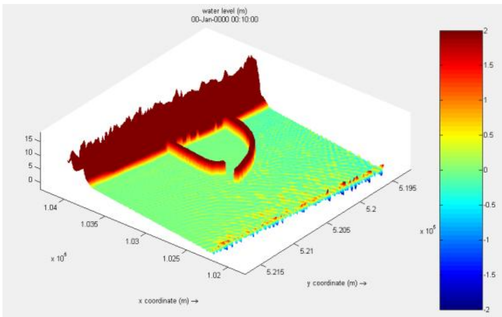


Figure10: *Wave direction of 350 degrees, most predominant wave direction at summer time*

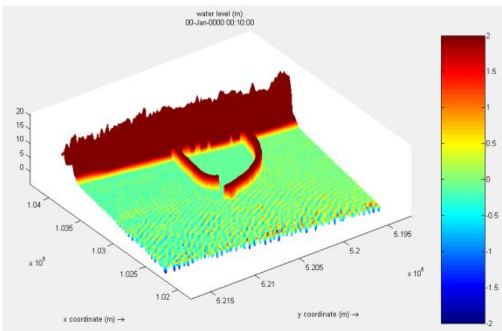
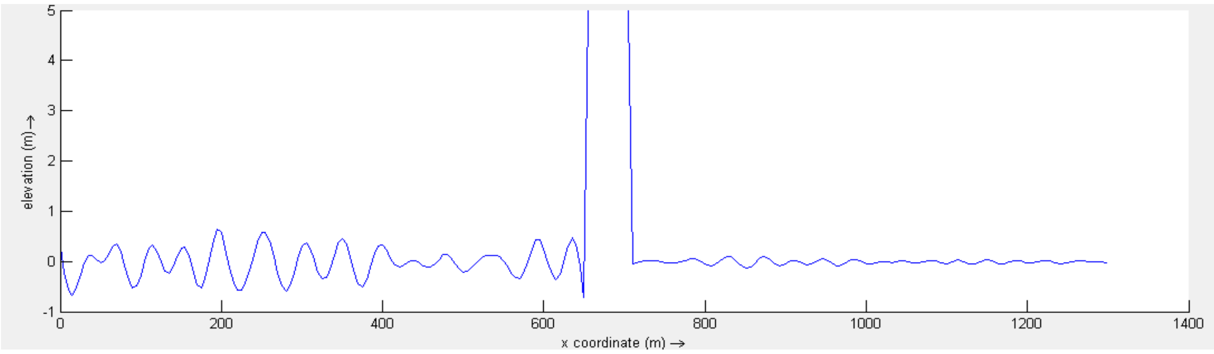


Figure 11*: Wave direction of 220 degrees, most predominant wave direction at summer time*

In order to compare the water elevation of the offshore points with inside marina, the following figures illustrates the wave action and dissipation along these observation points.Figure 12 shows how the wave dissipates inside the marina for the 3 scenarios (3 different wave directions).These results show that the breakwater accomplish the safety conditions of the marina.



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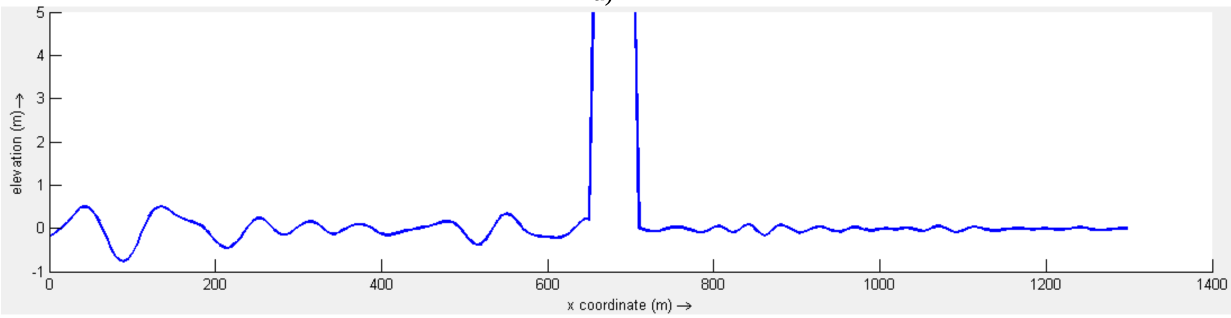

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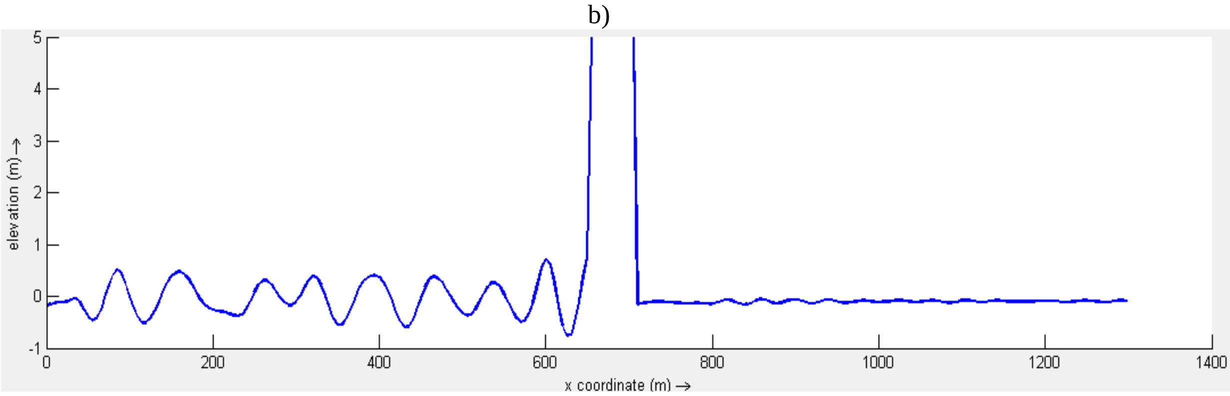
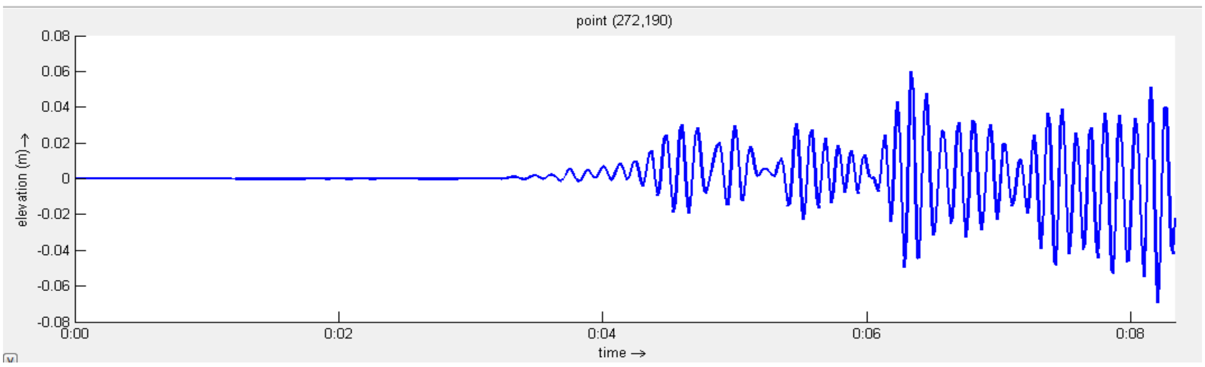


c)

Figure 12*: Water elevation along the observation points. a) 280 °, b) 350°, c) 220°*

Figure 13 illustrates the water levels obtained for selected points inside of the marina. It can be well noticed from these results that the wave penetration inside the marina is not significant. From these water levels, wave heights were calculated in the order of 0.1 m, which according to the safety criterion should be less than 0.6 m. Therefore, the breakwaters are accomplishing the objective to decrease the effect of wave action and current



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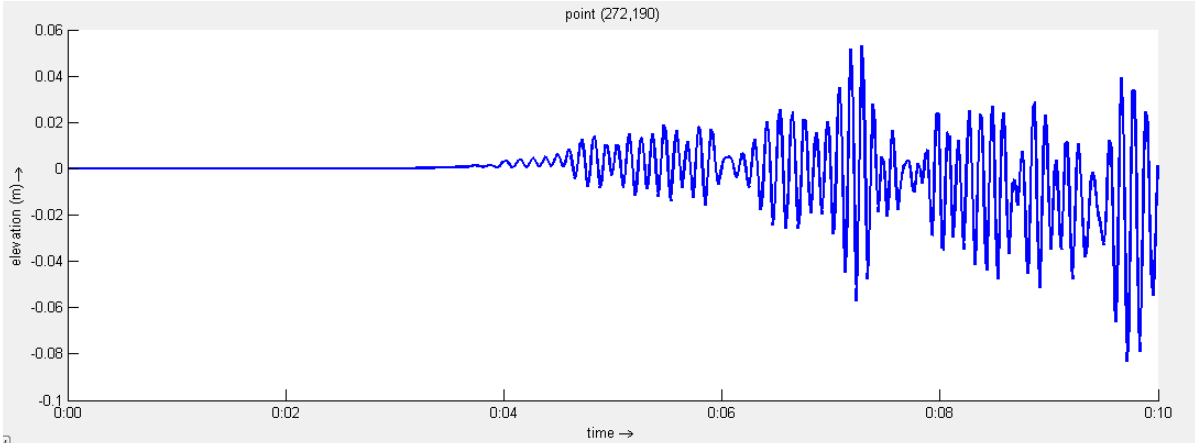

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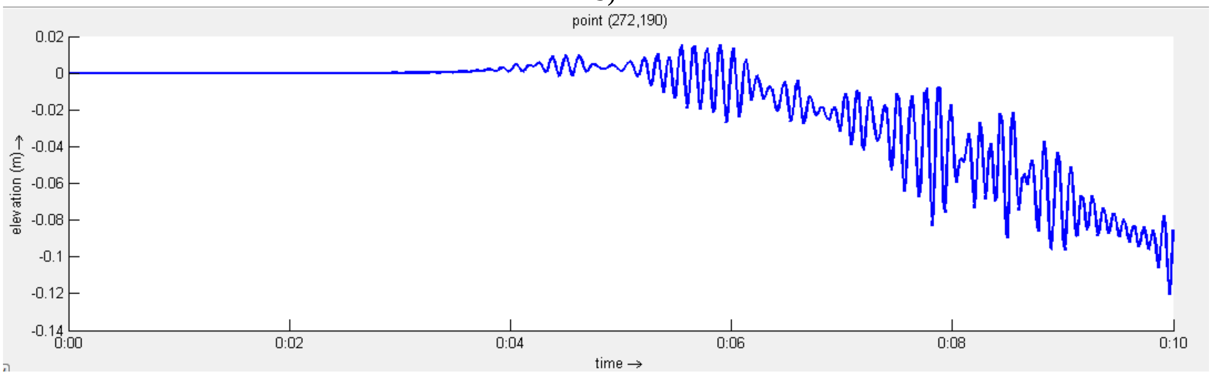

c)

***Figure 13**: Water elevation at the point inside the marina. a) 280 °, b) 350°, c) 220°*

6. Conclusions:

This paper was intended to investigate the wave penetration inside the marina for designed layout and wave conditions. The model results showed that the wave penetration inside the marina is not significant for considered layout and designedwave conditions. The observed wave heights are in the order of 0.1 m, which according to the criterion should be less than 0.6 m. Therefore, it can be concluded that the breakwaters are accomplishing the objective to decrease the effect of wave action and currents inside the marina.

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