The impact of approach channels on the waves in the port

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Abstract. This study presents a comparison between the monochromatic and spectral mode disturbances on the basis of numerical models of the ARTEMIS for different configurations of LPG Terminal. The results show that the use of the monochromatic mode, the excitement leads to an overestimation of values of wave characteristics in the channel and in port. This is due to the nonlinear effects of the approach channel. Diffraction and reflection of waves from the edge of the channel for focusing the wave energy in the waters of the port, and the use of mono-directional waves significantly enhances this effect. However, when using the spectral approach, focusing effects are smoothed out as the different components of the spectrum of the waves reflected and refracted in different ways. Refraction and reflection of waves at the edges of the channel can potentially lead not only to serious focusing of energy waves, but also to the areas of reduced wave action. It is important to recognize these effects and use them for design optimization.

1. Introduction

The location of the designed LPG Terminal is on the east coast of the Gulf of Ob. Figure 1, shows the map of the Gulf of Ob, and the scheme of Layout option No.2.

Based on the simulation of waves on the approach to the Terminal, it is possible to identify four main areas which can be dangerous for the construction of the Terminal, which are North-West (NW), West (W), South-West (SW) and the South (S)directions. At the same time, the West W direction is the most dangerous for all layout options.

To receive the distributions of waves with a different frequencies and the protection of the offshore Terminal, the spectral model SWAN, calculated the parameters of the extreme wind waves for over 30-year period, on the approach to the construction of the Terminal. Then by using the Weibull distributions the elements of waves are calculated with a different frequency and the protection in the control points for the four selected areas, which in turn are used to initialize the refraction-diffraction model based on the mild slope equations (MSE). The refraction-diffraction model gives the parameters of waves with a different frequency and the protection of the offshore Terminal.

For the study of wave modes in the port for all layouts of the Terminal, the selected wave, which has a west direction W, is repeated 1 time in 100 years, 1\% of the securities, the parameters of which were obtained from the statistical processing of the 30-year period extreme waves. The wave azimuth was 270°, the wave period-7.03s while the wave height was 3.57 m.
2. Set-up of the models
To determine the mode of the excitement of the offshore Terminal, was selected the wave model ARTEMIS[1], which based on elliptic MSE, part of the TELEMAC software system[2]. The model solves MSE using the finite element method on unstructured computational grid with triangular elements. It describes the reflection of waves from obstacles, and behind obstacles, the refraction of waves by the in homogeneities of the bottom, bottom friction and weak wave. It allows us to enter different coefficients of reflection of the waves in the border areas of the computational domain, and appropriate different types of the port facilities: vertical piers, the piers of the trestle type, a variety of slopes with different slope and dumping. The model allows simulating regular monochromatic waves and irregular waves with a given spectral distribution.

Grid model ARTEMIS should be constructed by using the given conditions from the numerical scheme of the model. For a detailed computational grid, it is necessary to consider that the wavelength had at least 7 grid nodes. For the coarse grid, consider less sufficient stringent conditions, about 4-5 nodes per wavelength.

The basis for building meshes for all the layout options were taken, the wavelength distribution in the region corresponding to the monochromatic wave with period 5 seconds (wavelength ≈37.5 m). Accordingly, the cell size of the grids is equal to the ratio $\lambda/7$, changed from 2 m in shallow water to 5.4 m at the greatest depth.

The modeling border region is shown in orange in Figure 1. The simulated wave is generated on the Western border of the computational domain. The Northern and southern boundaries freely release wave.

Considering the Layout option No.1 (Figure 2), the modeling grid has a size – 1,325,395 nodes and 2,644,390 elements. Bathymetry of the computational domain is presented in Figure 2. Figure 2 also shows the position of control points and the results of modeling wave mode.

Considering the layout option No.2 (Figure 3), the modeling grid has a size – 1,325,395 nodes and 2,644,390 elements. Bathymetry of the computational domain is presented in Figure 3. Figure 3 also shows the position of the reference points and the results of the simulation of the wave regime.

Figure 1. Map of the Gulf of Ob. Red color shows a diagram of the Layout of option No.2. Orange – border region modeling. UTM43 Projection, EPSG: 32643
Figure 2. The position of control points and the results of modelling wave mode

Figure 3. The position of the reference points and the results of the simulation of wave regime
3. Results and comparative analysis

The calculated wave field at the offshore Terminal for all layouts are shown in Figures (4, 6) for monochromatic mode, and in Figures (5, 7) for the spectral regime. The Figures (8, 9) also show the wave disturbance coefficient Kd (=Hs/Hs, outside of harbour) at the control points, which is calculated with the ARTEMIS model for the selected wave W direction.

**Figure 4.** The height of the waves in the water of the LPG Terminal, layout option No.1, for the wave with 1% probability, W directions. Monochromatic mode
**Figure 5.** The height of the waves in the water of the LPG Terminal, layout option No.1, for the wave with 1% probability, W directions. Spectral mode

**Figure 6.** The height of the waves in the water of the LPG Terminal, layout option No.2, for the wave with 1% probability, W directions. Monochromatic mode
**Figure 7.** The height of the waves on the waters of the LPG Terminal, layout option No.2, for the wave with 1% probability, W directions. Spectral mode

**Figure 8.** The relative wave heights at the control points of the offshore LPG Terminal, layout option No.1, calculated by the model ARTEMIS monochromatic and spectral wave mode for the W direction
The relative wave heights at the control points of the offshore LPG Terminal, layout option No.2, calculated by the model ARTEMIS monochromatic and spectral wave mode for the W direction.

The feature of all layout options of the Terminal, is the availability of the approach channel to run West from the piers, with a small deviation, of about 7-10° from the West direction.

It is well known that the navigational channel affects the propagation of waves in the shallow zone [3-5].

When the wave of shallow water accumulates in a deeper part of the channel, it experiences refraction. Therefore the angle between the wave direction and the axis of the channel decreases (Figure 10-a).

![Figure 10](image_url)

**Figure 10.** The direction of the movement of a wave in the case of profound channel: a) $\theta > \text{critical angle}$; b) $\theta < \text{critical angle}$; c) $\theta \approx 0$

While the angle of wave incidence in the channel decreases, the wave inside the channel becomes parallel to the axis of the channel at a certain angle, which called the critical angle. Waves, which impinge on the channel under smaller angles experience internal reflection from the slope of the channel (Figure 10-b).

If the angle of the incidence of the wave on the channel is approximately equal to zero, the wave refracts from the center of the channel, decreases along the channel and concentrates along its sides (Figure 10-c).

The nature of the interaction of waves with the approach channel depends on their orientation, wave height, length and period. The wave height becomes more significant in the case of the impact of nonlinear effects of transformation of waves in shallow zone.
For the layout option number 1, the angle between the direction of a suitable wave and the axis of the channel is 10.15°. The wave is partially reflected from the channel, concentrating along its Southern side that can be seen in Figures (4, 6). Accordingly, at the Northern side of the channel is formed in the region of small wave heights.

Similar pattern was observed in the study of the transformation of waves, which impinge at small angles on the depth of the channel [5].

Wave is concentrated through the channel, going along its Southern side and fall to the area of dredging at the berths of the terminal with large angles, respectively, less bouncing off the slope dredging.

For layout option No.2, the angle between the direction of a suitable wave and the axis of the channel is 7.16°. The approach channel is longer than the Layout option number 1 is about 5.5 km versus 3.2 km of option No.1. The water area of the terminal is protected by the Northern and Southern breakwaters.

As in the considered option No.1, as well as in the layout option No.2, there is a concentration of waves at the southern slope of the channel with the subsequent fall of the waves, which concentrated in the area of dredging of berths Figures (5, 7). However, in this embodiment, the Northern end of the Southern breakwater is suitable for the navigational channel; the wharves are closed from the waves, concentrated along the southern edge of the channel. Also in the embodiment No.2 for the wave W direction is less than the angle between the wave direction and the axis of the channel.

Figures (4, 7) show that waves with 270° direction of approach, will be reflected from the windward edge of the channel and will lead to the concentration of the wave energy that was reflected by the ARTEMIS model. Also on the windward side, one can see the featured interference patterns in the form of strips (tracks). The width of the strips depends on the direction of the excitement, but it is usually about half the length of the waves reflected from the edge of the channel. On the leeward edge of the channel the wave energy is on the contrary reduced, which leads to a decrease of the wave height. It is important to note that these effects appear stronger when using a monochromatic wave mode, which leads to an overestimation of the wave heights in the port Figure (8, 9). However, by the using of the spectral approach, the interference patterns are smoothed because of the various components of the spectrum of waves reflected and refracted in different ways. The same conclusions were reached by a number of authors in the numerical simulations of waves in the approach channel[3,4,6].

4. Conclusions
Refraction and reflection of waves at the edges of the channel can potentially lead not only to serious concentration of the wave energy, but also to the areas of reduced wave action. It is important to recognize these effects and use them for design optimization. Appropriate use of numerical models allows us to estimate the hazardous areas of wave effect at an early stage of design, to optimize the project in terms of cost and development perspective. The article presents examples that demonstrate how the availability navigation channel can affect the wave conditions in the port.

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