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DEVELOPMENT OF «ICE SCOURING» MODULE AT THE SPECIALIZED INFORMATION SYSTEM «YAMAL» (*SIS - YAMAL*)

B.V. Arkhipov[1], A.V. Marchenko[1], V.V. Solbakov[1]
[1]Engineering Production Society «Eco-System», Moscow, Russia

ABSTRACT

The mathematical model of ice scouring at the sea bottom is considered in the scope of Specialized Information System «Yamal» (SYS-Yamal). The common features of SIS- Yamal are described and the some details of the ice scouring module are analyzed.

1. INTRODUCTION

Russian Gas Joint Stock Company «Gazprom» has formulated the purpose to develop the Specialized Information System «Yamal» (SIS - Yamal) with the project «Yamal» (Odisharia et al., 1997a, 1997b). This System is intended to implement the realization of uniform information technology for the accumulation, processing and analysis of data on natural environment and technical decisions for the utilization of gas deposits in the Yamal Peninsula. The SIS-Yamal consists of functional subsystems: Archive data bank, Integrated data bank and Problem - Oriented Applications (POA) (Tsvetsinsky et al., 1997). The last one is intended to analyze the various applied problems, including the technical objects environmental impact estimation. One of the POA modules is the sea bottom ice scouring model.

Icebergs, ice ridges and stamukhas are typical examples of ice formations (IF). The ice scouring is the action of floating and standing on sea bed IF on sea bed soil. When the keel of drifting IF impacts into sea bed the gouge is formed in the sea bed soil. Because the appearance of icebergs in the Bayadartskaya Bay is a low-probability phenomenon, the ice scouring is related to the influence of ice ridge keels and stamukhas on sea bed in this region. Most intensively the gouging takes place in spring and summer, when the Baydatskaya Bay is free from compacted ice cover. At this time, the motion of non melting ice ridges and stamukhas is not constrained by ice cover. Tide velocity can reach 0.5 – 0.8 m/s in the region; therefore, the coupled influence of the currents and the wind can accelerate the IF up to velocities like 1m/s.

The mathematical modeling of ice scouring processes developed from the 1970`ies. One of the most important problems is the description of the motion of single IF, which has a contact to sea bed. The main difficulty is related to the parametrization of the reaction of the bottom soil the IF. The first one-dimensional model was developed by Chari & Allen (1974), where the methods of the strength of materials theory had been used for the approximate estimation of bottom soil reaction on submerged part of cubic IF. It was assumed that horizontal motion of the IF is realized under the influence of the balance between the inertia force and the force of bottom soil reaction. The bottom soil was modeled by Coulomb-More material. Various modification of this approach have been developed in the papers (Ryabinin et al., 1995; Kioka et al., 1995, 1998; Beloshapkov & Marchenko, 1998). In the paper of Ryabinin et al. (1995) the influence of soil embankment on the frontal part of the IF is taken into account. In the papers of Kioka et al. (1995,1998) the vertical displacement of the IF, due to the interaction with bottom soil, is modeled. In the paper of Beloshapkov & Marchenko (1998) the bottom soil reaction in three dimensional problem is been estimated using the theorems on the estimation of bearing capacity of foundations (Rabotnov, 1988). In the paper of Foriero (1998) the bottom soil is modeled by creep material.

In the papers of Beloshapkov, Marchenko and Dlugach (1998) and Foriero (1998) it is assumed that the motion of the IF is quasistationary. The problem is described by the balance between the external active forces (which acts on the IF from the wind, sea currents and ice cover) and bottom soil reaction force. It is supposed, that the longest gouges are formed, when the IF moves in this manner. In this paper we formulate three dimensional model of ice scouring on the basis of this approach. This model takes into account the displacement of the IF in horizontal directions, the vertical displacement of the IF is defined by sea level variation.

This paper is organized as follows: In Chapter 2 a general description of problem oriented application (POA) of SIS-Yamal is presented. In Chapter 3 the basic equations of ice scouring model are formulated. Chapter 4 illustrates Graphic User Interface used to put the parameters and shows samples of output data representation. In the conclusion the advantages of the using the subsystem POA for the investigation of ice-scouring phenomena are discussed.

2. COMMON DESCRIPTION OF *SIS-YAMAL* PROBLEM ORIENTED APPLICATIONS

The subsystem POA is a set of thematic data, previously obtained knowledge and applied programs, intended to implement the methods and models to obtain environment characteristics. These models were included in the system as information-technological complex to deduce the new data needed to make a choice of ecological and economical beneficial project decisions for the promotion of gas deposits. From the end-user point of view, the subsystem POA is perceived as a number of automatic work sites (AWS) to select and to browse the investigation results, to implement scenario prescribed data processing, to realize analysis and interpretation of the obtained information and to repeat calculations in case of changes in this scenarios.

The common procedure can be represented as the number of steps. At the beginning, the user should have a choice of subsystem («Arkhive bank», «Integrated bank», «POA»). With this choice one of the components can be loaded, viz. SDBM (System of Data Base Managing), Geographic Information System (GIS) and others. Subsystem POA at present is performed as ArcView user application.

After this choice, the first view «Work Region Choice» of POA is activated. On this view the Yamal peninsula and Baydaratskaya Bay maps are shown. Whole region is divided on the three subregions (Fig.1).

For each of subregion in the system, the number of models to decide needed tasks and the set of views to visualize the map information were collected. At present, main model set is related to the regions of «Baydaratskaya Bay» and «Bovanenkovskoe Gas Field».

For the Baydaratskaya Bay the set of models is divided in two groups «Background» and «Environment Impact Estimation» (EIE). In the first group, two models are included: longwave sea and current oscillations and wind wave.

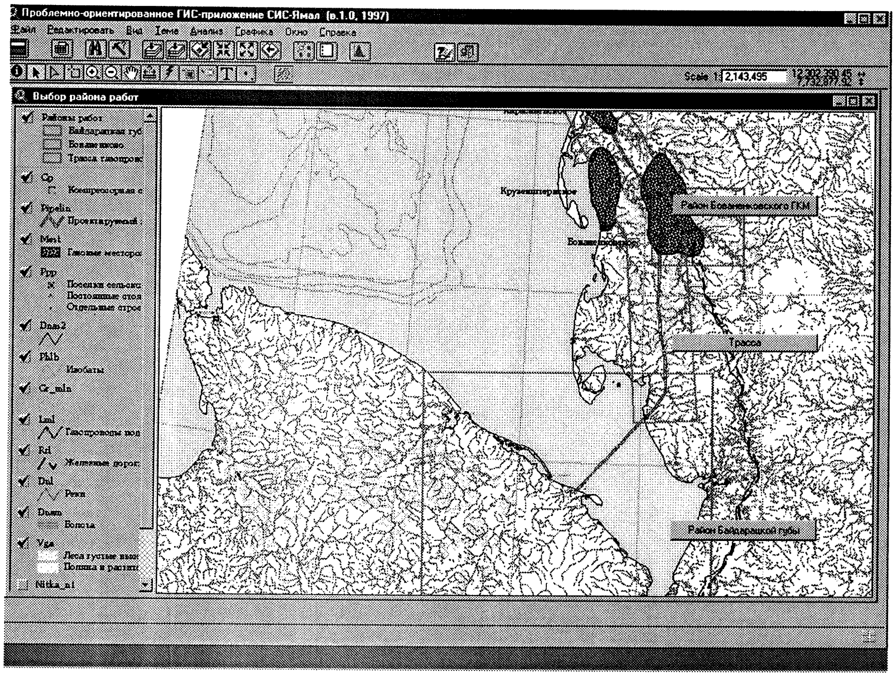

Figure 1. Main view of SIS - Yamal with underwater crossing of pipeline magisterial system «Yamal-Center» and region choicing buttons

In the second group there are: the model of suspension dispersion during pipeline development, the model of permafrost heating and ice-scouring model.

For the region «Bovanenkovskoe Gas Deposit» the following models were included: the freshet of Se-Iaha and Mordy-Iaha rivers, the ravine erosion, the degradation of plant cover and the dispersion of atmosphere contamination.

The model interfaces are realized on the basis of ArcView extension «Dialog designer». The example of such dialog is shown in Chapter 4.

3. BASIC EQUATIONS

The mathematical model of ice formation (IF) single act interaction with sea bed includes the following blocks: the parameterization of IF shape, the parameterization of external active forces, acting on the IF from the wind, sea currents and ice cover, the calculation of the reaction of sea bed soil on the IF and the calculation of IF motion. The main assumption of the model is that the variation of the vertical coordinate of the IF gravity center is defined only by the variation of sea level. Therefore, the depth of the penetration of IF keel into sea bed soil is calculated simply, when the sea depth, IF sizes and trajectory of the motion are known. The main difficulties are related to the estimation of the reaction force of sea bed soil. We shall use to define this force the approach deduced in Beloshapkov & Marchenko (1998), and Beloshapkov, Marchenko and Dlugach (1998).

In our approach the rotation of the IF with respect to the center of gravity is not taken into account. It is assumed, that the orientation of the IF relatively the environment has no influence on the motion of the IF. Actually, it means that the IF has cylindrical shape. It is assumed that IF shape is characterized by two parameters W_1 and W_2, which define the typical horizontal and vertical scales of the IF. The mass of the IF is equal to $M_{IF} = \rho_{IF} S W_1$, where ρ_{IF} is the density of ice composing the IF. The quantity $S = W_1 W_2$ is equal to averaging area of a section of the IF by vertical plane, passing through the center of gravity.

The IF can float or stand on the surface of sea bed. It is assumed, that the IF has protruding from the keel, which can impact into the sea bed almost without changing the buoyancy of the IF. Assume, that the IF floats, if $\chi < 0$, where $\chi = (1-\delta)W_2 / H - 1$, $\delta = (\rho_w - \rho_{IF})/\rho_w$, H is sea depth and ρ_w is water density. The IF stands on sea bed, when $\chi > 0$. In the last case the additional pressure p of the IF on the sea bed is equal to the difference between Archimedean buoyancy force and IF weight. This pressure equals to

$$p = \rho_w g S H \chi \tag{3.1}$$

Denote typical vertical size of IF parts, protruding from the keel, as w_2. Assume, that the IF does not interact with sea bed, if $\mu < 0$, where $\mu = \chi + w_2 / H$. Denote the typical horizontal size (total width) of these parts as w_1.

Local sea depth is defined by the formula

$$H = H_0 + h_f(t) - h_b(x,y) \tag{3.2}$$

where H_0 is averaging sea depth, the equations $z = h_b(x,y)$ and $z = H_0 + h_f(t)$ describe sea bed surface and the level of sea surface respectively. The level of sea surface is the function of the time t, the variations are due to the tides.

The vertical coordinate of the center of gravity of the IF is defined by the formula

$$z_c = \left(h_b(x,y) + \tfrac{1}{2} W_2\right)\vartheta(\chi) + \left(H_0 + h_f(t) - \left(\tfrac{1}{2} - \delta\right)W_2\right)\vartheta(-\chi) \tag{3.3}$$

where $\vartheta(x) = 1$ by $x \geq 0$ and $\vartheta(x) = 0$ by $x < 0$.

The horizontal location of the center of gravity of the IF is defined from the following system of ordinary differential equations, which follows from the law of impulse balance and the definition of the velocity,

$$M_i \frac{d\mathbf{v}}{dt} = \mathbf{R} + \mathbf{F}, \quad \frac{d\mathbf{x}_c}{dt} = \mathbf{v} \tag{3.4}$$

$$\mathbf{F} = \mathbf{F}_a + \mathbf{F}_w + \mathbf{F}_i$$

Here the vector $\mathbf{x}_c = (x_c, y_c)$ defines the location of the center of gravity on the horizontal plane and $\mathbf{v} = (v_x, v_y)$ is the horizontal velocity of the IF. The force, $\mathbf{F}_a$ acting on the IF from the wind, is defined by the formula

$$\mathbf{F}_a = \rho_a C_a \delta S \,|\, \mathbf{V} \,|\, \mathbf{V} \tag{3.5}$$

where $\mathbf{V}$ is wind velocity, ρ_a is air density, C_a is drag coefficient. The force, $\mathbf{F}_w$ acting on the IF from sea current, is equal

$$\mathbf{F}_w = \rho_w C_w (1-\delta) S \,|\, \mathbf{v}_w - \mathbf{v} \,|\, (\mathbf{v}_w - \mathbf{v}) \tag{3.6}$$

where $\mathbf{v}_w$ is current velocity, ρ_w water density, C_w is drag coefficient. The force $\mathbf{F}_i$ acts on the IF from the ice cover. Its value and direction are defined by internal ice stresses in the vicinity of the IF. The maximal value of this load is not more, than the pressure, which is needed for ice ridge formation. Hence we have the estimation

$$|\, \mathbf{F}_i \,| < \pi_r W_1, \quad \pi_r = \tfrac{1}{2} k \rho_w \delta g h_i^2 \tag{3.7}$$

where $k \in (1,15)$, h_i is ice thickness and g is gravity acceleration.

It is assumed that the reaction force of sea bed soil $\mathbf{R}$ is directed in the opposite direction to the motion of the IF

$$\mathbf{R} = -R\frac{\mathbf{v}}{v}, \quad R = |\, \mathbf{R} \,|, \quad v = |\, \mathbf{v} \,| \tag{3.8}$$

The absolute value of this force is defined by the formulas

$$R = \vartheta(\chi) K p W_1^2 + \vartheta(\mu) h (w_1 + \vartheta(\chi) W_1)(2.5\tau + 0.5\rho_s g h) \tag{3.9}$$

where K is drag coefficient on contact surface between the IF and sea bed soil, τ and ρ_s are soil cohesion and soil density. The depth h of the penetration of IF keel into sea bed is equal to

$$h = (1-\delta) W_2 + w_2 - H \tag{3.10}$$

For the finding of the reaction force $\mathbf{R}$ it is supposed, that this force is the superposition of two forces with various physical sense. Two components in the formula (3.9) are related with these forces. The first component defines the friction law between lower surface of the IF and sea bed in the case, when the IF stands on sea bed. Assumed, that this force is proportional to the pressure of the IF on sea bed, p with proportionality factor K. The second term in (3.9) defines soil reaction due to breaking of the soil on the surface of sea bed. This force acts on forward sides of the protruding from IF keel parts, which are penetrated into sea bed soil. The expression for the second term have been found in the paper

Beloshapkov, Marchenko and Dlugach (1998) with using of the theorems about the estimations of bearing capacity of foundations (Rabotnov, 1988).

The system of equations (3.3) is simplified considerably, if we assume, that IF motion is defined by the balance between the forces $\mathbf{F}$ and $\mathbf{R}$ in general, and the influence of IF inertia on the motion is negligibly small. In this case the velocity of the IF $\mathbf{v}$ is found from the algebraic relation $\mathbf{F} + \mathbf{R} = 0$. It is needed to solve the system of two differential equations $d\mathbf{x}_c / dt = \mathbf{v}$ to find the trajectory of IF motion.

4. REPRESENTATION OF ICE-SCOURING MODEL RESULTS IN THE POA SUBSISTEM

Graphic User Interface of Ice-Scouring module gives possibility to chose the parameters W_1, W_2, w_1 and w_2, which determine the shape of IF. The possibility to vary W_1 and W_2 is defined by typical sizes of ice ridges and stamukhas, which have been collected at Baydaratskaya Bay region (Stepanov, 1998). Parameters w_1 and w_2 do not exceed the values of W_1 and W_2 respectively. The initial position of IF is marked by cursor or by point coordinate setting on Baydaratskaya Bay map. The other model parameters are defined during the calculation session.

The IF motion calculation program uses data characterizing the given structure of sea bed soils, sea current calculated in the Longwave sea surface and velocity oscillation module of subsystem POA. The trajectory of IF motion are presented on the Baydaratskaya Bay map. The trajectory segments were IF floats are marked by blue color, whereas the segments were IF keel impacts into sea bed are marked by red color. By clicking on any point of red segment the user can see the ice scouring depth at the point (Figure 2).

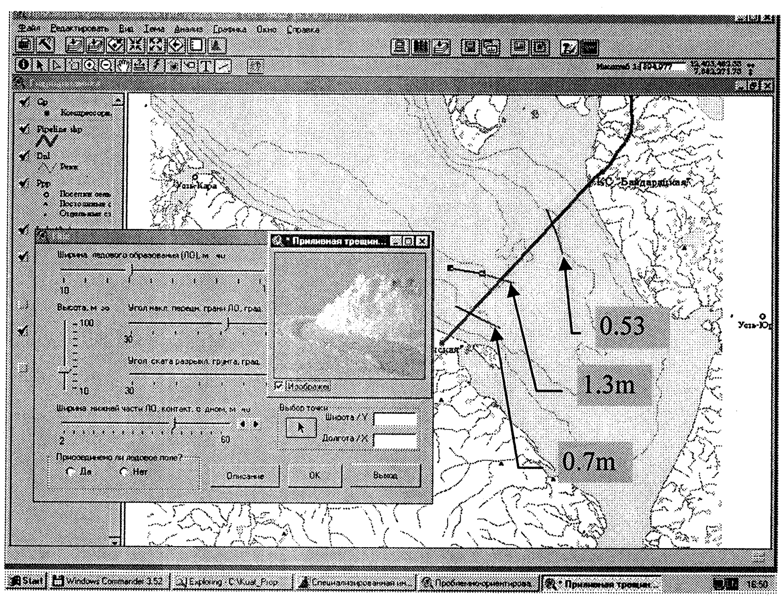

Figure 2. The user interface of ice-scouring model with examples of IF trajectories and stamukha photo

5. CONCLUSIONS

The methodology of the incorporation of ice scouring model into the SIS-Yamal subsystem POA has been described in the paper. It is shown that the means of ArcView give possibility to estimate the influence of ice formation on sea bed operatively and visually represent the results of the investigations on electronic map of Baydaratskaya Bay. At present the model interface gives possibility to represent the results of numerical calculations of ice scouring processes, which are found with using only one model. Nevertheless, it is planned to extend ice scouring module of SIS-Yamal by incorporation alternative ice scouring models, for example the approach represented in Ryabinin et al. (1995).

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