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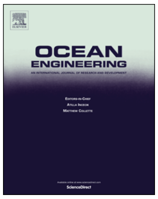

Ice collars, development and effects

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ABSTRACT

Ice interacts with offshore structure by number of ways. If structure is located in the stationary (or temporary stationary) level ice then structure freezes in the ice and ice collars occur during constant water level and cold temperatures. The duration of the freezing process and the temperature during it as well as structure thermal conduction properties are the main factors for the ice collar growth. Ice collar is an additional thermo-developed thick ice on the structure surface below level ice. Such additional ice is common for many structures and ships; however the basics are poorly described in the literature. Ice collars can lead to a significant increase of the total load on the structure and complicate moorage operations. The increase of the load on the structure appears as a result of the big ice-structure contact area and additional adhesion forces. The article goal is to provide overview on the main aspects related to the ice collars which should be considered. It includes mathematical formulation of the task, some aspects of the numerical modeling and possible preventive measures.

1. Introduction

Nowadays Arctic is a region under significant attention due to economic and scientific reasons. Economic interest refers to deposits of the mineral resources and fishery areas as well as to the development of the possible water ways. Scientific value of the Arctic region consist of: polar, atmospheric, paleontology, climate change, satellite equipment base and other important subjects of interest.

Constructions in arctic areas and seasonal ice cover areas must resist severe environmental conditions. For such constructions as offshore platforms ice actions are vitally important and should be considered as to be the key factor while design and constructing. Ice can act on the structure by many ways. Possible variety of the actions from the ice creates a huge number of factors which should be taken into account for safe exploration. A lot of gaps in ice load estimation still exist (Timco and Croasdale, 2006 ; Frederking, 2012). Such gaps on one hand can lead to the risks of the safe exploitation of the structure for the people and the environment. On the other hand the overestimation of the environmental actions can lead to a significant money waste.

One of the factors which is poorly described in the modern literature is the development of the additional ice on the structure surfaces below the waterline. The International Standard Organization, American Petroleum Institute, Russian Construction Norms as well as Canadian General requirements do not provide methods to estimate the phenomena (ISO-19906, 2010 ; API-RP-2N, 1995; SNiP-2.06.04-82, 1989 ; SP38.13330, 2012 ; VSN-41.88, 1988 ; S471-04, 2004). Such extra ice forms due to high thermal conductivity of the structure. Additional thermo-developed adfreezed to the structure below waterline ice called ice collar as on the cylindrical structures it reminds of “collar”. A method to examine ice collar influence on the loads from the ice was investigated in the work (Sharapov and Shkhinek, 2014). Current article provides a method for mechanical calculation of the loads from ice collars which was not previously described. Example of ice collar around the cylindrical vertical pipe is presented in Fig. 1.

2. Ice collar growth

Offshore structures usually are made of steel or/and concrete. Steel or concrete material has large thermal conductive abilities then water and therefore water around them cools down faster than surrounding water. Ice is being formed on the structure surface when it cools down below freezing point. Ice growth process is highly dependent on the variety of the parameters: density, salinity, insulation, water currents, sub-ice water movements, etc. (McGuinness, 2009; ISO-19906, 2010; Buzuyev et al.,

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Fig. 1. Ice collar on the vertical cylindrical pipe submerged in the marine water.

1988). Ice collars can alter the total design load due to enforcing of the ice-structure contact. Therefore the calculation of the ice collar sizes is important.

2.1. Mathematical formulation in Cartesian and cylindrical coordinates

Mathematical formulation of the ice collar growth based on the general equation of the thermal balance. The method is similar to the numerical calculation of the level ice growth (Sharapov and Shkhinek, 2013). Mentioned work contains the general equation of the thermal balance in Cartesian coordinates. However for the cylindrical structures such as piles and legs of the platforms it is reasonable to rewrite thermal balance equation in cylindrical coordinates. It allows to consider two-dimensional calculation models more accurately. The equation in cylindrical coordinates is presented below (Eq. (1)):

$$\rho c\frac{dT}{dt}=\frac{1}{r}\frac{\partial}{\partial r}\left(r\bullet k\frac{\partial T}{\partial r}\right)+\frac{1}{r}\frac{\partial}{\partial \varphi}\left(\frac{k}{r}\frac{\partial T}{\partial \varphi}\right)+\frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial z}\right)+f \tag{1}$$

where ρ – material density; c – thermal capacity of the material; k – thermal conductivity of the material; f – internal heat formation; T – temperature; t – time; r, φ, z – radius, angle, vertical coordinate in the cylindrical coordinate system;

Due to the axial-symmetry the angle derivative is zero $\frac{\partial}{\partial\varphi}=0$ for the considered task (central symmetry), therefore Eq. (1) can be rewritten Eq. (2):

$$\rho c\frac{dT}{dt}=\frac{1}{r}\frac{\partial}{\partial r}\left(r\bullet k\frac{\partial T}{\partial r}\right)+\frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial z}\right)+f \tag{2}$$

After transformation of Eq. (2), the difference between 2D statements in Cartesian coordinates and cylindrical coordinated is in the term $\frac{1}{r}\frac{\partial}{\partial r}\left(k\frac{\partial T}{\partial r}\right)$. This term is decreasing with increase of the structure diameter. After series of the numerical experiments for real models it was confirmed that for relatively big structure diameter (>0.5 m) Cartesian and cylindrical statement provide identical result. For the rough estimation for the wide cylindrical structures the 2D solution in Cartesian coordinates can be used.

2.2. Expressions for variable properties

The ice, water and structure parameters are represented by corresponding coefficients. Ice-water phase change is represented by change of the coefficients in the equations. This change is modeled with the Heaviside functions $\theta(v)$ Eq. (3).

$$\begin{aligned}&\theta_1(v)=1 \quad \text{if } v>0; \quad \theta_1(v)=0 \quad \text{if } v<0;\\ &\theta_2(v)=1 \quad \text{if } v<0; \quad \theta_2(v)=0 \quad \text{if } v>0;\end{aligned} \tag{3}$$

where v – govern value of the function.

During phase change the following parameters must be modified:

ρ – material density; c – thermal capacity of the material; k – thermal conductivity of the material;

The equations can be simplified by using material density and material thermal capacity production ρc as a single function. The latent heat l of the material formation can be also included in this function ρc (Eq. (4) (Meirmanov, 1992; Stefan, 1981; Salva and Tarzia, 2011; Mccue et al., 2008).

$$\rho c_{eff}=\rho_w c_w\theta(T_f-T)+\rho_i c_i\theta(T-T_f)+\rho_i l\delta(T-T_f) \tag{4}$$

where

ρc_{eff} – the effective material density and material thermal capacity production for the equation of the heat balance;

Index (w, i) – shows the relation to the water or to the ice material (w – water, i – ice);

T_f – temperature of the phase change ($\approx -1{,}7$ for marine water);

δ – Dirac Delta-function (Ram, 1983; Marchenko, 2008);

The coefficient of the thermal conductivity is not included in Eq. (4), but can be also modified by Heaviside function $\theta(v)$ (Eq. 5):

$$k=k_w\,\theta(T-T_f)+k_i\,\theta(T_f-T) \tag{5}$$

According to Eq. (5) thermal conductivity coefficient k is equal to k_w for the temperatures above freezing point, and coefficient k is equal to k_i for the temperatures below freezing point.

Above mentioned expressions provide continuous definability for the coefficients which is important for the numerical computer simulation.

2.3. Ice grow calculation results

For the numerical calculation of the ice collars shape and size – commercially available finite-element software can be used (e.g. Ansys, Abaqus, Comsol Multiphysics, etc.). Those programs allow introducing user-defined variables and equations.

For the calculation the area should be defined. Boundaries are chosen from the condition that they should not influence the calculation result. For the heat calculation it is possible to assume no heat flux through the lateral boundaries (thermal insulation), Eq. (6).

$$-\mathrm{n}(-k\nabla T)=0 \tag{6}$$

The bottom boundary assumes to have the temperature of the considered water basin bottom. At the top of the model the temperature is equal to the air temperature of the considered site (Eq. (7).

$$T=T_a, z=0; T=T_f, z=-h \tag{7}$$

where: T_a – air temperature (surface temperature); T_f – freezing temperature (at the bottom surface of ice); z – vertical axis, normal to the ice surface; h – ice thickness;

Initial condition is zero ice thickness and plain distribution of the temperature field in the model, Eq. (8).

$$h=0; \quad t=0 \tag{8}$$

The number of the finite elements in the model should assure the low enough element size to provide the reliable distribution of the temperature field.

A series of the calculations were conducted for different steel thickness, temperature and duration of freezing. The results are presented in Table 1 depending on the FDD.

Data from the table was used for mechanical calculation of the ice collar influence on the loads.

Results show good correlation with field experiments. The example of 3D numerical calculation of ice collar is presented in Fig. 2 (right). The numerical result shows good correlation with the field experiment at the same conditions (Fig. 2).