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An estimation of the amount of the thermal energy for the moorage wall heating in the Arctic harbors to avoid ice accumulation

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ABSTRACT

Nowadays a lot of ports and quays are constructed in the areas with seasonal ice cover. Ice can prevent marine operations and lead to lost of time and therefore lost of money. One of the solutions to prevent ice adfreeze to marine and ocean structures is heating of the quayage. Heating prevents ice formation and provides acceptable conditions for loading/unloading of the vessels. The process and technology for this process are not properly described in the existing literature. However, estimation of the amount of the heat which is needed to prevent ice formation is vitally important and influences the entire construction project. The amount of heat can be estimated by a numerical simulation. The work also proposes the mathematical way for rough estimation of the power needed to prevent freezing in the ice. Mathematical estimation correlated with the numerical estimation. Calculations are made for possible time for the vessel to spend in the port – two weeks of freezing during $-10\,^{\circ}$C (140 freezing-degree-days).

1. Introduction

Nowadays a lot of interests exist towards Arctic exploitation. That interest is determined by a few important reasons, such as rich mineral deposits (including hydro-carbonates) and important seaways for transporting gods. Cold area harbors and Arctic constructions are required to resist against the cold temperatures and severe Arctic conditions. One of the main factors is ice. Calculations of the ice resistant constructions are very specific due to huge variety of the possible actions from the ice. Ice adfreeze and accumulation on the harbor walls and ship walls are important when considering close water areas. In one hand, big amounts of the accumulated ice can make difficulty for the ship to moor, in the other hand ship could spend much time loading–unloading, and during this time much ice could grow around making difficulty for the ship to leave, and even cause danger. Such problems exist for the river and lakes constructions and can appear in the variety of the countries (Canada, Norway, Russia, Finland, Sweden, Denmark, Iceland, Alaska (USA), etc.).

A lot of efforts from well-known scientist were given recently for the understanding of the ice and possible actions from the ice. Nevertheless a lot of uncertainty exists when estimating ice loads (Frederking, 2012). At present a lot of gaps in the knowledge about ice are exists. These gaps do not allow engineers to give unique estimation of the some of the ice actions and therefore some uncertainty could exist. As ice loads are one of the main factors for the construction of the Arctic and cold ports then uncertainty in ice loads could lead to significant overdraft of the financial resource or even to the lack of the safety.

If ice grows in the areas with tide water level changes then ice bustles on the piles are formed (Fig. 1) (Loset and Marchenko, 2009). Ice bustles can reach significant width and prevent moorage operations. Small ice adfreeze similar to ice bustle presented in the Fig. 1. If ice grows during no water level change (close water areas, marine docks, rivers etc.) then ice collars are formed (Fig. 1) (Sharapov and Shkhinek, 2014). Those phenomena's are weakly described in the normative documents and existing literature. Nevertheless well-known and recognized documents, such as ISO-19906 (2010) points out the necessity to consider such phenomena's. Following norms considered to be fundamental for ice engineers: (API-RP-2N, 1995), (ISO-19906, 2010), (RMRS, 2008), (SP38.13330, 2012), (VSN–41.88, 1988). From above mentioned norms only (SP38.13330, 2012), (VSN–41.88, 1988) describe possible coefficients for calculation of the ice adfreeze effect. SP38.13330, 2012 recommends increase ice thickness for calculations for taking into account additional ice. VSN-41.88 presents empirical data without relation to the structure thermal properties. None of them (SP38.13330, 2012 and VSN-41.88) provide information regarding possible heating to avoid ice accumulations.

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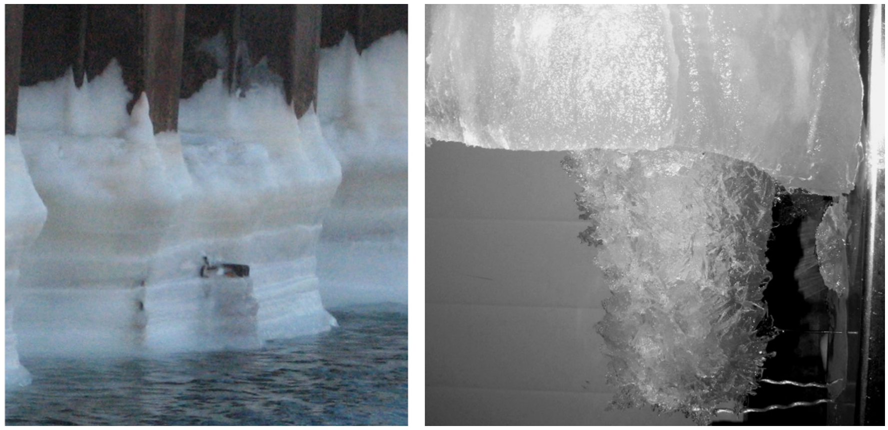

Fig. 1. Ice accumulation onset on piles (left), and Ice collar (right).

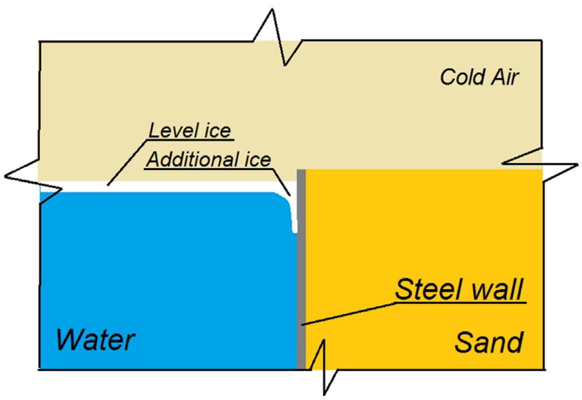

Fig. 2. Simplified 2D model of the considered task.

The goal of the present work is to give estimation of the possible ways for the calculation of the amount of the heat which is needed to avoid freeze-in the ice. The heating of the mooring walls and quay piles often considered as a solution to avoid additional ice formation. Currently estimations from different experts about amount of heat could vary more than 100 times (Timco and Croasdale, 2006). The heating increase service costs but can significantly decrease cost of the structure. Finite element method (FEM) and mathematical model are to be introduced.

2. Description of the task

Simplified scheme of the considered task includes: a steel wall between sea area (water area) and landside area (quay). Water area considered to be not limited by other borders and therefore natural currents and thermal conduction and convection processes should occur. The water surface influenced by cold air and therefore growth of the thermal developed ice should occur. Type of the water in the basin (salt water or fresh water) influences the processes of the ice formation and thermal transportation (Berti et al., 2013). For the first consideration fresh water is taken. Steel wall is about 5 cm thick. Corrosion could influence ice–steel adhesion and thermal transportation (Wall and Wadsö, 2013). Due to short period corrosion are not considered. Influence of the wall thickness on the ice collars was considered in the (Sharapov and Shkhinek, 2014). Authors showed that ice collar size mainly depends on the amount of FDD (freezing-degree-days). Parameter FDD introduced in ISO-19906 as one value to substitute freezing time and temperature during freezing (ISO-19906, 2010). Landside consists of the sand, and for the simplification considered not to be influenced from other borders then water basin. Such structures, as described above are usually made for the ships mooring and loading/unloading of the vessels. For the simplification of the thermal transfer model tides are neglected in the initial formulation of the task. 2D model of the above mentioned case to be considered. The plane is to cross described structure perpendicular to the waterside.

If the temperature goes below zero (Celsius) than after some time ice will occur. During no level change ice adfreeze to the quay and additional ice will form due to high thermal conductivity of the steel wall and sand fulfilment. Those additional ice formation and plain level ice when have certain size can prevent vessels from mooring or make already moored vessels trapped by ice (Loset and Marchenko, 2009). Those processes should be prevented for the normal operation of the port where those quays are located. The simplified model of the considered task is presented in the Fig. 2.

In Fig. 2 it is seen that model includes four main domains. Those are Sand (or other fulfillment of the quay) water, steel wall and air. Air domain can be substitute with right border conditions at the top of the other domains. Water domain mathematically described as matter with properties which depends on the temperature and can work as water and as ice depending on the temperature.

Thermal source (heating element) is introduced in the model for the estimating of the amount of the heat which is needed to prevent or significantly decrease ice adfreeze to the quay construction and ice growth. The position of the heating element should be inside sand domain near the ice growth area to prevent big wastes of the heat energy. The goal is to estimate the amount of energy which is needed, and to provide mathematical formulation of the task.

3. Thermodynamic formulation of the task for the FEM estimation

For the thermodynamic FEM estimation of the amount of heat to prevent additional ice formation 2D section is used. Third dimension assumed to be unit for the calculations. Volume as described above (Fig. 2) is taken. Vertical and horizontal sizes are determined from the conditions that they do not influence ice formation near the structure and do not change curves of the heat transfer through the model. At the vertical borders of the model it is assumed no heat transfer (thermal isolation) as follows:

$$-n \cdot (-k\nabla T) = 0 \quad (1)$$

where n – normal to the model border,

k – coefficient of the thermal conductivity of the matter.