Coastal Engineering 88 (2014) 69–74

Contents lists available at ScienceDirect

Coastal Engineering

journal homepage: www.elsevier.com/locate/coastaleng

A method to determine the horizontal ice loads on the vertical steel structures which adfreeze to the ice level

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ARTICLE INFO

Article history:
Received 21 October 2013
Received in revised form 12 February 2014
Accepted 13 February 2014
Available online 4 March 2014

Keywords:
Horizontal ice load
Freeze-in ice
Ice Collar
Arctic engineering
Numerical simulation
Adfreeze

ABSTRACT

In this work the estimation of the load from the ice level on freeze into the ice structure is presented. Nowadays a big uncertainty exists when estimating a freeze-in effect. Considerable inexactness in the ice loads estimation could lead to great differences in the cost of the structures. Proper estimation of ice loads will reduce the cost of constructions. If the structure is freezing-in during no change of sea level — ice collars are occurring. Ice collars could lead to increase of the horizontal ice load from the ice level on the structure. The overview of the existing recommendations is presented. The thermo-dynamical task for calculating ice collar profile was investigated during the present work. The numerical methods were used to calculate an increase of the load when freeze-in effect occurs. Physical experiments were conducted to verify the models. Results of the work provide provisional method for estimation of the ice loads on the freeze into the ice structures.

1. Introduction

Arctic offshore structures in the areas with arctic conditions are influenced by ice loads. Calculation of ice load on these structures is one of the most important steps while designing. However, the estimates of ice load done by each engineer can vary. This difference appears because of the various ways of calculations of the phenomena which are not described in the normative documents. One of the reasons for ice load increase could be the situation when structure is freezing-in the ice level during the period of time. If freezing of the structures in the ice appears during no water level change around structure then "ice collar" is formed around structure. No change in water level can be because of the absence of tide in the area or when structure is floating and fixed by anchors. In the areas with little tide ice collars can also occur around the structures. If water level changes during the period of freezing then "ice bustle" is formed (Loset and Marchenko, 2009). In the present work the constant water level is considered or structure assumed to be moving with the tide.

Freezing of the structures into the ice level is not properly described in the existing literature, especially in relation to horizontal ice loads. However, most of the norms and recommendations point out the necessity of the consideration of the freeze-in effect for the calculation of the ice loads on the structures. Norms (API-RP-2N, 1995), (ISO-19906, 2010), (RMRS, 2008), (SNiP-2.06.04-82, 1989), (VSN–41.88, 1988) were analyzed — only norms (SNiP-2.06.04-82, 1989), (VSN–41.88, 1988) contained information about ice loads on the structures when freeze-in the ice. SNiP-2.06.04-82 suggests that if freezing continues for more than three days, then one-and-a-half of ice thickness should be assumed for the calculations; this doesn't allow estimation of the freeze-in effect for longer periods and for the different temperatures, however the difference can be significant, and therefore the reliability and cost of the structure can significantly differ. VSN-41.88 has some data related to the freeze in the ice, however the dependence is doubtful as relative dependence from structure diameter to ice thickness should decrease, because relative effect of freeze-in effect decreases with diameter of the structure, but in VSN-41.88 opposite is presented. The comparison is presented in the result comparison section. Works (Sharapov and Shkhinek, 2011b), (Sharapov and Shkhinek, 2013) describe the primary results which were taken into consideration for designing of a new method, which is described in this work. First, the paper presents the comparison of SNiP-2.06.04-82 and VSN-41.88 norms in relation to freeze in the ice. Second, the method of calculation of ice thickness is presented. The book "Actions from Ice on Arctic Offshore and coastal Structures" (Loset et al., 2006) states that ice loads should be calculated with respect to freeze-in effect, however the method doesn't present. Comparison of modern norms were inspected by (Loset et al., 1999), (Frederking, 2012), (Shkhinek et al., 1994), but the freeze in the ice haven't been investigated yet. Described literature

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http://dx.doi.org/10.1016/j.coastaleng.2014.02.005
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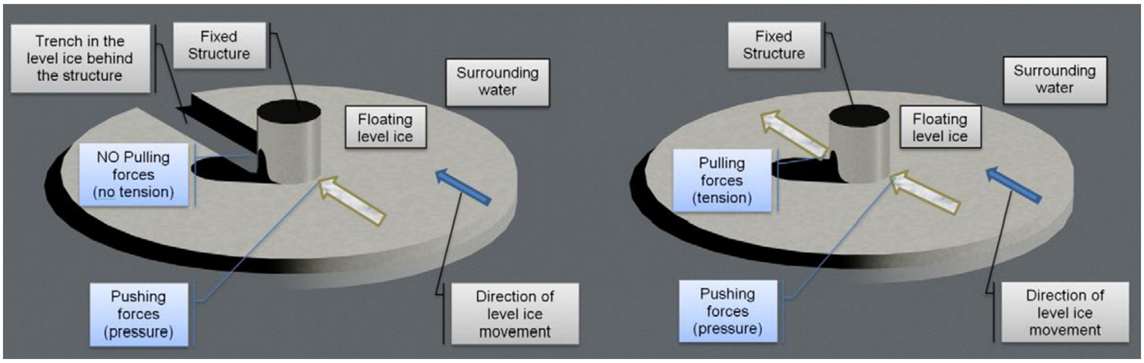

Fig. 1. Popular scheme for determining ice loads (trench behind the structure) (left), and scheme which takes into consideration pulling forces behind structure when it is surrounded by ice (right).

sources, contain useful data for determining ice loads, however those did not consider any trusted methods for determining horizontal ice loads on the structures freezed into the ice. The goal of the present work is to establish a new method for determining the horizontal ice loads on structures freezed-in the ice. Usually, the arctic structures are calculated for the loads from the moving ice level. Two main factors could lead to significant increase of the ice load on the structure freezed-in the ice:

1. If the ice is moving towards the structure — the trench in the ice level forms behind the structure (Fig. 1). Ice trench usually filled up with ice rubble. Therefore ice loads only act on the front part of the structure. If the structure is freezed into the ice — then ice also acts (pull) on the backward part of the structure. Therefore total load on the structure increases.
2. Because the structure is more thermally conductive then surrounding ice therefore forms additional ice formations around the structure — they are called “ice collars”. Ice collars increase the thickness of the ice at the contact areas with the structure and therefore have influence on the total ice load on the structure. After ice level starts to move ice collar collapsed and it is assumed to be the highest load on the structure at this moment.

In the work the vertical cylindrical structures were considered. For the development of the method three different subtasks were solved and three different models (FEM and FDM) were used.

2. Methods of the physical and numerical investigations

Following methods were used for the calculation of the freeze-in the ice effect on the horizontal forces from the level ice: physical investigations of the ice collar growth process, numerical simulation of the ice collar growth and numerical simulation of the ice action on the freezed-in the ice structure. Physical experiments were conducted to obtain shapes and thicknesses of the ice formations around the structure depending on the environmental and structural parameters. Physical experiments were conducted in the tank and in the open water during cold season (examples in part 3). Steel and concrete constructions were submerged in water, and ice formation around them was observed, environmental parameters were recorded. Obtained shapes and thicknesses of the ice formation were correlated to the initial parameters. For the numerical simulation of the ice formation thermo-dynamic formulation of the process was used. Solution was found as a variation of the structure's thermo-dynamic properties and environmental properties and time of the freezing process. Numerical simulations were used to verify mathematical model and obtain data regarding different scenarios of freezing in the ice level. Data regarding ice profile used as input to the numerical simulation of the structure interaction with level ice when structure freezed in the level ice. Numerical simulations of structure-ice interactions were conducted in the specially designed software (parts 4, 5), where ice domain was represented by disk of different diameters. This allows considering time-dependent process of the ice failure and deformations of ice formation before failure. Numerical simulations were conducted in the relative units. In a result the output data was correlated to the initial input environmental and structure parameters and dependences for the practical use were found.

3. Thermodynamic task for estimation of ice collar dimensions

Following task was considered: A hollow cylinder with certain thickness of the wall (2 cm, 4 cm or 6 cm for different calculations) was partly immersed in water while the other part in air. The water had temperature near the freezing point and the air had temperature below the freezing point. The solution of this task was calculated in the FEMLAB at the University Centre in Svalbard. The solution of the thermodynamic task was based on the equation of the energy balance, which describes the temperature distribution in the water, ice and the movement of the ice-water boundary (the growth of ice collar). Similar thermodynamically model was used by Marchenko A. for calculation of ice rubble consolidation (Marchenko, 2008). A discretization model with moving ice-water boundary was used. Ice-water boundary was identified according to the temperature in the considered domain point. Physical

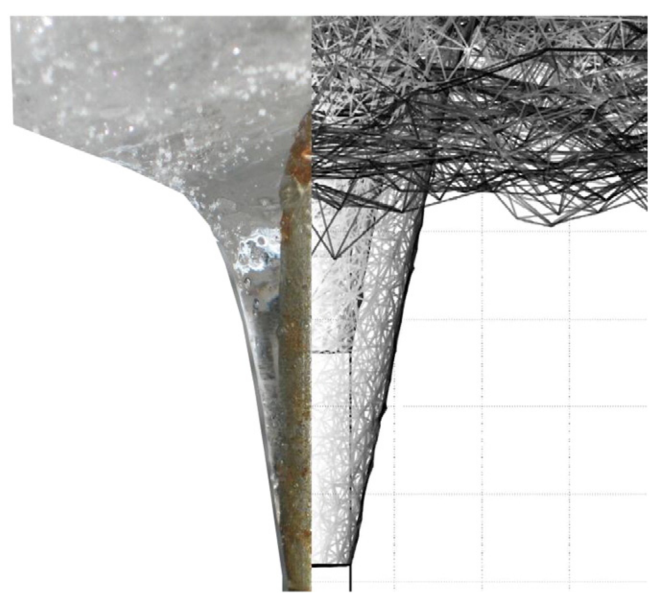

Fig. 2. Results of the numerical calculation (right) and physical experiment (left); in the middle it is a vertical steel core of 3 cm in diameter, it is covered by ice; lines in the right part (numerical calculation) show the locations where the temperature became below freezing point and therefore ice formed.